Strategies for Deploying Virtual Representations of the Built Environment

(aka The ESP-r Cookbook)

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Prior editions:

February 2006

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It has been translated into Italian, French, Korean and portions into Greek (under separate copywrite). A condensed version can be found on the web at:

`http://contrasting.no-ip.org/ESP-r_tour/Index.html`

This document is designed to be printed in one of the following formats:

Two pages per sheet of B4 paper

At 86% scale on A4 paper (wide margins for notes)

At 100% scale on B5 paper (86% on A4 to cut to B5)

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ACKNOWLEDGMENTS

This book could have been completed only within the exceptional group environment of the Energy Systems Research Unit of the University of Strathclyde in Glasgow Scotland. Where else could an architect compose tens of thousands of lines of source code and then use the resulting virtual edifice to explore and support the design process and then turn the process on its head to return to the written page to explore strategies for its use.

For the July 2011 edition, the author would like to acknowledge the time which Samsung Construction allowed the author during a period of secondment in Seoul.

The 2015 edition included an expanded introduction. Many discussions included perspectives from multiple simulation tools. There were also revised examples for planning and implementation, new thermal resolution topics, a chapter on coupled CFD assessments, an updated system components chapter, as well as expanded appendices. Many ESP-r specific *to the keyboard* sections were re-implemented as exercises in an Appendix.

The 2017 edition updates the discussion about construction databases, new facilities for predefined entities and the treatment of uncertainty.

The February 2018 edition updates the discussion and examples of translating construction documents into zones and surfaces. It also refreshes many of the figures and tables to reflect recent changes as well as filling in a number of topical gaps.

As always, words and phrases have been updated to reflect changes in technology (who would guess that one could run simulations on a range of ARM based single board computers such as the Raspberry Pi or on an Android tablet). And the emergence of fully populated interiors in buildings has defined new frontiers in terms how we might use performance data that could include the energy balance of desks and chairs and zonal representations of the humble radiator and wall thermostat.

CONVENTIONS USED

Some blocks of text apply only to ESP-r and if you are using a different simulation tool then there is an indication to skip a few paragraphs. And where Appendices or other Sections should be consulted before you proceed, the following icons are used:

 ESP-r specific   Appendix   Section   Section

If you are asked to study a particular section prior to continuing the subsequent text will assume that you have read the reference material.

Sections of interest to technical staff and uber-geeks are marked with...

For example, commands entered to compile from source are rendered as:

```
./Install_o1 -d /opt/esru --debug --gcc4
```

then look out for that symbol. And when the definition of a model entity or a rule for the use of model entities is described look for this...

There are grey corners in simulation tools and working practices that can so easily grow out of control and lead to calamity. These are highlighted via:

CFD is powerful. And also wrapped up in jargon which sounds like English. It is a place where dragons live. ESP-r's interface to CFD has a steep learning curve.

And there are many places where small differences in approach (and attitude) can have a significant impact. These are highlighted via:

QA works better if something that looks like a door, is named door and is composed of a type of construction which is associated with doors. Where attributes reinforce each other it is easy to notice if we get something wrong!

With few exceptions, the command sequence needed to undertake most tasks is almost identical across each of the user interfaces that ESP-r modules supports as well as most operating systems. Where facilities differ you may see one of the following icons followed by specific instructions...

When describing a path through a menu structure the following convention is used: `[Model Management] -> [browse/edit/simulate] -> [composition] -> [geometry & attribution]` where the menu titled [Model Management] has an entry [browse/edit/simulate] which has an entry [composition].

A word about ESP-r interfaces

ESP-r is under active development by a community of developers and is developed and distributed under a GPL license. On any given day there may several *commits* of code, documentation or model updates to the ESP-r repository. Thus, references to facilities and interface elements may diverge somewhat from what you see on your computer.

There are currently three different interfaces for ESP-r. The X11 interface has its roots in the world of UNIX and Linux. There is also a port of ESP-r to the cross-platform GTK graphic library which, for some, has a more familiar look and feel. The third interface is a pure-text interface which is intended for scripted production work or to enable ESP-r to act as a background engine for other software.

Look in the *Interface Appendix* to see typical dialogues as well as a discussion of how to automate (script) simulation tasks. Where the discussion makes reference to an ESP-r dialog or menu selection a mix of the X11 or GTK or text version forms will be used.

A word about exercises

Exercises illustrate the translation of simulation theory into specific working practices. These are marked via

Exercise 2.3   Using the planning sketch (Figure 2.1) and with reference to the geometric transforms (Figure 2.6) complete Exercise 2.3.

Well worth following, even if you are not working with ESP-r.

INTRODUCTION

1 Introduction

Strategy is a high level plan to achieve one or more goals under conditions of uncertainty...and where the resources available to achieve these goals are usually limited.

tactics are the actual means used to gain an objective/goal

round up the usual suspects is a quote from Casablanca (1942) and is the 32nd most used film quote.

Wikipedia [http://en.wikipedia.org/wiki/Strategy], [http://en.wikipedia.org/wiki/Casablanca_(film)]

Strategies for Deploying Virtual Representations of the Built Environment presents a mix of strategies, tactics and methods for:

- translating client questions into virtual representations that are are no more and no less complex than is required for the task
- responding to what if questions and making models that are also fit to answer the *next question* the client will ask
- discovering valuable patterns in the clutter of performance data
- re-discovering the power of pencil and paper planning
- clearly observing what is to be simulated in order to capture its essential character.

What you are reading is the antithesis of *rounding up the usual suspects*. It proceeds from the belief that there is both art and science in the design of the virtual worlds which exist within simulation tools. We choose what to include and we set the boundaries for numerical tools.

In this book the general purpose simulation suite ESP-r is used as a platform for exploration (as in the *aka ESP-r Cookbook* in the title). ESP-r unashamedly defers to the user's judgement for the level of abstraction and detail included in each analysis domain and thus is a fertile ground for the discussions which follow. In ESP-r:

- there are multiple approaches to most simulation tasks which the discussion and the accompanying exercises explore,
- there are multiple solution domains and thus many of the complex interactions which can be observed and measured in the real world are available within the virtual world,
- *functionality follows description* and thus the discussion can explore a range of complexity from models created over a coffee break to those which can only be managed within the resources of well-founded simulation groups,
- and there are rich facilities to explore performance patterns.

And although users can coerce ESP-r to use non-dynamic representations, ESP-r is unashamedly a tool for the solution of dynamic thermophysical interactions within the built environment.

1.1 Virtual physics in the design process

The design process proceeds on the basis of the *beliefs* the design team holds about how the current design satisfies the needs of the client. Testing whether such beliefs are well founded is a classic use of simulation and the way we design such tests and use numerical tools are core issues in this text.

For example, some architects and engineers operate on the assumption that buildings constantly require environmental controls. *Are such assumptions true for a given design?* Let's use simulation to test how often a building works well enough to satisfy occupant requirements without such interventions and then explore options.

Many design methods focus on extreme conditions and ignore what happens at other times. *What is the cost of this?* Let's use simulation to explore the nature of the building's response to transient weather and occupation and, by understanding the pattern of demands, devise environmental control regimes which work well in intermittent demand scenarios.

Practitioners employ a variety of working practices. Unfortunately, some of these make excessive demands on staff and computational resources to the point where we fail to deliver on time, fail to notice opportunities or fail to identify risks inherent in designs.

For simulation to *do it quicker, cheaper and better* guidance is needed. Reference handbooks such as the CIBSE AM-11 *(http://www.cibse.org/knowledge/cibse-am/am11-building-energy-and-environmental-modelling)* include valuable discussions about working practices and procedures. A must-have for any library and a rich resource for saving time and sanity.

Software vendors are a mixed resource as they often seem to believe their own hype about ease of deployment. And contextual help within tools, no matter how extensive, deals with a sub-set of the skills needed to make informed decisions.

Learning how to use simulation tools has tended to follow three paths - the *mentor path*, the *workshop path* and the *there-be-dragons* path. Existing groups working with simulation who have a mix of experienced and novice staff often use a mentor-based approach. This has been seen to work exceedingly well in increasing expertise and productivity but is difficult to scale. Two or three days of initial workshop sessions, with subsequent advanced workshops and occasional email support allows some practitioners to use simulation suites productively. In the absence of contact with mentors and workshops, practitioners are often confronted by the arbitrary conventions which are endemic in simulation tools. Each button press enters new territory - thus the term *there-be-dragons*.

What you are reading aims to clarify the jargon used in the simulation community. It provides background for those who are delivering workshops or formal courses. Those who manage simulation practitioners will find commentary on working practices which extend and complement standard resources such as CIBSE AM-11.

The author has observed that users of simulation tools have ranges of model complexity within which they are comfortably productive and beyond which there is an increasing risk of fatigue and error. Whether you are a solo practitioner or a member of a team, a clear recognition of limits is critical.

The discussion will also inform your exploration of example models distributed with simulation suites. Some illustrate semantics and syntax. Others are derived from real projects which focus on specific building performance design issues and might be considered *exemplars* of best practice.

Abstract training models may not be representative of best practice, they may not scale well and may attract the attention of an attorney if used in a real project.

Consulting or research derived models might push the limits of the tool in order to deliver specific performance information.

Example models are thus excellent reference materials if you *know what you are looking for* and have the *observational skills* necessary to discover patterns.

▶ Exercise 1.1 In order to explore simulation you need a working folder on your computer for simulation models. Exercise 1.1 covers the steps needed for Linux, OSX and Windows.

1.2 An example of quicker, cheaper better

Back in the days when Intel Pentium 4 processors were becoming fashionable, the author had a project to evaluate whether mechanical dampers in a facade of an office building could be used as an alternative to mechanical ventilation during transition seasons.

In order to assess the performance opportunities and risks of this hybrid scheme, a base-case and three variants of the model in Figure 1.1 were created. It included explicit internal mass, facade elements and shading devices, as well as two variants of air flow network and three control schemes.

▶ Exercise 1.2 The model can be browsed from within the ESP-r *project manager* in the *real projects* category of the training exemplars. Exercise 1.2 takes you through the steps of exploring this model.

How long should a client expect to wait for feedback? In the event, a synopsis of the findings was available five hours after the plans and sections were first opened. Examples of its performance can be seen in Chapter 11 Figure 11.31.

The subsequent evolution of the interface and improvements in data recovery might reduce the overall time by ˜45 minutes (for that same class of computer). A modern user might increase the geometric resolution by using pre-defined desks rather than manually creating them and select a diversified room occupancy pattern rather than creating from scratch. A modern computer would, of course, support a finer time resolution in the assessments, a visual assessment via Radiance or additional hybrid mechanical ventilation options within the original time frame of this project.

To ensure the facade ventilation model contained no more and no less than was required to satisfy the brief and could be completed well within the time allocation, the first hour and a half was devoted to planning the model:

- establish what needed to be included in the model and the likely nature of what-if questions
- review existing models which addressed similar issues
- identify weather patterns which would clarify the building's performance
- review available common constructions, identify additional items needed and possible variants
- define the extent of the building and systems required to answer performance questions
- define the resolution of the model (form, composition, controls, schedules)
- define the analysis resolution of the model (e.g. radiant exchange, air flow, systems)
- plan model zoning, sketch the model, decide naming strategies and note critical co-ordinates
- sketch out the air flow network and gather relevant data
- outline room usage patterns, internal gains and environmental controls
- plan the calibration tests to be carried out
- review sketches and the approach with colleagues as a reality check
- define the sequence of tasks needed to implement the model
- begin documentation of the model and its assumptions and ensure these are updated as the project evolves.
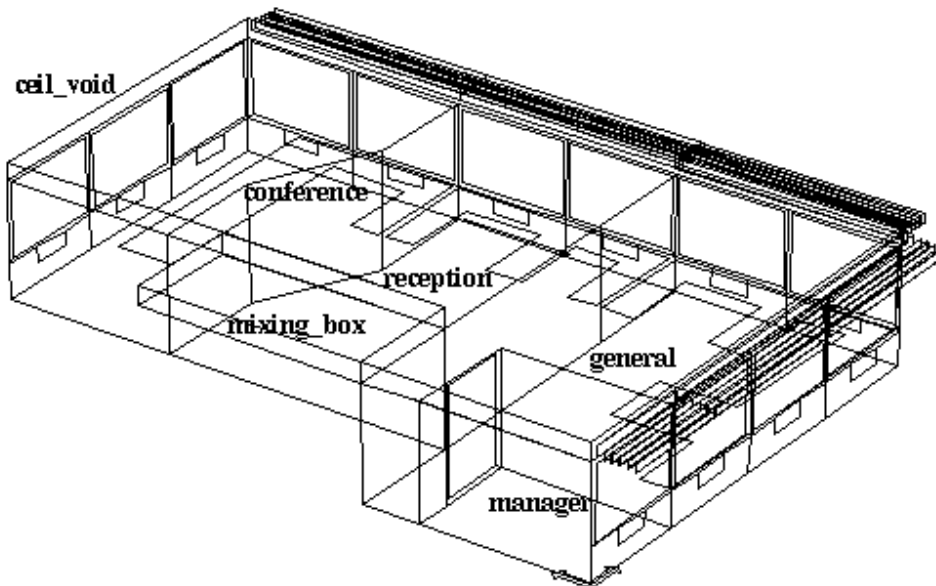
Project: Office model for network flow studies
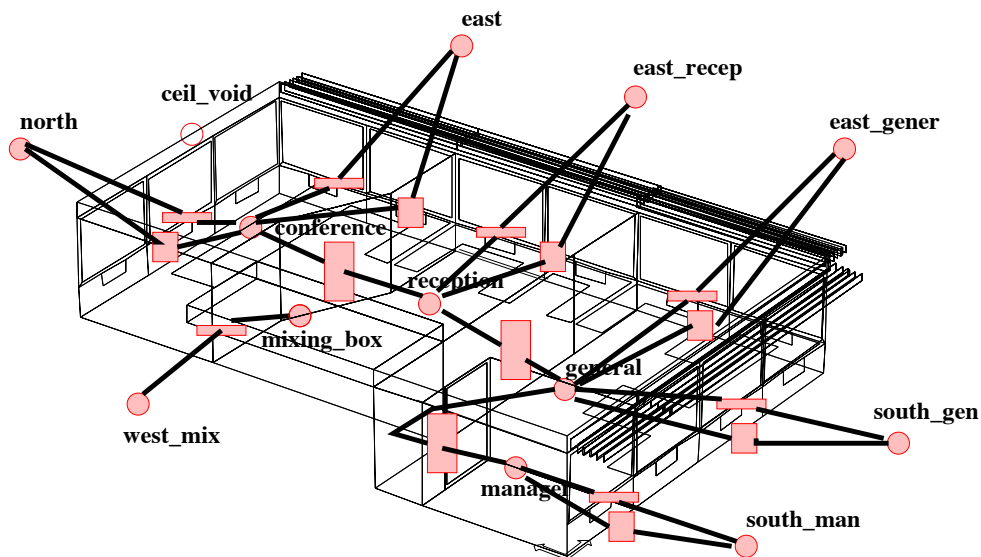
Project: Office model network for dynamic infiltration and facade vents

○ Un–used node   ▭ Component – crack   ▪ Component – orifice

● Node   ▮ Component – door (bidirectional)
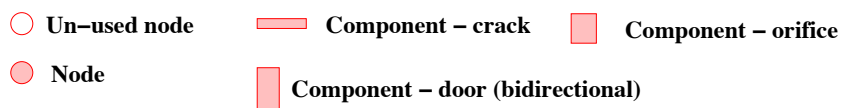
Figure 1.1: Portion of an office building - the five hour project

This sequence of planning steps has been used with scores of models. For other simulation suites the specifics and sequencing of planning tasks might diverge slightly.

With this information gathered, model creation was straightforward and attribution could proceeded without interruptions. The model creation sequence was:

- populate materials and constructions databases
- define model calendar with day types needed for subsequent operational and control regimes
- use an image of the floor plan to generate initial layout of the rooms and ceiling void

- focus on managers office, adapt framing and glass in facade and passage and attribute surfaces

- change rooms, replace initial facade surfaces with manager facade elements

- create desks in the general office and then replicate/adapt to other spaces

- adapt the ceiling void via copy/invert of ceiling surfaces in rooms below

- use the automatic *topology checker* to establish thermophysical links between rooms

- generate a model contents file and do a quick scan for *the usual QA suspects*

- carry out shading and insolation analysis for each of the zones with facades

- calculate surface-to-surface view-factors to support low-wave heat transfers within rooms

- define the operational characteristics of the managers office (including some diversity) and then adapt for other zones

- define air flow networks - infiltration only for calibration followed by infiltration plus vents

- define air flow controls - a sticky open/close controller and a proportional opening controller

- define assessment periods for winter-cloudy, winter-sunny, spring, summer-cloudy, summer-sunny weeks

- update model contents report and invoke a weekly assessment to confirm model syntax

- explore model variability of air movement and risk of overheating or overcooling.

This sequence of tasks is efficient in terms of the data model and facilities of ESP-r. It is pedantic where needed and ruthless in constraining the bounds of the problem. Users of other simulation suites will, of course, discover slightly different paths to derive working practices that reduce risk and fatigue.

About one and a half hours was spent creating the model. There were a couple of typos in defining the schedules of internal gains that were identified in the model contents report so the model was accepted by the simulation engine on the initial pass.

About a half hour was spent in calibration using the one week assessment periods identified in the planning stage. Calibration started with a base case with fixed infiltration assumptions and was then compared with the infiltration-via-flow variant and patterns of differences in temperatures and loads from air movement recorded. The second phase calibration incorporated damper controls. Checks were made over the range of weather conditions in the defined weeks and the controls tweaked.

The remaining time was *living with the model* in order to understand the conditions associated with beneficial use of the dampers as well as the risk of discomfort. Graphs and reports from interactive sessions were collected along with wire-frame images of the model for inclusion in an executive summary.

Let's turn to the strategy and tactics demonstrated in this project.

1.3 Questions we should be asking

Clients ask us questions - but what are the *questions we ask ourselves* as we plan and then compose our virtual worlds?

Let's begin by deciding what kind of model we are going to make and then *plan the work* so that it fits our resources. Being pedantic during the planning stage *often speeds up subsequent tasks*. In the left column are high level issues which managers might identify and on the right is a translation into the language used in the simulation realm.

Table 1.1 Initial questions:

Design Question	Simulation questions
What *specifically* do we want to know about the design?	What thermophysical issues should be addressed by the model?
How will we know if a design idea is well-founded?	What kinds of performance should be measured? Where should these measurements be located? What signifies acceptable performance? What level(s) of model detail are required?
How do we match the available information with tool requirements?	What is the essence of the design in terms of form, composition, operation and control? What thermophysical interactions need to be represented? What tool facilities should be employed and what skills are required?
Is our approach robust?	Can I sketch my ideas for the model and explain my methodology? Are the project goals matched with staff skills and the tool? How might the design and the model evolve? What would we do now to make it easier to work with this model again after a four month delay?
Are the performance predictions credible?	What assessments need to be undertaken to gain confidence in the model? What diversity should be included in use and control? What is expected of a best practice design? Who else should review these performance predictions?
How might the design fail?	What boundary conditions and operating regimes might cause failure? What might be the unintended consequences of a design change?
What are the opportunities?	What would provide clues for improving the design? What change signifies improved performance? What is the next question the client will ask?

Without careful consideration of these questions we miss out on the value-added aspects of simulation which cost little to implement but deliver substantial benefits. It is also an excellent filter for identifying aspects of a design that can be handled abstractly or even omitted from the programme.

1.3.1 What is fit for purpose?

The approach we take to create the form of the model is dependant on the *questions* we wish to address with the model as well as the specifics of the *data model* and input facilities offered by the simulation suite.

The question "*What specifically do we want to know about the design?*" can generate valuable insights - if we pause long enough to clearly focus on what we are about to model.
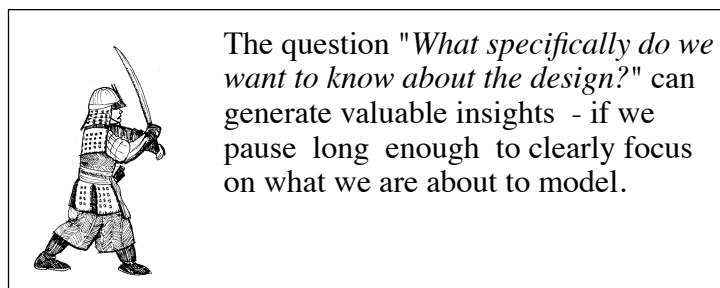
Having a good idea about what we want from a model, or perhaps a sequence of models, helps when considering the resources required, as the following considerations show:

- questions about general comfort and energy demands at peak and moderate weather conditions require only a moderate geometric resolution e.g. correct volume of the space, approximate location of doors and windows

- questions related to comfort at a specific location require higher geometric resolution, especially if surface temperatures are likely to be vary across a surface
- questions which involve control actions require that the characteristic temporal response characteristics of the building and environmental controls are reflected in the model and that the assessments are carried out at a time step which supports control sensing and actuation
- questions involving the comparison of predictions and measurements require an utterly pedantic approach to match the description, operation, and controls within the virtual and physical realms
- questions related to visual comfort will require higher geometric resolution for facades and may require furniture within rooms and outside obstructions to be accounted for
- questions related to the distribution of air temperature within a physical space may require that it be represented by more than one thermal zone or that it include a computational fluid dynamics (CFD) domain

Sometimes it is the nature of the design which will influence the model resolution. A passive solar design will be sensitive to heat stored in the fabric of the room as well as details of glazing in the facade and in partitions to adjacent rooms. The surface temperatures in a sun patch might be elevated. To find out where the sun falls in the room at different times of the year we might create a rough model and then check what we can see in a wire-frame view at different times of the year. Our goal would be to find out if we need to subdivide surfaces to better reflect the temperature differences in insolated and un-insolated portions. We can then make a variant of the zone with higher geometric resolution and compare the predicted surface temperatures.

In the office building in the previous section, the end of one floor of the building provided sufficient context for questions related to air flow via facade vents, cross-ventilation and inclusion of the managers office ensured that (possible) single-sided ventilation was included. The zoning allowed for differences in the resulting temperatures to be tracked.

Focusing initially on a portion of a building is a powerful approach. Experts often generate focused models that evolve quickly and are then discarded once the *question of the moment* is dealt with.
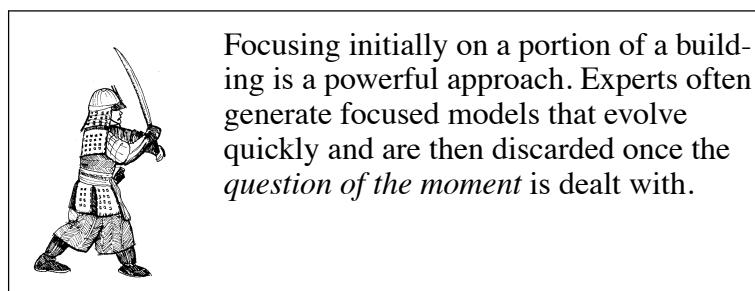
The model included a suspended ceiling zone because it was likely to be at a different temperature from the occupied space (lighting was embedded in the ceiling). The inclusion of desks at the perimeter provided visual clues for ease of client recognition as well as ensuring that overheating from solar gains near the facade are accounted for. The mixing box was included for a possible subsequent assessment of hybrid ventilation.

Some simulationists might choose not to include all of these details in a project with tight time constraints. Tactically:

- it was quicker to include entities in the initial model than to retrofit it at a later point
- it made the wire-frame view of the model self-explanatory so that the focus of the reporting could be about the performance rather than geometric abstraction
- starting with a crack-infiltration-only flow network variant helped prove the network, provided early indicators of facade sensitivity as well as the temperature driven flow between spaces prior to adding complexity to the network.

1.4 Responding to the client specification

Simulation models have a context within which they are created and evolve. In a design project the client's specification and design questions form the context from which the project is planned and implemented. In a research project the goals of the project are no less critical to planning and implementation of tasks.

The following table includes issues which may confront simulation teams in the planning stage.

Core issue	Related issue	Actions
Does the client/design team have prior experience with simulation based assessments?	Prior experience eases the *educational task* otherwise client expectations could be an issue.	Ensure time and resources for clear communication with the client. Brief the client on the nature of the information they will be asked to provide.
Does the client/design team know the types of performance data and reports which can be generated?	Management of reporting expectations. Selection of reporting format(s).	Review client preferences and clarify potential misunderstandings in deliverables.
Has the client used language or provided sketches that indicate *beliefs* about how design will work?	Test beliefs is as soon as they are noticed. Create focused models which can deliver information quickly.	Confirm if typical data for the type of building is available. Create a test case to confirm that staff have captured the essential characteristics of the design.
Has the client indicated what criteria would signal success?	Value for each criterion? What additional data might help calibrate the model?	Do these suggest future what-if questions?
Has the client indicated what criteria would signal failure?	What magnitude/frequency equals failure? What are likely modes of failure? What needs to be measured to identify risk?	Confirm criteria are in keeping with current practice or are client-specific. Define assessments to test its robustness. Identify operational regimes or weather that would expose risks.
Is the project focused on a range of issues or a single issue?	Multiple issues might require several models or model variants.	Confirm if staff can cope with multiple models and/or model variants. Define naming strategy for variants.
Are what-if questions in the form *what happens if we use a better quality low-e glass* or *what happens if we use product X*?	Is the role of the simulation team reactive or pro-active?	Identify methods might to identify *a better quality low-e glass*. Is a supplied specification appropriate and in the clients interest?
Do what-if questions pose parametric questions (e.g. which skylight area between 12 and 36% is the point where cooling demand escalates)?	Consider resources needed for parametric studies. Early confirmation is essential.	Confirm tool supports the creation of model variants. Manually check 12% and 36% options to establish sensitivity prior to implementing parametric tasks.
Is this project similar to previous projects? Can we adapt a past model for this new project?	What did we learn in the previous project? What were the difficult issues in past projects of this type?	Confirm if staff have the skills to adapt existing models. Review its documentation. Review procedures and staff resources against the current resource allocation.
Does the current state of the model reflect the ideas and concepts developed during the planning stages?	Is the complexity of the model consistent with the resources allocated? Have the resources used matched the initial plan?	Consider if staff tasks need to be adjusted. Consider if additional staff required. Plan for contingencies. Notify the software vendor or developer of points-of-friction.

Core issue	Related issue	Actions
A potential project will be discussed with a client in a meeting tomorrow.	Who should take part? What key phrases are important to listen for? How much do we need this project?	Review details of similar projects. Review bidding criteria. Ensure that presentations and sample reports are available if needed.

Each core issue can be expanded to related issues which are more specific and might lead to specific tasks during the planning phase. You will discover in practice many more related issues as well as associated actions which can form the basis for procedures and checklists.

1.5 Model entities

The art of creating models fit for purpose draws on our ability to select appropriate entities from within the simulation tool. Each has rules-of-use, descriptive and/or operational attributes and takes part in specific thermophysical interactions within the solution process. To illustrate this some definitions of zone entities are defined below:

- A *thermal zone* represents a volume of air at a uniform temperature and which is fully bounded by surfaces (see below). Within the complexity constraints of ESP-r a zone can take an arbitrary form. A thermal zone might represent the casing of a thermostat, a portion of a physical room or a collection of physical rooms depending on the requirements of the project and the opinions of the user.
  - Within a thermal zone there is an air-node energy balance. Air movement with the outside and with other zones in the model is included in this energy balance. Casual gains from occupants, lights and small power are also included.
  - A CFD domain can be associated with a thermal zone and/or mass flow nodes can also be associated with a thermal zone.
  - Long wave radiant exchange is supported between all surfaces associated with a zone. The default treatment is weighted by area and emissivity and the *mrt* utility is able to calculate explicit view-factors for thermal zones of arbitrary complexity.
  - Direct and diffuse solar radiation is tracked within a zone. The default treatment is diffuse distribution of solar radiation entering the zone from the outside or adjacent spaces. The *ish* utility is able to calculate shading patterns on the facade as well as insolation patterns within a thermal zone of arbitrary complexity, including explicit internal mass represented via surfaces.
  - Ideal environmental controls can sense and actuate at the zone air node. Sensors can reflect the current air temperature or a mix of air and MRT. Actuation can be a convective injection at the air node or a mix of convection and radiation to be absorbed in the zone surfaces on an area/emissivity basis.
  - As zones must be fully bounded by polygons, openings between thermal zones must be represented by a surface (typically composed of a construction which minimally restricts heat flow). Air movement (mixing) associated with such openings is a separate definition in ESP-r e.g. a scheduled zone ventilation or via cracks and bi-directional flow components within a mass flow network.
- A *surface* is a polygon composed of vertices and edges with attributes of name, boundary condition, thermophysical composition, optical properties and use. Within the limits of complexity a surface polygon can be of arbitrary shape as long as it is flat.
  - During assessments a surface energy balance is maintained at the inner face and other-side face of each surface. Each has a single temperature at any moment in time and the surface energy balance is consistent across each face.
  - For purposes of control, a sensor can be located at the face or within the construction or it can be the point of control actuation (e.g. an embedded pipe). Radiant heat injected into the zone via an environmental control is part of the energy balance of the surface.
  - One face is in contact with the zone air volume and it also participates in long-wave and short-wave radiant exchanges with other surfaces in the zone. Potentially short-wave diffuse radiation may pass

to and from adjacent rooms. Convective heat transfer is evaluated at each time step and can option-
ally follow specific correlations or values derived at that time step from the CFD solution.

- Surfaces have a boundary condition attribute specifies the nature of thermophysical interactions at
the *other face* of the surface (see Entities Appendix).

- *internal mass* may be represented via pairs of surfaces connected to each other (i.e. back-to-back)
rather than to a surface in another zone and thus each pair presents two faces to the thermal zone for
radiant and convective heat transfer. These surface pairs can be of arbitrary shape (as long as their
edges match). Usually the construction of each represents the thickness of the actual mass. Creating
explicit furnishings and fixtures is simplified via a *pre-defined entities database* which is populated by
office and residential furniture, light fittings, facade elements and stairs. These entities include both *vis-
ual elements* and *thermal mass* representations. An example of these can be found in the *technical fea-
tures simple office with high resolution and internal mass* exemplar model.
If the position of thermal mass is not critical then surface-pairs can be sized to aggregate the total sur-
faces area of thermophysical clutter in the room. Otherwise thermal mass surface-pairs can be placed as
required up to the limits of geometric complexity within the room and fully participate in the zone
energy balance.

 Appendix   This is a fraction of the data model that simulation tools deal with. You are invited
to check out the extended list in the *Entities Appendix*.

 Exercise 1.3   In addition to browsing models we want to be able to return to a prior model and
continue working. To explore options for working with existing models go to
Exercise 1.3.

1.6 Model planning rules

There are a number of decisions required to arrive at a design of a simulation model which is appropriate
for your skills, the goals of the project and the available computational and time resouces. As a general
rule, the design of models should ensure that the volume of the air and surface areas of facades and inter-
nal partitions and floors are captured. We also want the mass within the rooms and within constructions to
be appropriately distributed. Among other things consider:

- The scale of the building - a residence might be abstracted so that each room is explicitly represented
and the surfaces bounding the rooms and facade elements are located correctly in space. If this was
attempted in a larger buildings with complex facades and scores, if not hundreds of rooms, the model
might exceed the available skill sets and resources. A degree of abstraction may be needed. It may be
useful to focus on a subset of such buildings.

- The regularity of the plan. A plan with a 1.3m x 1.7m repeating pattern will not easily fit within an
input discritization regime unless you are using a 100mm or finer grid. A 100mm grid might be imprac-
ticle to work with in a 50m long office space. Rooms which are non-orthogonal are tedious to fit to a
cartisian grid. Curving walls or facade elements will, of course, need to be subdivided into flat surfaces.

- The depth of the facade. For many simulation tools the *elephants in the room* are the non-trivial depth
of facades, their complexity and the prevelance of deep extrusions.

- Mixes of fixed and operable elements within facades can host a variety of thermal bridges, air leakage
paths and non-uniform thermal properties. Far to often framing approaches 50% of the rough opening
area and there can be a considerable difference between the inside and outside surface area of framing.
It is difficult to justify 1D heat transfer representations in the images below.

Figure 1.2 Facade details that impact model planning.

- The existance of ceiling voids or raised structural floors. If there is little or no air movement these are often represented as layers of air in constructions. Where air movement is likely, temperatures are expected to differ, or there are heat gains within the void they may be better represented as separate thermal zones.

- The thickness of intermediate floors. As ceiling-to-floor distances increase it makes sense to take height co-ordinates literally.

The quality of the source drawing/images/CAD file has an influence on how we proceed. At one extreme there may be no construction documents. Sketches from a site visit may form the basis of the model. Documents may be archival hard copy and will need to be manually digitized. The CAD data might take the form of thousands of triangles or 2D entities or not sorted into the thermal zones needed for simulation.

- The level of clutter in the source, for example, architraves, window opening hardware, skirting boards and wiring chases. If the source includes one or two magnitudes of polygons that are actually required what filters are available? Would visual filtering while discritizing an image be more appropriate?

- Some clutter may be useful to represent, either abstractly or explicitly. For example, most buildings include furniture and fittings which can alter the response characteristics of the building as well as our perception of local comfort. Planning needs to consider their inclusion.

1.6.1 Discritizing designs

One approach is to adopt a centre-of-partition and inside-face-of-facades approach. Thick facades and structural walls this can be problematic. And what about ubiquitious spaces such as wardrobes and cleaners closets which might not be worth explicitly representing but which impenge on the treated floor areas and air volumes we are interested in? What about service voids, raised floors and ceiling voids which might be at a different temperature?

Such questions apply irregardless of the form of the construction documents (CAD, archival hard-copy, site visit sketches). Lets use a scan from an archival document of a 1961 tower block to explore such decision points.
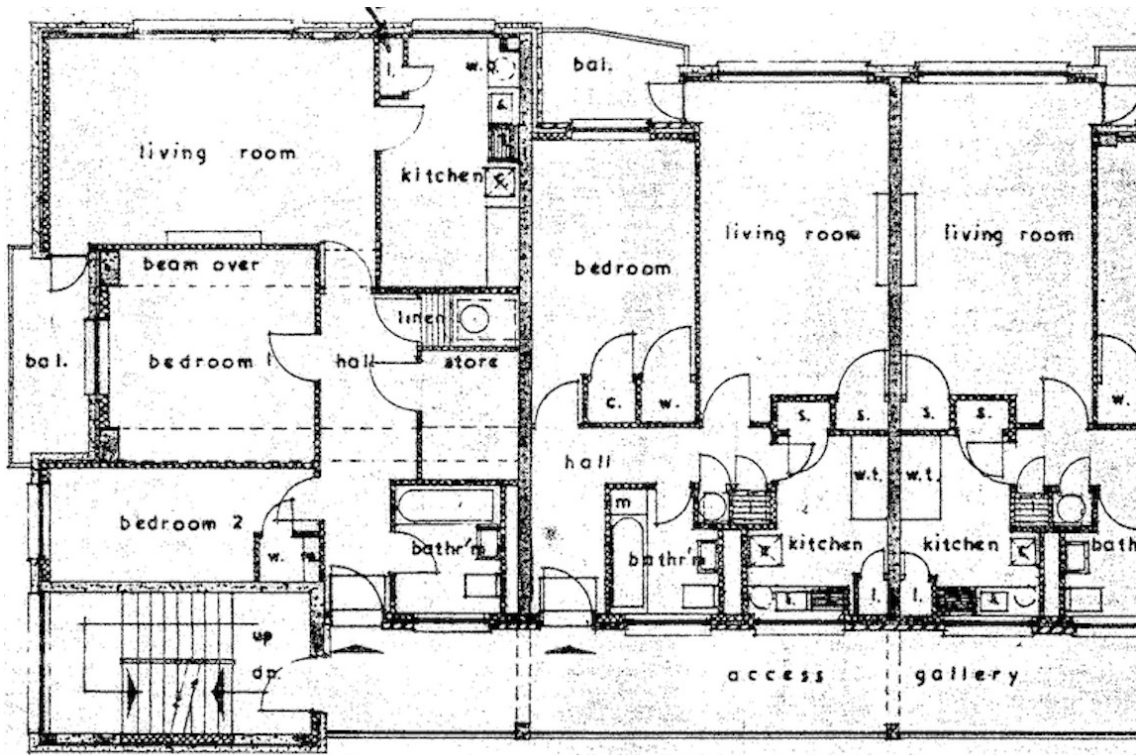
Figure 1.3: Review of archival building plan

- Most internal walls are ˜100mm thick and choosing center-line vs wall face will have a limited impact on the volume of rooms or surface areas. The structure between apartments is, however, ˜200-250mm thick. A compromise is to use centre-line for the thin partitions and face-of-wall for the structure.

- There are a number of vertical service voids. Ignoring them impacts zone volume and floor area and it is likely that voids are rather different in temperature. The approach taken is to represent the walls but set them to a [similar] boundary condition and not expicitly define the void as a zone, at least for initial assessments.

- There are a number of small spaces marked [w.] and [c.]. Their bounding walls have been defined but no explicit zone used. There are also small [linen cupboards] which tend to be 1-2 °C warmer than adajacent rooms and their walls set as [similar +2 deC] boundary conditions in their adjacent rooms. The figure below shows how these spaces were adapted during the discritisation.

- The access gallery are naturally ventilated spaces which act as a minor buffer to ambient conditions. They need to be represented by thermal zones so as to reduce the solar radition and wind exposure of the adjacent rooms.
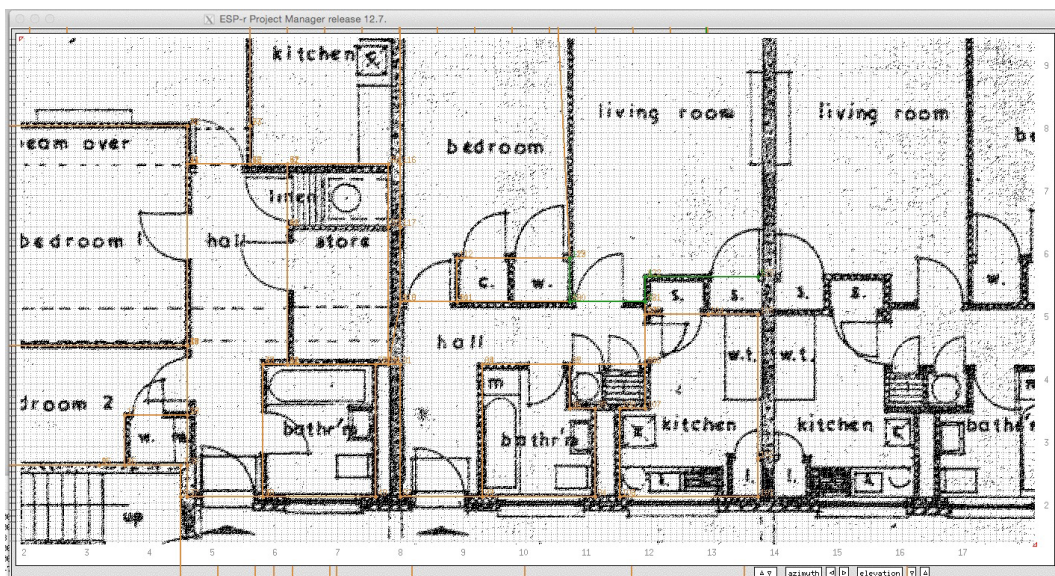
Figure 1.4: Translating plans into model entities

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The initial model form which was derived from ESP-r's in-built click-on-bitmap facility (explored in Seciton 2.8.2) is shown below. There are 42 thermal zones and ~640 surfaces. To complete the model geometry the rough openings in the facade need to have frames inserted (the frame area approaches 50% so is difficult to ignore). The stair zones could be adapted to expand over several floors as could the lifts. Once the initial level of rooms are **fully attributed** they could be replicated to form other levels of the tower block.

Zones such as the drying area behind the lifts are well ventilated and thus form an important boundary condition for adjacent rooms. And there are 14 other drying rooms in the building so the initial polygons could be replicated above and below to form a single tall zone with suitable internal mass to represent the intermediate floors.
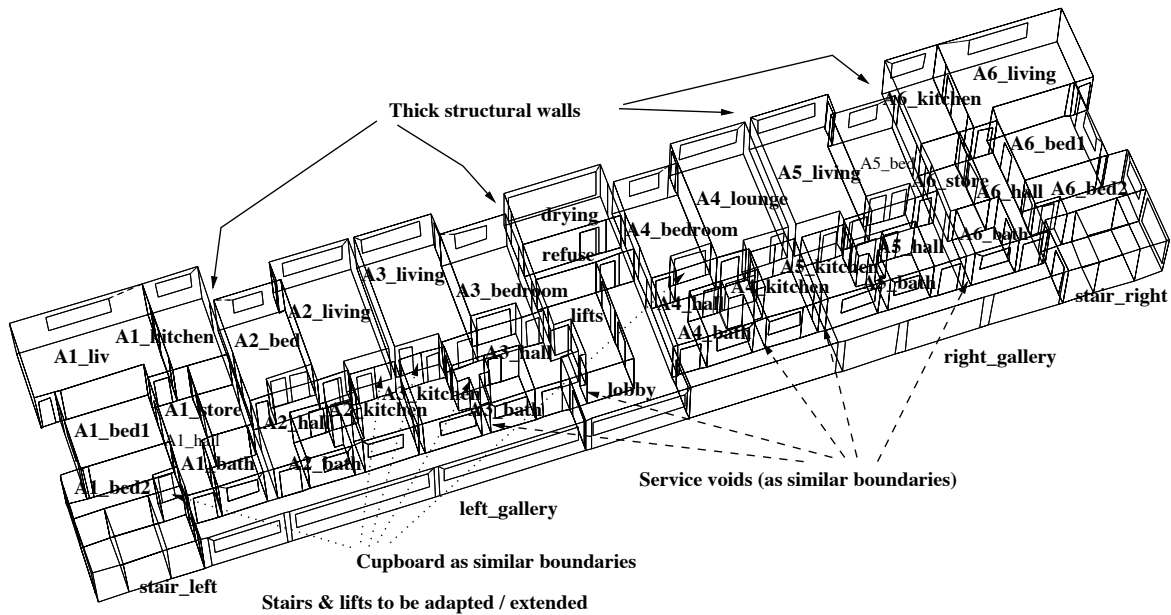
Figure 1.5: Resulting initial model

Another approach is to adopt a *face-of-wall* regime when creating a model. In smaller models this presents a minimal burden (in the order of minutes) for data input as well as
 afew seconds for assessments. The model shown below was created from site sketches drawn on graph paper assuming a 100mm grid and then scanned to underly the input grid in the interface.

In ESP-r the boundary condition directive which specifies the *thermophysical connection* between two surfaces that make up a partition is an attribute which may be applied whether or not the two surfaces are a perfect geometric match. Thus a centre-line approach with two surfaces in the same plane or surfaces which are separated in space are both valid approaches. ESP-r includes facilities to automatically discover that two surfaces likely represent faces of a partition or of internal mass and ask for confirmation from the user. Chapters 3 & 4 includes a number of examples of how building coordinates are treated in ESP-r models.

Wire-frame displays of zones and buildings in simulation tools often present facades as having little or no thickness. These displays may allows us to forget that real facades have thickness. This is particularly the case with high performance facades.

Consider the modern office construction in Figure 1.7 (left) there will be little or no change in predictions whether the centre line or the actual coordinates-in-space are used.

When confronted with complex sections, such as seen in Figure 1.7 (right), simulation practitioners often resort to abstraction to capture the overall heat transfer. How do we derive an appropriate abstraction when there are raised floors, ceiling voids, fan coil cabinets and spandrel sections? The latter are topologically solar collectors, and can easily reach over 60°C — a far higher delta T for the facade section at the ceiling void than most designers would expect. There are also thermal bridges at the spandrel to complicate matters.
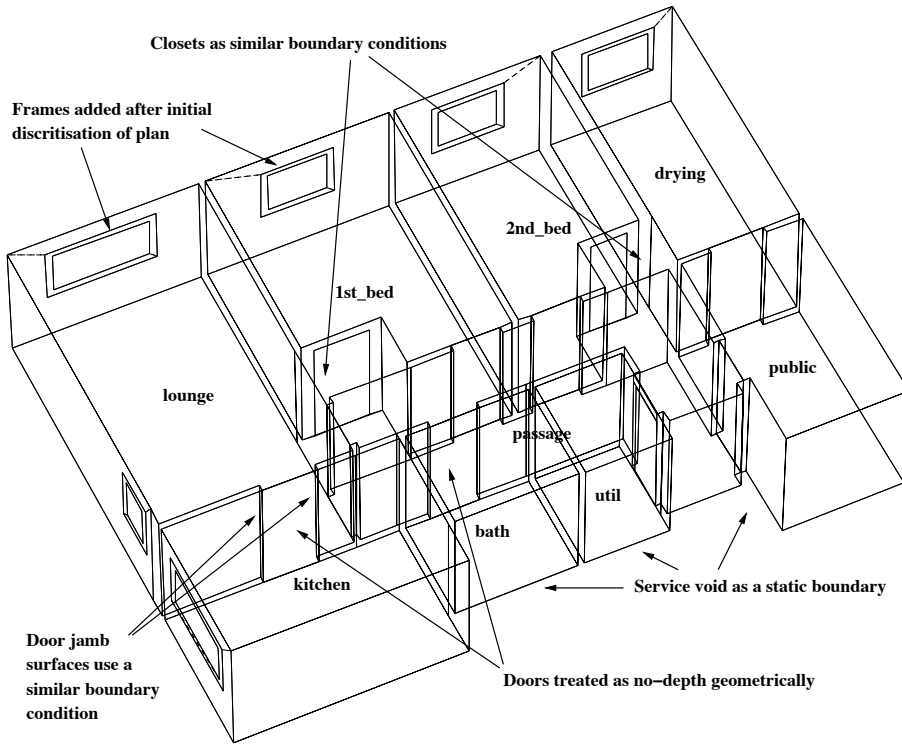
Figure 1.6: Model creation following a face-of-wall regime.

At the other extreme, historical buildings can have facades and partitions which vary in thickness. In Figure 1.8 the inside and outside faces are multi-faceted the shape of the window surround influences the distribution of light within the room. Some partitions are thin enough to be treated as centre lines and others are more than 1m thick and result in a noticable separation of the thermal zones.
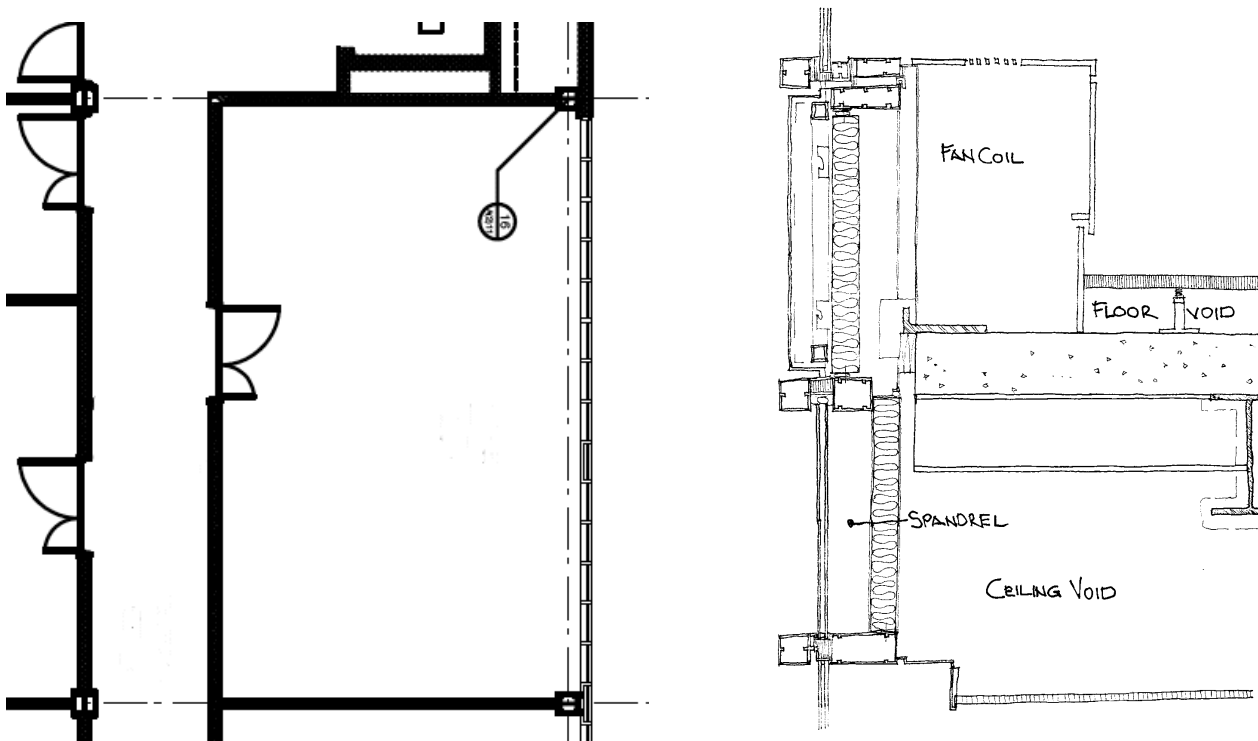
Figure 1.7 Plan of a modern building and section at spandrel.
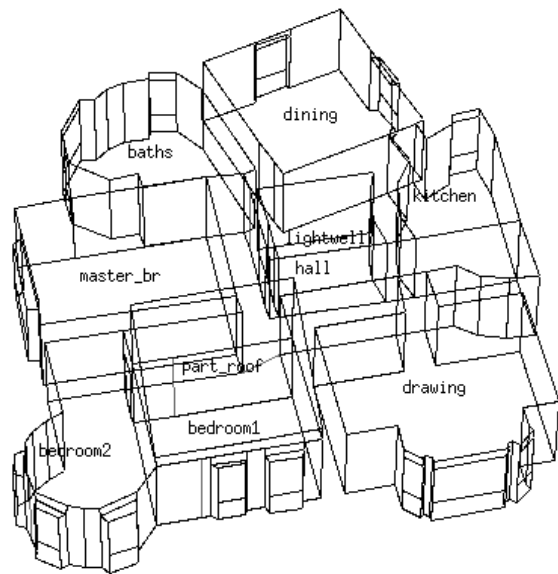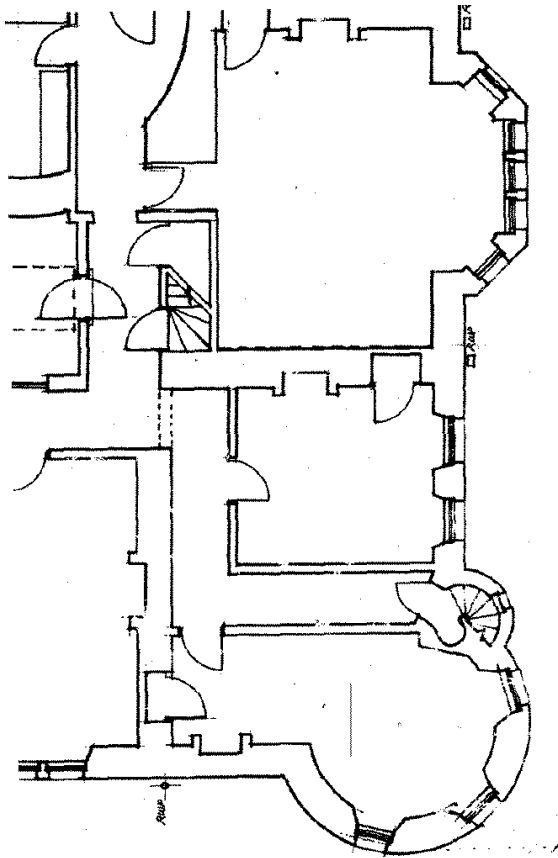
Figure 1.8 Plan and composition of a historic building.

Essentially we are approximating 3D heat flows via a collection of surfaces, each with a bespoke composition. The result, shown in Figure 1.8, substantially retains the volume and positions of the spaces rather than the exterior form of the building.

Consideration also needs to be given to tolerances in dimensioning:

- would patterns of temperature and heating change if the volume of the space was off by the thickness of the wall?
- would more sunlight enter the room if a window was lowered by 5cm or the framing was accurately rendered in space?
- is it necessary to include furniture?

Essentially our concern is to ensure that the uncertainty in the model is constrained to the point where it would be unlikely to change design decisions. Each of the above bullet points could, in fact, be tested by creating model variants and then looking at the performance differences between each descriptive approach.

An alternative to the manual creation of model variants to represent uncertainty is to formally describe what is uncertain in the model (e.g. the thickness of insulation in constructions, the density of concrete blocks, the magnitude of equipment gains, the arrival time of occupants, setpoint in thermostats, intensity of wind speeds etc.) and the scope of the uncertainty (e.g. which constructions, zones, control laws or which time period weather differs) and then comission Monti-Carlo, Factorial or Differential assessments and have ESP-r's [res] module process the sets of predictions. This is discussed further in Section 11.6.

A further discussion about options for interpreting complex three dimensional designs and commercial facade sections into appropriate models can be found in Chapter 4.

1.7 Model composition

The planning process also includes consideration of the composition of walls, floors, roofs and facade elements. Simulation tools invariably describe the composition of zone surfaces in terms of named constructions which are made up of an ordered list of materials (each of which have a set of thermophysical attributes). Each simulation suite has its own approach to implementation in terms of the form of the data and in its provision of facilities for user access, selection and management of the constructions and materials. At the planning stage the issues confronting users are largely generic:

- Identification of existing entities which are appropriate for the age and type of building
- Confirming that the attributes of entities are consistent with the construction documents
- Setting up place-holders for aspects of the building which have not yet been decided
- Identifying alternatives for possible *what-if* questions which may arrise.

ESP-r is distributed with files which hold *common materials*, *common constructions*, *common optical properties* and other common entities referenced within simulation models. There are subtle differences which will be covered in Chapter 3. The management of common data files within the ESP-r distribution database folder or in the model involves clearly defined procedures as discussed in chapter 14.

Whatever the tool's facilities, we inevitably find that some entities are ready-to-use, others might be adapted and some projects require us to add new entities from our own information sources.

Working practices which limit error during entity selection as well as supporting adaptation of existing entities to the needs of a project are critical. Tool facilities and data stores must, however be balanced with domain knowledge. Remember, construction drawings might not be a straightforward match with existing entities. For example they may not include relevant details i.e. percentage of framing, may not be sufficiently detailed or may indicate thermal bridges.

In projects which involve both models and physical experiments, good agreement with embedded temperature sensors requires model constructions with complementary thicknesses.

If we are interested in the temperature profiles within walls (for example to see how much of a 500mm thick masonry Trombe-Michel wall is impacted by a solar load) then cross sectional temperatures as in Figure 1.7 are critical to understanding. In this case the inner faces of the wall is geometrically offset from the faces associated with the stacked zones of the front facade air space where air flow is based on a dynamic solution. If you want to find out more look for the *trombe_wall* example models - there are several variants with and without control of the dampers between the front facade and the office.
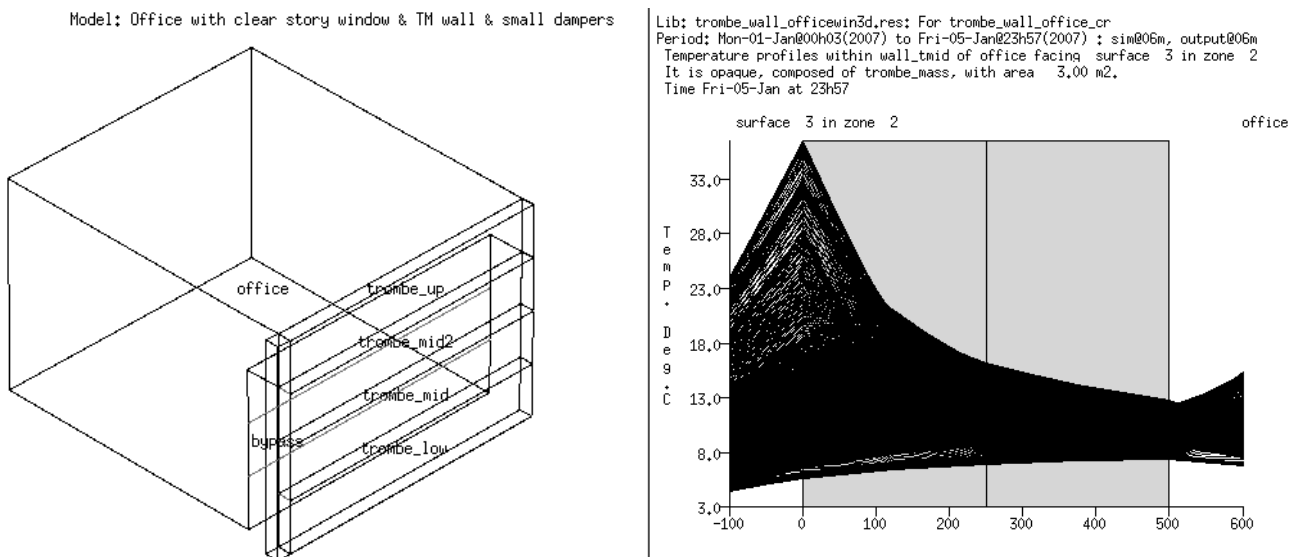
Figure 1.7 Explicit Trombe-Michel Wall and temperatures.

As building facades adapt for ever higher performance thermal bridges also become an issue — this is discussed in Chapter 4. These can be approximated in ESP-r via linear thermal bridges, but such entities require additional information which must be sourced from 3rd party software and translated into the syntax of ESP-r.
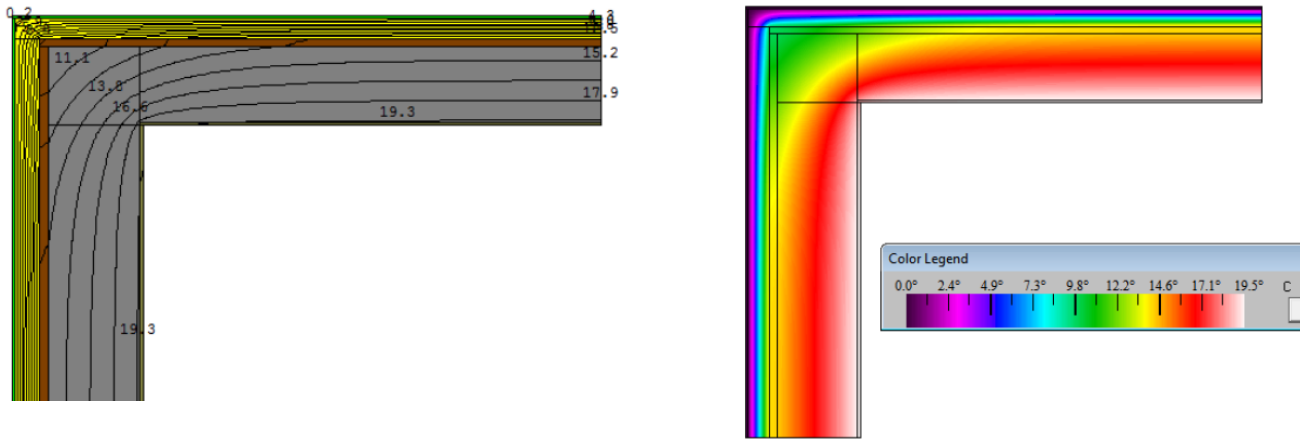
Figure 1.8 Thermal bridge effects at a corner.

Most simulation tools default to one dimensional (1D) heat transfer within constructions with homogeneous and/or nonhomogeneous layers. ESP-r offers this, but the greater challenge is that many building junctions are not well represented by 1D heat transfer. Although ESP-r can solve 2D and even 3D heat conduction the information requirements are daunting and not discussed within the current document.

1.8 How buildings are used

If we modelled a library and did not include some representation of the book collection we would need to justify our actions. It is no less important in the model planning process to consider what is happening within a building in terms of the patterns of occupancy and the heat generated by lighting and equipment. The client specification must be transformed and experienced users pre-plan the schedules for each calendar day type to aid data input and subsequent checking tasks and provide descriptions to clarify the numbers in the schedules.

The largely discredited approach "all staff are here all the time and copy machines have a constant queue of telephone directory length reports" is not indicative of the diversity which might be expected in buildings. In simulation the term diversity is used to take account of intermittent use and distribution of casual gains within buildings. Schedules can be crafted to test a range of room usage scenarios in addition to default assumptions such as those associated with code compliance tasks.

Why bother? Early clues to how buildings may fail and how environmental systems respond to different usage scenarios are a valuable input to the design process.

In ESP-r you can lump all casual gains together for definition and reporting purposes or define up to three named casual gains. Typically these will be occupants, lights and small power (equipment). If there were two kinds of lighting one gain might be *LED* and another *fluorescent*. If there is only small power in a zone then only that needs be defined.

The magnitude of a casual gain over each calendar day type is defined as a profile comprising one or more periods (no overlaps) which cover the entire day (0h00 to 24h00). Each period defines the sensible and latent loads with optional electrical characteristics (used if an electrical power flow network is defined). It is also possible to include clothing and metabolic attributes for so-called *dynamic occupants*.

During model planning sketch the pattern of the various casual gains for each of the day types indicating the different periods and the magnitude of the gains. Sketches save time during input and model checking!

If you want to explore a variety of schedules for different building types, browse through the example models and focus on how schedules are treated. Figure 1.9 shows a typical schedule for an open plan

office with a fixed schedule for a *new staff* day where everyone and every thing is assumed to be running at full tilt, diversity included on weekdays and a saturday schedule with a standby schedule.

Casual gains for L1_open_off

Casual gains in L1_open_off				
1 import from profiles database				
2 electrical data >> not included				
3 loads >> weekdays	(22)			
Period	Label	Unit	Sensib	Latent
a 0 8	Occupt	m2p	100.	0.
b 8 9	Occupt	m2p	13.	0.
c 8 12	Occupt	m2p	8.	0.
d 12 14	Occupt	m2p	15.	0.
e 14 16	Occupt	m2p	8.	0.
f 16 19	Occupt	m2p	16.	0.
g 19 24	Occupt	m2p	100.	0.
h 0 8	Lights	Wm2	1.	0.
i 8 9	Lights	Wm2	3.	0.
j 9 11	Lights	Wm2	10.	0.
k 11 14	Lights	Wm2	5.	0.
l 14 17	Lights	Wm2	9.	0.
m 17 19	Lights	Wm2	4.	0.
n 19 24	Lights	Wm2	1.	0.
o 0 8	Equipt	Wm2	1.	0.
p 8 9	Equipt	Wm2	4.	0.
q 9 12	Equipt	Wm2	10.	0.
r 12 13	Equipt	Wm2	8.	0.
0 Page --- Part: 1 of 2 ---				
@ edit casual gain labels:types				
+ add/delete/copy/import gains				
* scale existing gains				

Figure 1.9 Profiles for an open plan offices.

In ESP-r there are additional options for defining schedules of greater complexity. For example, there is a short time-step data facility which allows casual gains to be specified at each time-step.

1.9 Environmental controls

The design process involves balancing the inherent response of the building form and fabric with the patterns of activities within rooms as well as weather patterns. Sometimes these inputs into the *energy balance* of the building result in confortable conditions and sometimes environmental controls are needed. How much, how often and where questions are at the core of many research and consulting projects. How we *choose to approach* such tasks influences when information gets delivered as well as its accuracy.

Simulation suites implement environmental controls via one or more arbitrary conventions:

- *Idealised* representations of specific equipment, for example, EnergyPlus offers the *ZoneHVAC:IdealLoadsAirSystem* which is an idealised terminal VAV unit which controls a room without the need for descriptions of the central plant.

– The attributes are specific for the device but the control logic, control action and sensors are pre-defined.

- Ideal control laws which define what is sensed e.g. dry bulb air temperature, control logic that responds to the sensed condition and some form of actuation e.g. the injection of flux at some point in the model. Usually there are a limited number of parameters that can be set by the user and such controls tend to be applied to individual thermal zones. ESP-r includes this option.

– Ideal zone controls approximate real systems but present users with a mix of abstract terms e.g. radiant/convective splits and behavior e.g. proportional/integral action rather than physical devices. Frustratingly, ideal zone controls often ignore the parasitic losses and electrical demands that many practitioners are interested in.

– Ideal systems, often only roughly approximate what the practitioner has in mind. Vendors have reacted by adding more variants and/or providing additional input parameters.
Practitioners are confronted by the black art of tweaking an existing system to mimic a different design variant. Occasionally the mimicry takes on elements of a farce.

- Ideal system descriptions which define a generally recognised pattern (e.g. VAV terminals with a perimeter trench heater), via high-level parameters which are then associated with a number of thermal zones in the model. The DOE-2 simulation tool is a classic example of this approach.

- Libraries of detailed system components e.g. fan coils and valves, which can be assembled by the user into a variety of environmental systems as required and linked with control components and logic.

  – Libraries of components are, in many ways a reaction to the constraints of pre-defined system lists. Opinionated practitioners are able to be specific and evaluate alternative designs and explore many more aspects of system performance. ESP-r supports networks of system components, optionally in conjunction with mass flow network components and electrical power networks. Unfortunately detailed descriptions are tedious to set-up, manufacturers data may omit critical details, they are difficult to calibrate and debug. Few interfaces or QA reports are able to communicate fully the attributes and relationships within a network of components.

- Templates which define an environmental control system from detailed components. The template expand a limited number of descriptive terms into scores, if not hundreds of components of a known topology, typically including control components and control logic. Templates often use a high level language to support the creation of component networks.

  – Templates offer the detailed performance characteristics of components with most of the tedium removed. Whereas the older ideal systems approach might have expanded a score of user inputs into a score of equations to be solved, the template approach can generate a network of hundreds of components, and generate thousands of lines of description using *someone elses naming scheme*. Clearly the author of a template would have an advantage in understanding the resulting network composition and using it to support the design process. For others who have *any level of curiosity* about a newly created system the QA implications are substantial. If the practitioner needed to adapt or revise such a network what methodology might they use to ensure this was done correctly? If *you think* your tool only offers detailed components, look closer to see if there are abstract components available. In the early stage of design they may be more than adequate.

Many practitioners would, no doubt, feel compelled to jump into the details of their usual environmental control system. Actually, many simulation tools make it difficult not to be specific in the early stages of a simulation project. Vendors sell Wizards that offer scores of pre-defined system templates which expand into networks of wondrous detail. Wow, so much from so little work (and it didn't crash so it must be ok)!

Understand options for controlling a building by observing how it works without mechanical intervention.
Focus on demand-side management - exploring architectural options and alternative operational regimes.
Focus on transition seasons and environmental controls that can cope efficiently with part-loads and intermittent demands.
Discover patterns that stress the building and explore how interventions that mitigate the extremes can be integrated into the design.

Rounding up the usual suspects is the antithesis of a strategic use of simulation. Establishing patterns of demand as suggested in the above box provides opportunities to deliver new kinds of information.

ESP-r supports fast-track strategies to establish:

- patterns of heating and cooling demand over time,
- the frequency of extreme conditions,
- the frequency of minimal demand,
- what might happen if heating or cooling failed,
- what might happen if heating or cooling was critically undersized,
- how often will the building work satisfactorily without mechanical intervention.

Such early indicators are valuable to other members of the design team and may also result in well-founded opinions about demand side improvements and likely environmental control regimes.

So what approach to take? Here is a list of questions which might help identify whether a network of system components is suitable at the current stage of the design process:

- Do we have sufficient information to generate a network?

- What performance indicators of the network and/or components are we interested in?
- Can we explore broad-brush 'what-if' questions?
- Can we tweak component details during the detailed design phase?
- Are the physics within an idealized control or abstract component sufficient to explore a design issue? E.g. mimicking a radiant cooling system with 'purchased air' might be torturing the physics.
- What form of tool-generated documentation is available to support QA tasks?
- How does one validate a template-based system design? Is a systematic exploration of templates and components possible?
- Does the interface support detailed modifications of an initial template-based design?
- Does the interface support sufficient variants of an ideal control to allow a design team to pose relevant what-if questions?
- What support is available to move from an abstract representation to one with a higher resolution?

If the environmental controls have a schedule this should be recorded in much the same way as occupancy schedules. Indeed, there are often dependencies between occupancy patterns and environmental controls that should be resolved at the planning stage.

If there are options for the type of system or the control actions which can be applied, ESP-r can accept alternate controllers which can be tested in subsequent assessments with little additional effort.

1.10 Design of assessments

A *tactical approach* limits the quantity of information we have to deal so both the model and its performance is easier to *understand* and the *QA burden* is reduced. Computers may process a year in seconds while *staff discover opportunities and risk at a different pace*.
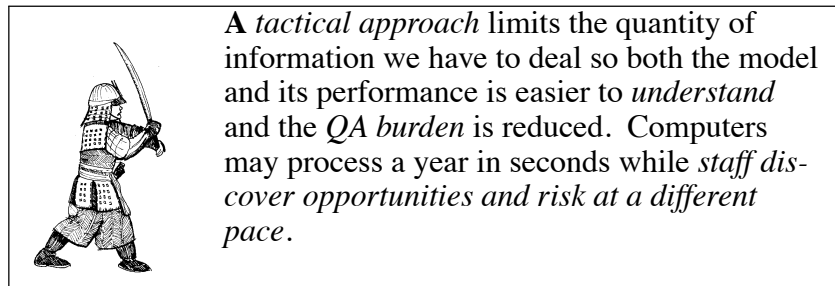
One of the early planning tasks is to identify the nature of assessments which will allow us to gain confidence in the model and modelling approach as well as deliver performance indicators well-matched to the design team goals.

This often requires that we avoid the *usual suspects* when deploying numerical tools. For example, many tools default to annual assessments and thus entrap the practitioner in a data-mining exercise.

A key initial objective is to support our own *understanding of performance* by looking at patterns in a limited set of data and so be able to spot glitches in our model as well as opportunities for improvements to the design (or the clients specification) as soon as possible.

A key tactic is to define *performance metrics* (e.g. what can we measure in our virtual world) early in the process. Some metrics e.g an energy balance within a zone, might contribute to our own understanding of the design and other metrics e.g. thermal comfort might be useful to report to others in the design team.

ESP-r workshops typically devote as much time to exploring building performance issues as is spent on model creation. Simulation suites which do not include an interactive exploration facility will include a descriptive language to specify what performance metrics are to be captured during each assessment - so learn that language!

ESP-r includes a results analysis tool *res* which scans the files which hold the domain-specific predictions from an assessment e.g. building fabric results, electrical performance, mass flows and system components. This will be covered in detail in Chapter 10. This review of planning tasks can now be tested in the context of a doctor's office.

2 Building your first model

For new users of simulation tools, the process of creating models will seem slow and will require seemingly arbitrary information. An experienced user will, of course, do the same work in a fraction of the time. In ESP-r workshops eight out of ten participants create models which simulate correctly the first time. Most are able to re-create their initial model with minimal support and in ~25% less time. Let's get to work!

This first simulation model involves refurbishment options for a general practitioner's office (UK nomenclature, in other regions this is a doctor's office or a neighbourhood medical centre). The client says the existing facility, in Birmingham, is sometimes uncomfortable and they would like to explore ideas for reducing heating costs. The client has limited resources and has requested rapid feedback on two initial ideas - improving facade glazing and reducing infiltration.

Figure 2.1 is a sketch of the surgery indicating names, composition critical coordinates as well as facade and door details. It also includes notes which will guide the creation and attribution of the model.

The composition (constructions) are described as typical late-1980s small scale commercial constructions with masonry wall U values ~0.6, the flat roof of the reception U ~0.4 and the sloped roof of the examination U ~0.4. It has air filled non-coated double glazed windows with U ~2.8 with wooden frames U ~1.6. The floor is slab-on-grade with carpet and no foundation insulation and a U ~0.7.

In Figure 2.1, the dashed lines at the upper-left indicate another room which has similar environmental conditions but no other information. ESP-r supports this level of abstraction via a boundary condition attribute - in this case *dynamic similar*.

Initial information from the client is that this is a busy practice with, on average, two people in the examination room during the hours from 9h00 to 16h00 on weekdays with staff in until 18h00. The reception area serves other examination rooms and there might be up to five people plus a receptionist.

Further questioning elicits that Thursday afternoons are for staff only and the practice is also open Saturday mornings with up to seven visitors. Lighting in the reception is 150W during the hours of 8h00 to 19h00 and the examination room is 100W over the same hours.

ESP-r represents internal (casual) gains as a schedule which applies to each defined calendar day type. By default there are weekdays, Saturdays, Sundays and holidays. For this model we need to extend the standard day types to reflect Thursday afternoons.

The room use description implies some diversity. For example, there is a lunch hour and there is a ramp-up and ramp-down of gains at the start and end of the day to represent cleaning staff in the morning and stragglers at the close of work. There are periods during the morning and afternoon with full loads so that capacity issues and the potential for overheating need to be addressed.

Even the best of buildings have infiltration. There is a discussion about both scheduled and network based air flows in the *Flow* chapter. For now let's use an initial engineering assumption that there will be 0.5 air changes per hour (ac/h) infiltration at all hours.

The detailed planning need to turn this brief of room uses into simulation entities is provided in Chapter 5. Once the form and composition of the doctor's office have been defined you will be asked to proceed to Chapter 5.

The heating set point is 21°C and the cooling set point is 23°C between 9h00 and 17h00 on weekdays with frost protection (15°C) at weekends and outside office hours. This is supplied via an air heating and cooling environmental control.
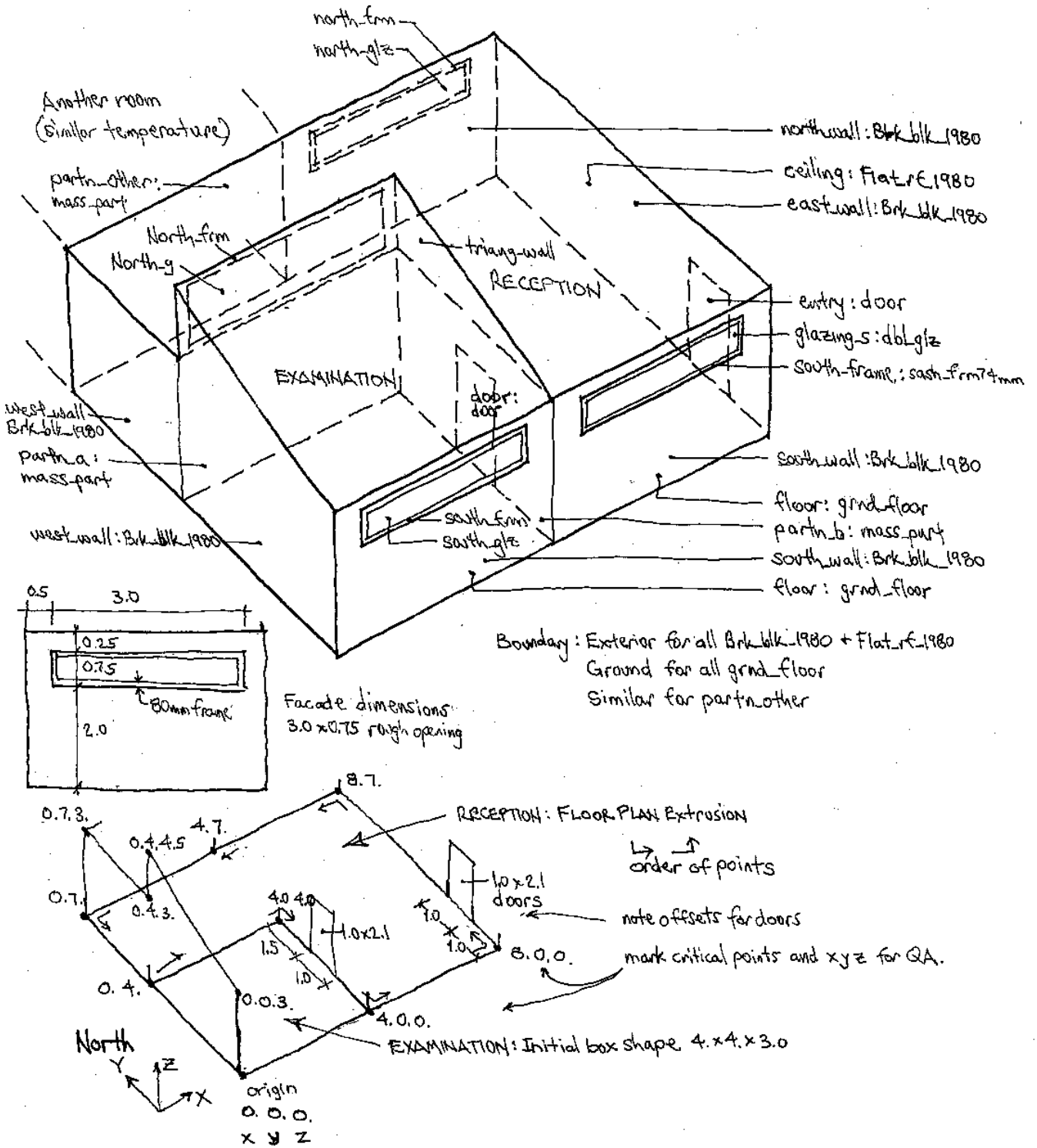
Figure 2.1: Overview of surgery.

Let's assume that we do not have a detailed specification of the components of the environmental control other than the set points, and that heating and cooling are delivered convectively. Since the design goal is to appraise changes in heating or cooling demand, not the control logic or system component performance, there is little point in providing detailed component descriptions.

Let's use an ideal zone control to characterize the response of a convective heating and cooling system to the client's set points. We do not know the capacity, so we will make an initial guess (say 4kW heating and 4kW cooling) and see how well that matches the demands.

2.1 Pre-processing information

The client has beliefs about what might make make for a better working environment and the task for simulation is to provide quick indicators of these two refurbishment options.

Get out your grid paper and note pad and keep the laptop lid closed for now. Pre-processing information and sketching the composition of our model will limit errors and make it easier for others to understand what we intend to create, and, after we have made it, will help check that it is correct. This rule applies whether we are going to import CAD data or use the in-built CAD functions of our simulation tool.

The XYZ coordinates in the lower left of Figure 2.1 take the centre-line of partitions and the inside face of exterior walls, floors and ceiling and the origin of the model is at the lower left corner of the examination room. The critical vertical points to record on your notepad are 0.0 (ground), 2.0 (window sill), 3.0 (ceiling), 4.5 (top of sloped roof).

With reference to the topics in Table 1.1 and the planning tasks above Table 2.1 sets out a methodology.

In terms of the level of detail needed in the model, the windows are not large and the questions are general and so the exact location of the windows in the model would not normally be considered critical. It is however necessary to represent the window frame accurately as it is one of the design variants the client is interested in so accuracy is needed for the glazing as well.

Table 2.1 Method for general practitioner surgery

Design Question	Simulation questions
What *specifically* do we want to know about the design?	Current frequency and extent of discomfort as well as winter heating demand Performance improvements likely from upgrading the facade glazing and reducing infiltration.
How will we know if a design idea is well-founded?	Check for improved comfort, use resultant temperature as proxy for comfort with Fanger Predicted Mean Vote (PMV) if time permits. Check for reductions in overheating hours, heating capacity and winter monthly demands. PMV at centre of each room, difference in room dry bulb temperature and Mean Radiant Temperature (MRT). Check time-response to heating. Check conditions prior to overheating periods. Start with one week in each season. Change in number of hours of discomfort, heating and cooling hours needs to be at least 20%. Capacity change criteria not established.
Model extent and level of detail?	Choose one examination room and the whole of the reception with adjacent spaces represented only as 'similar' boundary conditions. Include facade frames and accurate glazing positioning but do not bother with furniture, or doors to the un-represented adjacent spaces.
How might the design fail?	The changes in performance might be minimal. Analysis might indicate that overheating from internal gains is not mitigated by the suggested upgrades. Changes in infiltration might result in poor air quality.
What are the opportunities?	Other facade upgrades might work as well. Shading? Mechanical ventilation rather than air conditioning? Consider what would be required to implement such changes and if that would make the initial model more difficult to implement?
How do we match the available information with tool requirements?	Estimate time to implement the form, composition, operation and control for the spaces. Consider who to do the work and who checks the work. Establish data input requirements for controls. Review available reporting options e.g. thermal comfort reporting, timing of peak demands and energy use over time.

Design Question	Simulation questions
Is our approach robust?	Sketch the rooms, identify critical dimensions and check. Look to see if changes in room use are related to occurrences of discomfort and environmental controls.
	The initial model might need to be extended to check additional design variants. Consider if an air flow network or detailed environmental system components may need to be implemented and estimate resources.
	Confirm naming scheme for model entities. Ensure supporting documents are archived and notes transferred to electronic form.
Are the performance predictions credible?	Check predictions with senior staff. Consider a quick assessment with code compliance tool to see if it indicates a similar change in heating and cooling demands.
	Consider whether diversity assumptions for occupancy and small power use are adequate - adjust the duration of peak occupancy.

Questions to ask about equipment size:

- what boundary condition(s) and operational regime(s) are associated with peak conditions?
- how often do these happen?
- what criteria are used to determine component size?
- what criteria might you use to judge part-load performance?

ESP-r, unlike some simulation suites, includes both *ideal zone controls* and component based descriptions of environmental systems. For this initial model we can begin with *ideal zone controls* and heating and cooling delivered convectively. ESP-r demands an initial guess at the heating and cooling capacity, but otherwise we can maintain our focus on demand-side issues.

2.2 Model registration

With planning complete we can take the client's specification and our sketches and notes and startup the simulation software. If you are using another simulation tool adapt as required.

In subsequent sections interface interactions and typing are shown in `typewriter text`.

Choose naming schemes which will clarify what you are creating. This initial project is related to a doctor's surgery. Surgery is a clearer name than TEST1. Think. Before you press [OK].

Exercise 2.1   Exercise 2.1 in the *Exercises Appendix* will guide you through the *model registration* process. After you complete Exercise 2.1 the interface will look like Figure 2.2 and there will be a set of folders as in Figure 2.3.

Exercise 2.2   Exercise 2.2 in the *Exercises Appendix* will guide you through a *model archiving* process. Archiving is a good habit. ESP-r has facilities without an undo option so trigger points in work-flow are needed.

> Make a note of where your model is located and the intent of the model.
> **Now is the best time** to make the first archive of your model!
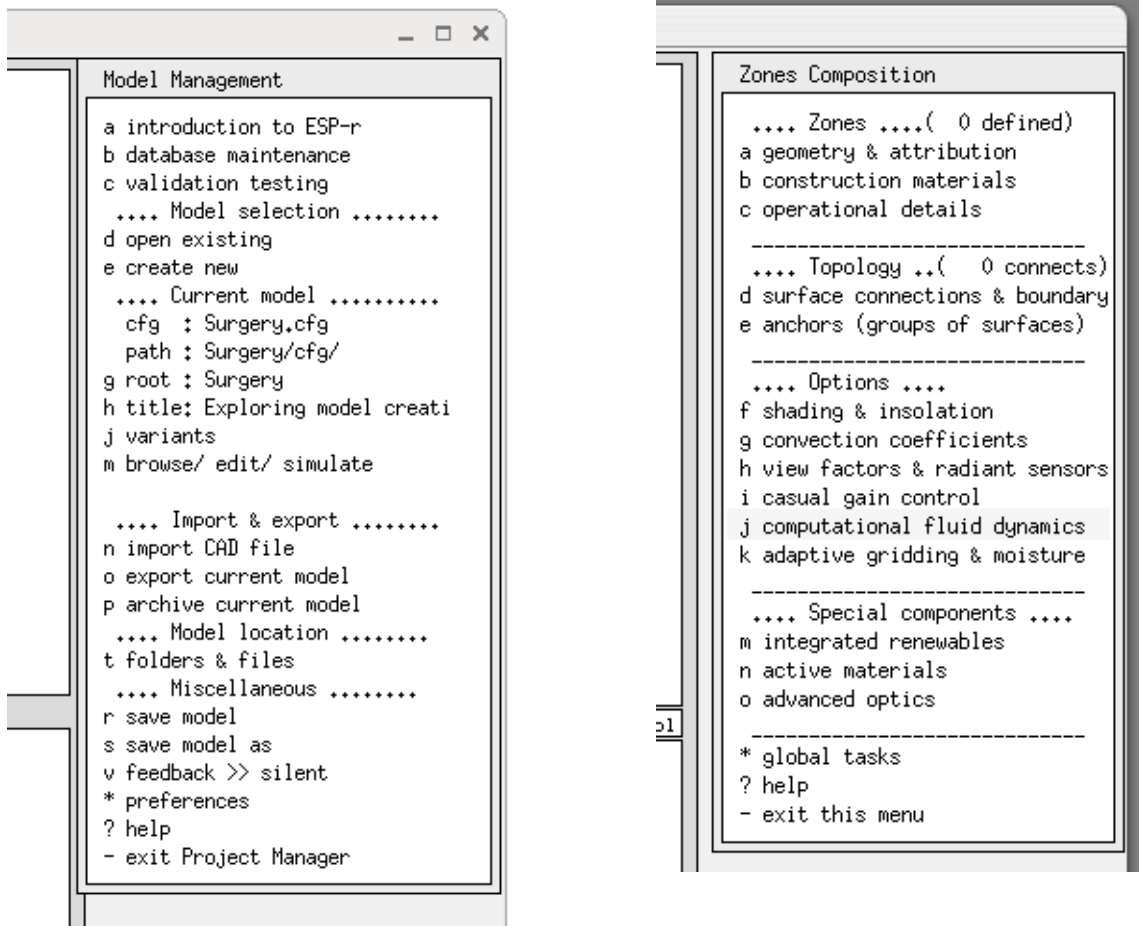
Figure 2.2: Model management and zones menus.
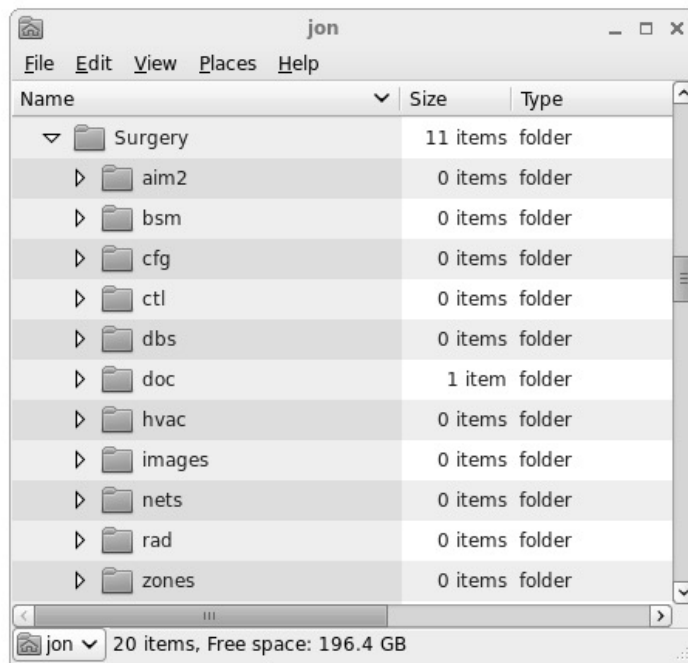
Figure 2.3: Naming pattern for ESP-r model folders.

2.3 Review of weather patterns and common data

At this point we have registered a new project. There are a number of tasks to complete before defining the form and composition of the surgery. This section and Section 3.1.1, Section 3.5 and Exercises 3.1

and 3.3 in the *Exercises Appendix* are concerned with the following tasks:

- Find a weather file and typical periods for our assessments.
- Review common materials and constructions.
- Select or create place holders for constructions and materials.

A *tactical approach* uses short weather sequences for model calibration and focused explorations. As examples, what can a Monday morning start-up after a cold weekend tell us much about the characteristics of a building? Do peak summer demands coincide with the hottest day or they follow a series of hot days?

The ESP-r weather module (**clm**) provides facilities to explore weather data sets via graphs, statistics and pattern analysis facilities (see Section 3.1). Our initial task is to use these facilities to better understand the patterns in Birmingham and identify useful assessment periods.

To work with weather, select the menu option `Model Management -> Database Maintenance` and in the options shown in Figure 2.4 select the `annual weather` option.

```
 Standard data maintenance:
   Folder paths:
   Standard <std> = /opt/esru/esp-r/databases
   Model <mod> = no model defined yet
 _____
a annual weather          : <std>clm67
b multi-year weather      : None
c material properties     : <std>material.db4.a
d optical properties      : <std>optics.db2
e constructions           : <std>multicon.db5
f active components       : <std>mscomp.db1
g event profiles          : <std>profiles.db2.a
h pressure coefficients : <std>pressc.db1
i plant components        : <std>plantc.db1
j mould isopleths         : <std>mould.db1
k CFC layers              : <std>CFClayers.db2.a
l predefined objects      : <std>/predefined.db1
 _____
? help
- exit this menu
```

Figure 2.4 List of ESP-r common data stores.

 Section

Read Section 3.1 about search techniques for identifying an appropriate week in winter with a cold weekend, and a summer week with a sequence of warm days. For the surgery the Birmingham UK weather mentioned in Section 3.1 note the relevant periods to include in assessments.

2.4 Locating constructions for our model

Identification of constructions and required materials prior to defining the geometry of the surgery forces us to consider aspects of its composition during planning and allow attribution of our model as we create it. It can also identify relevant questions for the design team early in the process. In the surgery we have only a limited specification of the building composition. Our challenge is to populate the surgery from existing common construction data.

Chapter 6 provides an in-depth discussion about the common data files distributed with ESP-r, how to manage materials, constructions, optical property sets, how to explore common data items and how to embed new information. For example, common materials are held in classes such as Brick, Concrete, Metal, etc. and each class holds a list of related materials as seen in Figure 2.5. In projects we may need to adapt existing constructions by selecting alternative materials or creating material variants that match what will be used in a specific project.

```
Materials Classes

  Description          No. Items
a Brick                      11
b Concrete                   20
c Metal                      11
d Wood                       23
e Stone                       9
f Plaster                    15
g Screeds and renders        12
h Tiles                      18
i Asphalt and bitumen        14
j Asbestos                    4
k Insulation materials (1)   21
l Carpet                     12
m Glass                      12
n Earth                      11
o Insulation materials (2)   22
p Board and Sheathing         7
q Non-homogeneous             6
r GAPS                        6
  _____
+ manage classifications
! list database entries
? help
- exit
```

```
X  ESP-r Project Manager release 12.0.

Materials in Concrete ( 2) with 20 entries.

  Units: Conductivity W/(m deg.C), Density kg/m**3
  Specific Heat J/(kg deg.C) Vapour (MNs g^-1m^-1)
  |Conduc-|Den- |Specif|IR  |Solar|Diffu|Description of material
  |tivity |sity |heat  |emis|labs |resis| name        : documentation
a  0.380 1200.   653. 0.90 0.65     6. light mix co: Light mix concrete (inorganic-p
b  0.240  750.  1000. 0.90 0.65    10. aerated conc: Aerated concrete block (inorgan
c  0.160  500.   840. 0.90 0.65    13. aerated conc: Aerated concrete (inorganic-por
d  0.250   10.   837. 0.90 0.65    12. refrac insul: Refracory insulating concrete
e  0.170  450.   837. 0.90 0.65    12. vermic aggr : Vermiculite aggregate concrete
f  0.960 1800.   840. 0.90 0.65    18. no fines con: No fines concrete
g  0.250 1040.   960. 0.90 0.65     8. foamed slag : Foamed slag concrete
h  0.510 1400.  1000. 0.90 0.65    10. block inner : Block inner (3% mc)
i  0.160  600.  1000. 0.90 0.65     6. foamed inner: Foamed inner block (3%mc)
j  0.170  600.  1000. 0.90 0.65     8. foamed outer: Foamed outer block (5%mc)
k  0.900 1950.   840. 0.90 0.65    18. Glass reinf : Glass fibre reinforced concrete
l  1.400 2100.   653. 0.90 0.65    19. heavy mix co: Heavy mix concrete
m  1.400 2100.   653. 0.90 0.48    19. Stone clr co: Stone colour heavy mix concrete
n  1.400 2100.   653. 0.90 0.21    19. white ptd co: White painted heavy mix concret
o  0.510 1400.  1000. 0.90 0.25    10. block white : block white painted inner (3% m
p  1.060 1950.  1000. 0.90 0.40    18. concrete blo: concrete block (milton keynes)
q  0.230  800.  1000. 0.90 0.65    13. aerated_conc: Aerated concrete autoclaved  .8
r  1.930 2400.  1000. 0.90 0.70    13. concrete hi-: Concrete high density (UK code)
s  1.350 2000.  1000. 0.90 0.70    13. Cast concret: Cast concrete (UK code)
t  1.130 1800.  1008. 0.90 0.70    13. Concrete med: Blockwork (UK code)
  _____
* add/ delete/ copy material
! save materials file
? help
- exit this menu
```

Figure 2.5 List of materials classes and concretes.

▶ **Section**

For the surgery, read Section 3.4 (common materials) and Section 3.5 (common constructions).

▶ **Exercise 3.7**

When you have done that, carry out Exercises 3.7 and 3.8 in order to locate the following entries in the standard common constructions file multicon.db5):

```
Construction Classes

  Description             No. Items
a opaque facade constructions    9
b internal partitions            6
c inside and outside doors       4
d glazing (transparent construc) 8
e frames for doors & windows     8
f flat and sloped roofs          9
g internal ceilings and floors  14
h ground floors & crawl-spaces  14
i equipment cases furniture etc. 20
j legacy constructions & models  6
k constructions for UK compliance 22
  _____
+ manage classifications
! list database entries
? help
- exit
```

```
Constructions in walls ( 1) with  9 entries.

  Constructions in category walls
a AWI_06   OPAQUE AWI_06 wall from IBO book
b AWI_06_inv  OPAQUE AWI_06 inverted wall IBO book
c cavity_brick  OPAQUE UK uninsulated cavity brick 1930
d Brk_blk_1980  OPAQUE UK cavity brick-block 1980
e brk_blk_2012  OPAQUE UK cavity brick-block 2012
f Brk_sip2013  OPAQUE UK brick facing over SIP 2013
g TimberU0.23  OPAQUE timber rainscreen over stud wall
h DAI_04   OPAQUE IBO DAI_04 wall with rainscreen
i DAI_04_inv  OPAQUE inv IBO DAI_04 wall w rainscreen
  _____
# view g-value
1 add/delete/copy/invert
! list contents
> save data
? help
- exit this menu
```
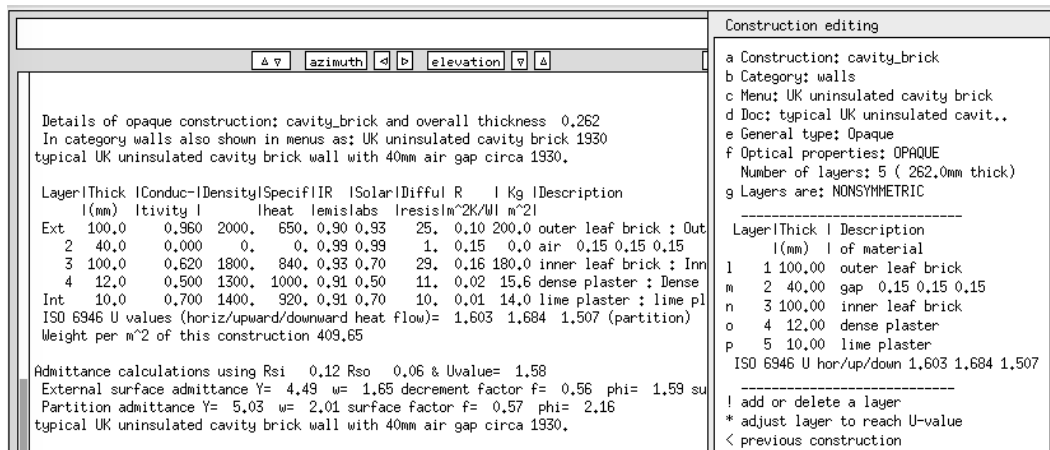
Figure 2.6 Constructions categories, wall category, & entry for cavity brick.

- an exterior wall - Brk_blk_1980 a mid-80s insulated brick & block wall 0.273m thick U=0.618
- a commercial grade exterior door - door is 25mm of solid oak 0.025m thick U=3.316
- a thermally-broken alternative door - door_u1.5 is oak with insulated core 0.061m thick U=1.5
- an interior fire door - int_doors internal solid wood door 0.025m thick U=2.554
- an internal heavyweight partition - mass_part is a white painted concrete block 0.240m thick U=1.561
- double glazing for the existing windows - dbl_glz uncoated double glazing with 6mm glass with DCF7671_06nb optics 0.024m thick U=2.811
- low-e glazing for alternative windows - tripglz_1.8 is non-coated triple clear float glazing with trip_glz_18 optics 0.042m thick U=1.897
- standard wood window framing - sash_fr55mm is a wood sash frame 0.055m thick U=1.686
- thermally-broken alternative framing - drei3holz insulated wood window frame 0.064m thick U=0.730
- a floor which includes some ground layers - grnd_floor carpet on sleepers over slab floor with earth below 0.975m thick U=0.699
- a ceiling for the sloped roof of the examination room which also acts as a roof - Pitch_rf1980 concrete tile pitched warm roof from mid-80s 0.300m thick U=0.413
- a flat ceiling/roof for the reception - Flat_rf_1980 flat insulated light concrete with ceiling 0.204m thick U=0.390

The thermally broken alternative framing in the list above is intended for a PassivHaus project and one with a U value of ~1.0 would be more in keeping with this project.

When you have completed the exercises you will have compiled a list of the construction names to associate with the Surgery model.

2.5 Zone composition tactics

Before we begin defining our zones let's review tactics. For the purpose of this exercise we are going to use ESP-r's in-built CAD facilities. We are going to use these facilities so as to minimize the number of keystrokes and avoid errors. Here are the tactics:

- plan for maximum re-use of existing information
- use the information in your planning sketches and notes
- take opportunities to embed documentation in the model
- give entities meaningful names and use attribution early-on in the processing
- learn the tool well enough to use in-built facilities to copy, edit and transform

ESP-r has numerous places to document assumptions. Of course you never lose scraps of paper and you always remember the assumptions you made four months ago and not be asked to demonstrate that you followed procedures or used the correct values.

> QA works better if something that looks like a door, is named door and is composed of a door type of construction. Where attributes reinforce each other it is easy to notice if we get something wrong!

Simulation suites typically provide alternatives for describing common room shapes. ESP-r supports rectangular shapes (origin plus length/width/height and rotation), extruded floor plans (ordered list of points on the plan plus a Z value for the base and top) as well as general polygon enclosures.

The surgery reception is L-shaped and thus a floor plan extrusion is a good initial starting point. The examination room could be built from a floor plan or a rectangular shape. CAD and attribution facilites can then be used to insert facade elements and adjust geometric properties.

Figure 2.7 shows the development of the floor plan into the reception and subsequent transforms:

- The initial floor plan of the reception is extruded into an enclosure with 7 walls, base and top.
- The initial surfaces are attributed for name.
- Doors are inserted into the partition and to the right facade of reception, named and attributed.
- The rough-openings for horizontal windows are inserted into the reception north and south facades. These are made of the frame material.
- The glazing is inserted (via frame facility) into the frames, named and attributed.
- The surfaces in reception are attributed for composition.
- The initial box for the examination is created.
- The Z values for two vertices edited to form the sloped ceiling.
- The right and back walls of the examination are removed.
- The attributed partitions and door from the reception are copy-inverted into the examination.
- The triangular wall is created from the existing vertices, named and attributed.
- The frame of the upper north window via existing vertices, then named and attributed.
- The glazing for the upper north window is inserted at 80% of the parent, named and attributed.
- The remaining surfaces of the examination are named and attributed for construction.
- The topology check facility is run to define the boundary conditions for all surfaces.

This sequence supports the tactics outlined above, in particular the re-used surfaces are already attributed and thus can be inherited. It takes less time to copy a partition and door than to re-create and avoids the risk of mis-alignment. The exercises allow you to explore such sequences and after you gain experience you may find further tweaks to improve your work-flow.

Defining the reception

If you are working with something other than ESP-r you will need to adapt.

▶ **Exercise 2.3**   Using the planning sketch (Figure 2.1) and with reference to the geometric transforms (Figure 2.7) complete Exercise 2.3.
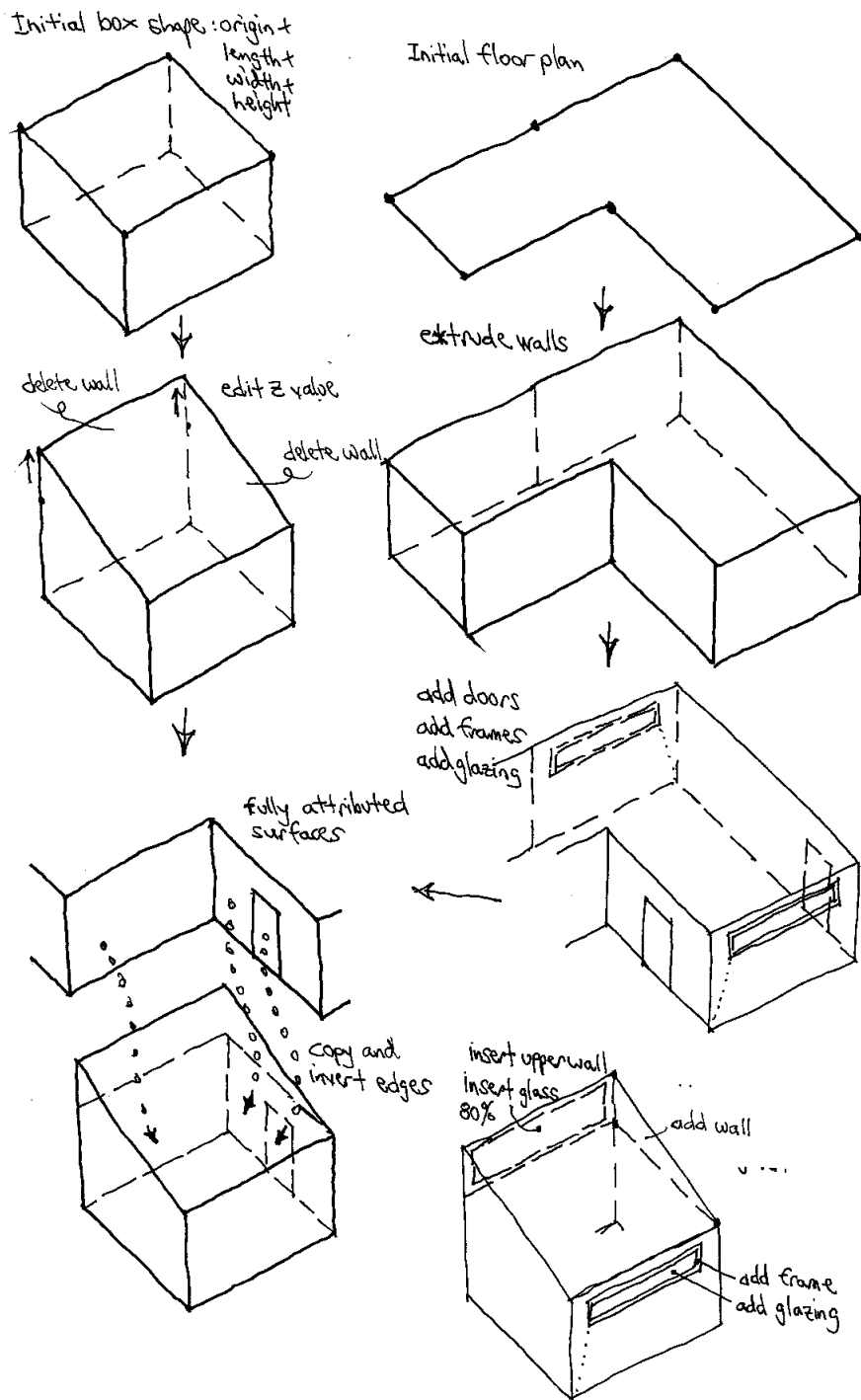
Figure 2.7 Sequence of geometric transforms for the surgery.

Figure 2.8 shows the reception after the initial extrusion of the floor plan. Notice that:

- The zone geometry menu has been updated to reflect the new surface information. For example the volume of the reception is 120.0 m^3 and the base of the reception changed to 40m^2.

- The text summary includes a synopsis of the geometry of the zone and a list of the attributes and derived values for each of the surfaces. You will notice that the word UNKNOWN shows up many times so there is still work to be done!

- You will also notice that the surfaces have been given names like Wall-1 and Base-9. These are unambiguous without being particularly helpful.

Model: Exploring ESP-r syntax via an initial model

←Wall-5
←Top-8
←Wall-4
←Wall-6
reception
←Wall-7 ←Wall-1 ←Wall-2 ←Wall-3
↑Base-9

△ ▽ azimuth ◁ ▷ elevation ▽ △ image control capture

Zone 1 Geometry

a name: reception
b desc: reception describes an L
   attribution incomplete!
   origin @   0.0   4.0   0.0
   volume: 120. m^3
c base/floor area: 40.0 m^2
   opaque constr.: 170. m^2
   transp. constr.: 0.000 m^2
─────────────────────────────
d vertex coordinates   (14)
e surface list & edges   (9)
f surface attributes
─────────────────────────────
g solar dist. & calc directives
h solar obstruction
i rotation & transforms
j linear thermal bridges
k BASESIMP defiitions
l visual entities (Radiance)
m predefined entities
n ≫ zone is air filled
─────────────────────────────
* list zone & surface details
! save
t reporting ≫ silent

> jump to next zone
? help
- exit this menu

A summary of the surfaces in reception(1) follows:

Sur	Area	Azim	Elev	surface		geometry			construction	environment
	m^2	deg	deg	name		optical	locat	use		name	other side
1	12.0	180.	0.	Wall-1	OPAQUE	VERT	–	–	UNKNOWN	< not yet defin
2	12.0	270.	0.	Wall-2	OPAQUE	VERT	–	–	UNKNOWN	< not yet defin
3	12.0	180.	0.	Wall-3	OPAQUE	VERT	–	–	UNKNOWN	< not yet defin
4	21.0	90.	0.	Wall-4	OPAQUE	VERT	–	–	UNKNOWN	< not yet defin
5	12.0	0.	0.	Wall-5	OPAQUE	VERT	–	–	UNKNOWN	< not yet defin
6	12.0	0.	0.	Wall-6	OPAQUE	VERT	–	–	UNKNOWN	< not yet defin
7	9.00	270.	0.	Wall-7	OPAQUE	VERT	–	–	UNKNOWN	< not yet defin
8	40.0	0.	90.	Top-8	OPAQUE	CEIL	–	–	UNKNOWN	< not yet defin
9	40.0	0.	-90.	Base-9	OPAQUE	FLOR	–	–	UNKNOWN	< not yet defin

Figure 2.8: And here is what it looks like after initial extrusion!

Exercise 2.4

The default viewing parameters for the wire-frame geometry can be adjusted to alter the viewing direction, focus and the extent of information displayed. Control of the wire-frame view is a basic skill which is covered in Exercise 2.4. Spending a few minutes exploring these controls will speed up your interactions.

2.5.1 Doors and windows

In ESP-r, windows and doors should be included as surfaces in a model *if they are thermally important*. A tactical approach also includes windows and doors if they make it easier for *others to understand* the model - we save time because we do not have to explain why we have omitted entities.

Essentially a surface is a window or door if you decide it is and give it a name that reminds you of this decision and attribute its composition accordingly. The rules are:

• any surface in a model can be glazing or a door with the exception that a transparent surface cannot be used for a back-to-back connection representing mass *within a zone*

• their shapes are constrained only by normal polygon rules (flat and less than 120 edges)

• frames around windows are doors are optional

• there is no requirement that glazing or doors are a *child* of another surface (see *Entities Appendix* for more on this)

- doors and glazing can be bounded by more than one surface (e.g. glazing could have a frame on the left and top and right but adjoin a spandrel panel on the bottom edge)
- the base of a door (or glazing) can be at floor level or it can have a raised sill
- door and window composition can be any valid construction e.g. doors can be transparent or opaque. Windows can be opaque (even though that would tend to confuse others)
- if you want to represent the *adjacent-to-frame* portion of glazing differently from the *centre glass* create two separate glazing surfaces
- one or more linear thermal bridges can be associated with edges in the zone (based on analysis done in 3rd party applications)

In ESP-r, solar radiation will pass through any surface facing the outside or another zone which has an optical attribute set to something other than OPAQUE. There are also options to use optical and thermal properties from so-called *Complex Fenistration Components* which draw on bi-directional data in the *IGDB* databases. One exeception - back-to-back partitions within a room which should both be OPAQUE.

Other simulation tools may treat doors and windows as simplified entities e.g. a solar heat gain fraction might be used rather than explicitly treating radiation and convection.

You have several choices in the treatment of window frames. You can explicitly represent frames as one or more surfaces in the zone. A frame may wrap around the glazing or you can lump all frames facing one orientation into a single surface.

If the accurate positioning is important then create zones with explicit representations of glazing. If only area and orientation are important use an abstract approach lumping glazing by type and orientation into single surfaces. Issues to consider:

- if a large pane of glass is used in a room with small surfaces then you may wish to subdivide the glass
- if you are calculating view-factors then small dimensions may confuse these calculations - a frame 20mm wide around a large glazing or door surface may not get enough grid points for an accurate calculation.
- if you are interested in local comfort then you should consider increasing the geometric resolution in the portion of the zone where comfort is being assessed.
- if the impact of solar distribution is important (e.g. a passive solar design) then you may want to subdivide the floor and the major thermal mass to account for the patches of sunlight.

In ESP-r, air passes between rooms ONLY if you define ventilation via an air flow schedule or create an air flow network. It is optional to include explicit surfaces as visual clues.

If your ESP-r model is going to be exported to an application which has a different set of rules for windows include such criteria in the model planning. For example, Energy Plus requires glazing to be a child surface of an opaque parent surface. Test various approaches to find which works best.

ESP-r provides a number of options for adding and/or inserting new surfaces into a zone. You will use these frequently so it is useful to review the options on the left portion of Figure 2.9:
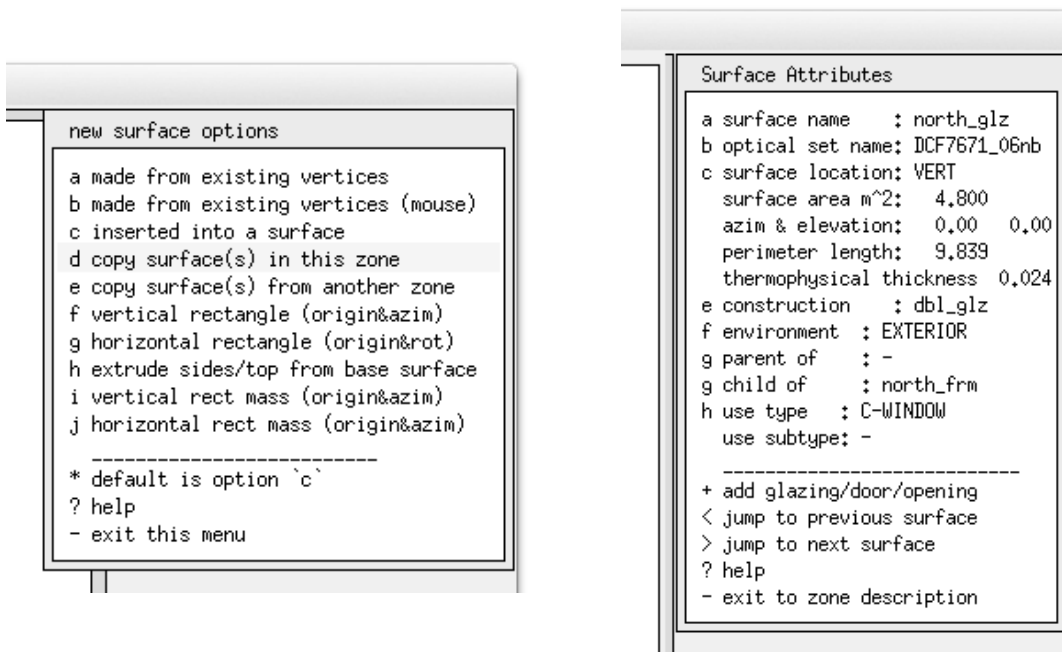
Figure 2.9: Options for creating surfaces and defining use.

- *made from existing vertices* - you type in an ordered list of (existing) vertices in the zone. If looking from outside go anti-clockwise from the lower left corner if possible. If looking from the inside go clockwise from lower right corner.

- *make from existing vertices (mouse)* - click on points of the wire-frame view to create the ordered list.

- *inserted into a surface* (with further options to do it at the base of a surface (door), inside the parent via offsets and width and height, as a percentage of the parent surface or as a fixed width frame within the parent surface.

- *copy surface in this zone* - does what it says with an option to transform and rotate and rename the copied surface.

- *copy surface in another zone* - with option to invert edge ordering (flip the surface around) rotate and/or transform the surface. Attributes are retained except for boundary conditions.

- *vertical rectangle* - creates a rectangular surface given an origin XYZ, width, height and rotation.

- *horizontal rectangle* - ditto but horizontal

- *extrude sides* - takes a surface of arbitrary shape and orientation and extrudes along the surface normal to form sides and an end. Like a floor plan extrusion, but based on an existing surface.

- *vertical rect mass* - like vertical rectangle but creates two surfaces with joined boundary conditions. Might represent a bookcase or a demountable partition.

- *horizontal rect mass* - like horizontal rectangle but creates two surfaces with joined boundary conditions. This is an easy way to form a desk-top.

Surfaces, in addition to a name, have a usage attribute. Some building codes require that facade surfaces are identified in ways support automated modifications to surface sizes or attributes. In ESP-r we might identify a surface as a code compliant WINDOW. A future version of ESP-r will also make use of an opening type attribute to help form air flow network (currently usage and opening attributes are only used for documentation).

Exercise 2.5   Exercise 2.5 inserts the entry door and the door to the examination room and then the frames and windows on the north and south facades.

Of course, at this point all of the initial entities have default names and many of their attributes are UNKNOWN. Surface attribution is the subject of the next section.

2.5.2 Completing attribution

To name something is to own it.
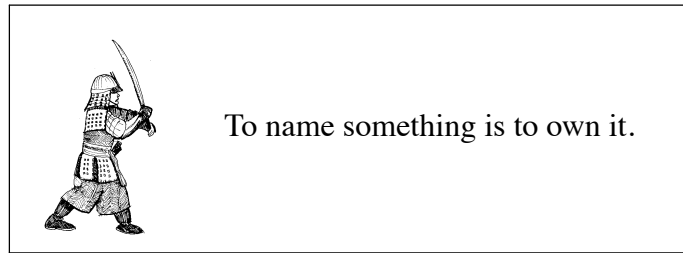
Tactically, we want to make it easy for others to understand our models. Clear names increases the speed and accuracy of selection from lists and clarifies reports. So attribute names of surfaces first.

One pattern that has been seen to work is roughly:

- names like floor, ceiling, entry_door have almost instant recognition
- if the floor or ceiling is represented by several surfaces then append a unique identifier e.g. floor_a, floor_b or floor_front, floor_bk
- walls that face the outside might indicate which way they face via north_wall, east_wall but if a model might be rotated such names can be confusing so front_wall is better
- naming partitions based on the zones on each side e.g. kitchen_partn, coridor_partn, some prefer partn_a, partn_b.

This pattern gives a clue about the location and composition of the surface. Note: non-English names are ok as long as the ASCII character set is used.

Figure 2.10: Surface(s) attribution before and after.

Please review and explore Exercise 2.6 *Attributing surfaces*.

 Exercise 2.6
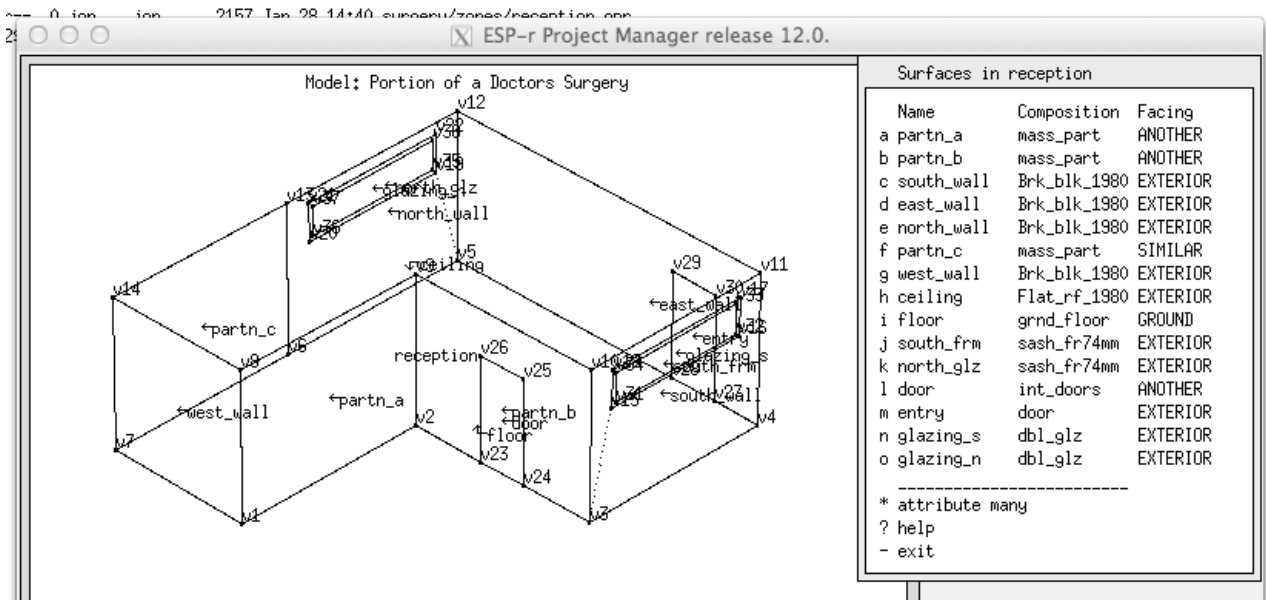
Figure 2.11: Reception after the addition of frames windows and doors.

2.5.3 Adding the examination room

The examination room is rectangular in plan, but has a sloped roof and it shares partitions with the reception. The geometric transforms in Figure 2.7 starts with a simple box shape, transforms it by editing coordinates to elevate the roof, deleting two surfaces and then copying surfaces from the reception and then using existing vertices to create the remaining surfaces.

▶ Exercise 2.7 The specific steps to add the examination room are the subject of Exercise 2.7. When you complete the exercise compare with your initial sketches. The transition from a box (in the upper part of Figure 2.12) to the room in the lower part of Figure 2.11 involves lots of steps and plenty of opportunities for error. The process of checking model details is covered in Sections 15.6-15.9.
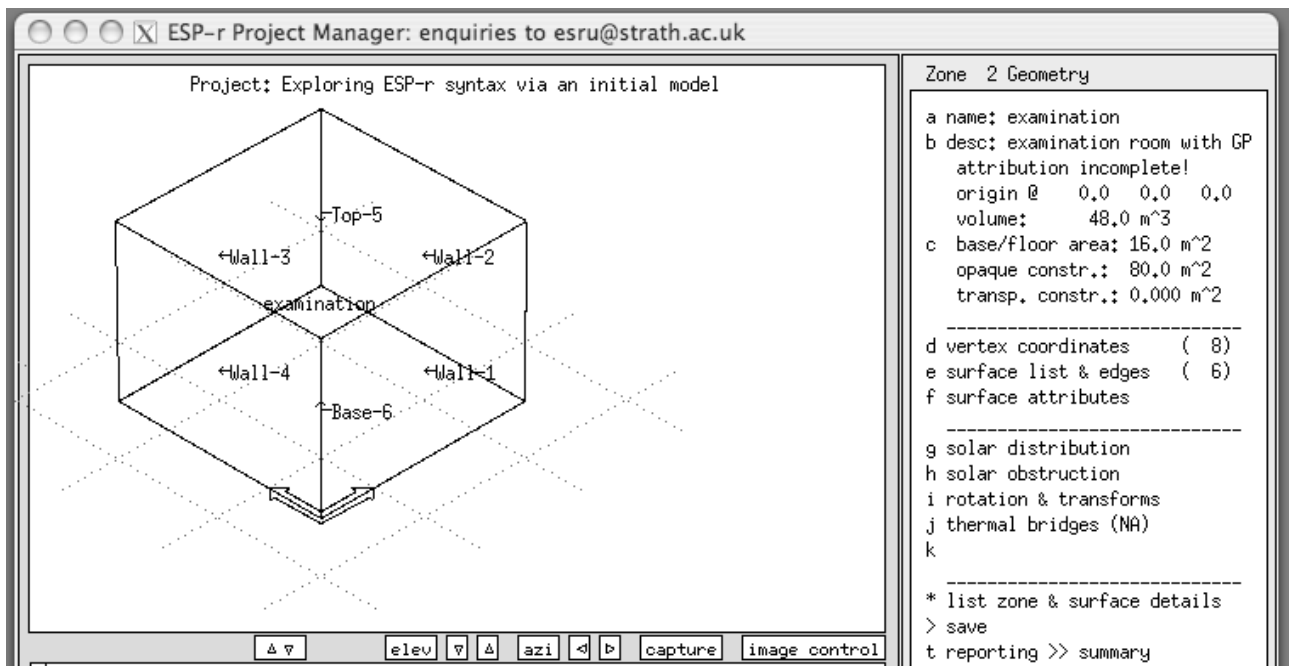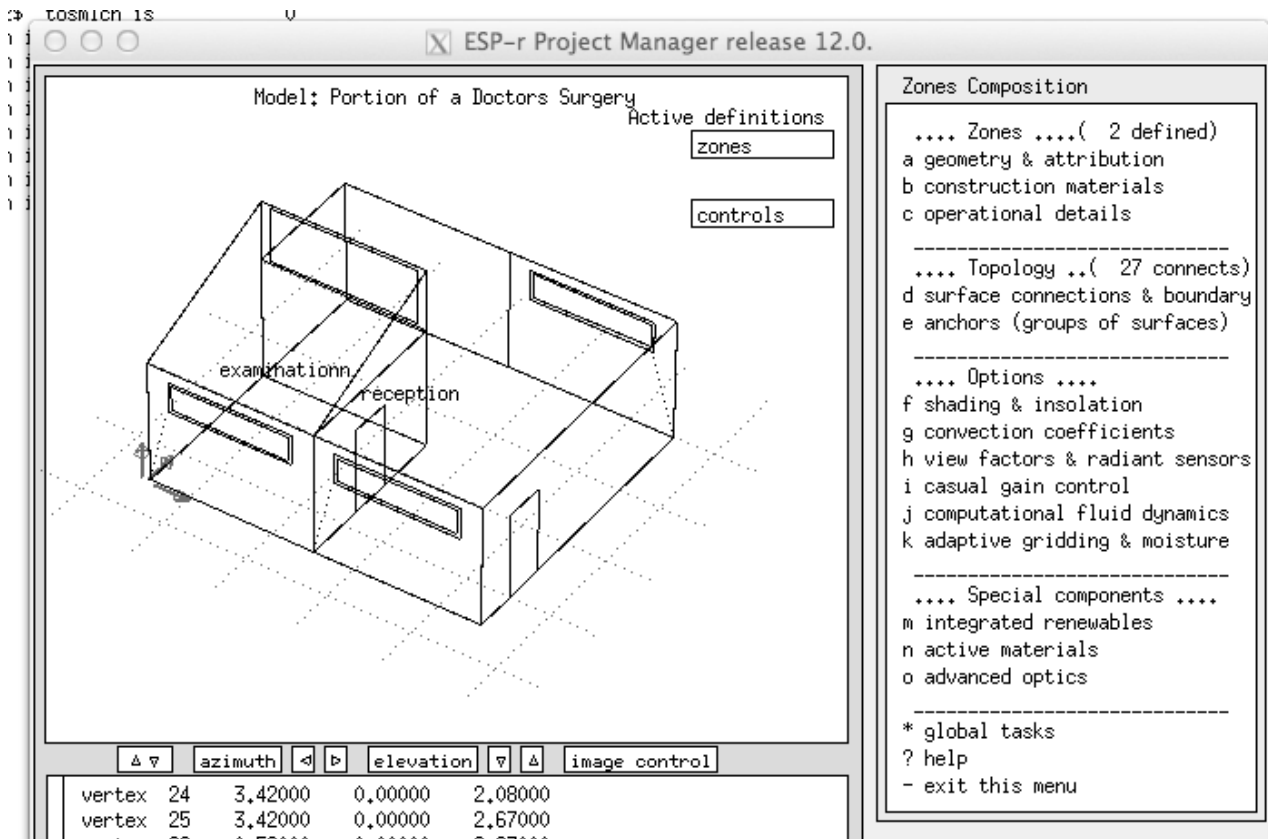
Figure 2.12: Examination initial box and surgery after attribution.

2.6 Model topology

Surfaces have attributes which define *what happens on the other face* in terms of a boundary condition. In ESP-r this attribute begins with UNKNOWN (see left Figure 2.13). One path for setting it is via `zone geometry -> surface attributes -> (list) -> environment -> surface boundary (list)` The listed surface boundary options (see right Figure 2.12) are defined in the *Entities Appendix*.
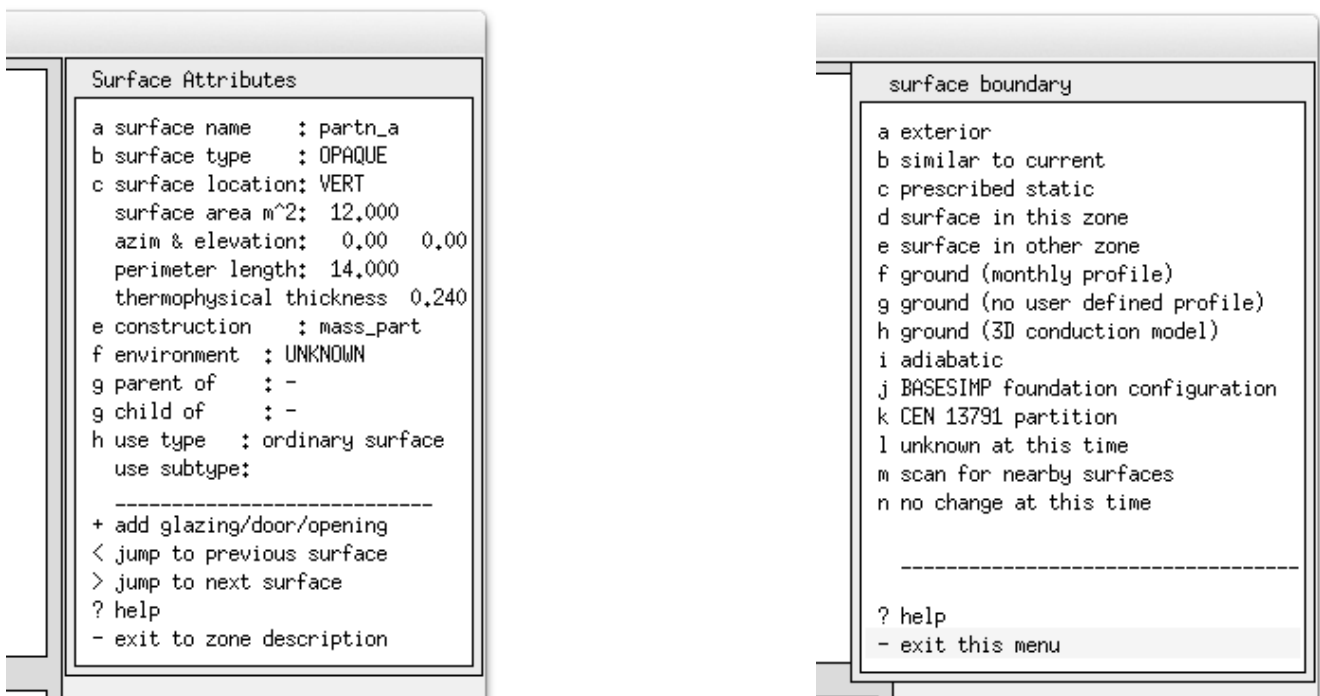
Figure 2.13: Surface attributes and boundary options list.

And if there are many surfaces which have the same boundary condition e.g. they face the outside we could use the `Zone geometry -> surface attributes -> attribute many -> boundary condition` And there is also an automated process for this which we will explore shortly.

In the context of the surgery, the wall of the reception named *partn_other* in Figure 2.1 is facing another room for which there is no description other than that conditions are similar to that of the reception. For *partn_other* the boundary type would be *similar to current*.

The floors of both zones are slab-on-grade and are composed of *grnd_floor* (which includes 1m of earth) and it would make sense to use a monthly ground temperature profile. If we knew what the temperatures at 1m depth were we could enter these as a user defined ground temperature profile. Failing that we can select from one of the in-built profiles.

In the exercises we initially defined a *partn_a* in the reception and made it out of the *mass_part* construction. We then performed a *copy-invert* operation so that a surface with that name and composition exists in the examination. Clearly the two surfaces have a thermophysical relationship, however the *copy-invert* operation did not set the boundary condition, as can be seen in the right of Figure 2.13. This is intentional so that you remain in control of boundary conditions.

If you know which surface in another zone is the match then you can select `surface in other zone` but you might mis-select which will cause all kinds of chaos. There is another option `scan for nearby surfaces` which will look for surfaces in other zones which are similar in size and have a likely orientation (~180 degrees from the current surface) and if there is only one match then it will set the boundary condition for this surface and the surface in the other zone as well. The `scan for nearby surfaces` is useful for the most simple models or in the case of a large model where changes have been made and you want to establish boundary conditions for a few selected surfaces. This does not scale well - it requires lots of keystrokes as well as lots of mental attention. And, more importantly you might miss something. The better way is to use the ESP-r topology facility.

The topology facility scans the polygons of a model looking for surfaces in various zones which are close matches in terms of shape and position and makes inferences from this to complete the boundary condition attribute of each surface. You control the tolerance and the extent of the search parameters and if the tool is unsure of what to do it will pause and ask for confirmation or allow you to select one of the standard boundary conditions.

> **▶ Exercise 2.8**
>
> To experience the automated process for establishing topology, take a few minutes to carry out the tasks in Exercise 2.8. While working on the exercise notice *that every surface in your model is presented in sequence*. It makes a great way to review your model. If you periodically invoke the topology facility (say after adding two zones) you will have a chance to review the model at the same time it is searching for matches to the new surfaces you have added.

Up to this point the strategy has been to follow procedures which help us to create correct models. How do we know they are correct? One of the steps in checking the quality of our models is to generate a QA report and then review this against our initial sketches.

> **▶ Section**
>
> Chapter 13 is all about model quality tasks. Now is a good time to read Section 13.9 which focuses on model contents reports as well as carrying out the steps for creating the report via Exercise 13.1.

The report should be familiar to you - it contains the entities that you created and named along with some derived data. If your review indicates that all surfaces are fully attributed then it is possible to proceed to the next step of instantiating the zone construction thermophysical properties.

2.7 Instantiating zone construction data

In order to run a simulation, each zone in a model must include full thermophysical data for each layer in each surface. These are held in so-called *zone construction and zone tmc files* which are derived from the attributes of the surfaces and with reference to the common materials and common construction data associated with the model.

Exercise 2.9

There is a one-time task for each zone to initially build the zone files. Once these are in place subsequent changes to the zone or surface composition will trigger an automatic refresh. Follow the steps in Exercise 2.9 to create these zone files. If your initial zone geometry is properly attributed the task will only take a moment for each zone.

At this point we have defined the form and composition of the surgery using the basic facilities of ESP-r. This is not the only approach we could have taken.

2.8 Geometry alternative inputs

Simulation tools may offer alternative schemes for creating the form and fabric of models. ESP-r offers several options for geometric input:

- in-built CAD facilties for creating rectangular bodies, extruding floor plans or working with polygons
- in-built facilities (in the X11 interface version) to use mouse clicks on a regular geometric grid to define floor plans of rooms to extrud into zones with the option of including door jambs, window jambs and the origins of furniture and solar obstructions,
- or to load monochrome images of plans and/or elevations, create a grid over them and click on points to define rooms, doors, windows, furniture origins or solar obstructions,
- or importing gbXML files (a legacy DFX inport facility is being depreciated).

2.8.1 Clicking on a grid

In ESP-r one option (via the X11 interface) is to define a regular X and Y grid and use this as the basis for establishing points for the floor plan of a building. Lets explore this via re-creating the surgery.

The planning stage for creating the surgery via a grid is essentially the same. The overall dimensions of the model are 8m (east-west) and 7m (north-south). Have Figure 2.1 available so you can complete the process in one session.

Exercise 2.10

Exercise 2.10 focuses on clicking on points on a grid of the Surgery model. You will extrude both zones as well as their doors and windows in sequence and then use the normal geometric manipulation facilities to make the examination roof sloped and add the frames for the windows. This exercise helps you acquire the skills needed to use the click-on-grid facility (Figure 2.14).

Exercise 2.11

For additional practice in clicking-on-plans (highly recommended) have a look at Exercise 2.11 Keep a note of what worked for use in future projects.
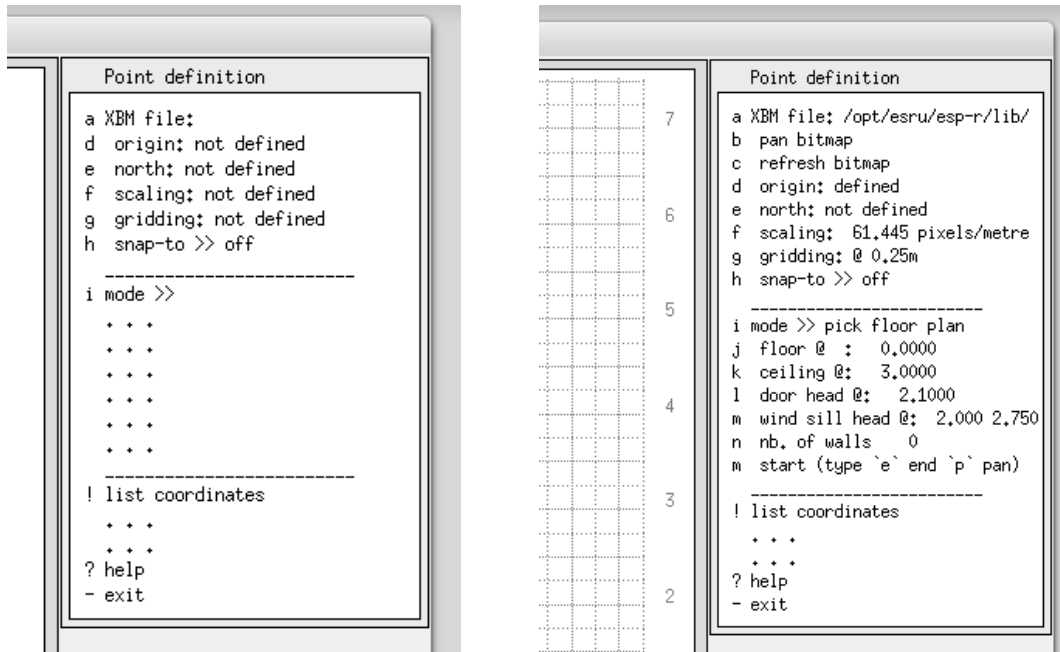
Figure 2.14: Opening menus of click-on facility

After completing the exercise the two zones on the grid will be similar to Figure 2.15 (left) and in the wire-frame view the steps remaining will be to create the frames for the glass and raise the ceiling of the examination room as well as adding in the clear-story window.
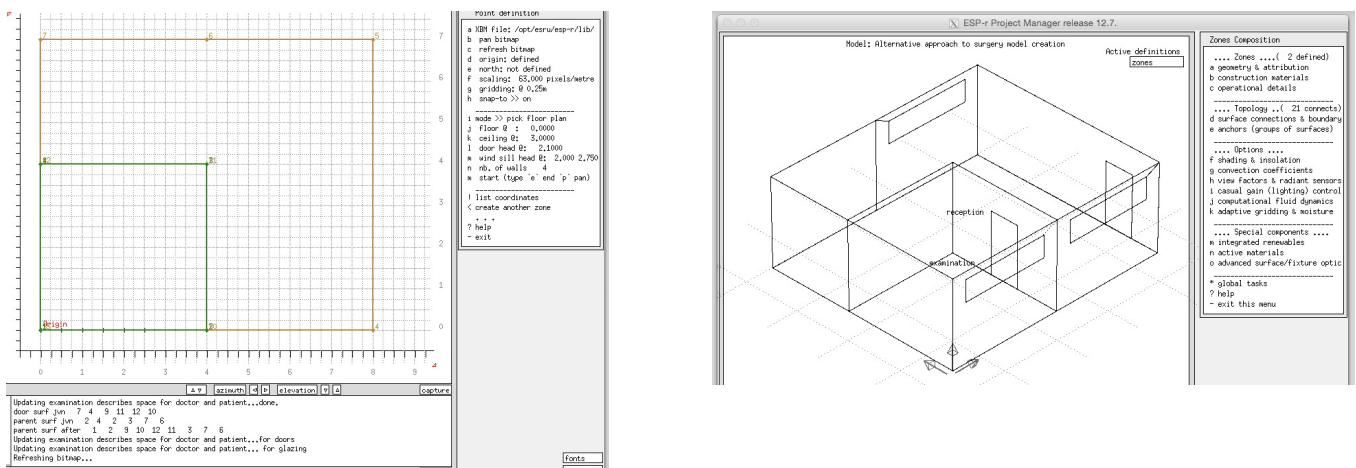
Figure 2.15: After finishing the second zone.

2.8.2 Clicking on a bitmap

You can also supply your own bitmap of the building plan and click on points found in that image to create one or more thermal zones.

Practice is essential as is planning. The facility is intended to be used in a single session (points collected are lost when you exit the facility). So ALWAYS...

- mark-up your image with indications of the critical points you want to capture and the bounds of the zones you will be creating,
- if you have bitmaps for more than one level in the building ensure critical points for the other levels can be identified or that the scale and origin of the other layer bitmaps are equivalent,
- sketch your model in three dimensions so that you can plan how partitions between zones work.

2.8.3 Examples of approaches to take

With the requisite skills it is possible to create substantial models with some speed (be warned, extreme concentration is required). The two examples that follow illustrate the creation of models which the client can recognize and which capture the spacial characteristics of the building.

The eighteenth century theatre shown in Figure 2.16 is an example of using scanned images of the building plans (there was no CAD data available). It is also notable in that almost nothing is rectilinear and many of the walls are ˜1m thick.

The model in Figure 2.17 was initially composed by clicking on points from Figure 2.16 which were placed in dummy zones. Surfaces and points from those dummy zones were then used to build up the model zones. A detailed plan of the zoning had been worked out prior to the use of the click-on-bitmap facility. Even with this, considerable care was required and post-processing and reconciliation of the partition surfaces was needed. This is an example of what can be accomplished by an experienced user and is just the sort of project which would be cruel and unusual punishment for a novice.
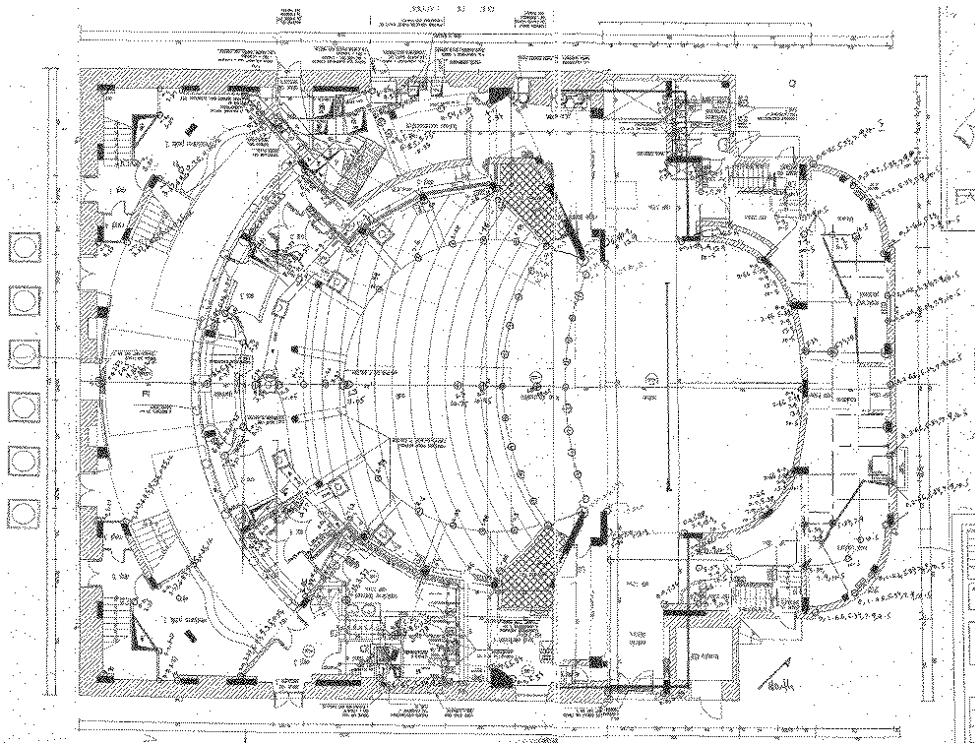
Figure 2.16: Bitmap image from historic building.
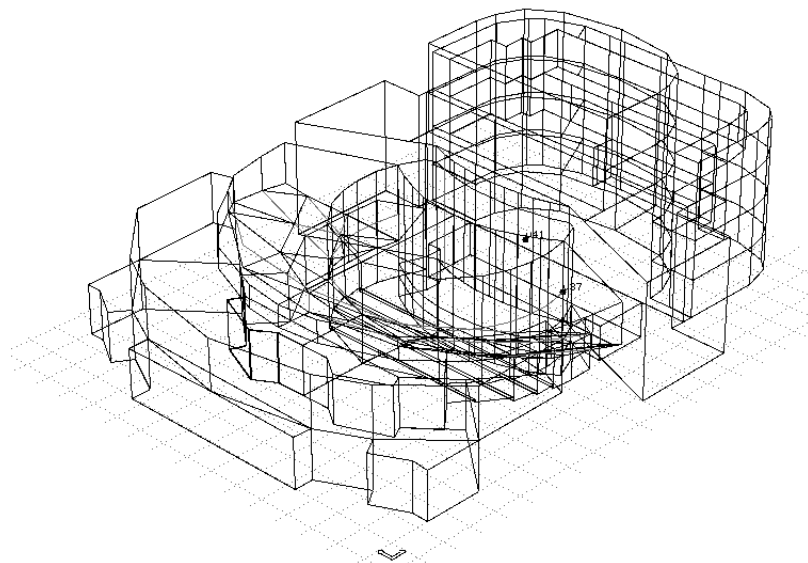
Figure 2.17: Model of historic building.

The second example involves an urban study, as shown in Figures 2.18, which was largely composed by a digitizing on a mix of Ordnance survey maps, Google street view and spot site measurements. Some of the buildings are thermophysically complete and the others abstractions for context. Over time the high-rise buildings will be populated. In this case the ground topology is treated as a thermal zone.
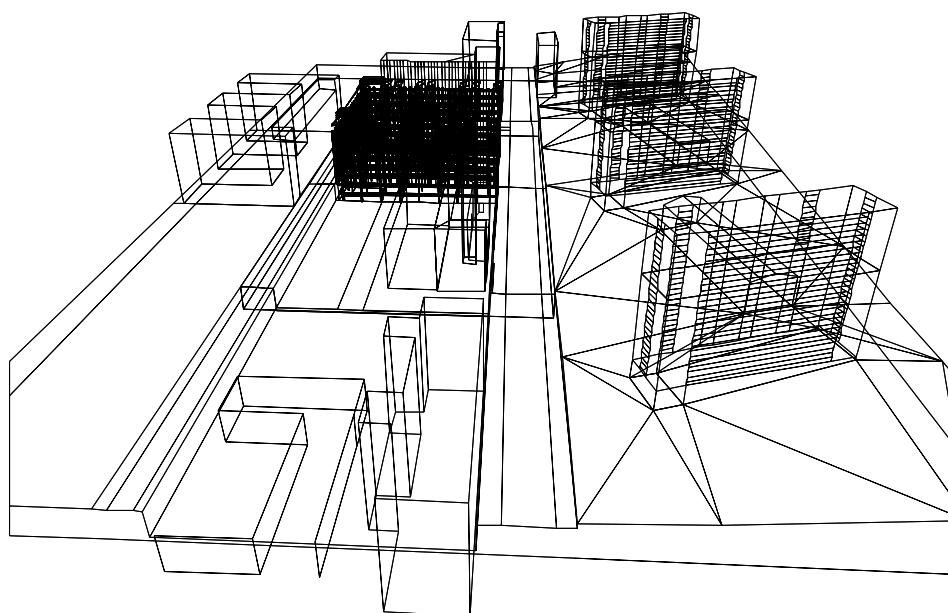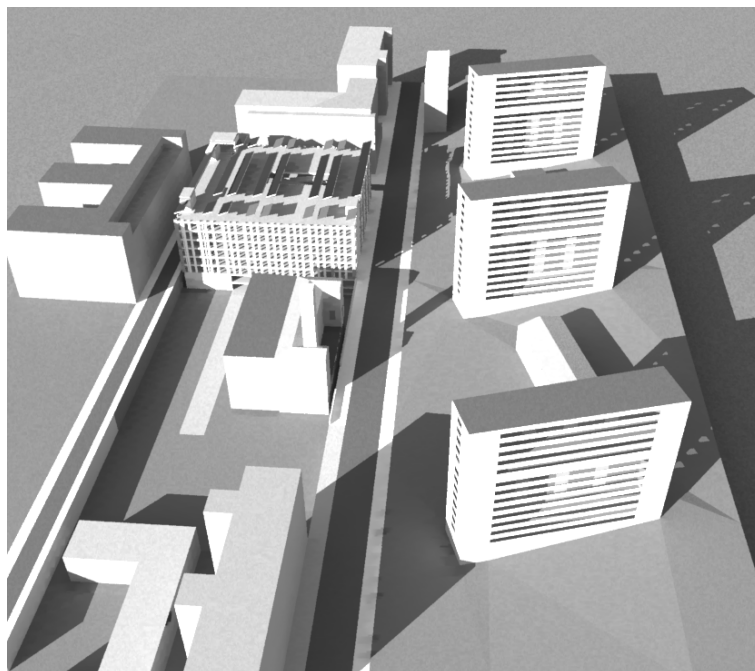
Figure 2.18: Layout and rendering of an urban setting.

2.8.4 gbXML inport

Importing third party model descriptive files involves establishing equivalence between the entities in such files and entities within simulation. DXF cad files include few attributes as well as many 2D entities that have limited application within simulation. gbXML file format is based on a richer data model from which a simulation model can be built.

ESP-r facilities for parsing ASCII gbXML files are *evolving*. Sucess is dependent on the source of the gbXML file and the nature of design which is embedded within the file. Although the syntax of gbXML is well documented, vendors may implement sub-sets of the standard. The mix of entities included may not fit within the ESP-r data model i.e. surfaces with hundreds of edges are incompletely parsed. Sometimes

the topology within the file does not conform to the internal rules of ESP-r i.e. floors or ceilings edges do not join with edges of adjacent walls.

The process of creating an ESP-r model from a gbXML file follows the following steps:

- Ensure the gbXML file is in ASCII format rather than unicode format. The heading should look similar to:

```
<?xml version="1.0" encoding="UTF-16"?>
<gbXML useSIUnitsForResults="true" temperatureUnit="C" lengthUnit="Meters"
  areaUnit="SquareMeters" volumeUnit="CubicMeters" version="0.37"
  xmlns="http://www.gbxml.org/schema">
  <Campus id="aim0002">
    <Location>
      <StationId IDType="WMO">142882_2006</StationId>
      <ZipcodeOrPostalCode>00000</ZipcodeOrPostalCode>
      <Longitude>-0.12721</Longitude>
  . . .
```

Both SI and Imperial units are accepted.

- preview the gbXML file in a viewing application to check that the underlying design is suitable. Some gbXML files are faulty, included zones may be incomplete or with orphaned surfaces.

- Start prj with no `-file [name]` directive in your usual location and select the `use CAD tool or parse gbXML file` option from the opening menu. Provide the full path to the gbXML file and then a path for the new model folder to host the new model. `Prj` will then invoke the `ecnv` application passing it the relevant instructions. `ecnv` will provide various levels of feedback as it process the gbXML file.

```
Input file is: /home/jon/Models/gbxmltest2/ConferenceCenter.xml
The esp-r configuration file will be: /home/jon/Models/gbxmltest2/ConferenceCenter
 xmlns is http://www.gbxml.org/schema
 temperatureUnit is F
 lengthUnit is Feet
 areaUnit is SquareFeet
 volumeUnit is CubicFeet
 useSIUnitsForResults is false
 the campus id is Boston, MA, USA
Latitude:   42.36
Longitude:  -71.06
 the building id is bldg-1
 noticed zone           1  sp-1-Space    sp-1-Spac_01
 zoneIdRef is zone-2
 the space id is 1 Space
 Volume:   424.99
  . . .
 current surfacename is su-4
 near side zone index sp-1-Space          59         1         0
 other side zone index sp-2-Space          59         2
true partition between sp-1-Space   1 & sp-2-Space   2
 the CAD obj is 282519
 current surfacename is su-5
 near side zone index sp-1-Space          59         1         0
 other side zone index sp-2-Space          59         2
true partition between sp-1-Space   1 & sp-2-Space   2
  . . .
Summary....
nb zones 59 their names sp-1-Space sp-2-Space sp-3-Space sp-5-Space sp-6-Space sp-7-Space sp-8...
  surfs in each 11  8 14  9 13 15 16 17 17 19 18 16 16 28 15 115  9 813   8 32 105 7  9 11 ...
  verts in each 28 16 32 18 46 41 55 60 62 64 62 58 57 98 23 422 16 14 449 57 449  18 22 28 ...
surf     su-1   RaisedFloor  OPAQUE brk_blk_2012 FLOOR    EXTGRND   EXTERIOR        000   000
surf     su-2   ExteriorWall OPAQUE brk_blk_2012 WALL     -         EXTERIOR        000   000
surf     su-3   ExteriorWall OPAQUE brk_blk_2012 WALL     -         EXTERIOR        000   000
surf     su-4                OPAQUE partition    PARTN    -         sp-2-Space      002   001
surf     su-5                OPAQUE partition    PARTN    -         sp-2-Space      002   002
surf     su-6                OPAQUE partition    PARTN    -         sp-3-Space      003   001
  . . .
```

You will be asked about what occupancy pattern to apply to each zone in the new model. Default constructions will be applied and if there are in-built directives for boundary conditions these will be applied to the new model. When it's work completes `prj` will restart focused on the new model.

Although the resulting model may support assessments *out-of-the-box* you will probably want to update the surface attributes for composition and specify your own environmental controls.

There may be some topology or boundary condition faults to correct. The Figures that follow show one of the standard gbXML test models. The originating tool allows a looser set of rules for how polygons bound zones. For example, the offices walls extend above what is probably a dropped ceiling. Is the boundary condition of the upper portion of the walls the occupied space or the ceiling void? In ESP-r users would either stop the walls at the dropped ceiling or create a ceiling void as a separate zone. This will simulate but ESP-r will complain that the zone is not properly bounded.
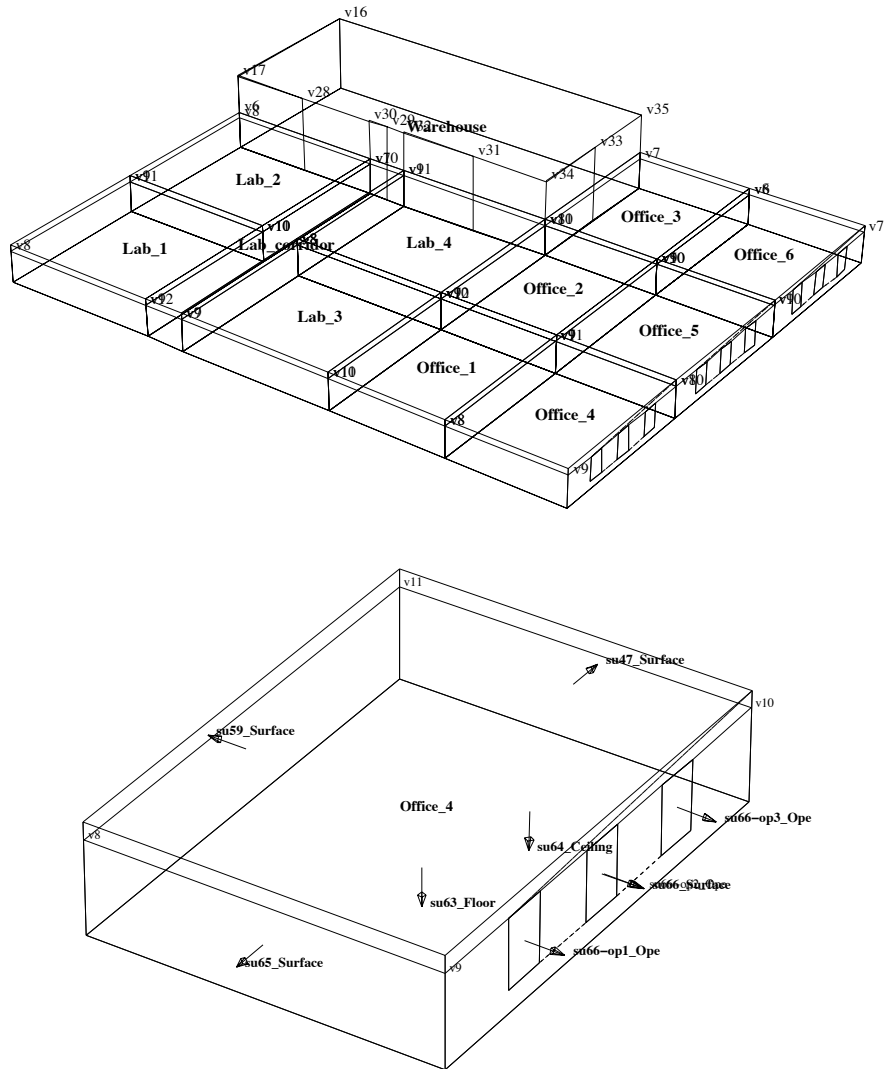
Figure 2.14: ESP-r model after a sucessful import.

The new model might be incomplete. For example the parser will skip past surfaces or openings or doors which exceed array limits. And a gbXML file which contains non-sensical forms will likely translate to an ESP-r model with non-sensical forms.

The next chapter discusses several alternatives for creating zone forms and composition.

3 Common data stores

Simulation tools tend to describe the composition of surfaces in terms of named constructions which are made up of an ordered list of materials (each of which have a set of thermophysical attributes). Each simulation suite has its own approach to implementing compositional information, providing user access for selection and management tasks. For example:

- Energy Plus provides a folder with IDF files holding instances of window, frame, opaque wall and shading elements. The entries in these files are tag:data formatted. Users might use text editors to cut and paste relevant entries into the model file. Third party interfaces would provide these as selection lists.

- IES VE provides lists of constructions by building type and, again, these reference named materials with thermophysical attributes.

ESP-r is distributed with files which hold *common materials*, *common constructions*, *common optical properties* and other entities referenced within simulation models (see Figure 3.1). These files include ready to use entities as well as acting as templates for practitioners to populate from their own information sources. It is possible to configure ESP-r to load an initial set of common data files that are appropriate for a given region and building type (see Install Appendix).

ESP-r is also distributed with a collection of weather files which represent sites in many regions of the world. This collection can be extended via conversion of a number of standard weather file formats and user-supplied definitions of seasons.

```
Standard data maintenance:
  Folder paths:
  Standard <std> = /Users/jon/esru_jwh/esp-r/databases
  Model <mod> = no model defined yet
  _____
a annual weather       : <std>clm67
b multi-year weather    : None
c material properties   : <std>material.db4.a
d optical properties    : <std>optics.db2
e constructions         : <std>multicon.db5
f active components     : <std>mscomp.db2
g event profiles        : <std>profiles.db2.a
h pressure coefficients : <std>pressc.db1
i plant components      : <std>plantc.db1
j mould isopleths       : <std>mould.db1
k CFC layers            : <std>CFClayers.db1.a
l predefined objects    : <std>/predefined.db1
  _____
? help
- exit this menu
```

Figure 3.1 List of ESP-r common data stores.

Note that each of the menu entries is proceeded with a <std> which indicates that the files are located in the standard ESP-r distribution folder. Files in that folder should be treated as read-only as many simulation models reference them. Variant files for a project should reside with the project and are preceded with a <mod> notation. Once selected a list of common management tasks (see Figure 3.2) is presented:

- browse/edit - work with the currently open file. Care is required when modifying files in the distribution database folder.

- select file from list - all of the files in the distribution database folder are presented and the one you select is associated with the model (not copied into the model folder). In the case of weather files the list is created from information held in a so-called *climatelist* file.

- select from model ../dbs - any files in the model ../dbs folder are listed for selection

- copy default file to model - whatever file is specified as the default (via the defaults file) will be copied into the model folder and given an initial name consistent with the model root name.

- ascii >> binary - most common files are ASCII files in a tag:data format however some older models include materials in a binary form and conversion functions are included. Plant component templates and weather files, which require frequent random access are normally in binary form with an ASCII conversion to allow transfer between computer types.

- create new - writes a minimal contents file that can then be populated by the user as required.

```
   Material properties <mod>
ions
     a browse/edit
     b select file from list
     c select from model ../dbs
     d copy default file to model
     e copy file from common to model
     f binary >> ascii export
     g ascii >> binary
     h create new materials

     -----------------------
     * default is option `a`
     ? help
     - exit this menu
```

```
   Constructions <mod>
ions
     a browse/edit
     b select file from list
     c select from model ../dbs
     d copy default file to model
     e copy file from common to model
     f not applicable
     g create new constructions

     -----------------------
     * default is option `a`
     ? help
     - exit this menu
```

Figure 3.2: Typical management options.

Details of weather, materials, constructions and optics common data files are discussed in the next sections.

3.1 Weather data

Organisations which gather, store and distribute weather data serve a broad audience. Over time a plethora of file formats have evolved. Simulation tools accommodated this via a proliferation of conversion utilities. The overhead for vendors and users was substantial as well as the risk of error and misunderstanding.

The author, with Dr. Dru Crawley, who at the time was managing the EnergyPlus program, designed and proposed the EPW weather file format which has become a widely used standard repository format for the simulation community with over 2000 locations available for download. EPW is a super-set data model [ref] from which other tools can extract data.

Many of the weather files distributed with ESP-r are sourced from EPW files. For sites which are not included in the distribution ESP-r provides facilities to convert downloaded EPW files. Details of this and other import facilities are covered in Section 3.4

ESP-r weather data is composed of a header which defines site information - a name, year, latitude, longitude (degrees from the local time meridian) and a tag which defines whether solar data is measured as direct normal or global horizontal. Weather data is typically hourly for 365 days of the year but can be a fraction of the year. An annual ESP-r simulation would begin in January and end in December. A whole-winter assessment i.e. November to March would require a November-December period and a January-March period. Sub-hourly weather data is accomodated via a temporal file (see Section 19.9).

At each hour the weather data comprises diffuse horizontal solar radiation, dry bulb temperature, direct normal or global horizontal solar radiation wind speed and wind direction. There are no entries for cloud type, cloud percentage, dew point, precipitation (or snow) or ground temperatures.

ESP-r can also hold additional attributes of weather such as the start and end date for each season (winter beginning in January, spring, summer, autumn and winter ending in December) as well as a typical week for each season. Seasonal definitions are user specified and typical weeks can be determined via scanning of the weather data and this is the topic of the next section.

3.1.1 Exploring weather patterns

The use of short weather sequences for model calibration and focused explorations have many advantages. For example, a Monday morning start-up after a cold weekend can tell us much about the characteristics of a building. Do peak summer demands coincide with the hottest day or is it a function of several hot days in sequence? There is little point in using an annual assessment to explore such issues and considerable advantage to identifying and using specific weather patterns for calibration and to support early identification of opportunities.

To work with weather, select the menu option `Model Management -> Database Maintenance` and in the options shown in Figure 3.1 select the `annual weather` option. This is followed by a selection of weather management functions including `[select from list]` (Figure 3.3). Assuming ESP-r was installed correctly, you will now be presented with a list of known weather files.

Select an existing weather file such as Birmingham IWEC, look at the summary in the text feedback area and confirm the selection. The ESP-r weather module (**clm**) will start, and your first task is to confirm the weather file name in the initial dialogue. After this the main menu of **clm** looks like the right section of Figure 3.3.

There are a number of options under synoptic analysis (Figure 3.4) which are useful for finding weather patterns with which to test a building. To generate a statistical report as in Figure 3.5, first select the weather data you wish to analyze e.g. `dry bulb temperature` and then the type of analysis e.g. `maximum & minimum` and then the reporting frequency e.g. `day/week/month.` Near the bottom of the is an option `find typical weeks.`


```
Weather <std>

a browse/edit
b select another from list
c select from model ../dbs
d create new weather
e copy it to model
f weather >> ascii export
g ascii >> weather import
h EPW >> weather import
----------------------------
* default is option `a`
? help
- exit this menu
```

```
                                    Climate sets
ns
                            ESRU standard climates
                            --------------------------
                            a Default UK clm Climate
                            b Aberdeen - Dyce  GBR
                            c ARE Abu Dhabi iwec 412170
                            d ALBUQUERQUE NM USA iwec 723650
                            e Aughton - GBR (033220)
                            f Aswan EGY 624140
                            g Baltimore MD USA iwec 724060
                            h Belfast NI GBR
                            i BESTEST drycold Denver USA
                            j Berlin DEU IWEC 103840
                            k Birmingham - GBR
                            l Boulder Colorado USA
                            m Brescia-Ghedi - ITA
                            n Brussels Belgium IWEC WMO 0645
                            o Burlington VT USA iwec 726170
                            p CAIRO - EGY
                            q Calgary Intl AB CAN
                            r Chicago IL USA iwec 725300
                            s Copenhagen Denmark IWEC 061880
                            t Dijon - FRA (47.27N 5.08E)
                            u Dublin Ireland (039690)
                            v Dundee 1980
                            w Duluth MN USA iwec 727450
                            x El Paso TX USA iwec 722700
                            0 page: 1 of  4 ------
                            < user defined climate db
                            * new climate db (all zeros)
                            ? help
                            - exit
```

```
    Climate Analysis

a climate: /usr/esru/esp-r
b Sun-01-Jan-Sun-31-Dec 19
----------------------
c synoptic analysis
d graphical analysis
e psychrometric analysis
f table (one day) analysis
----------------------
g radiation >> dir normal
----------------------
h edit site data
i edit climate data
j export to text file
k import from text file
l manage climatelist
----------------------
s preferences
r reporting >> summary
> output >> screen
^ delim >> normal
? help
- end
```

Figure 3.3: Weather options, available weather sets and Clm module opening menu.

This facility works as follows:

- the average & total heating and cooling degree days (HDD & CDD) and solar radiation for each season,

- for each week, average HDD & CDD and solar data is found and compared with the seasonal values and the week with the least deviation (using user supplied weighting factors) is reported. For this weather and with the default heating and cooling base temperatures the best-fit weeks start on 27 Feb, 10 April, 19 June, 5 Oct and 4 Dec. Write these dates down and then go review these periods by

graphing and/or gathering statistics about them.

- The weather module has alternative views the data so see which 'view' tells you the most!

The provision of different views of the weather data can assist in locating patterns and answering different questions that clients might pose. Time spent exploring this module can provide critical clues as to patterns that may be used in the design process.

An example is the graph of temperatures over the year (Figure 3.6) with the current seasons (as defined in the `Manage climatelist` menu on the right side of Figure 3.4) is indicated at the top of the graph. There are a number of times when it is below freezing, but the graph indicates that these tend to be brief. This might support the use of brief performance assessments for winter heating demands and capacity. It also indicates scope for testing whether a design might be optimized to cope with brief rather than extended cold periods.

```
          Synoptic analysis

  p set period
  --------------------
  0 set time of day
  --------------------
  1 dry bulb temperature
  2 direct normal solar
  3 diffuse horizontal solar
  4 wind speed (m/s)
  5 wind direction (deg)
  6 relative humidity (%)
  --------------------
  m maximum & minimum
  r days within a range
  d degree days or hours
  a average values
  i integrate radiation
  h frequency histogram
  --------------------
  c climatic severity index
  s find typical weeks
  --------------------
  ? help
  - exit
```

```
2.0.
          Weather list item

  a menu str: Birmingham - GBR
  b menu aid: Brimingham - GBR (03540) w
  c clm file: /Users/jon/esru_jwh/esp-r/
  d available: ONLINE
  ----seasons--------------------days
  e  1st win Sun-01-Jan  Sun-05-Mar  64
  f  spring  Mon-06-Mar  Sun-14-May  70
  g  summer  Mon-15-May  Sun-27-Aug 105
  h  autumn  Mon-28-Aug  Sun-29-Oct  63
  i  2nd win Mon-30-Oct  Sun-31-Dec  63
  ----typical periods------------days
  j  1st win Sun-29-Jan  Sat-04-Feb   7
  k  spring  Mon-03-Apr  Sun-09-Apr   7
  l  summer  Mon-19-Jun  Sun-25-Jun   7
  m  autumn  Mon-11-Sep  Sun-17-Sep   7
  n  2nd win Mon-04-Dec Sun-10-Dec    7
  < scan weather for best-fit weeks
  ----documentation (27)----------
  o list/generate/edit documentation
  --------------------------------
  > save item documentation
  > edit climatelist file
  * graph ambient T & seasons
  ? help
  - end
```

Figure 3.4: Synoptic analysis and manage climatelist menu.

```
Dry bulb temp.       deg.C

Week                  Minimum  Time        Maximum  Time      Mean
Wk of Wed  1 Jan    -15.0 @24h00 Tue  7      6.8 @ 4h00 Wed  1     -5.2
Wk of Wed  8 Jan    -23.9 @ 7h00 Sun 12      2.8 @17h00 Fri 10    -15.3
Wk of Wed 15 Jan    -23.3 @ 1h00 Thu 16     -1.1 @14h00 Mon 20     -9.6
Wk of Wed 22 Jan    -25.0 @ 5h00 Mon 27     -5.0 @ 4h00 Thu 23    -14.4
Wk of Wed 29 Jan    -22.8 @ 8h00 Wed 29    -10.0 @18h00 Thu 30    -15.0
Wk of Wed  5 Feb    -15.8 @ 1h00 Thu  6     -3.6 @16h00 Fri  7    -10.0
Wk of Wed 12 Feb    -16.9 @ 7h00 Mon 17     -1.3 @16h00 Fri 14     -8.1
Wk of Wed 19 Feb    -14.4 @24h00 Tue 25      4.7 @14h00 Thu 20     -3.9
Wk of Wed 26 Feb    -21.1 @ 7h00 Wed 26      5.6 @14h00 Sun  2     -5.5
Wk of Wed  5 Mar    -12.2 @ 5h00 Thu  6      9.4 @10h00 Wed  5     -3.6
Wk of Wed 12 Mar    -10.6 @ 7h00 Sun 16      5.6 @23h00 Fri 14     -3.0
Wk of Wed 19 Mar    -11.7 @ 6h00 Wed 19     11.1 @17h00 Mon 24     -0.4

All period     -25.0 @ 5h00 Mon 27 Jan    11.1 @17h00 Mon 24 Mar     -7.6
```

Figure 3.5: Weekly statistics.

Another example is Figure 3.7 where the psychometrics of the outside air have been plotted over the whole year for the same location.
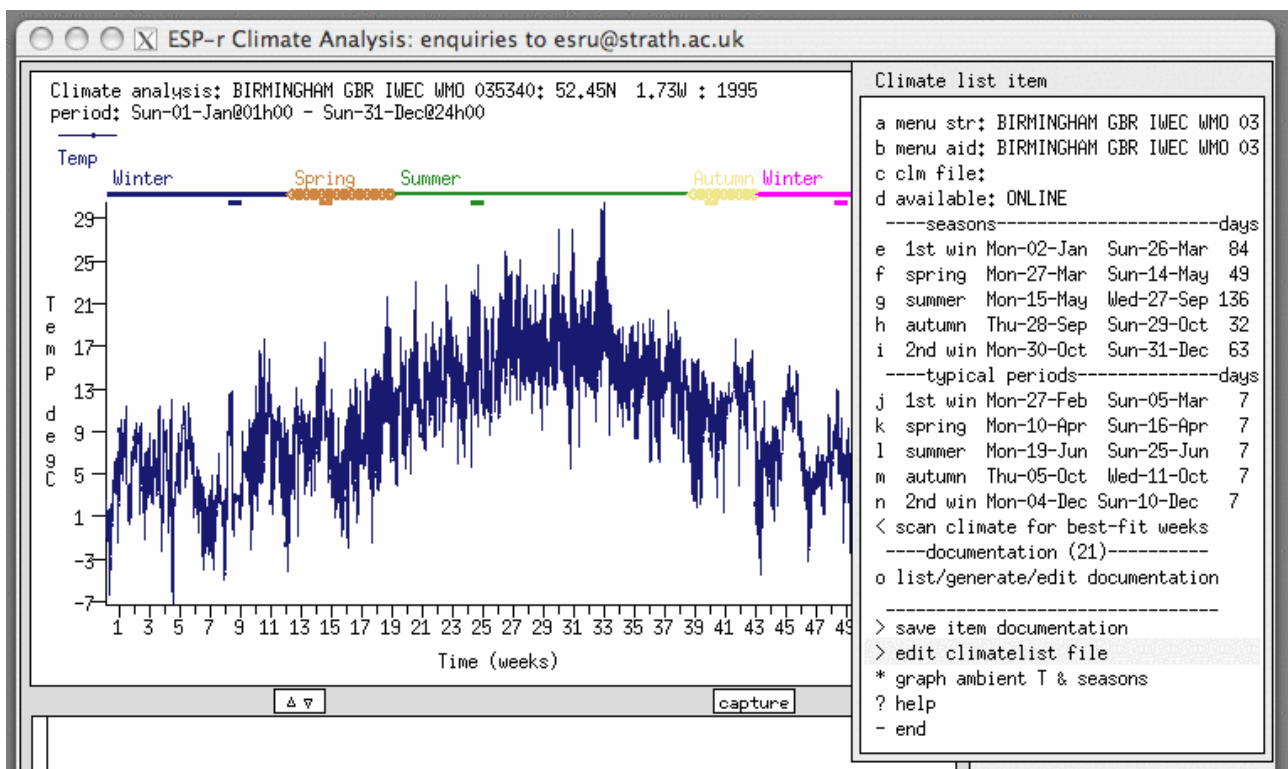
Figure 3.6: Annual plot of temperatures.
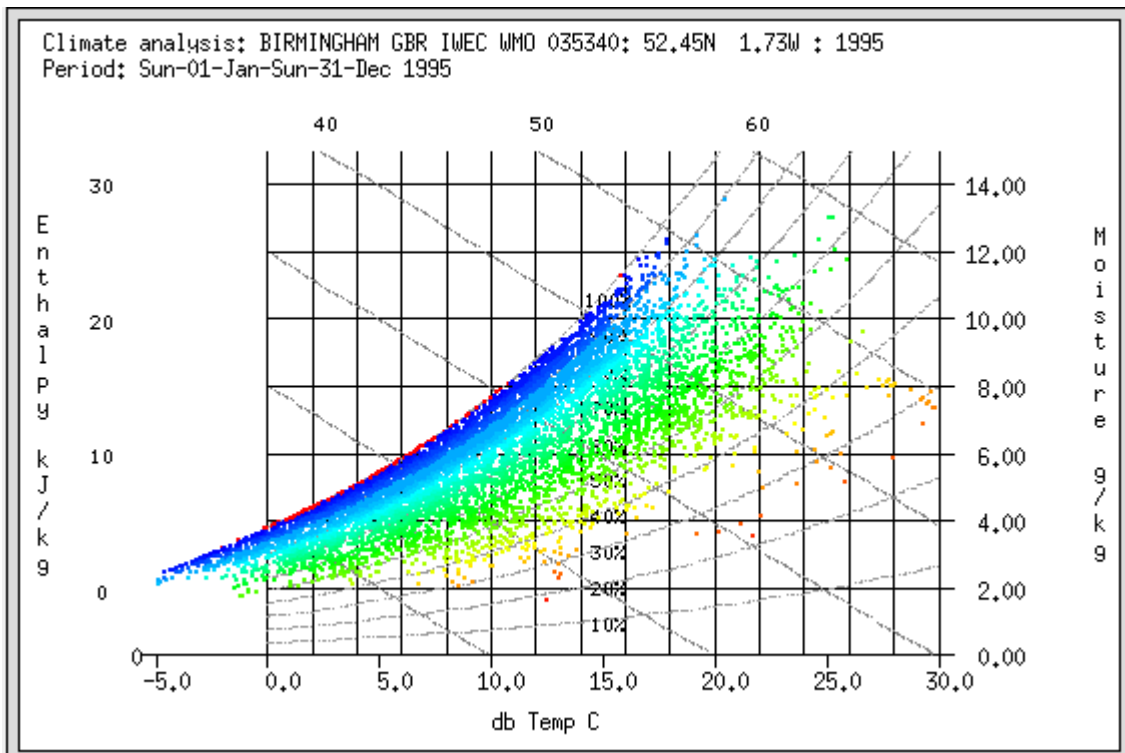
Figure 3.7: Annual psychrometrics.

Exercise 3.1

Identification of weather patterns supporting a Monday morning building warm-up test is the subject of Exercise 3.1.

Exercise 3.2

Identification of weather patterns supporting overheating assessments is also useful. Many practitioners look for the hottest day of the year this will support understanding of building overheating and cooling demands. For some buildings it takes a sequence of warm days to stress the building. Indeed, for offices the gradual build-up of heat reaches a peak on Friday even if it is not a particularly hot day. Exercise 3.2 allows you to explore this.

Exercise 3.3

Many regions have two types of winter weather than stress buildings and their occupants. The first is clear and cold conditions. Solar radiation can offset colder temperatures and often the wind speeds are low. The second pattern is cloudy periods which tend to be milder for temperature but often have high winds. Identifying both of these patterns can have advantages over the usual coldest-day-of-the-year approach. Explore this via Exercise 3.3. Later when you come to define the assessments to be undertaken you can use this information.

3.2 Scaling assessments

ESP-r has a number of facilities which allow us to scale our models and assessments - so we get, for example, annual heating and cooling for a whole building without simulating every day of the year or every floor of an office building. These facilities evolved over time based on observations about how practitioners adapted their models and the assessments they commissioned to fit within their computational and staff resources.

For many building types there is a strong correlation between predictions over one or two typical weeks in each season and seasonal heating and cooling demands. This can be demonstrated by commissioning short period assessments and full season assessments and looking at the relationship between the two performance predictions. Commissioning full season assessments to determine scaling for a building does

50

take time and so alternative methods were investigated. Over scores of projects it emerged that there were relationships that could be used to identify suitable short assessment periods. The key to this was in the practitioners definition of the extent of each *season* and search criteria for *typical* periods.

For many readers seasons are demarcated by four month intervals or by notes in a reference guide. If we pause to consider what constitutes winter in Hong Kong we might conclude that it is triggered by something other than temperature. The start of spring might be a day on a calendar but often there are cultural clues such as observing cherry blossoms which trigger changes in how we dress and how we operate our buildings. Astute practitioners leveraged this insight when they review weather data.

Before we had access to computers which supported numerical simulation simplified methods such as heating degree day (HDD and later cooling degree day CDD) methods were used. We observed that practitioners often did a quick check of HDD and CDD to judge, for example the onset of demand for environmental controls or the likely period that the building might be allowed to free float with minimal loss of comfort.

ESP-r encapsulates this approach and extended it to also allow for solar radiation to be taken into account and weightings to be give to HDD, CDD and radiation. We will cover this topic later in the section about Integrated Performance Views (IPV).

```
Weather: GENEVA - CHE: 46.25 (46deg 15' 0.0")N  -8.87 ( -8deg52'12.0")W : 2001
period: Mon-01-Jan@01h00 - Mon-31-Dec@24h00
Degree day analysis: heating base at  17.0 & cooling   21.0 Deg C
Week     (starting)       Heat dd            Cool dd
                          avg/day   total    avg/day   total
Week: 1 (Mon-01-Jan)      15.43    108.02     0.00      0.00
Week: 2 (Mon-08-Jan)      15.85    110.93     0.00      0.00
Week: 3 (Mon-15-Jan)      14.01     98.08     0.00      0.00
Week: 4 (Mon-22-Jan)      15.80    110.60     0.00      0.00
Week: 5 (Mon-29-Jan)      14.29    100.02     0.00      0.00
Week: 6 (Mon-05-Feb)      13.02     91.16     0.00      0.00
Week: 7 (Mon-12-Feb)      13.93     97.52     0.00      0.00
Week: 8 (Mon-19-Feb)      15.83    110.82     0.00      0.00
Week: 9 (Mon-26-Feb)      15.92    111.43     0.00      0.00
Week:10 (Mon-05-Mar)      11.78     82.44     0.00      0.00
Week:11 (Mon-12-Mar)       9.91     69.40     0.00      0.00
Week:12 (Mon-19-Mar)       8.52     59.64     0.00      0.00
Week:13 (Mon-26-Mar)      11.83     82.83     0.00      0.00
Week:14 (Mon-02-Apr)       4.64     32.46     0.03      0.18
Week:15 (Mon-09-Apr)       8.38     58.69     0.00      0.00
Week:16 (Mon-16-Apr)       8.21     57.46     0.00      0.00
Week:17 (Mon-23-Apr)       6.59     46.10     0.00      0.00
Week:18 (Mon-30-Apr)       7.58     53.06     0.01      0.08
 . . .
```

Figure 3.8 Season HDD, CDD, Radiation summary.

```
 Degree day analysis: heating base at  17.0 & cooling   21.0 Deg C

Winter (early year) season period: Mon-01-Jan@00h00 - Wed-28-Feb@24h00
 Heat DD avg/day       14.91  Cool DD avg/day       0.00  Rad avg/day       1.23
 Heat DD avg/week     104.38  Cool DD avg/week      0.00  Rad avg/week      8.58
 Season heat DD       879.81  Season cool DD        0.00  Rad total        72.35

Spring season period: Thu-01-Mar@00h00 - Mon-30-Apr@24h00
 Heat DD avg/day        9.08  Cool DD avg/day       0.00  Rad avg/day       3.47
 Heat DD avg/week      63.54  Cool DD avg/week      0.02  Rad avg/week     24.28
 Season heat DD       553.74  Season cool DD        0.18  Rad total       211.55
 . . .
Weightings for HDD CDD Solar: 1.0 1.0 1.0
Winter (early year) season.
period: Mon-01-Jan@00h00 - Wed-28-Feb@24h00
 Week: 1 starting Mon-01-Jan DD total/week    108.02    0.00  Rad total/week    6.433
 Params (heat|cool|solar)    0.035    0.000   0.251 Params total     0.285
 Week: 2 starting Mon-08-Jan DD total/week    110.93    0.00  Rad total/week    6.087
 Params (heat|cool|solar)    0.063    0.000   0.291 Params total     0.354
 Week: 3 starting Mon-15-Jan DD total/week     98.08    0.00  Rad total/week    5.455
 Params (heat|cool|solar)    0.060    0.000   0.364 Params total     0.425
 Week: 4 starting Mon-22-Jan DD total/week    110.60    0.00  Rad total/week    6.781
 Params (heat|cool|solar)    0.060    0.000   0.210 Params total     0.269
 Week: 5 starting Mon-29-Jan DD total/week    100.02    0.00  Rad total/week    7.573
 Params (heat|cool|solar)    0.042    0.000   0.118 Params total     0.160
```

```
Week: 6 starting Mon-05-Feb DD total/week      91.16     0.00  Rad total/week   14.203
Params (heat|cool|solar)     0.127    0.000    0.655 Params total    0.781
Week: 7 starting Mon-12-Feb DD total/week      97.52     0.00  Rad total/week    8.661
Params (heat|cool|solar)     0.066    0.000    0.009 Params total    0.075
Week: 8 starting Mon-19-Feb DD total/week     110.82     0.00  Rad total/week   11.682
Params (heat|cool|solar)     0.062    0.000    0.361 Params total    0.423
Week: 9 starting Mon-26-Feb DD total/week      52.66     0.00  Rad total/week    5.471
Params (heat|cool|solar)     0.496    0.000    0.363 Params total    0.858

 Best week number is   7 Mon-12-Feb with HDD of  97.52 & CDD of    0.00

early winter ratio of season/assessment days:  8.000
early winter ratio of season/assessment heat DD:  9.022 & cool DD: 1.000
Use best-fit week for the 1st winter season?
```

Figure 3.9 Winter fit criteria.

The method embedded in the ESP-r weather module *clm* codifies the manual techniques and is illustrated in the listing Figure 3.9. Weather data is scanned week by week for the average HDD and CDD for each day and the total for each week as well as the daily mean direct and diffuse solar radiation. To allow fine-tuning of the scan the user can provide weighting factors for HDD, CDD and solar radiation as well as the base temperature for HDD and CDD. The weekly data are then compared with the average and total values for the season and the week with the least deviation is suggested as the best fit.

Model calibration exercises that use such best-fit weather patterns in each season can provide a reality check which is both constrained in computational time but sufficiently focused for staff to notice patterns that would not be evident in a worst day winter/summer assessment.

To make it easier for practitioners to use selected weather patterns ESP-r support META data about seasons (early-year winter, spring, summer, autumn, late-year winter in the Northern Hemisphere, early-year summer, autumn, winter, spring later-year summer in the Southern Hemisphere) as well as typical assessment periods.

3.3 Defining seasons and typical periods

When working with a weather file which is already selectable in the Project Manager weather list it will already have meta data defining the duration of each season as well as a typical week in each season which can be used for short duration assessments.

The concept of a season can be leveraged in several ways. The *clm* module provides a number of views of weather data, including statistics, which can help you identify weather patterns which conform to your own definition of seasons.

Exercise 3.4 Jump to Exercise 3.4 in the *Exercise Appendix* and use the different reporting options to identify that start and end dates for seasons of the year that are consistent with local preferences or traditions. The module also offers a facility to scan weather data for find the best fit week for each season using a combination of temperatures and solar radiation.

When you have completed the exercise you will a seasonal display such as Figure 3.6 which shows the seasons along the top and the ambient temperatures on the graph below.

Exercise 3.5 Once you have explored seasons you can record the information in a block of text that can be included in the so-called *climatelist* file. Exercise 3.5 goes through the steps of creating this block of text and it also provides information about the format of the *climatelist* file.

3.4 Importing weather data

Although ESP-r is distributed with several dozen weather files (in the climate folder of the ESP-r distribution) associating new weather data so that you can select it quickly and use it robustly within projects requires a number of steps.

The instructions in Exercise 3.6 in the *Exercise Appendex* allow you to install a new weather file, specify the days in each season and then use clm facilities to discover typical assessment periods in each season.

A good source of weather data is the United States DoE web site which is located at the following address (on one line) `<http://apps1.eere.energy.gov/ buildings/energyplus/ cfm/weatherdata.cfm>`. The site offers US locations, Canadian Locations and International Location.

3.5 Common materials

Common materials files hold information on material thermophysical properties. These are held either in the ESP-r distribution database folder or in a model's *dbs* folder in the case of project specific materials.
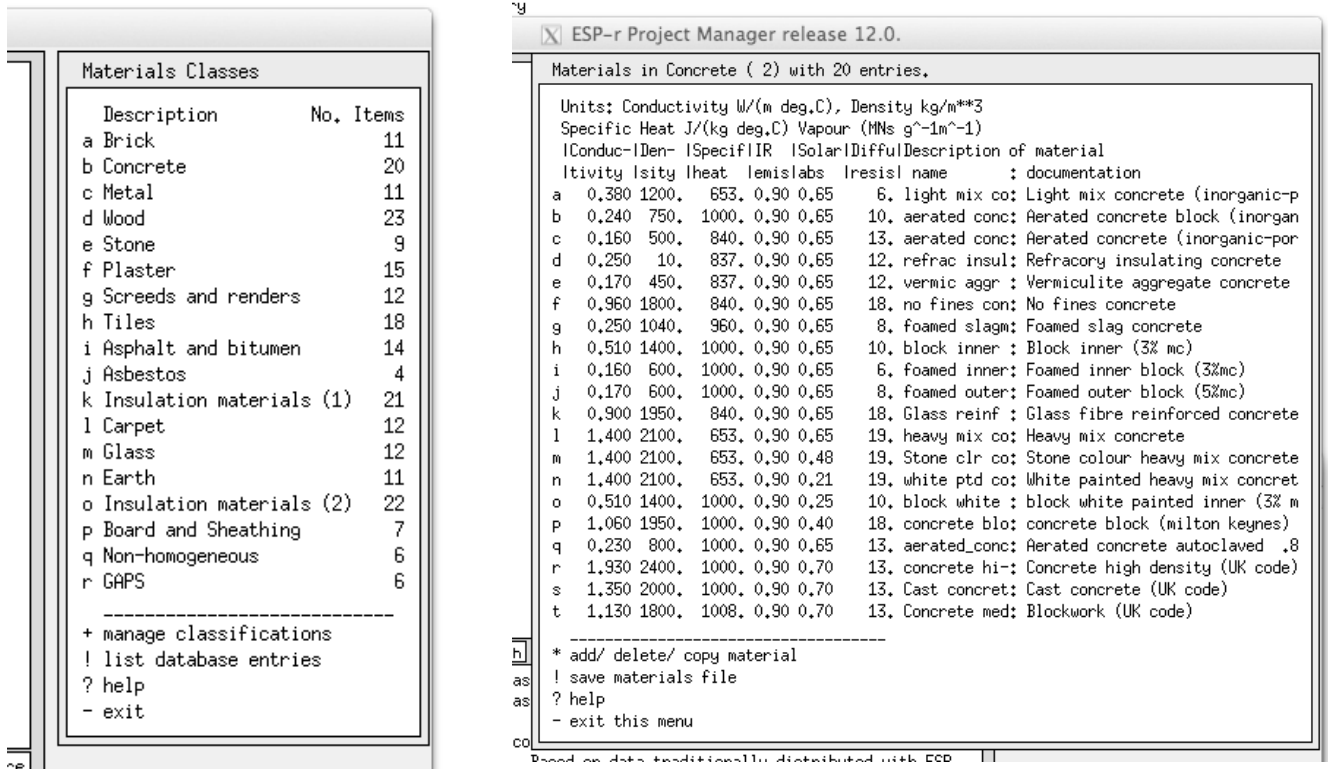

Figure 3.10 List of materials classes and concretes.

As seen in Figure 3.8, materials are held in classes e.g. Brick, Concrete, Metal. A category such as Concrete, shown in Figure 3.10 contains general types of concrete such as *heavy mix* concrete and adapted materials such as *which painted heavy mix* which has adjusted surface properties to represent painted surfaces.

Each material has the following attributes:

- name is a short identifier
- description - block of text describing the material, the material name and the initial portion of the material descrition are included in the construction definition
- conductivity (W/(m-K))
- density (kg/m^3)
- specific heat (J/kg-K)
- emissivity in the long wave band (-)
- absorptivity in the short wave band (-)
- tyical thickness (mm)
- tag indicating whether it is opaque, transparent, or a gas.

ESP-r differs from other tools such as DOE-2 and EnergyPlus in that materials are only given a specific thickness when they are associated with a construction layer. Thus a single brick material might be used in several constructions with different thicknesses.

Exercise 3.7 Exercise 3.7 will give you practice navigating the categories of materials and searching for items which meet specific criteria. When adding new materials it is recommeneded that you document the source of the thermophysical data as well as any assumptions made within the material description. Any changes you make will be held in memory so the ! `SAVE materials database` entry should be used frequently. If you need to evolve a materials database for purposes of a specific project then make a local copy of the materials file via the `copy default file to model` or `copy file from common to model` options.

The category named GAPS is included to signal a non-solid layer which is treated as a resistance to heat flow (for vertical and sloped & horizontal positions). For example, a low-e coating in glazing increases the resistance to heat flow across the cavity and the resistance values would reflect this. Unless you are working with non-homogeneous constructions where an air gap is represented as a conductivity, stick with the first air gap material (see figure 3.11) and supply the resistance values for the standard orientations.
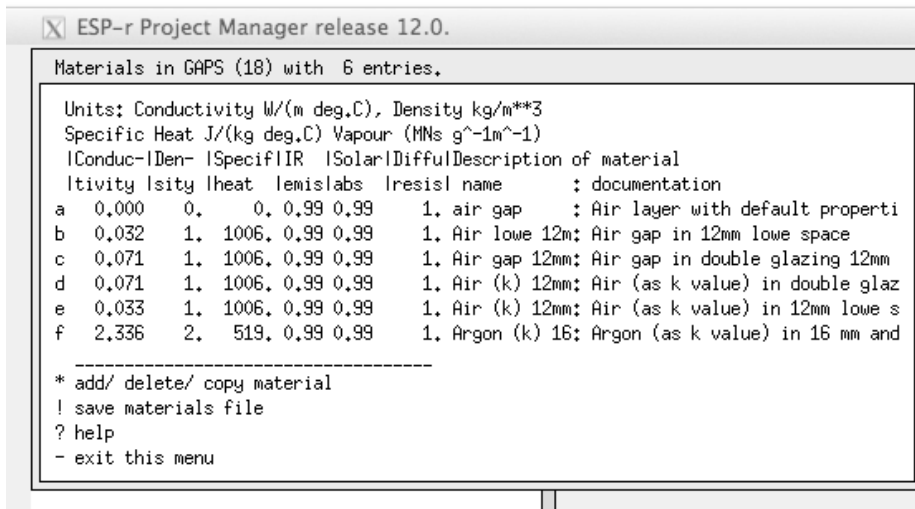
Figure 3.11 List of GAP materials.

Normally, a simulation group would seek to protect their common materials from corruption. One way to do this is to insist that new materials or material variants are held in model-specific materials files and only incorporated in the distribution common (database) folder by trained staff.

In the next section Figure 3.12 (and the listing on the next page) shows a raised floor system over a thick concrete slab. If we needed to include this in a model we would review the specification of the materials, see if there was an equivalent material. Let's say that the raised floor is a Kingspan RG Series Gravity Lay access floor <www.kingspanaccessfloors.co.uk/>. The product is made up of 2mm steel, 28mm of high density particle board and 2mm steel. Generally carpet of 8mm is laid on top.

The materials database only has medium density boarding so we must search for data on high density particle board. There is an entry in Thomas Irvine's Handbook of Heat Transfer which list a density of 1000 kg/m^3 and specific heat of 1300 J/kg.K and conductivity of 0.17 W/m.K.

Exercise 3.9

To limit risk we want to create the new material in a common materials file associated with our model. Later we can get this incorporated into a corporate database. The steps required to copy a standard materials file into a model is covered in Exercise 3.9.

```
*item,HighDensityParticleBd, 91, 4,HDF based on info in Handbook of Heat Transfer by Thomas Irvine
0.170,1000.000,1300.000,0.900,0.900,0.700,0.700,55.000,9.0,-
# layers  description  type  optics name  symmetry tag
    4     flr_ov_pln    OPAQ  OPAQUE         top_pln
# material ref thickness (m) description & air gap R
   42    0.0020  steel : Steel
   91    0.0280  HighDensityParticleBd : HDF based on info in Handbook of Heat Transfer
   42    0.0020  steel : Steel
  228    0.0050  grey loop pile : Grey loop pile synthetic carpet
```

3.6 Common Constructions

ESP-r holds information about walls, roofs, partitions, internal fittings and facade elements in common constructions files. These are located in the databases folder of the ESP-r distribution. For models with project specific constructions the construction file will be located within a model's dbs folder.

A common constructions file holds categories of constructions such as opaque walls, partitions, frames, doors, fittings, earth etc. Several hundred constructions can be accommodated and thus the interface includes a number of management facilities. Recently the data structure has been extended to support categories as well as longer names and documentation for each construction. In ESP-r a construction is also sometimes referenced as a MLC.

A construction has the following attributes:

- name - up to 32 characters, must be unique, used internally and in reports
- menu entry - up to 32 characters to clarify selections from a potentially long list
- documentation - up to 248 characters describing the source and provenance of the construction.
- category name - the name of the category it relates to
- optical property name or the key word OPAQUE
- number of layers - up to a dozen
- tag indicating whether construction is symmetric
- name of associated reversed layer construction

Each layer has the following attributes a) name of the material, b)thickness of the layer. For for air gaps the resistance to heat flow for horizontal, vertical and sloped positions. You may notice that reports about constructions include U values for the case of horizontal flow, vertical and sloped heat flow. These are derived values following conventions of ISO 6946. U-values are not used within assessments (they are a steady-state concept) but are included for purposes of comparison. Similarly glazing is often described with a *G* value which is a common reporting convention.

Exercise 3.8

If you are reading this section in preparation for creating the surgery in Section 2.2 the planning phase requires the identification of constructions which match a description e.g. a window frame or door and a desired U-value. Exercise 3.8 guides you through the process.
Review the reports as entities are selected to confirm the overall thickness of the construction, the placement of mass and insulation. Constructions which have an optical attribute will include optical properties.

Physically thick layers e.g. stone in castles and the ground under a foundation need to be subdivided. For example, in the list in Figure 2.17 the grnd_floor has multiple layers of Common Earth which add up to 1m. Splitting a material in to several layers is a common technique for massive materials or insulation

materials. It results in more nodes so the numerical solution is more efficient as well as providing higher resolution reporting of conditions within constructions.

```
Details of opaque construction: Brk_blk_1980 and overall thickness  0.273
In category walls also shown in menus as: UK cavity brick-block 1980
UK insulated cavity brick-block wall circa 1980 hard plastered.
Layer|Thick|Conduc-|Density|Spec|IR  |Solar|Diffu| R    | Kg |Description
     |(mm) |tivity |       |heat|emis|abs  |resis|m^2K/W| m^2|
Ext   102.0   0.770  1700. 1000. 0.90 0.70    12.  0.13 173.4 Brick outer leaf : Brick (UK co...
  2    20.0   0.000     0.    0. 0.99 0.99     1.  0.17   0.0 air  0.17 0.17 0.17
  3    25.0   0.040   105. 1800. 0.90 0.60     1.  0.62   2.6 mineral fibre : Mineral fibre (...
  4   100.0   0.240   750. 1000. 0.90 0.65    10.  0.42  75.0 aerated conc block : Aerated co...
  5    13.0   0.500  1300. 1000. 0.91 0.50    11.  0.03  16.9 dense plaster : Dense plaster (...
Int    12.5   0.160   600. 1000. 0.91 0.50     8.  0.08   7.5 light plaster : Light weight pl...
ISO 6946 U values (horiz/upward/downward heat flow)=  0.618  0.630  0.603 (partition)  0.585
Weight per m^2 of this construction 275.45

Admittance calculations using Rsi   0.12 Rso   0.06 & Uvalue=  0.61
External surface admittance Y=  2.93  w=  2.14 decrement factor f=  0.73  phi=  0.99
Partition admittance Y=  3.13  w=  2.13 surface factor f=  0.71  phi=  1.09

Details of transparent construction: dbl_glz with DCF7671_06nb optics & overall thickness 0.024
Layer|Thick|Conduc-|Density|Specif|IR  |Solar|Diffu| R    | Kg |Description
     |(mm) |tivity |       |heat  |emis|abs  |resis|m^2K/W| m^2|
Ext    6.0    0.760  2710.   837. 0.83 0.05 19200.  0.01  16.3 plate glass : Plate glass with ...
  2   12.0    0.000     0.     0. 0.99 0.99     1.  0.17   0.0 air  0.17 0.17 0.17
Int    6.0    0.760  2710.   837. 0.83 0.05 19200.  0.01  16.3 plate glass : Plate glass with ...
ISO 6946 U values (horiz/upward/downward heat flow)=  2.811  3.069  2.527 (partition)  2.243
Weight per m^2 of this construction  32.53

Admittance calculations using Rsi   0.12 Rso   0.06 & Uvalue=  2.73
External surface admittance Y=  2.81  w=  0.63 decrement factor f=  0.67  phi=  0.31
Partition admittance Y=  0.82  w=  5.64 surface factor f=  1.00  phi=  0.38
 Clear float 76/71,     6mm, no blind: with id of: DCF7671_06nb
 with 3 layers [including air gaps] and visible trn: 0.76
 Direct transmission @ 0, 40, 55, 70, 80 deg
   0.611 0.583 0.534 0.384 0.170
 Layer| absorption @ 0, 40, 55, 70, 80 deg
    1  0.157 0.172 0.185 0.201 0.202
    2  0.001 0.002 0.003 0.004 0.005
    3  0.117 0.124 0.127 0.112 0.077
 Total area of dbl_glz is       9.83

Details of opaque construction: grnd_floor and overall thickness  0.975
In category ground also shown in menus as: carpet conc floor hardcore-earth
An uninsulated slab on grade foundation over hardcore and 600mm of earth with a built-up of
chipboard and carpet above.
 Layer|Thick |Conduc-|Density|Specif|IR  |Solar|Diffu| R    |Description
      |(mm)  |tivity |       |heat  |emis|abs  |resis|m^2K/W|
 Ext   200.0    1.280  1460.   879. 0.90 0.85     5.  0.16 Common_earth
   2   200.0    1.280  1460.   879. 0.90 0.85     5.  0.16 Common_earth
   3   200.0    1.280  1460.   879. 0.90 0.85     5.  0.16 Common_earth
   4   150.0    0.520  2050.   184. 0.90 0.85     2.  0.29 Gravel based (non-hygroscopic)
   5   150.0    1.400  2100.   653. 0.90 0.65    19.  0.11 Heavy mix concrete
   6    50.0    0.000     0.     0. 0.99 0.99     1.  0.17 air  0.17 0.17 0.17
   7    19.0    0.150   800.  2093. 0.91 0.65    96.  0.13 Chipboard
 Int     6.0    0.060   186.  1360. 0.90 0.60    10.  0.10 Wilton weave wool carpet (org-hygro)
 ISO 6946 U values (horiz/upward/downward heat flow)=  0.699  0.714  0.680 (partition)  0.657
```

Figure 3.8 Examples of common constructions to be used in the surgery.

Constructions are defined from the outside (the other face) working inwards towards the room face. If a construction presents the same order of layers looking from the room side or from the other side then it is SYMMETRIC.
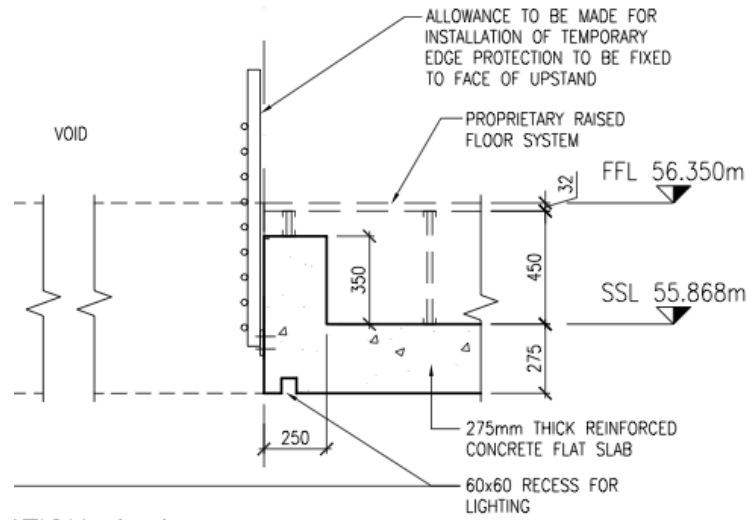
Figure 3.12 Section of raised floor system.

An example of a non-symmetric construction is the intermediate raised floor shown in Figure 3.13. Looking from the room below the 'other' face is carpet and the room face is white painted concrete. From the room above the 'other' facde is the white painted concrete and the room face is carpet.

The raised floor system includes a significant air space/layer. If the air space acts as a supply or return plenum then it might need to be represented explicitly as a thermal zone. In this case there are additional constructions listed below would be required:

- Looking down from occupied space - 32mm raised floor (other face), 5mm carpet (inside face).
- Looking up from the plenum - 5mm carpet (outher face), 32mm raised floor (inside face)
- Concrete slab is the same from both viewing directions.

It is important to name constructions in a way which will allow reliable selections. In the above cases if we consider the observers position and look at the construction the names below might work:

- floor_raised or room_to_raised - looking down from occupied space to lower occupied space
- ceil_raised or ceil_to_raised - looking up from lower occupied space to upper occupied space
- floor_over_plen - looking down from occupied space to floor plenum
- ceil_under_plen or slab_275 - looking up from lower occupie space to floor plenum
- top_pln - looking up from plenum to upper occupied space

Unlike common materials, constructions do not (yet) have a documentation phrase attribute. With a short name, the risk of confusion increases and simulation groups should find additional ways to document constructions.

3.7 Common optics

Constructions which are transparent require additional attributes to describe how solar radiation passes through (or is absorbed in) the layers of a construction. Information to support this is held in common optics files either in the databases folder of the ESP-r distribution or in a model's dbs folder.

Common optics files hold a list of optical property sets. Each optical set has the following attributes:

- name (up to 12 characters with no space), typically single layer optics start with an **S**, double glazing starts with a **D** but you can use any naming convention.
- description (block of text up to 36 characters)
- visible transmittance for use in exporting models to Radiance and for daylighting calculations
- solar absorption and reflection at the outside face for documentation purposes
- U values for documentation purposes - manufacturers data is often input here so the user can compare with the calculated U value found in the common constructions
- number of layers (air gaps are considered separate layers)

- five angular data for direct solar transmission (normal to the surface and at 40°, 55°, 70° and 80°)
- five angular data on heat gain factors for documentation purposes

For each layer the angular solar absorption factors are held (at the same five angles as direct solar transmission).

Populating common optics files requires the use of third party software such as LBL Window 6 <www.windows.lbl.gov/software/window/6>. These produce reports which document the overall optical properties as well as layer-by-layer optical properties. These reports can be imported into an ESP-r common optical file. It is up to the user to create a matching construction. Care is requied to ensure that any air gaps in the construction have appropriate resistances defined so that the reported U value matches the documentation in the optical data set.

ESP-r supports control of optical properties within the zone construction facility (look for `transparent layer properties`). This allows you to associate an alternative optical property set that is used if certain logical conditions are met. A simple example is a double glazing unit with a mid-pane blind. One optical set might represent the blind in an open state and another with the blind partly closed. Both optical states should have the same number of layers.

3.8 Complex Fenistration Components

An alternative to the standard ESP-r optics database, which holds moderate levels of optical attributes and resolution, is the concept of Complex Fenistration Components. The work which was originally carried out in Canada, attempts to represent a variety of facade build-ups which include blinds as well as offering a more explicit treatment of heat transfer within gaps in glazing. In many cases the entities in the CFD database support *black-box* treatments which solve the optical and thermophysical transfer within glazing systems and pass information back to the solver. A classic case is a blind which is mounted in the room with an air gap between itself and the glass. Without explicitly representing the gap as a zone it is difficult to represent the heat transfer at the blind. `CFC2` in the attributes of the surface.
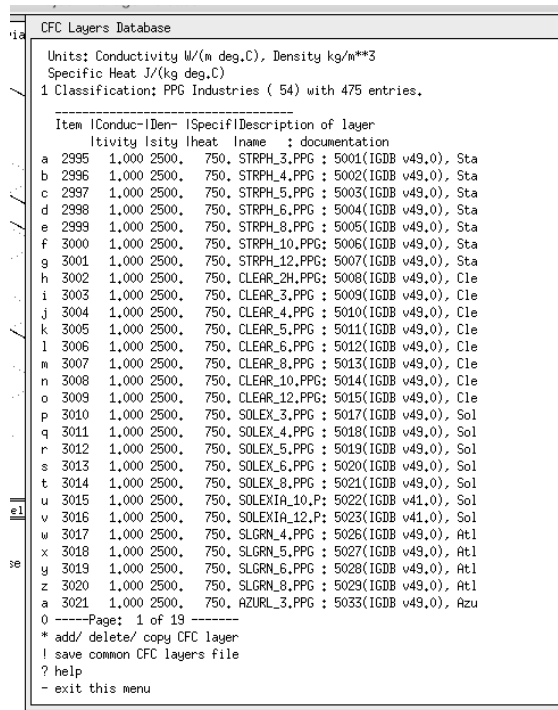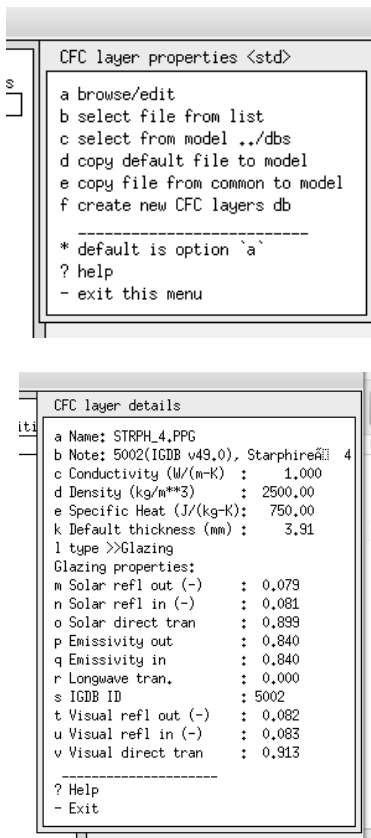
The figures above and below show views of the CFC database, categories of entities, entity lists and the attributes of a typical entry. There are hundreds of different manufacturers data sets which have been extracted from the IGDB. Constructions when they are built up point to these layer entries and the solver uses their attributes. When a room surface uses a CFC related construction the CFC solver is used rather

than the standard optical code and the surface attribute shows up as a
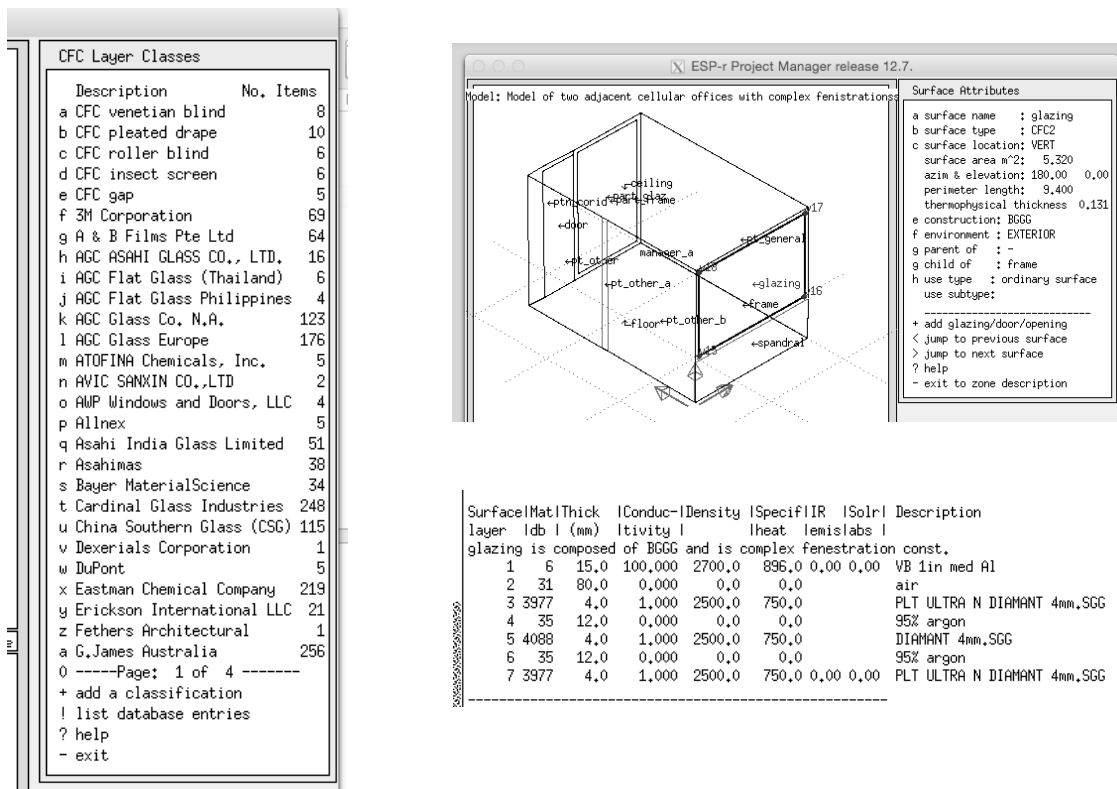
Figure 3.13 Complex Fenistration Components selection and use.

3.9 Common pre-defined entities

ESP-r treats explicit thermal mass with the same level of thermophysical detail as facade surfaces. And while there are facilities to create internal mass pairs - doing this from scratch is tedious, prone to error and does not scale well. Visual assessment tasks would be enhanced if one could populate the Radiance model with visual entities during the export-to-Radiance step rather than having to hack the Radiance files. And there are building entities such as stairs which are tedious to create but which, if absent, may mis-represent the inertia within the building.

ESP-r thus includes a database of pre-defined entities which have the following attributes:

- short name, text entry for list selection
- blocks of descriptive text includes notes on use, applicability and provenance
- intended domains e.g. visual, mass, zone-enclosure
- origin and bounding box (for preview)
- list of vertices
- list of mass pair surfaces (name, composition, optical properties, bounding edges)
- list of boundary surfaces (name, composition, optical properties, bounding edges)
- list of visual entities (origin, length/width/height, rotation, name, composition
- list of named objects with associated visual entities

Pre-defined entities are accessed via the *databases menu* as shown below:

59
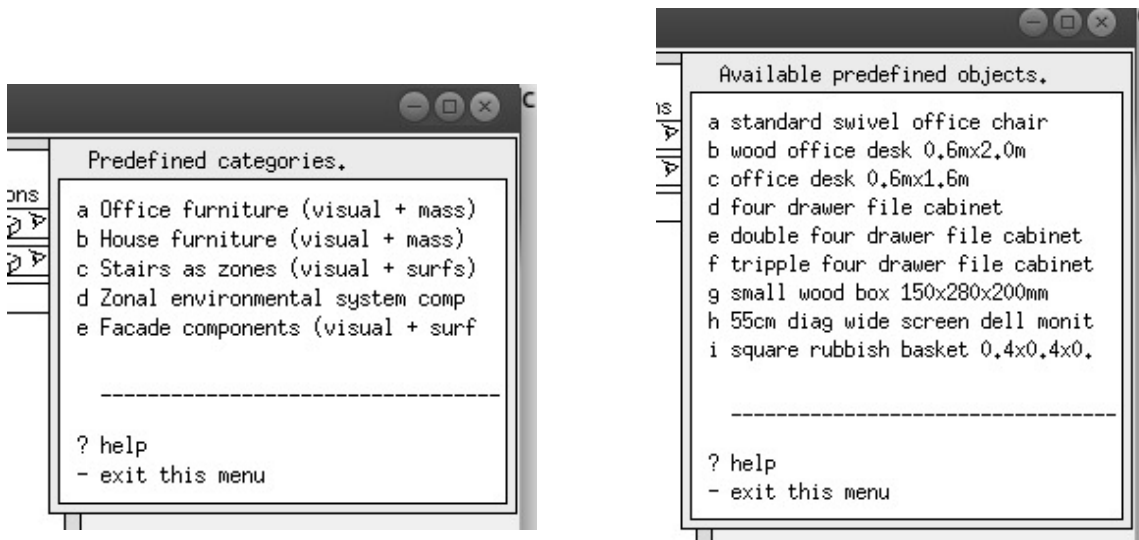
Figure 3.14 Predefined categories & office entities

Below are two typical entities. The first is an office chair which is made from 8 vertices, two pairs of thermal mass and 13 visual objects. These are intended to be imported into a thermal zone as required to populate the space for purposes of both thermal and visual assessments. An office space might have a dozen such entities, each will be given a unique name and thereafter will fully participate in insolation and long-wave radiant transfers.

The second is a residential stair which, when imported into a model forms a complete thermal zone (there is a matching entity for the space above the treads). Other zone-based entities include an explicit room thermostat (including an explicit thermistor, circuit board and case).
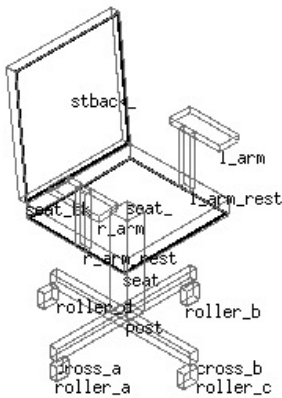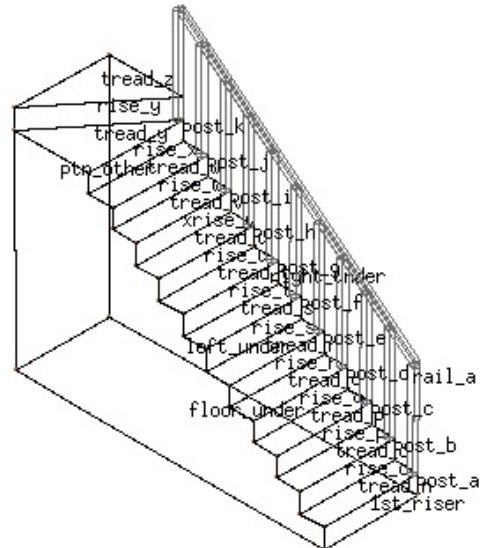
Figure 3.15 Pre-defined office chair and stair zone.

Entities are typically created within ESP-r as zones with whatever mass and boundary and visual entities required then transformed to the origin. The zone file can then be imported and documentation added to the entry.

THERMOPHYSICAL RESOLUTION

4 Thermophysical resolution

This chapter is written from the author's perspective as a trainer of Passive House practitioners - a standard with an extreme focus on building sections, especially the joins between facade elements. The author also practiced architecture for many years with clients with somewhat less extreme performance goals as well as working as a consultant on simulation-based projects assessing the performance of a range of building types and ages.

And from the perspective of a general purpose simulation tool such as ESP-r, artefacts within the built environment, from the housing of a thermostat to an open plan office space are subject to the same physics. Even though their scales are different users could compose models (the virtual physics) at similarly disparate scales.

From these perspectives construction documents often contain:

- complex junctions which are not well represented by 1D heat conduction
- exceptions to standard sections i.e. where structural elements are found at non-standard spacing
- instances where the external surface area of a facade differs from the inside surface area e.g. deep facade frame extrusions, window reveals and frames
- thermal bridges which degrade the performance of building sections
- instances where facades are geometrically thick rather than thin planer forms.

Sometimes small changes in building sections can result in better performance at little or no additional cost. Definitely a win-win scenario that simulation might contribute to. Unfortunately, some building sections (i.e. thermal bridges) form explicit instructions for future failure (e.g. condensation, micotoxin growth, local discomfort). With good pattern matching skills Architects can identify and correct inappropriate building sections prior to construction and contractors can identify and avoid faults.

Pattern matching skills for simulation practitioners are key skills which support the planning and implementation of simulation models with appropriate geometric and thermophysical resolution to identify both the win-win and potential faults.

Observations, identification and planning skills are largely platform independent. However, representations of linear and point thermal bridges and options for representing depth in facades vary between simulation tools and thus some of the discussion to follow is ESP-r specific.

ESP-r specific

The geometric forms discussed thus far use polygons as the building blocks of our virtual built environment. While modern (thin) constructions, such as those used in Figure 1.5 are often approximated by conventional polygons, historical buildings (see Figure 1.6) and the thick walls and insolation seen in Figure 4.1 highlight the limitations of this convention.

Focusing on Figure 4.1, there are several aspects of the section which need to be considered during the planning and creation of models:

- the thickness of insulation is substantial and in some places tapering
- the wall section comprises a number of material types
- the overhang (and window reveals) act to shade the facade of the building
- the overhang forms a boundary for the upper section of the wall.
- there appears to be an air space below the tiles which is separate from the air within the roof space.
- above the tapering insulation is a channel for eaves air to mix with the roof space
- it is not clear from the section whether the roof ridge is ventilated.
- the area at the top of the insulation layer is somewhat different from the surface area at the ceiling.
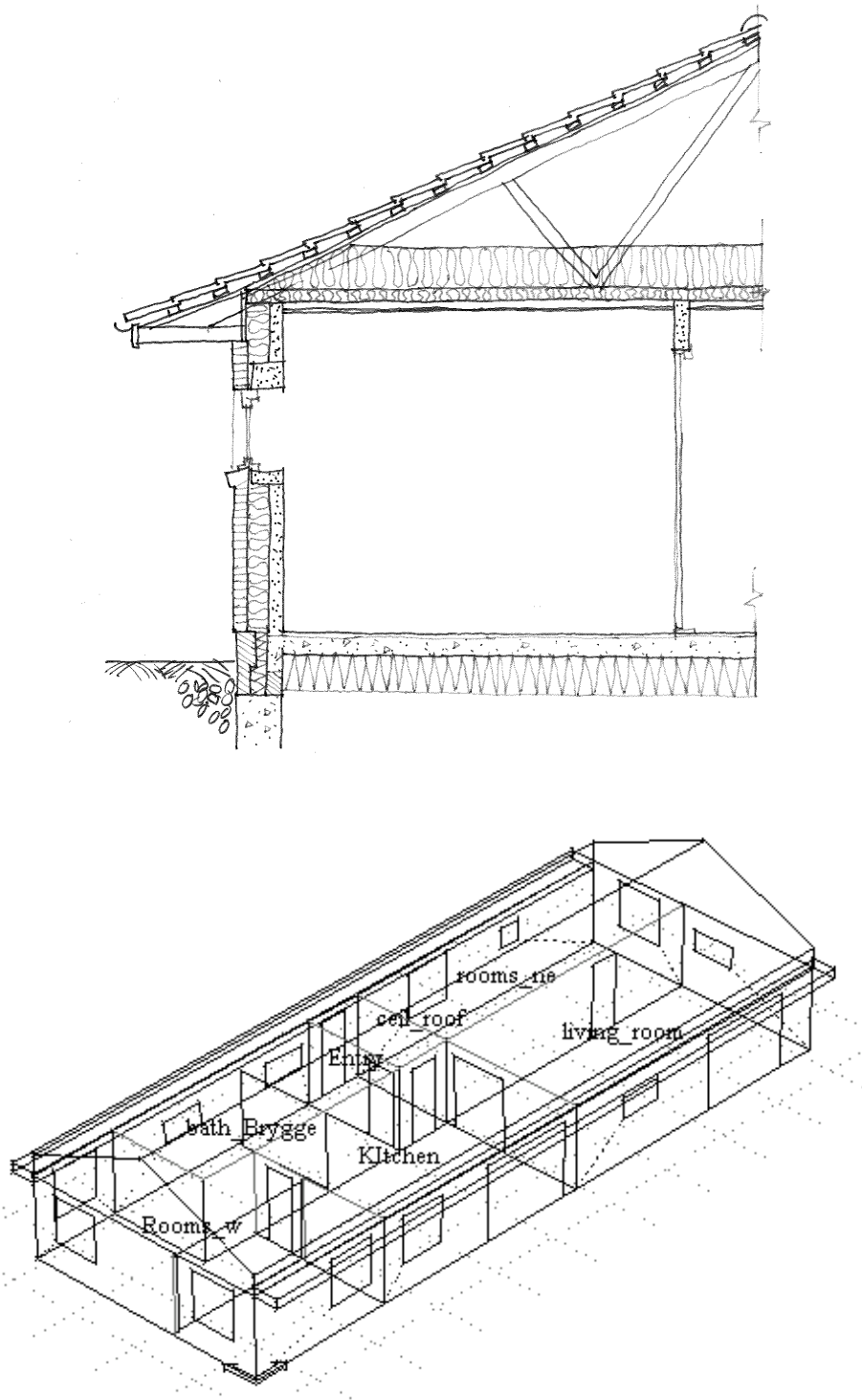
Figure 4.1 Section and view of a low energy house

The list of bullet points could be much longer. We need strategies for ranking thermophysical issues and deciding **what** needs to be included in our model(s).

4.1 Modelling approaches

The geometric and compositional resolution of a simulation model depends on the questions being asked and the resources available. Some thermophysical relationships may require simplification and others might not be possible to represent within our model. All virtual environments are abstractions. Simulation tools support one or more levels of abstraction for each of the domains they solve. Options allow experts freedom at the cost of a steep learning curve for novices.

A *tactical approach* to simulation uses the planning phase to constrain options. The following is *one possible ranking* of what to preserve while abstracting a design into a model:

- the volume of air

- the slope of the roof

- the location of mass within the roof and occupied spaces

- the surface area in contact with the air

By default, most whole-building simulation tools, including ESP-r, default to one-dimensional conduction. The thickness of the insulation in Figure 4.1 thus poses a challenge. Do we choose to ignore the ceiling thickness when defining geometry? Use of physical co-ordinates would help to preserve the volume of the roof space and the surface areas although this takes more time.

A *high resolution model* might sub-divide the roof space to have an upper and lower section so that the temperature near the peak of the roof can be different from the air adjacent to the insulation layer. It might also include linear thermal bridge descriptions if these had been calculated.

A *medium resolution model* might subdivide the surfaces to represent full thickness and the partial thickness insulation and extend the roof zone to allow it to form a boundary at the upper wall section as well as including an air channel from the soffet to the roof space. It is a user choice whether to set the bounds of the zones at the inside face of the facade (right of Figure 4.2) or the outside surface of the facade (middle of Figure 4.2).

A *low resolution model* might treat the overhang as a solar obstruction and ignore the different thickness of the insulation. It might assume the air is well mixed within the roof space (i.e. there is no temperature stratification). It would also not explicitly represent the overhang as a boundary condition for the upper portion of the wall and would omit the internal reveal of the window (right of Figure 4.2). This is visually crude and the height of the building is not correct.

The lower portion of Figure 4.1 is a variant which raises the roof surfaces to their correct coordinates. The side-effect is an inaccurate roof space volume.

In the case of ESP-r, the user has considerable freedom to create models that fit the users opinions. Many example models distributed with ESP-r *appear* to ignore the thickness of partitions while other example models indicate a separation between rooms. Such differences are typically related to the method of data input. Geometry digitized from CAD drawings will have rooms separated in space. Zone geometry created from dimensioned data or sketches may tend to have partitions at the centre line of walls and the inner face of a facade. The good news is that such differences typically have little or no impact on predicted performance. The solver knows from the thermophysical composition of the partition whether or not the two faces are separated in the co-ordinate system or lie in the same plane.
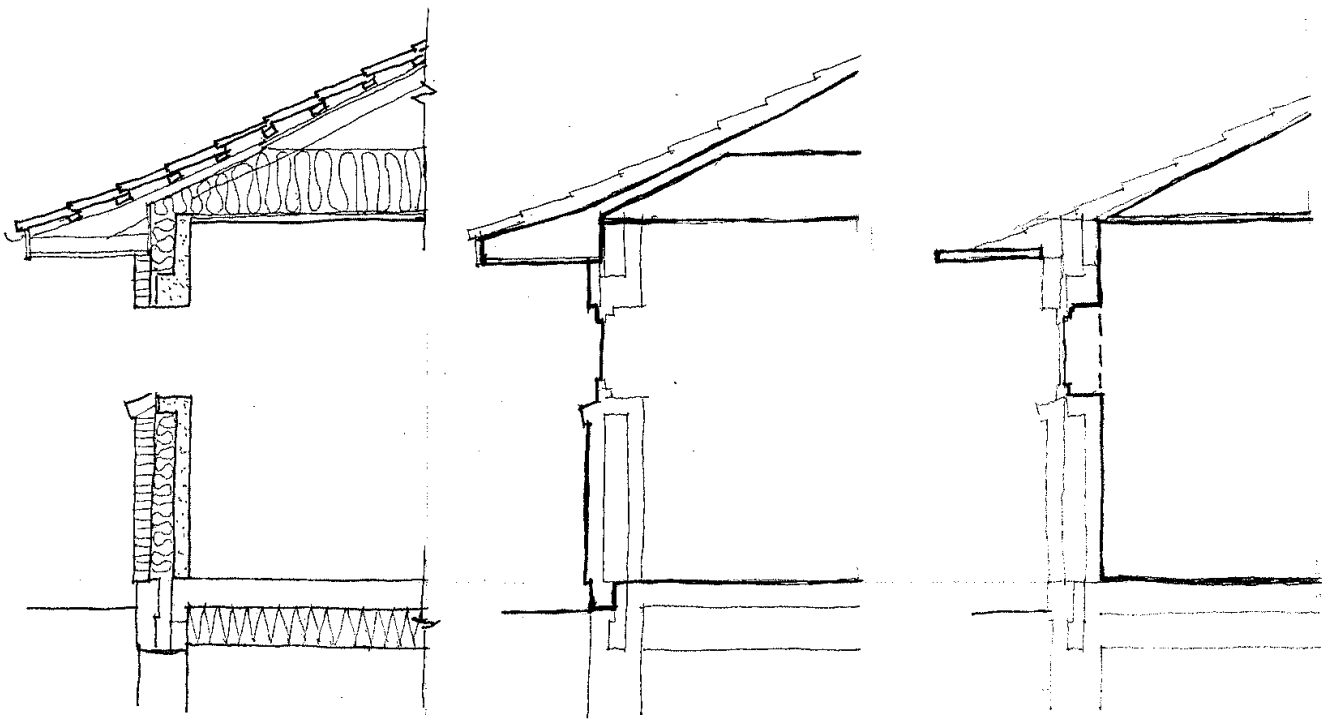
Figure 4.2: Matrix of geometrical approaches to room and roof spaces

Investing resources to increase model resolution is a decision that should not be made lightly. Some differences in performance predictions can be subtle rather than dramatic. A user who wishes to explore this could define variant models at different levels of resolution to test the sensitivity of predictions.

The explicit coordinate approaches involve more surfaces and additional planning and documentation of coordinates. Rather than simply reusing the ceilings surfaces of the occupied rooms via copy-invert into the roof space, there is a need for surface and vertex transforms.

Note that the surfaces forming the overhang do not (in the current version) shade the wall. Shading requires the use of shading obstruction blocks (as included in the earlier figures).

And this more-explicit approach introduces a problem for the occupied space. The overhang, as drawn in the building section is in contact with the upper portion of the wall. The geometry of the walls should be adapted to sub-divide the wall into surfaces that face the outside and surfaces which connect to the overhang.

4.2 Linear thermal bridges

The author's experience as a trainer of PassivHaus practitioners and consultants has highlighted the importance of thermal bridges in the assessment of building performance. The extreme performance objectives of PassivHaus rely on thermal-bridge-free construction details. In both modern and traditional construction thermal bridges are legion and result in reduced thermal performance which is not well represented in whole-building numerical tools.

So what is a thermal bridge? A portion of the facade which, because of the types of materials and their location can act as a bridge where heat flows through the facade at a different rate. The difference in heat flow between a length of facade with and without the thermal bridge indicates its magnitude - typically the steady-state representation is known as a psi value with units Watts/length/degree of temperature difference.

Psi values are evaluated via 3rd party software such a LBL THERM <www.windows.lbl.gov/software/therm/7>. From the point of view of ESP-r, linear thermal bridges are described as psi value and length. The summation of the heat flow in all the thermal bridges in a zone are included in the zone energy balance. Unfortunately, psi values are steady-state representations and there is no accounting for altered surface temperatures near thermal bridges. ESP-r is capable of working with dynamic 2D and 3D heat flows but that facility is rarely used and the facilities not well understood.

A timber framed wall where a solid wood stud is found at regular intervals is an example of a repeating thermal bridge. These are often represented as non-homogeneous layers within a construction so the performance is taken into account.

The junction of two walls has a much larger or smaller external surface area than is found adjacent with the room and thus forms a geometric linear thermal bridge (as in Figure 4.3 left). This section with an outside insulation thickness of 120mm has a psi value of 0.06 W/mK or the 80mm variants with a psi value of 0.062 W/mK.

The ESP-r geometry attribution includes an option to define thermal bridges. You can access it via: `Browse/Edit/Simulate -> zone composition -> geometry -> define linear thermal bridges` It uses a number of surface attributes as well as the polygon edges when a zone if scanned. Firstly, the `surface boundary attribute` is checked for facade surfaces and the `surface use attribute` is used to identify frames and doors. It is therefore necessary to fully attribute surfaces prior to using the thermal bridge facility. After scanning the polygons and surface attributes the total length of each edge type is listed, as seen in Figure 4.4 The length suggestions should be checked and edited as required. An additional type can be added as required. Experience indicates that good notes are essential.

The junction of an intermediate floor with an external wall (as in Figure 4.3 right) results in psi values of 0.072 or 0.073. Here the thermal bridge runs along the concrete floor structure and between the honeycomb brick.

WALL - WALL

Rse = 0.04 m^2K/W
FC = 25 W/m^2K
T = 0 C

Rsi = 0.13 m^2K/W
FC = 7.69 W/m^2K
T = 20 C

Rse = 0.04 m^2K/W
FC = 25 W/m^2K
T = 0 C

Rsi = 0.13 m^2K/W
FC = 7.69 W/m^2K
T = 20 C

adiabatic

adiabatic

adiabatic

ground floor

ext plaster (t = 10)
insulation (t = 120 or 80)
former plaster (t = 30)
honeycomb brick (t = 300)
int plaster (t = 10)

adiabatic

ext plaster (t = 10)
insulation (t = 120 or 80)
former plaster (t = 30)
honeycomb brick (t = 300)

Rsi = 0.13 m^2K/W
FC = 7.69 W/m^2K
T = 10 C

attic

insulation1 (t = 100)
screed (t = 40)
insulation2 (t = 40)

Rsi = 0.17 m^2K/W
FC = 5.88 W/m^2K
T = 10 C

Rse = 0.04 m^2K/W
FC = 25 W/m^2K
T = 0 C

adiabatic

Rsi = 0.10 m^2K/W
FC = 10 W/m^2K
T = 20 C

concrete (t = 220)
plaster (t = 10)
insulation3 (t = 100)

ground floor

ext plaster (t = 10)
insulation (t = 120 or 80)
former plaster (t = 30)
honeycomb brick (t = 300)
int plaster (t = 10)

Rsi = 0.13 m^2K/W
FC = 7.69 W/m^2K
T = 20 C

Rse = 0.04 m^2K/W

adiabatic

Figure 4.3 Wall to wall and wall to floor thermal bridge junctions
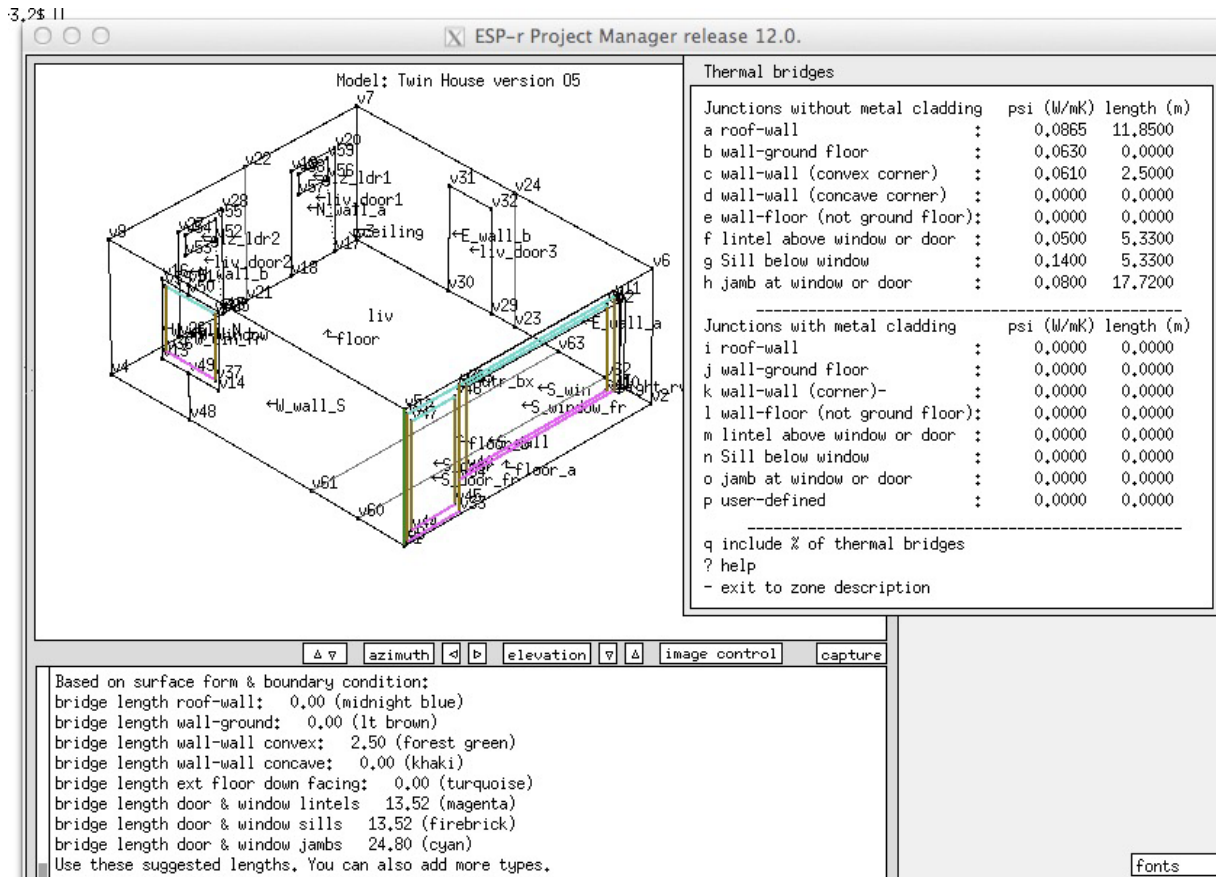
Figure 4.4 ESP-r thermal bridge definitions.

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4.3 Junctions and spaces in facades

Even the most visually clean facade can hide complexity in the form of ceiling and floor voids, small spaces, un-aligned layers of insulation. This can result in local temperature extremes, as well as paths for air movement and heat transport which are difficult to represent.

Consider Figure 4.5, the ceiling void is bounded by the spandrel which includes an insulated portion as well as the lower uninsulated and not-thermally-broken extrusion and a metal barrier adjacent to the fire-stop. The ceiling void includes lighting fixtures as well as contact with the structural mass. It is not clear whether the raised floor is also being used as a supply plenum but it certainly acts to isolate the occupied space from the structural mass.

The spandrel void temperatures often exceed 60°C, yet at the top of the spandrel the insulation layers are offset, creating a heat flow path across the upper extrusion and into the void adjacent to the Fan coil enclosure. At the lower edge the spandrel extrusion is in direct contact with the occupied space in the lower level.

A minimal abstraction would represent three facade sections (at the glazing, at the fan coil cabinet and at the spandrel). The depth of the ceiling void and the internal heat generation would suggest separate zoning of the ceiling void. To identify spandrel performance the spandrel space probably needs to be treated as a separate zone. Explicit treatment — would allow testing of alternatives such as single glazing of the spandrel. One might also explore conditions in the raised floor via explicit treatment. Is an explicit zoning worth the effort? Creating an explicit model of a small section of the building would identify the benefits as well as the resources needed for the additional resolution.
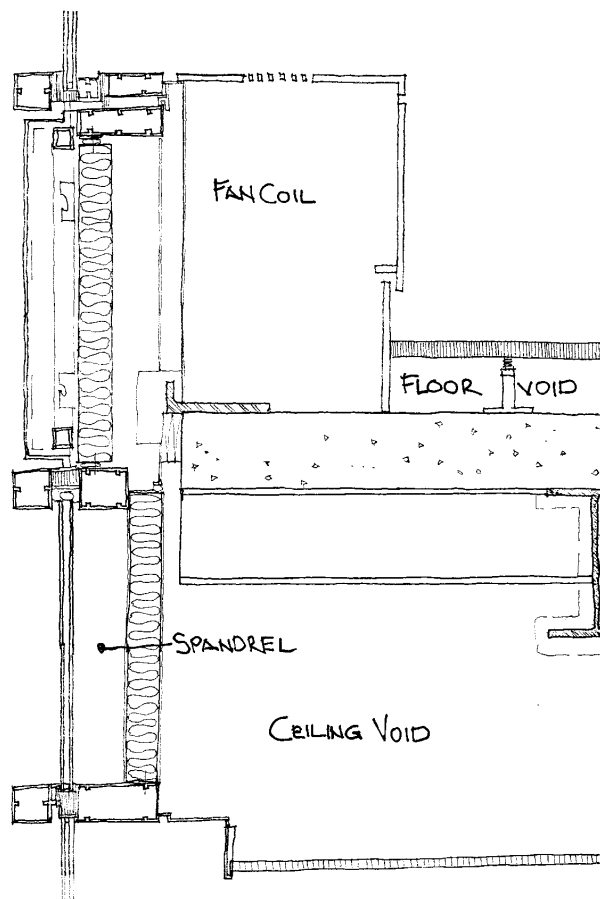
Figure 4.5 Junction at spandrel in a commercial facade

4.4 Increasing thermophysical resolution

Each simulation suite has a set of core facilities as well as options which may provide additional performance information or invoke an alternative solution techniques.

And the tag-line for ESP-r has long been:

functionality follows description

ESP-r gives considerable control to the user to define the descriptive and thermophysical complexity of the model. This chapter focuses on making informed decisions about which tool facilities needed to support a project.

A review of simulation suites by the Author and Dru Crawley [ ] indicated considerable diversity in tool facilities as well as the many challenges in comparing facilities offered by simulation suites. The stems, in part, from the diversity of simulation projects, preferences of simulation practitioners in different markets, the evolutionary path of the simulation suite as well as the demands on software vendors.

In response, tools provide a range of choices including abstractions which reflect belief rather than the physics observed in buildings. For example DOE-2 <doe2.com> limited support for free-floating environmental controls was consistent with the beliefs of many in the engineering community in North America at the time.

Engineering approaches, such as fixing infiltration rates or heat transfer coefficients may be appropriate at specific points in a project. Working procedures should, however, include decision points for evolving models based on the costs and benefits of adjusting thermophysical resolution.

For example, moving beyond scheduled air flows via the inclusion of a mass flow network will lead to the invocation of an additional solver and the recording of additional performance data. In some simulation suites the computational burden of this is considerable. In ESP-r the solution of flow networks is highly efficient and thus simulation run-time is rarely an issue although many practitioners assume it will be an issue.

In other cases, adjusting thermophysical resolution involves specifying directives to the simulation tool so that existing information e.g. surface geometry, is used to derive more detailed relationships such as long-wave radiation exchange between surfaces or with radiant sensors within rooms. These are calculated prior to assessments and the computational burden is roughly a function of the number of surfaces in the zone. Historic perceptions of paint drying are rarely applicable and thus the choice to invoke the facility is related to curiosity within a project to explore radiant asymmetry discomfort or check the impact of radiant exchanges.

Recent empirical validation projects such as IEA Annex 58, which focused on a pair of test buildings in Holzkirchen, Germany indicate that external and internal thermal bridges, dynamic representations of infiltration, heat exchanges with duct work and basement heat exchanges, which are normally treated as optional can have a notable impact on the fit between measured and simulated performance.

A degree of scepticism about the applicability of abstract approaches and *the usual suspects* is thus warranted. Whether differences in predictions are significant within the context of a specific simulation project is one of many reality checks that need to be carried out. This chapter uses ESP-r to discover some of the *implications* of altering thermophysical resolution, *techniques* to determine the resources needed and lastly, *value added opportunities* in performance data.

4.5 Radiation view-factors

Clear definition of the goals and resources of the project is a good way to drive the selection of facilities. Lets revisit Table 1.1 in the context of exploring two competing heating designs within a hospital. The design team want to deploy ceiling radiant heating panels in scores of private and small wards of a new hospital. One design was claimed to be less costly to install (rectangular panel parallel with the facade) and the other design was claimed to provide better comfort for the doctor and patient at a lower operating temperature. Ideally (tall) doctors as well as patients should not notice the system in operation. The assessment needs to provide suitable evidence for the design team to make a decision and main contractor to proceed.

What do we want to know?

- *Thermal comfort is a key issue*. Some comfort indicators such as PMV, PPD are sometimes treated as if the position of the occupant is not an issue. Radiant asymmetry at specific locations in the room would clarify the performance claims. The layout of the rooms are identical so we know where patients will be and where attending staff will likely be deployed.

- *Radiant heat distribution is a key issue.* The shape and operating temperature ranges of the two designs must be represented in the model as well as the distribution of radiation to surfaces in the room. Heat losses from panels into the ceiling void might result in a warmer ceiling surface. The glazing may result in cold surfaces which the panel may not fully counteract. ESP-r's option to compute how much each surface sees other surfaces in the room is thus more appropriate than the default assumption of area-emissivity weighted distribution of radiation.

- *Control response is a key issue.* Comfort delivery across a range of boundary conditions e.g. weather patterns, occupancy densities, needs to be assessed. Will such a system be viable for extreme cold weather as well as periods of minimal demand? How often are panel temperatures near their maximum? Weather patterns need to be identified which will clarify performance at the two extremes. The assessment should clearly indicate the response of the room to the proposed heating regime.

- *The essential characteristics of the radiant panels should be represented.* Heat injected into a panel results in a temperature rise and has several paths of escape. How quickly might panels respond to changes in demand? Although the specifics of the central plant were not yet decided a range of operating temperatures and heat injection densities were available.

What is the extent of the model and level of detail?

The model, shown in Figure 4.6, is a classic side-by-side virtual experiment with the rectangular panel proposal on the right zone and the L-shaped panel in the left zone. The design was constrained by the need to complete the model in a single session while the client was available to supply details and evaluate what was found in the assessments.

Furniture and fixtures are part of the thermophysical interactions within rooms. Given the focus of the study, there is no rational basis for excluding full thermophysical treatment of the beds and its inclusion provides a visual clue to the client.

The radiant panels form boundary surfaces in the rooms so both radiant and convective heat transfer are explicitly represented). The ceiling plenum above the room is a zone to allow tracking of heat build-up as well as providing a better estimate of the non-panel ceiling temperatures. This approach allows changes in the composition of the panels to be modified and assessed.

The adjacent wards were assumed to be at the same temperature as the rooms being investigated. In order to provide a suitable boundary condition the ceiling void below the room was also represented as a zone at the same temperature as the void above the panel. See section 6.2.3 for another example of using zones and controls to form robust dynamic boundary conditions.

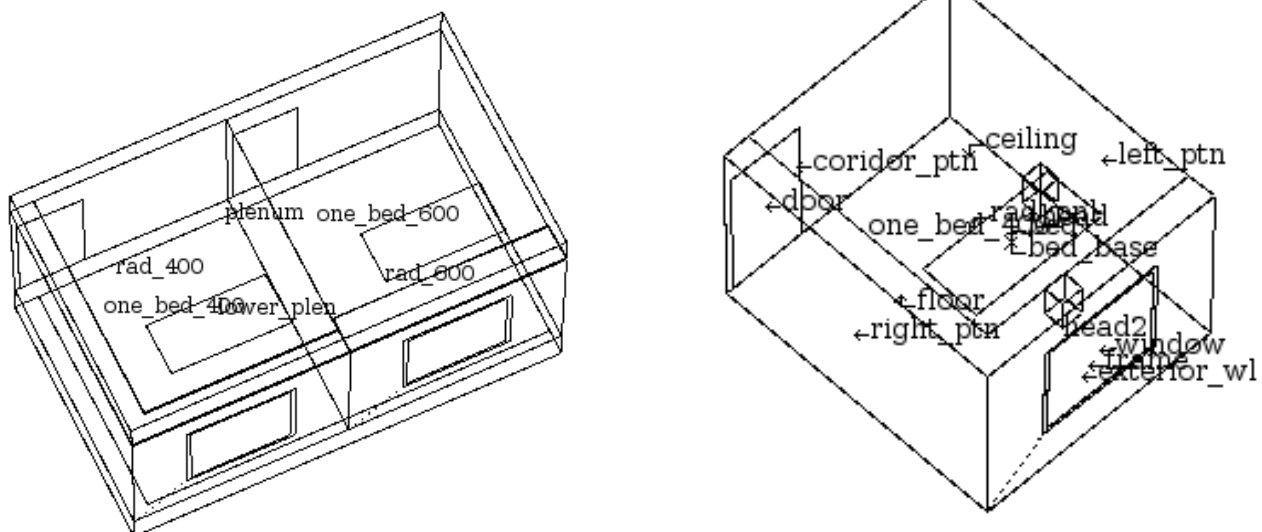Figure 4.6: Radiant panel side-by-side model and MRT sensor locations.

To represent heat injection into the panels, zones were created which represents the shape of each radiant pannel (see Figure 4.7). The lower surface is metal and the upper surface and sides are an insulated metal panel. High heat transfer coefficients are set so that any heat injected will be transferred to the bounding surfaces.

The panels were controlled via a multi-sensor controller which regulated the room temperature to 21° C based on allowing the thin-zone to rise to 74° C. To reflect the response time of the heating circuit the simulation time-step was set to one minute. Model calibration assessments were run to tune the heat injection so that it matched the expected panel surface temperatures.

This approach was used because setting up system components would have required additional time and supporting details were not available. For purposes of this assessment the approach was seen to represent the expected panel temperatures and response time while the explicit shape of the pannel surfaces worked well in the subsequent detailed comfort assessments.


```
                                    △ ▽   azimuth ◁ ▷  elevation ▽ △  image control    capt
Sur| Area  |Azim|Elev|  surface   |     geometry    |  construction |environment
    | m^2   |deg |deg |  name      |optical|locat| use |  name        |other side
  1  0.180  180.   0.  front_edge   OPAQUE  VERT -      alum_insu_i   ||< external
  2  0.020   90.   0.  right_edge   OPAQUE  VERT -      alum_insu_i   ||< join_400:rad_600
  3  0.160    0.   0.  back_a_edge  OPAQUE  VERT -      alum_insu_i   ||< back_a_edge:plenum
  4  0.195   90.  -0.  back_b_edge  OPAQUE  VERT -      alum_insu_i   ||< back_b_edge:plenum
  5  0.020    0.   0.  back_edge    OPAQUE  VERT -      alum_insu_i   ||< external
  6  0.215  270.   0.  left_edge    OPAQUE  VERT -      alum_insu_i   ||< external
  7  3.00     0.  90.  upper        OPAQUE  CEIL -      alum_insu_i   ||< upper:plenum
  8  3.00     0. -90.  base         OPAQUE  FLOR -      alum_panel    ||< rad_pnl:one_bed_400
```

Figure 4.7: Thin-zone radiant panel approach.

The critical performance metrics were the comfort for a tall doctor standing at the window and for the patient in the bed as well as the frequency the panels were on and how well they were able to control temperatures within the room on moderately cold days. In support of this two radiant sensors were defined in each room - one at the location of the patient's head and the other a doctor standing near the window (Figure 4.6 right). Radiant sensors are discussed in the next Section.

Diversity was included in the schedules for each zone and in particular the heat output of clinical lighting during the doctor's visit was included. And to ensure that solar ingress does not compromise comfort, facilities to predict the patterns of insolation are also enabled.

What performance information is available?

The side-by-side nature of the model allows all performance indicators in each test room to be compared as required. This model supports reports of:

- comfort at specific locations and in general
- panel surface temperature and rate of change
- ceiling, wall, floor, glass, bed and partition temperatures
- differences between dry-bulb and MRT
- heat demand for the room
- heat losses to plenums and through the facade and partitions
- frequency of overheating
- heat losses at the facade as well as the ceiling void
- the temporal pattern sun patch heat distribution

What assessments need to be undertaken to gain confidence in the model?

To support understanding of the performance and allow for quick calibration, assessments involve typical weeks in each season as well as an extreme winter period. To track potentially rapid changes in panel temperatures a one minute time-step is used.

How do we know if the design works?

In this project assessments are live and open to immediate feedback by the design team and contractor in order to determine:

- comfort indicies are within a specific range,
- the panel is sufficiently controllable to respond across a range of boundary conditions and
- if the system fails there is sufficient time for relocation or corrective action.

Overall the model was up and running during the visit to the clients offices and the predictions and fine tuning were carried out with feedback from the client. Assessments indicated that both designs resulted in substantially similar comfort levels for the doctor as well as the patient (see Figures 4.8, 4.9 and 4.10).

There was a slightly increased risk of radiant asymmetry discomfort for the case of the 600mm wide panel design. It was also clear, however that the 600mm wide panel was ON more often and tended to work at a higher temperature than the 400mm wide panel approach.

Another finding was that a 70-74° C working fluid is often not required and room comfort can often be maintained at panel temperatures of 40-60° C.
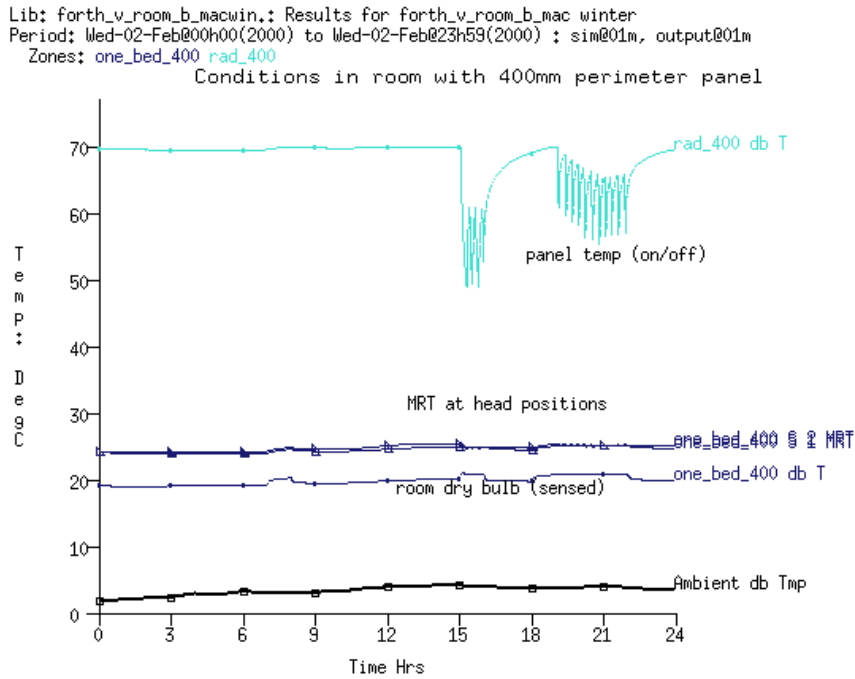
Figure 4.8: Predicted temperatures in left zone.
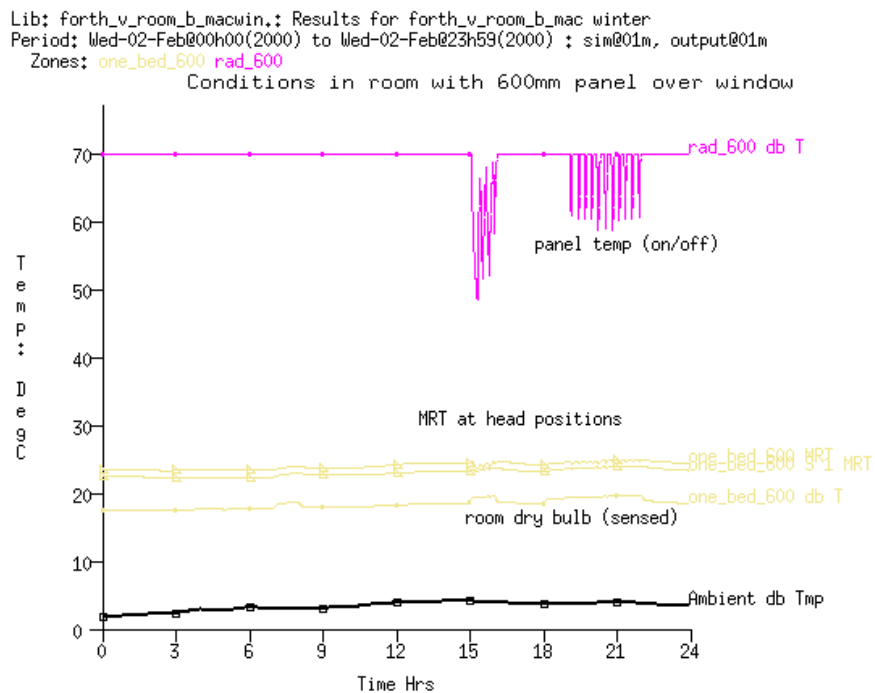
Figure 4.9: Predicted temperatures in right zone.
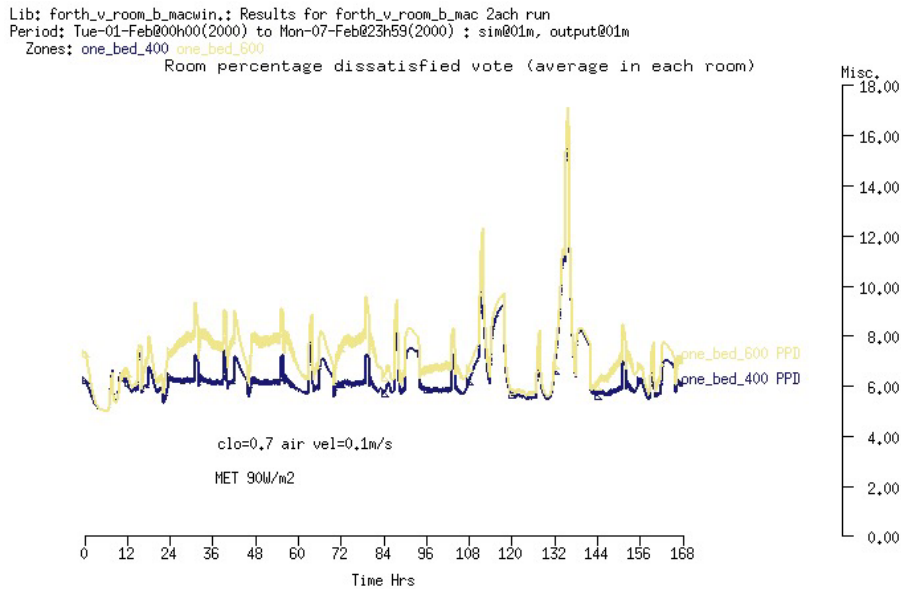
Figure 4.10: Predicted dissatisfied in both zones.

4.5.1 Enabling high resolution radiant energy exchanges

Long-wave radiant transfer between surfaces tends to get much less attention than convective heat transfer between the air in a room and the surfaces bounding and within the room. Most tools allow the distribution of radiant exchanges to be treated via simple area and orientation relationships. Some allow the distribution to be prescribed and others allow so-called view-factors between surfaces to be calculated.

Radiant transfer between surfaces is part of the *energy balance* of each surface at each time-step of a simulation in the majority of tools. Some tools report energy balances at the surface level so that the magnitude of radiant transfer can be judged in comparison with other heat flux paths.

The default assumption in many simulation tools is that long-wave radiant exchange between surfaces in rooms is diffusely distributed based on the emissivity of the surfaces and their area. This assumption is appropriate for highly cluttered spaces, where a limited range of surface temperatures is expected or where comfort is not an assessment criteria.

As rooms depart from simple rectangular shapes or employ radiant heating and cooling the diffuse distribution assumption becomes less valid. The information demands of a project may also suggest increasing resolution, e.g. to confirm the interactions with explicit internal mass in the room or test the response of lightweight constructions to sun patches.

Testing whether this additional resolution alters predictions is a classic virtual experiment between identical rooms with and without calculated view-factors.

ESP-r offers options to increase the accuracy of radiant transfer between surfaces as well as support radiant asymmetry calculations at MRT sensor bodies in support of detailed comfort assessments. In Energy-Plus tags are available in the IDF file to allow view-factors to be included, however their derivation must come from third party applications and it is probably safe to say that the facility is not heavily used.

In ESP-r, view-factor computations are currently carried out by ray-tracing calculations for zones of arbitrary complexity. The process places a grid on each surface in order to compute visibility and is generally robust. However, the calculation parameters may need to be adjusted to ensure all parts of complex surfaces include grid points. The results are recorded into a zone view-factor file (typically with the file ending *vwf*). The computing resource required is roughly in line with the number of surfaces in the zone. An eight surface box will take a few seconds and a room at the current geometric limits might require one or two minutes. Beyond the time required for pre-processing calculations, the inclusion of calculated view-factors does not impact the speed of simulation.

4.5.2 Position specific MRT sensors

ESP-r provides facilities to define block shaped radiant sensors within a room (e.g. the right side of Figure 4.6) and to calculate how much that sensor views the other surfaces in the room. This information is used in the results analysis module to generate radiant asymmetry values for position-specific comfort assessments.

In the case of the radiant heating proposals for the hospital, surface long-wave view-factors were computed for the patient rooms. The Project Manager interface after the computations is shown in Figure 4.11.

In ESP-r the menu selections would be `Calculate zone or MRT view-factors` and if there were any radiant sensors then the `Add a MRT sensor` requests the origin and size of the sensor. Note that existing sensors are not drawn in the wireframe unless you actually select that item to edit. Once you have the sensors defined request the calculation and a utility module will be passed the relevant information and provide the options seen in Figure 4.12.

The options you may be interested in are `grid division` and `patch division` which define the density of the gridding which is used in the calculations. The default is 10 and with this default the computational time is constrained. If the zone has small surfaces or surfaces with small dimensions the default may not be adequate. You will be notified if this is the case if some surfaces have a view-factors that sum to a value which is not close to 1.0. If this is the case you can re-set the grid and patch divisions and try again.

Remember to request both calculations before you exit the utility application. When you return to the Project Manager you will be asked whether you want to use the newly computed values.
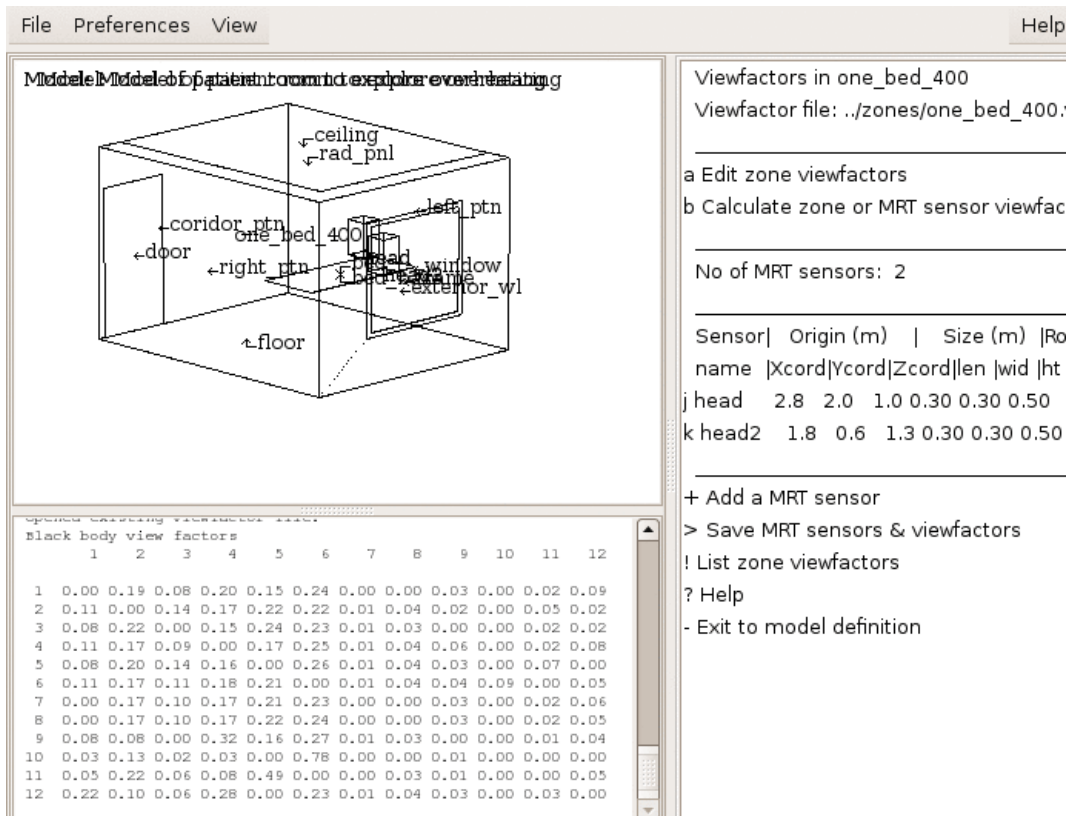
Figure 4.11: Prj interface to view-factors.
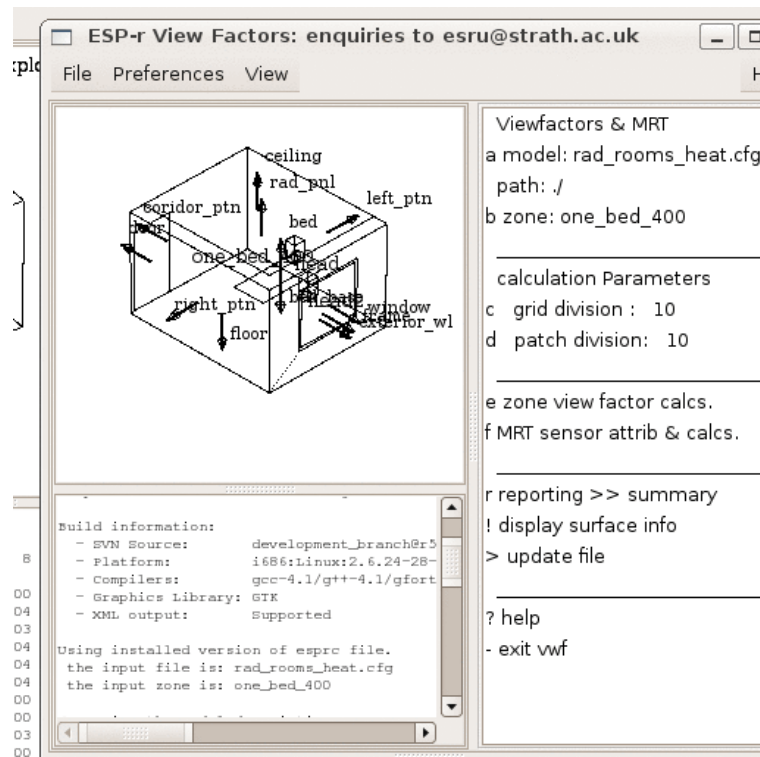
Figure 4.12: View-factor calculation interface.

4.6 Shading and insolation

One of the classic challenges of numerical assessments is that the form and composition of building facades and site obstructions entities varies considerably in scale, complexity and optical characteristics. The resulting complex patterns of solar radiation traversing facades can result in significant temperature variations across facades. For transparent facade elements these incident patterns become part of the source radiation entering the room and may be further perturbed by reflection and absorption while passing through the glazing or interception by facade framing.

Establishing relationships between direct and diffuse solar radiation sources and their time-varying distribution on and through building facades and subsequently within rooms has long been a component of dynamic whole-building simulation. The calculation of solar position and the angular relationship between the sun and surfaces within models are classic features.

Looked at another way, these well-established methods and classic blocks of code have proven highly resistant to change even as computing resources and the complexity of models have evolved by several magnitudes. Gaps in logic persist even as new facilities have been added. Current simulation tools are thus able to derive many of these relationships. However, each has its foibles.

Most tools offer several levels of shading and insolation assessments which attempt to match project requirements or the preference of the user. Simulation tools which lack 3D room geometry e.g. TRNSYS prior to version 17, deal with a subset of facade shading. Some tools assess shading from horizontal or vertical fins relative to windows or ignore shading opaque facade elements (DEROB in the mid-90s).

The discussion which follows focuses on how practitioners can adapt to the variety of methods used, the granularity of calculations and decode the language associated with the facilities.

4.6.1 Terminology and assumptions

The first barrier is jargon. The language used to describe tool facilities as well as interface text and data within reports masks subtle differences in the underlying meaning or in the assumptions made within tools. Participants in validation work are forced to be pedantic and struggle to unpick meanings. For the majority of practitioners jargon gets in the way of informed-consent within commercial and research deployments. Lets unpick some jargon...

The term [direct solar shading] usually refers to portions of facade surfaces which do not directly see the solar disk at a specific moment in time. A [shading pattern] typically refers to a sequence over time e.g.

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each hour of the day, for each facade surface. Some tools represent the pattern on each surface in detail while other tools resolve the pattern into a percentage of the surface which is shaded.

The term [obstruction] usually refers to entities in the simulation model that can block or reduce solar radiation falling on surfaces. In some tools, facade surfaces are also considered as potential obstructions. In other tools, such as ESP-r, hexagonal solar obstruction bodies (with optional Z and Y axis rotations and transparency) can be included in the model. Combinations of these bodies are used to represent complex objects. EnergyPlus also supports polygon obstructions of arbitrary complexity. Obstructions typically do not take part in the energy balance of zones, they do not alter wind patterns or modify the micro-climate adjacent to surface.

The term [diffuse solar radiation] includes radiation from clear portions of the sky and clouds as well as radiation reflected from adjacent non-specular surfaces and the ground. You might see the terms isotrophic and anisotrophic used. The term [diffuse shading] usually refers to the portion of the sky vault not visible from each surface. Assessments of diffuse shading make use of the same model entities as direct solar shading assessments but because the position of the sun is not an issue diffuse shading patterns are static.

The term [insolation] refers to the calculation of sunlit patterns on interior surfaces of rooms and internal mass as well as the transmission of solar radiation via transparent surfaces between rooms. Insolation assessments typically deal separately with direct solar radiation sources and diffuse radiation sources. In ESP-r, solar radiation falling on the inside face of zone surfaces (including those representing internal mass) form one component of the surface energy balance. Changes in surface temperatures will subsequently impact the zone air energy balance as well as the longwave radiation balance at other surfaces in the zone.

4.6.2 Initial reality checks

Differences in the solution of shading and insolation patterns have implications on how models are designed, the granularity of the solution and feedback to design teams. Establishing the extent of patterns of shade and shadow so that the resolution of the model and required computations fit the requirements of a specific project need not be a computational burden. Indeed, the task can be carried out in minutes during the early stages of a project via facilities that exist in number of simulation and CAD tools.

The technique involves a visual survey of the model at different times of the day and at different seasons. Importantly, we want to do it *looking towards the model from a position ~1 kilometer from the building along the line of the sun so that you see what the sun sees and what you can not directly see is in shadow*.

In ESP-r this facility is the `view from the sun` as seen in Figure 4.13
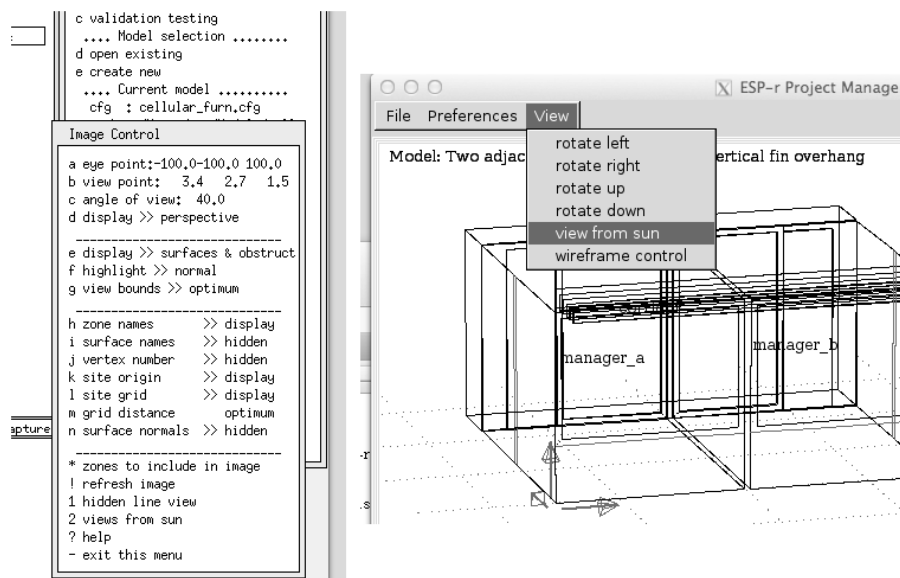
Figure 4.13: Invoking views from the sun (X11 and GTK interfaces).

You are given the option to jump to the previous or next hour to to run an animation (a sequence of views from the sun). Consider the standard ESP-r training model of two cellular offices with explicit desk and filing cabinets. If it is located in Cairo (31.1 North) the views on the morning of 21 December are shown

in Figure 4.14. At 9h00 sunlight entering the offices falls on the desk and side wall. At 10h00 some falls on the floor and at 11h00 the floor has a greater proportion. At no time does the sun reach the partition at the back of the room.
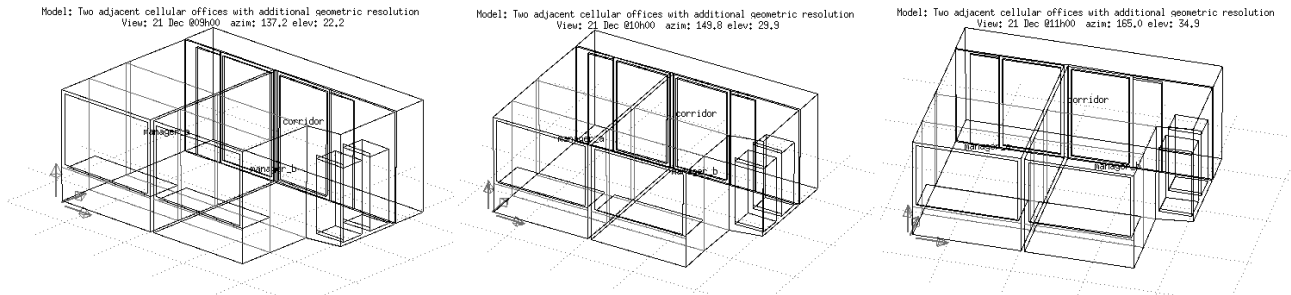
Figure 4.14: Cairo in the morning of 21 December 9h00-11h00.

If we consider 21 July the pattern in the afternoon is shown in Figure 4.15. Clearly very little solar radiation is entering the offices and mostly it falls on the desk at the window.
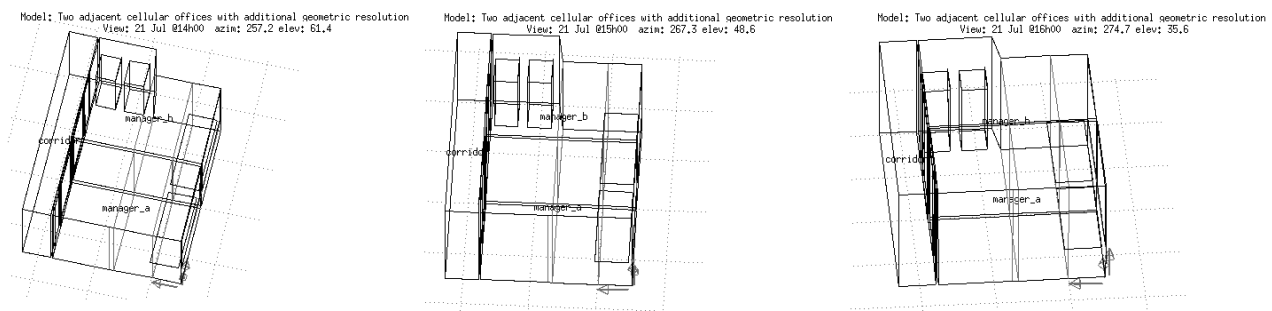
Figure 4.15: Cairo in the late afternoon of 21 July 14h00-16h00.

Placing the same offices in Learwick in the Shetlands (61.0 North) the morning of the 21st of December results in a substantially different solar access. At 9h00 the sun is not yet up. At 10h00 the sun falls only on the side walls and at 11h00 it falls on both the side walls and back partitons.
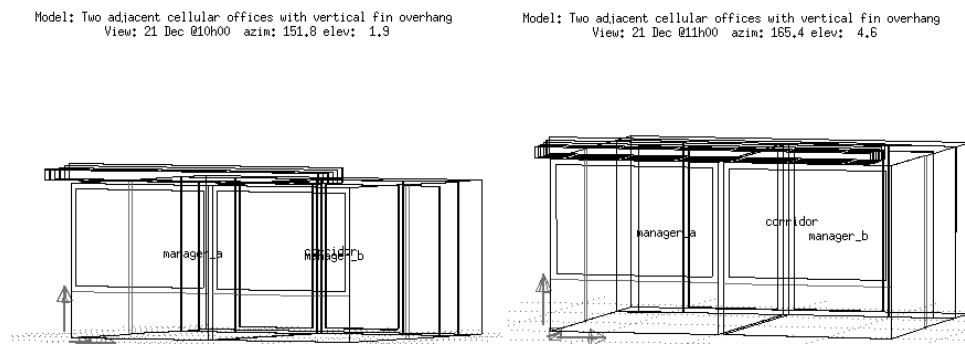
Figure 4.16: Learwick in morning of 21 December 10h00-11h00.

And the afternoon of 21 July in Learwick is shown in Figure 4.17. In this case with shading devices added very little sunlight is entering the rooms. As sundown is well past 21h00 the West facade is irradiated for up to eight hours a day at low angles so sunlight penetrates deep into any rooms with West facade glazing.
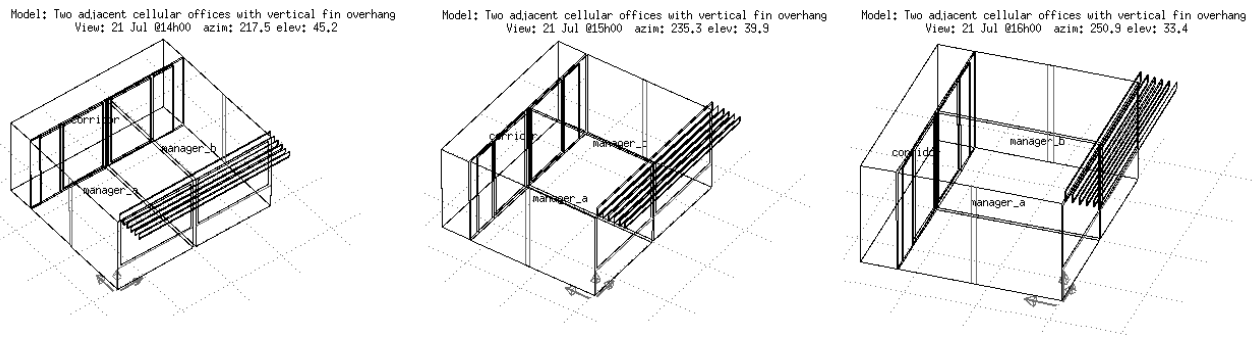
Figure 4.17: Learwick in afternoon of 21 July 14h00-16h00.

Visual checks quickly identify the extent of insolation into rooms, shade and shadow patterns, as well as the efficacy of shading devices. In several cases furniture near the facade was strongly impacted. In few cases did the sunlight fall primarily on the floor.

An alternative reality check is to pass the model to a visual simulation tool such as Radiance and create a sequence of images at different times of day. ESP-r's **e2r** module can automate this task, however it can be computationally intense to produce animations.

4.6.3 Computational approaches

Given the range of complexity in models and historical limitations in computational resources, most simulation tools allow users to select from a range of solution methods in order to manage the computational burden. Typically there are directives for shading computations, directives for insolation calculation and directives for specific combinations of shading and insolation.

In EnergyPlus these directives are *MinimalShadowing, FullExterior, FullInteriorAndExterior, FullExteriorWithReflections, FullInteriorAndExteriorWithReflections* (see below). In ESP-r there are options for user imposed shading and insolation distributions as well as options to pre-calculate shading and/or insolation patterns as well as setting the granularity of such calculations.

These choices impose specific assumptions and abstractions in the treatment of solar radiation. They may ignore nearby reflective facades, lightweight surfaces near the facade or deep facade elements and overheating from sun-patches may not be recorded. Some abstractions will over-predict direct radiation to ceilings and to the inside faces of facades. Others will over-predict radiation on the floor. Thus the imperative for reality checks via visual surveys.

One classic abstraction (termed *MinimalShadowing* in EnergyPlus) is to assume that all direct radiation entering a room falls only on the floor of the zone, or in the case of ESP-r to a pair of user nominated surfaces, and that surfaces facing away from the sun are in shadow and there is no diffuse shading. A visual survey will indicate whether this abstraction is appropriate.

Another low resource approach is to treat insolation as distributed within the room based on the surface area and surface absorption properties, typically with iteration of diffuse surface reflections within the solar distribution. On the first reflection direct solar radiation becomes diffuse and solar radiation passing between rooms is treated diffusely. For some rooms and with some assessment goals this is a pragmatic abstraction. There is no equivalent in EnergyPlus.

In ESP-r, only shading obstructions are taken into account in the calculation of direct and diffuse solar shading to the outside-facing surfaces of a zone. Self shading by zone surfaces must be approximated by shading obstructions. To support computations, a grid of points is placed on each surface (user specified density typically 20 x 20). At each hour each grid point is tested if it is obstructed (for direct solar radiation). The percentage of points for each surface and hour is recorded for use during the simulation. Diffuse shading is based on visibility between the model surface grid points and points on a sky dome which is calculated once and recorded for use during the simulation.

ESP-r calculates insolation for rooms of *arbitrary complexity*, including fully internal surfaces representing mass. A grid is placed on the inside face of all surfaces in the zone. Grid points on transparent surfaces which are not shaded at that hour are treated as radiation sources. At each hour source rays are projected into the room and the percentage of insulated points is recorded for use during the simulation.

As the simulation progresses, current weather data and surface orientations are used to derive the potential indicent radiation and the shading percentage for the surface is applied. For transparent surfaces the

optical characteristics are taken into account and the transmitted solar into the room is distributed according to the computed distribution. Insolation passing through internal transparent surfaces are recorded at the next timestep. Insolation which is lost from the zone back to the outside is also tracked. Figure 4.23 below shows a typical report of shading and insolation percentages for several surfaces during January.

If we assume that the form of the building facade and its surroundings are static then the *pattern of radiation* on the surface is a function of geometry and the position of the sun. Some tools, including ESP-r and TRNSYS (v17 onwards), support pre-processing the distribution of solar radiation to reduce the computational burden for the simulation engine (but requires bookkeeping to account for the operation of optical controls during the assessment). Patterns are computed and recorded hourly for the most typical day in each month.

Other tools, such as EnergyPlus, carry out shading and insolation during the simulation and thus allow the frequency of assessments to vary. EnergyPlus, accepts a number of user directives (key words and phrases taken from the EnergyPlus Engineering Reference) are:

- MinimalShadowing - (as mentioned above) where all beam solar radiation entering the room falls on the floor and there is no exterior shadowing except from window and door reveals.

- FullExterior - shadow patterns on exterior surfaces caused by detached shading, wings, overhangs, and exterior surfaces of all zones are computed. Beam solar radiation entering the zone is treated as for MinimalShadowing.

- FullInteriorAndExterior - as FullExterior except that the program calculates the amount of beam radiation falling on each surface in the zone (if the zone is fully enclosed and convex) otherwise as MinimalShadowing.

- FullExteriorWithReflections - as FullExterior but reflections are taken into account. ESP-r offers no equivalent to this.

- FullInteriorAndExteriorWithReflections - as FullInteriorAndExterior but reflections are taken into account. ESP-r offers no equivalent to this.

The EnergyPlus FullInteriorAndExterior is similar to ESP-r's shading and insolation analysis except for the EnergyPlus convex restriction, additional selections of obstructions and the inclusion of self-shading.

4.6.4 Incorporation of shading obstructions

So what is the process of defining obstructions like and what information is available to the user? Shading devices can be included or excluded from views of the model. The example model `training/simple/cfg/bld_simple_shd.cfg` includes a number of solar obstruction types which together represent an adjacent building and a tree (Figure 4.18).
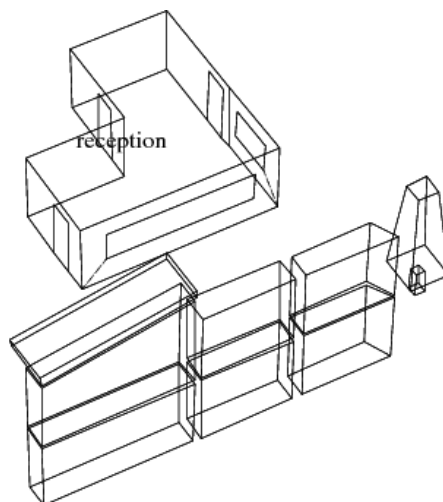
Project: L−shaped reception, external shading with various obstructions

Figure 4.18: Room with collection of solar obstructions.

The interface for defining shading directives and solar obstructions is found in the zone geometry menu in `solar dist. & calc directives` and `solar obstruction.`

The ESP-r shading and insolation directives menu is shown in Figure 4.19.

```
Zone shading and insolation:              Obstructions:
   zone: reception                         a Surface X&Z grid:  20  20
 a specified insolation to:               _____
   diffuse insolation distrib              Blk| description & compos
_____                    e  1  blk_1 extern_wall
 b calculated shading:                    f  2  blk_2 extern_wall
    all applicable surfaces               g  3  blk_3 extern_wall
 c calculated insolation:                 h  4  blk_4 door
    all applicable surfaces               i  5  gable extern_wall
 e invoke shade/insol analysis            j  6  xblk_2 extern_wall
                                          k  7  xblk_3 extern_wall
_____                    l  8  tree extern_wall
 ! list details
 ? help                                   _____
 - exit                                   * add/delete/copy obstruction
                                          ~ rotate/transfrm obstructions
                                          @ create window reveal
                                          > shading & insol directives
                                          ! list obstruction details
                                          ? help
                                          - exit this menu
```

Figure 4.19: Shading & insolation directives and obstructions menu.

The middle section of the directives menu instructs calculations for shading and insolation to be done for all applicable surfaces in the zone. Applicable surfaces are surfaces which conform to the standard rules - shading only on surfaces which face the outside and insolation sources must be transparent outside facing surfaces. There are several places in the interface where shading and insolation analysis may be requested. The first is within the directives menu, the second is in the `Zone composition -> options -> shading & insolation.`

If the zone form or composition or site location change you are offered the option of re-calculating shading and insolation. Let's look at the solar obstructions which are included in Figure 4.18 via the `solar obstructions` menu (Figure 4.19 right) The upper portion of the menu sets the gridding resolution for solar calculations. This defaults to a grid of 20 x 20 points placed on each surface in the facade. Some complex surfaces, e.g. a thin frame around a window, might require a finer grid in order for shading to be properly calculated.

The centre portion of the menu includes a list of solar obstructions. Each has a short name for purposes of identification (they must be unique within the zone) as well as a composition. The composition name is used if the model is exported to a visual simulation tool such as Radiance. The lower portion of the menu supports management functions as well as providing direct access to the shading directives menu.

The data which define basic solar obstructions are available by selecting an obstruction. The data for *blk_1* is shown in Figure 4.20.

There are several options for editing the origin of the block as well as its size. It is also possible to apply one or two rotations to the block. The option to `convert to general polygons` allows you to further customize an existing obstruction block to represent more complex shapes.

An example of a complex shape is the block named *tree* which began as a simple shape and then the upper corners were edited (see Figure 4.20).

```
Obstructions:?> e                          Obstructions:?> l
Block Details:                              Obstruction Details:
 a origin X Y Z: -4.90 -7.00  0.00            coords   X       Y        Z
 b block  W D H:  5.80  1.00  2.95          a 1:   10.400  -5.600   1.100
 c rotation (Z):     0.00                   b 2:   12.000  -5.600   1.100
 d rotation (Y):     0.00                   c 3:   12.000  -4.000   1.100
 e tilt (NA)   :     0.00                   d 4:   10.400  -4.000   1.100
 f name        : blk_1                      e 5:   10.800  -5.200   5.100
 g construction: extern_wall                f 6:   11.600  -5.200   5.100
 h opacity   :   1.00                       g 7:   11.600  -4.400   5.100
                                            h 8:   10.800  -4.400   5.100
   block coords     X         Y
   front left  :  -4.900   -7.000           i name          : tree
   front right :   0.900   -7.000           j construction: extern_wall
   back right  :   0.900   -6.000           k opacity   :   1.00
   back left   :  -4.900   -6.000
   top @       :   2.950 (Z)                  zone bounds   X       Y       Z
   zone bounds  X     Y     Z                 max:     9.000   9.000   3.000
   max:    9.000   9.000   3.000              min:     1.000   1.000   0.000
   min:    1.000   1.000   0.000
                                            < jump to next obstruction
 > jump to next obstruction                 > jump to next obstruction
 * convert to general polygons              ? help
 ? help                                     - exit
 - exit
```

Figure 4.20: Simple obstruction and tree obstruction menus.

Shading can, of course, be applied to real buildings with complex facades and to hybrid thermal and visual assessments. In the administrative building wireframe of Figure 4.21 has contributed to the Radiance internal and external assessments in the lower portion of the Figure.
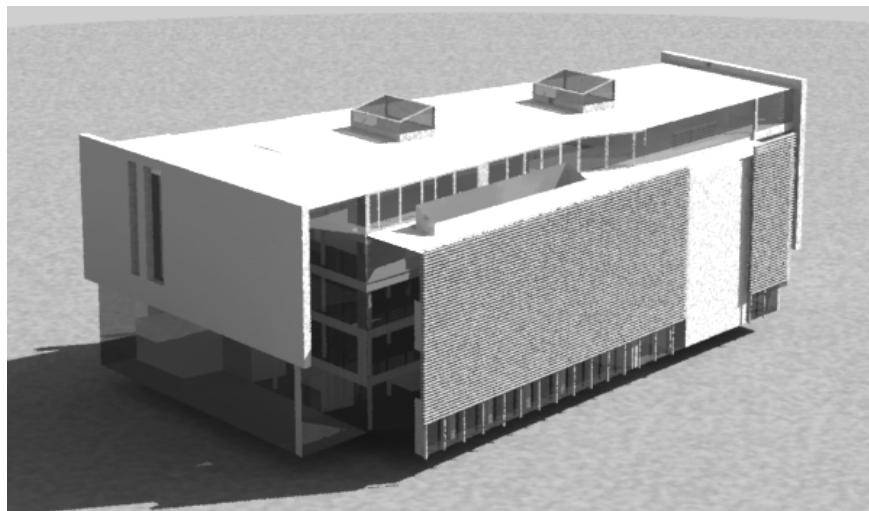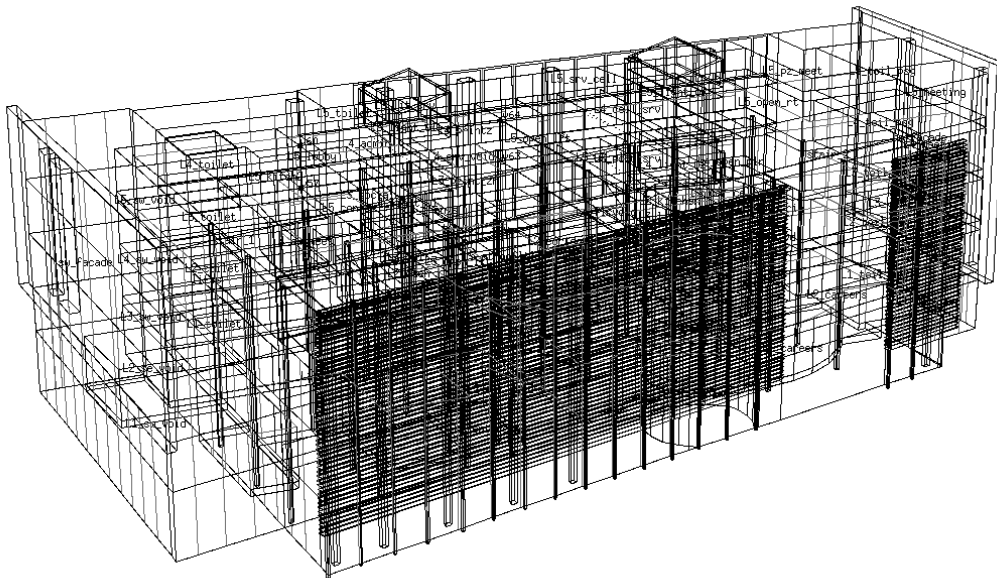
Figure 4.21: Shading in the context of complex facades.

4.6.5 Shading predictions

Once shading obstructions and shading directives are defined for a zone the computations can be undertaken. These are carried out by the *ish* module as shown in Figure 4.22. The primary selections are `calculate shading` and `shading synopsis` or `shadow image` for shading and the `calculate insolation` and `insolation synopsis` for insolation. If you toggle the sky type to non-isotropic the computational time increases quite a bit. Recent versions of ESP-r also support the calculation of diffuse shading.

If you request shading you are asked to confirm the period of the assessment (typically month one to month twelve). The text feedback will indicate the progress of the calculations (Figure 4.22).

After shading has been calculated the insolation analysis can be invoked (it needs to take account of the shading analysis data). The insolation calculations also grid the model surfaces and detect, for each source of insolation, the percentage of entering direct radiation that falls on each of the surfaces of the room. Shading and insolation patters are recorded in the shading file for use in simulations.

You can ask for a synopsis of the insolation patterns (see Figure 4.23). The first column is the time, the second column is the calculated shading, the third column includes the names of the surfaces that were insolated at that time and the fourth column provides the associated percentage of the radiation.

And you can also confirm visually the patterns of shading by requesting a view from the sun at a specific time of day and day of the year (Figure 4.23). The screen capture below is for 10h00 on a typical day in January. What you see if what-the-sun-sees. What you cannot see is in shade. This type of view is also

available from the Project Manager!
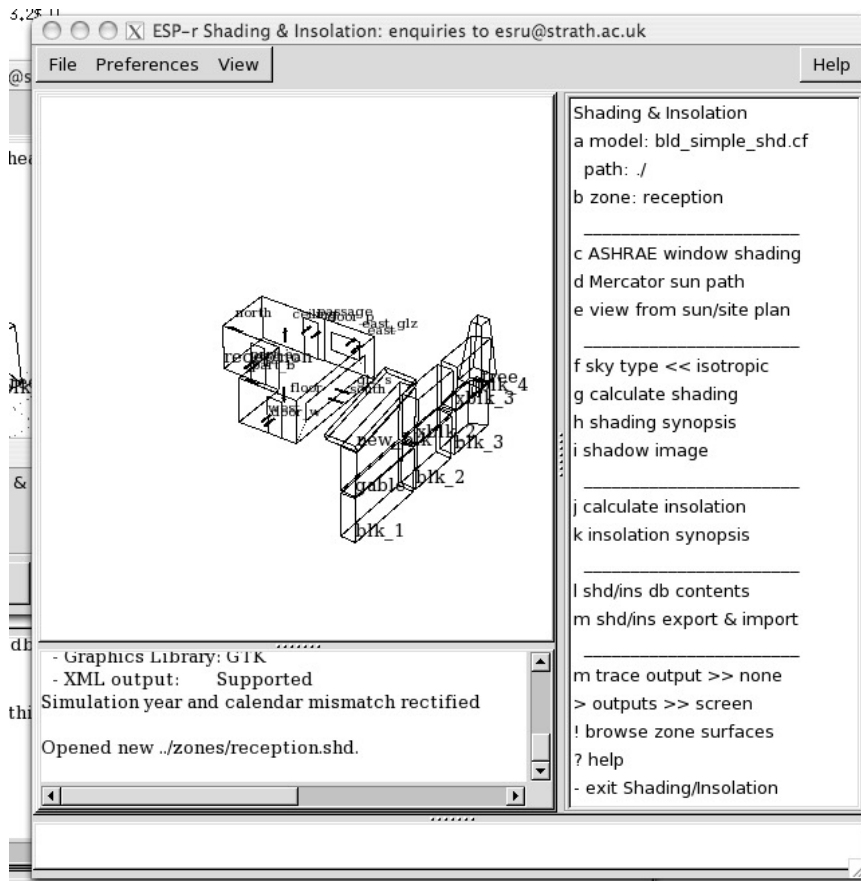
Figure 4.22: Shading module.
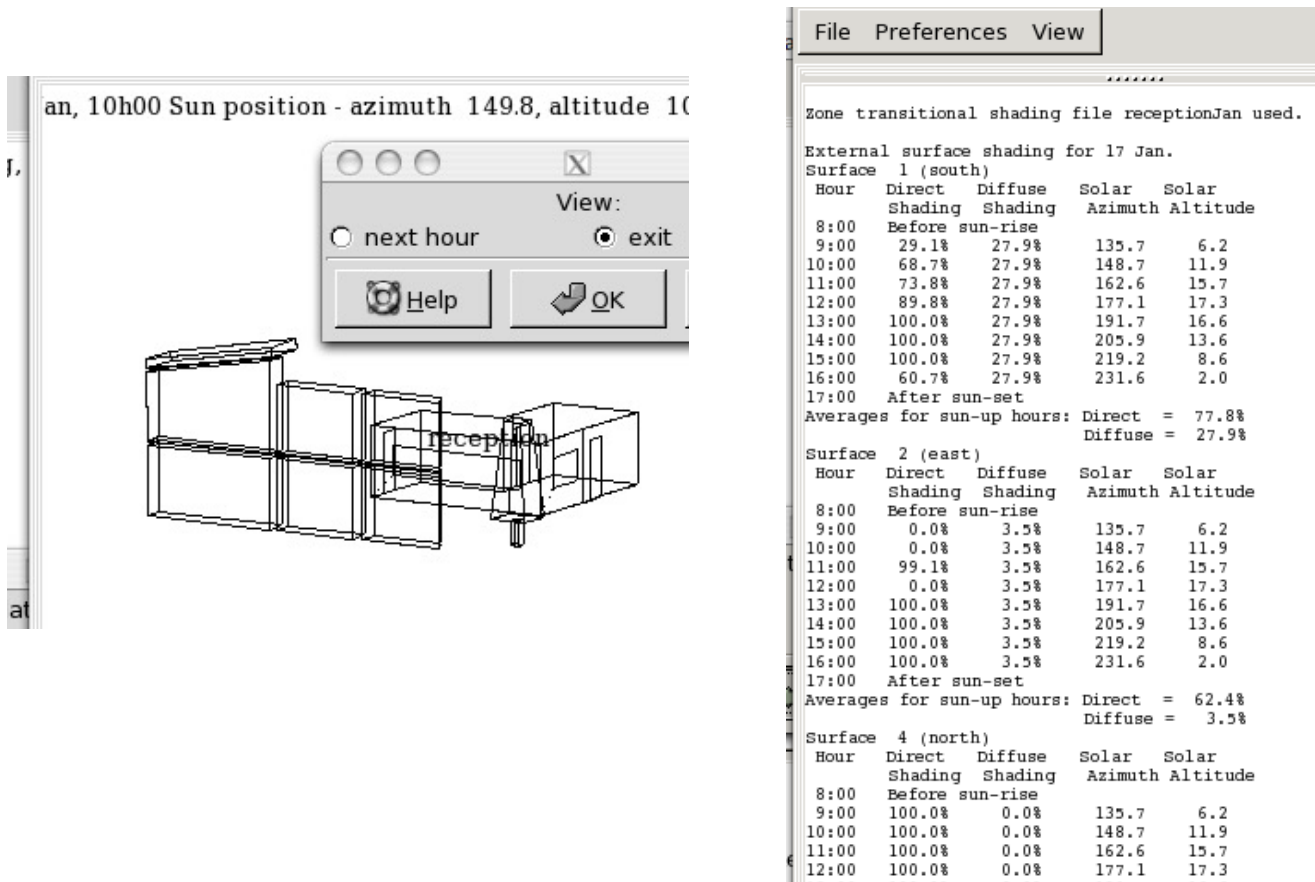
Figure 4.23: Visual confirmation of shading and synopsis.

4.7 Thermal bridges

In Section 4.2 the interface to linear thermal bridges was introduced. Typically design teams have only focused on the impact of thermal bridges in projects with extreme performance goals. In PassivHaus the usual example is one 3m length of poorly designed balcony can loose as much energy as the room facade associated with that balcony.

In the IEA Annex 56 experiments it was found that the thermal bridges in the exterior masonry construction made a significant contribution to the energy balance of surfaces.

```
Lib: twin_house_05_exp2_rcb.res: For twin_house1_05_exp2_rc temporal adj
Period: Wed-23-Apr@00h05(2014) to Tue-20-May@23h54(2014) : sim@10m, output@10m
 Causal energy breakdown (kWhrs) at air point for zone 1: liv
                                      Gain          Loss
 Infiltration air load               0.000       -13.614
 Ventilation air load                0.100      -213.853
 Casual Occupants                    0.000         0.000
 Casual Lights                       0.000         0.000
 Casual SmallPower                 216.070         0.000
 Thermal bridge (linear)             0.000       -76.412
 Heat storage @ air point            5.972        -6.231
 Convection @ opaque surf: ext      10.101       -31.915
 Convection @ opaque surf: ptn      56.539       -79.267
 Convection @ transp surf: ext      10.063       -28.063
 Convection @ transp surf: ptn       0.341        -6.025
 Convection portion of plant       156.234         0.000
 Totals                            455.420      -455.381
```

Figure 8.19: Energy balance at facade of experimental building.
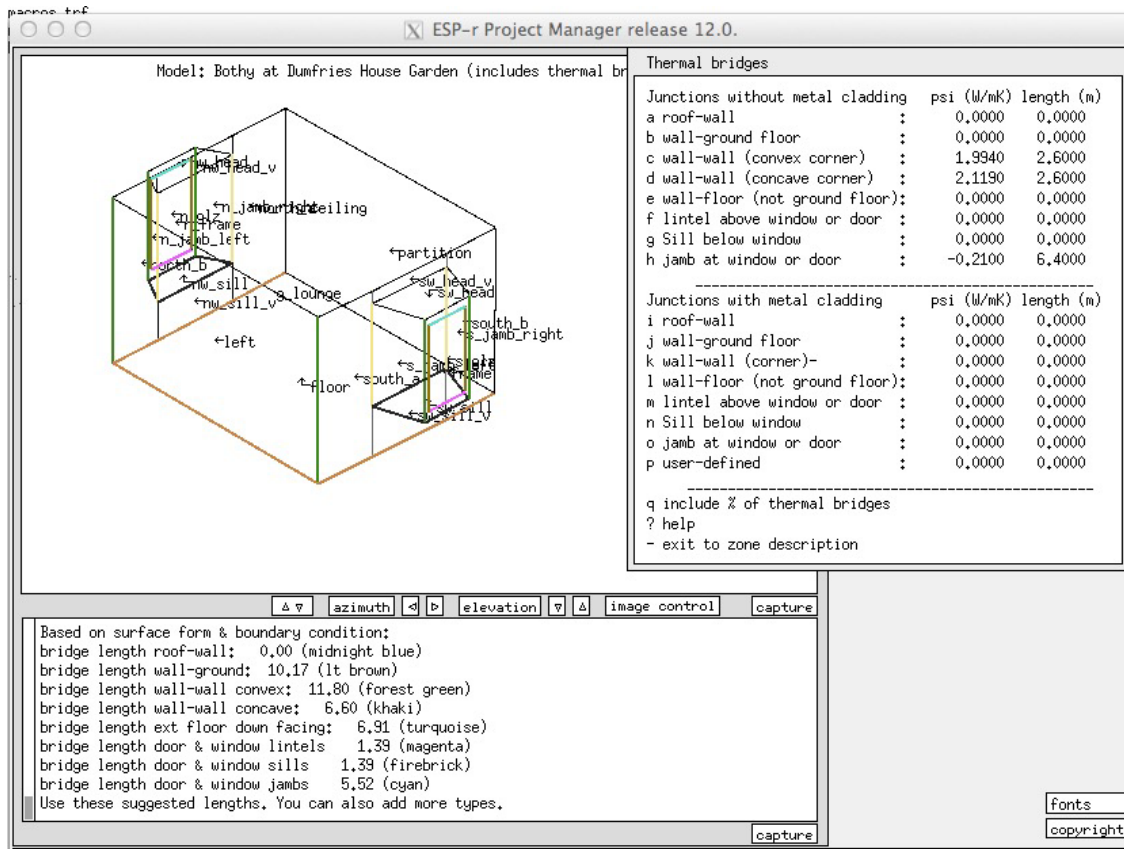
Figure 8.20: Definitions of thermal bridges in a historic building.

Classic examples of thermal bridges are found in traditional masonry and stone construction. Retrofit projects which attempt to improve the building fabric can be undermined by residual thermal bridges.

What is often missed is that projects with less extreme goals often embody significant thermal bridges. There are several in Figure 4.4. In an appalling number of common building sections heat transfer through thermal bridges is far from a trivial portion of the energy balance in zones. Some simulation tools do not directly support the concept of thermal bridges forcing practitioners to craft work-arounds.

4.8 Use of pre-defined entities

Many simulation teams create models of empty buildings e.g. without the thermophysical and visual arte-facts which are observed in the built environment or with highly abstract representations. And yet everything in a non-empty building is subject to the same physics and has the same thermophysical relationships as the facade and partitions that populate traditional simulation models. The potential to alter both the spatial and temporal distribution of heat exchanges within the room suggests the potential to alter the rooms response to environmental control actions as well as support comfort, visual assessments and model clarity.

Typically increasing model resolution is a tedious process and added detail if included, may not be fully utilised. Pre-defined entities, which include visual form, explicit thermophysical composition can be used to populate existing thermal zones with furniture and fittings or can be used to introduce standard facade elements or even standard zones to a model. Because the entities or zones added are *thermophysically real*, ESP-r facilities for calculating view-factors, insolation distributions and, of course the zone energy balance take these into account.

This section discusses issues related to creating and managing pre-defined entities. In the zone geometry menu users would choose the *predefined entities* menu and then either preview an entity or select one and then provide the coordinates of its origin in the zone and its rotation. As multiple entities can be imported the user is asked to pre-pend a character a-h to the entity name to prevent name clashes. After importing there will likely be entities in the geometry menu for *visual entities* as seen below:

Figure 8.21 Pre-defined geometry menu and visual entities in zone.

Taking the case of a cellular office the figure on the left includes the mass surfaces from furniture imported into the zone and the right are all of the visual and surface entities.
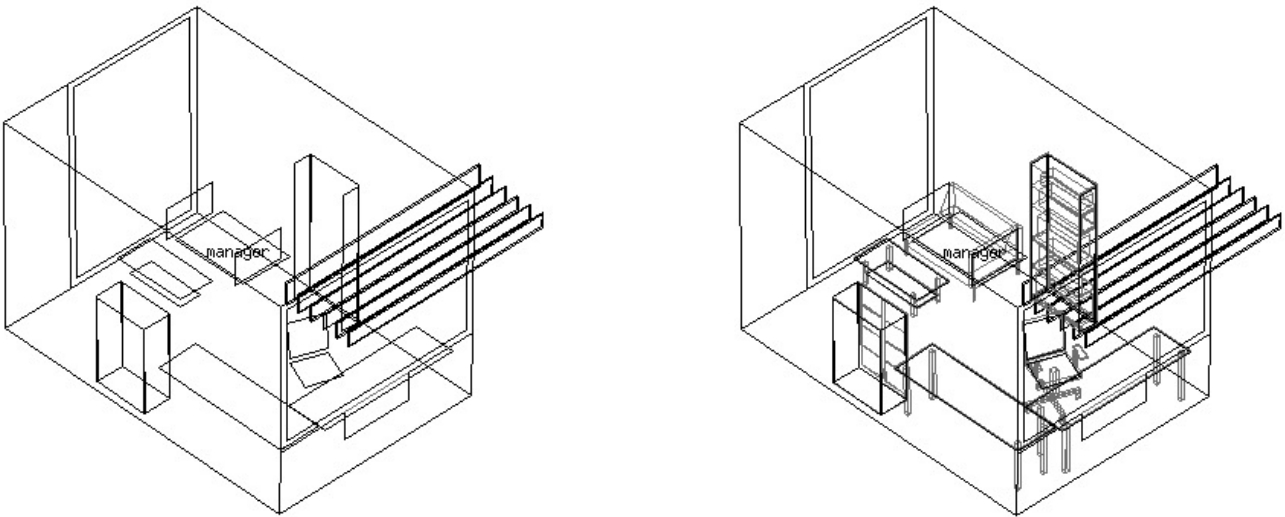
Figure 8.22 Mass surfaces (left) plus visual entities (right).

You can explore the impact on office space between modeling furniture and fittings as *empty, abstractly or explicitly* via the exemplar models
`training/office_vent_empty/cfg/office_vent_empty.cfg, train-`
`ing/office_vent/cfg/office_vent.cfg, training/office_vent_pre.cfg`
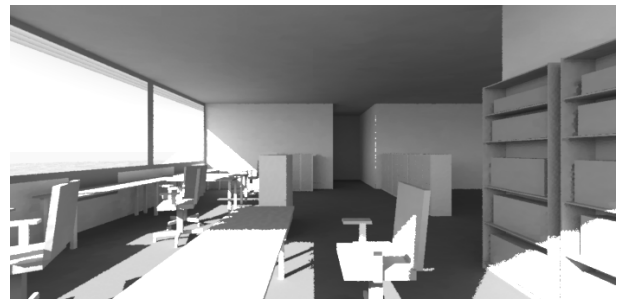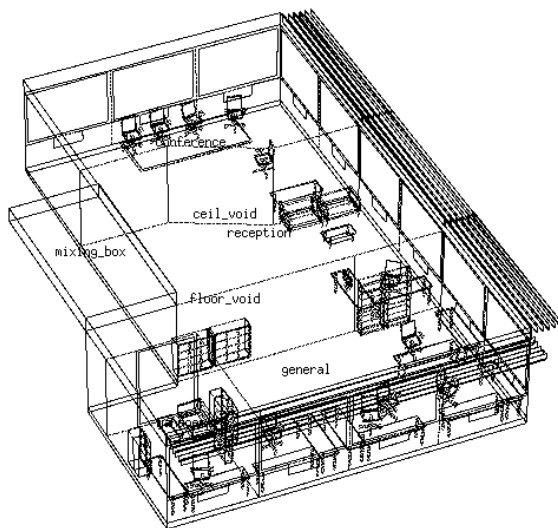
Figure 8.23 Office space populated with furniture.

Could we scale this up to explicitly represent the contents and lighting and stairs and other normally abstracted aspects of construction within a larger scale building? The images below show one such exploration which resulted in a model with 87 zones and ~5000 surfaces. The *elevator pitch*:

- Pushing the boundaries of a simulation tool can make it numerically more robust as well as evolving its underlying data model and QA reporting.

- Work flows which evolve to cope with zones with ~250 surfaces feedback into the application of explicit modelling in more constrained models.

- If you have a good business case for explicit representations it is certainly possible to explicitly represent just about everything within a building.

- ESP-r will simulate such models but provides a magnitude of thermal and visual performance data that few practitioners are yet capable of parsing.

- Care and attention is needed to plan the extent of zones and the entities within them to respect the limits of the simulation tool. Pre-defined entities come with many explicit mass pairs and it is easy to amass hundreds of surfaces and visual entities.

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- An investment compositional resolution should be matched with assessment resolution - viewfactors, local MRT sensors, shading & insolation, high resolution lighting fittings.
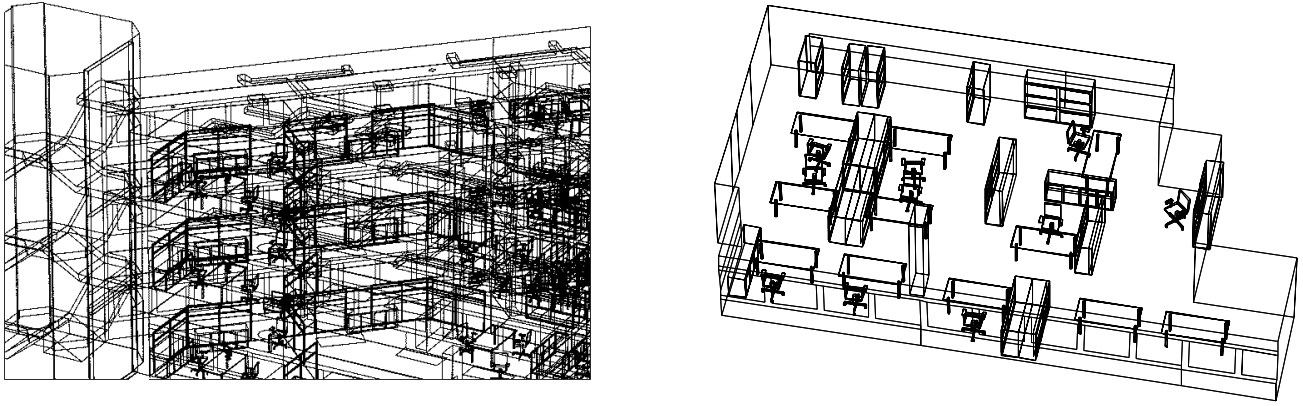
Figure 8.24 Portion of a large scale explicit office building.

Explicit models allow the exploration of space planning and visual comfort via Radiance.
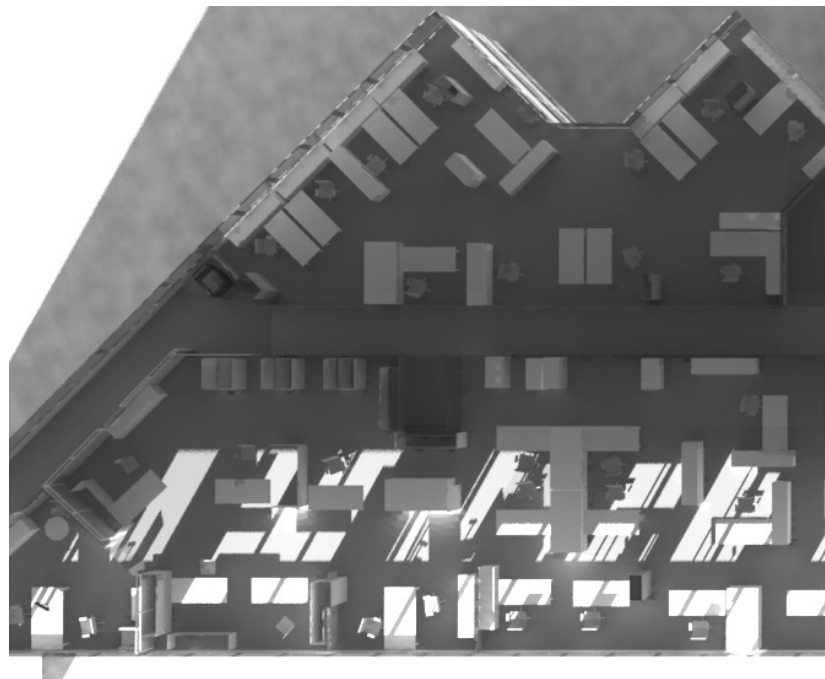
Figure 8.25 Radiance rendering of a portion of office building.

5 Schedules

The form and composition of a model is one part of the simulation process. Many users think they have almost completed their work when the geometry is done. Far from it, buildings are almost always places where people are coming and going and lights are being turned on and off and all manner of electrical devices are found.

Usually we lack both the information and resources to undertake an exhaustive definition. It is, however, in our interest to define the essential characteristics of what goes on in a building and learn from the performance patterns that emerge to imagine the circumstances where the building would perform poorly. This is one place where doing more than *rounding up the usual suspects* pays dividends.

ESP-r supports zone operational characteristics for each day type (see definition below from the Entities Appendix). The default is weekdays and two separate weekend days (typically labelled as Saturday and Sunday) and a holiday. There are several options for creating operational schedules including for some room use types which already include some diversity.

```
Operations File Options

a define from scratch
b air flow      < another zone
c casual gains < another zone
d air & gains  < another zone
e air flow      < from pattern
f casual gains < from pattern
g air & gains  < from pattern
h nothing happens in the zone
i cellular office (1 occ)
j open plan office (9 m2/occ)
k office corridor or stair
l meeting room (3-6 occ)
m dining room (house 2-4 occ)
n lounge (house 2-3 occ)

-----------------------
! cancel
? help
```

Figure 5.1: Options for creating initial schedules.

For projects like the surgery the client brief noted that the practice schedule involved different usage patterns and so additional day types for the calendar must be in place prior to the specification of any zone operations or ideal controls.

> a *model calendar* is composed of one or more *named day types*, each of which can be associated with one or more Julian days-of-the-year. Environmental controls and zone schedules make reference to these day types. Additional day types can be created as required but it is best to do this prior to the definition of operations and controls.

A bit of planning will (you guessed it) save time and reduce errors. With reference to the client description in Section 2 the following are relevant phrases:

- there are two people in the examination room during the hours of 9h00 to 16h00 on weekdays with staff in until 18h00...and there might be up to five people plus a receptionist

- thursday afternoons are for staff only

- the practice is also open Saturday mornings with up to 7 visitors

The default day type of weekday can handle conditions on Monday, Tuesday, Wednesday and Friday. We need a day type for thursday. And the existing Saturday day type can be used.

Exercise 5.1 covers the steps needed to add an additional day type to the Surgery model.

Casual gains (e.g. people, light, small power) are one operational characteristic of a zone. They are defined in the Entities Appendix as:

> *zone casual gains* are user defined profiles for each day type in the calendar. In addition to documentation strings, casual gains comprise a name e.g. fluorescent, teacher, photocopier and a type (e.g. people, lighting, equipment, other) and a profile of one or more periods covering the whole day. Each period has a start and end hour, sensible watts, latent watts, sensible radiant and convective fraction and optionally electrical characteristics (real and reactive power, voltage, phase and power factor) or occupant attributes (clothing, metabolic rates).

On average, there are two people in the examination room during the hours of 9h00 to 16h00 on weekdays with staff in until 18h00. The reception area serves other examination rooms and there might be up to five people plus a receptionist on a typical day. Thursday afternoons are for staff only and the practice is also open Saturday mornings with up to 7 visitors. The *up to* in the description signals diversity.

Why bother with varying the occupancy during the day? Several reasons - full time peak loads usually do not happen in reality so diversity is realistic, reducing the load during a lunch hour allows us to check whether the building is sensitive to brief changes in gains and the ramp-up just before office hours and the ramp-down after office hours approximates transient occupancy and cleaning staff.

The lights are on during office hours plus some time for cleaning staff. In the examination room there is 100W of lighting and 100W IT kit during office hours. In the reception lighting is 150W with 100W IT kit during office hours. Given the limited daylighting let's assume that lighting is not controlled.

Table 5.1 Casual gain periods for reception and examination

Monday, Tuesday, Wednesday, Friday					
	Occupancy (W)		Lights (W)		IT kit (W)	
Period	Recep	Exam	Recep	Exam	Recep	Exam
0-8	0	0	5	5	10	10
8-9	50	50	50	50	20	10
9-10	400	150	150	100	100	100
10-12	600	200	150	100	100	100
12-13	300	50	150	100	100	100
13-14	500	150	150	100	100	100
14-16	600	200	150	100	100	100
16-17	100	100	150	100	100	100
18-19	50	50	100	100	10	10
19-24	0	0	5	5	10	10

Thursday	Occupancy (W)		Lights (W)		IT kit (W)	
Period	Recep	Exam	Recep	Exam	Recep	Exam
0-8	0	0	5	5	10	10
8-9	50	50	50	50	20	10
9-10	400	150	150	100	100	100
10-12	600	200	150	100	100	100
12-13	200	50	150	100	100	100
13-18	100	100	150	100	100	100
18-19	50	50	100	100	10	10
19-24	0	0	5	5	10	10

Saturday	Occupancy (W)		Lights (W)		IT kit (W)	
Period	Recep	Exam	Recep	Exam	Recep	Exam
0-8	0	0	5	5	10	10
8-9	50	50	50	50	20	10
9-10	400	150	150	100	100	100
10-11	700	200	150	100	100	100
11-12	500	200	150	100	100	100
12-13	100	100	150	100	100	100
13-24	0	0	5	5	10	10

Sunday Holiday					
	Occupancy (W)		Lights (W)		IT kit (W)	
Period	Recep	Exam	Recep	Exam	Recep	Exam
0-8	0	0	5	5	10	10

In the reception the peak occupant sensible gain is 600W on typical days with 700W on Saturday mornings and 100W on Thursday afternoons. In the examination room the peak is 200W equating to 100W per person. The latent magnitude is roughly half the sensible value. Peak demands should last long enough to indicate whether heat will tend to build up in the rooms. We want to exercise the environmental

system and perhaps provide an early clue as to the relationship between building use and system demands. The following table is a summary:

To give you practice with creating zone schedules you will be working through the steps in Exercise 5.2. This exercise will take some time, there is a lot of data to provide and to check.

When finished the interface will look like Figure 5.2. Using the information on your notes you could also define the casual gains for the examination room. After completing this task the interface would look similar to Figure 5.3.
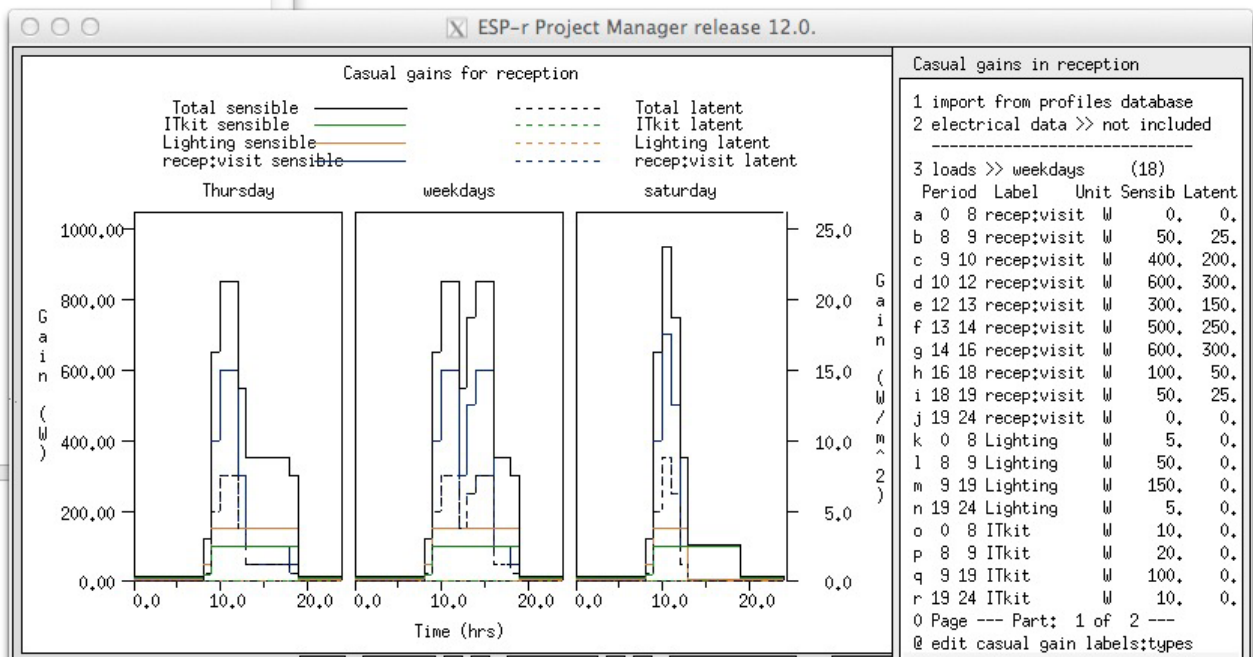
Figure 5.2 Reception casual gains completed.
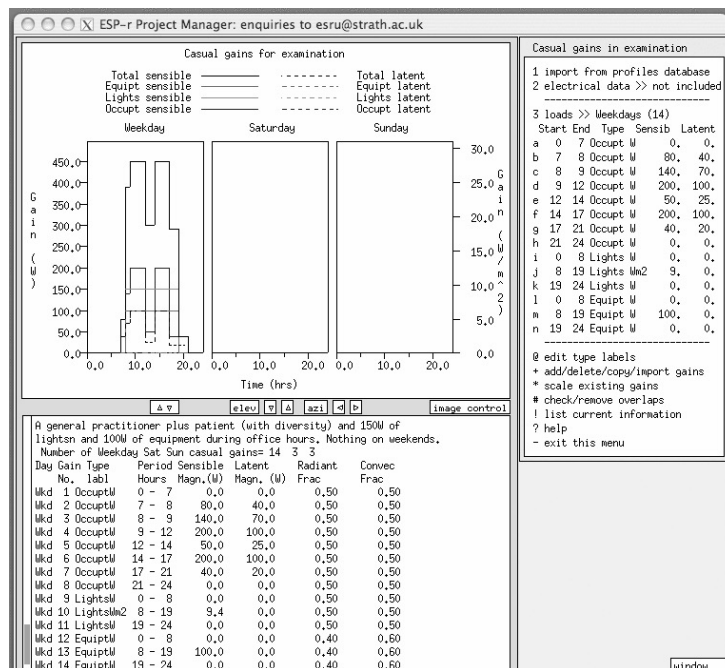
Figure 5.3 Examination casual gains completed.

Although the initial definition of zone schedules was tedious some tasks take few keystrokes. If later you wanted to upscale the small power would require only that you select the `scale existing gains` option and provide a scaling factor for the casual gain of interest.

5.1 Scheduled air flows

Early in the design process building details may not support a detailed description of how air moves within buildings or how tight the facade might be so engineering approximations are often used. If the project brief does not include directives an initial set of assumptions needs to be made. For many buildings there is considerable uncertainty in leakage characteristics and thus a range of infiltration rates should be explored. In an actual project discussions would be made within the design team to quantify this figure. It might be possible to locate pressure test data for a similar building.

ESP-r uses two descriptors for scheduled air movement. *Infiltration* is used for air exchanges with the outside including naturally induced flows via cracks in the facade and mechanical ventilation. There is no concept of scheduled exfiltration.

Schedules of infiltration (air from the outside via intentional sources such as fans or unintentional sources such as cracks in the facade) and ventilation (air from another thermal zone) can also be defined. There are a limited number of controls you can impose on infiltration and ventilation schedules and for some projects it is necessary to use mass flow networks and control. The definition provided in the Entities Appendix is:

> *zone scheduled infiltration* relates to air movement from ambient whether unintentional or mechanically forced. It includes a documentation attributes and user defined profiles for each day type in the calendar with the option to be controlled based on time, ambient or zone temperature as well as wind speed. If a mass flow network is defined, infiltration will be equated with the flow node associated with the zone.
> *zone scheduled ventilation* relates to air movement between thermal zones whether unintentional or mechanically forced. To represent mixing between zones there needs to be a matched definition of ventilation in each of the zones. It includes a documentation attribute and user defined profiles for each day type in the calendar with the option to be controlled based on time or zone temperature. If a mass flow network is defined, ventilation will be equated to the flow node associated with the zone.

Ventilation is specified in terms of a volume of air entering a zone from another thermal zone or from a non-zone source at a fixed temperature. There is no mechanism for specifying ventilation air leaving a zone other than as a source for ventilation for another part of the model. It is up to the user to correctly specify flows between zones so that a balance is maintained.

For purposes of this exercise let's have a rather leaky facade and assume that the doors are closed between the reception and examination room. We can represent this with one period each day covering the 24 hours with a value of 1 ac/h infiltration and no ventilation (see Figure 5.4). This is accomplished by revisiting the zone schedules and selecting `edit schedules air flows` and then asking to add a peeriod with 1ach infiltration for all hours on all days and then updating the documentation to reflect this. There is no ventilation (air flow between rooms) in the initial model definition.

Later we might decide to lower the infiltration rate to see if the building is sensitive to an upgrade in the quality of the facade. ESP-r includes facilities to alter the rate of scheduled infiltration or ventilation as a function of temperature or wind speed. This can be used to approximate window opening schemes or to introduce some sensitivity to changes in wind speed.

Range-based control uses the nominal infiltration or ventilation air change rate - but switches to an alternative rate as a function of the sensed condition - low rate if below low set point; mid rate if above a mid-range set point; high rate if above maximum set point and the nominal rate if between the low and mid set points as is shown in Figure 5.4.

Number of items for range controller = 6
  1st is low setpoint,
  2nd is mid setpint
  3nd is high setpint
  which yields 4 ranges as follows:
    low range < low setpoint,
    default range between low and mid setpoints,
    mid range between mid and hi setpoints,
    above high setpoint.
  4th is low range ratio (of rate or area),
  5th is mid range ratio (of rate or area),
  6th is high range ratio (of rate or area)

If within default range then the nominal rate or
area is used.

NOTE: this controller works with sensed conditions
such as node temperature and can be used with
components 30 35 40 and 110.

click to dismiss

Low range rate or area (fraction)   **Nominal flow rate or area of component**   **Mid range rate or area (fraction)**   **High range rate or area (fraction)**

Low setpoint   **Medium Setpoint**   **High Setpoint**

Figure 5.4: overview of range based control

For example, if infiltration is set at 0.5 ach, one might close windows if the room air temperature dropped below 20C, open windows more if the room air temperature went over 24C and close them if the room reached 25.8C (because mechanical cooling will start at 26C). The setpoints are thus 20 24 26 and the rates are 0.1 1.5 0.1. It is important to remember that you are imposing flow rates not simulating air flows.

Chapter 11 outline options for treating air movement via mass flow networks which can assess pressure and buoyancy driven flows between thermal zones or via Computational Fluid Dynamic Domains.

5.2 Importing operation schedules

Creating zone operations from scratch is time consuming so many users will collect their best zone operation patterns and store them in the pattern folder (located with the training models).

If you are working with a zone which has a room use which is similar to that of one of the pattern files (you will have to separately explore the files in the pattern folder and make notes), you could select the option `air and gains < from pattern` and a list of files will be shown. Select one of them (remember which one) and look at the summary and answer the questions about air flow and then about casual gains. Since it does not know the volume or the floor area associated with the pattern file it needs information from you. If the author of the file you are getting the pattern from was really clued-up such information would be included in the documentation.

You will have a opportunity to edit the documentation and this is you chance to ensure that what is included in your model is clearly defined, especially if you need to scale some of the values.

▶ **Exercise 15.1** Once a model includes the zone geometry and the thermophysical data files and the schedules of use it is possible to run a simulation. If you think you are at this point then have a look at Exercise 15 and see if you can assess your models performance. If you have not defined environmental systems then the assessment will be based on a free float assumption.

6 Zone controls

Environmental controls in ESP-r models, whether represented as ideal zone controls or networks of system components, are tightly coupled to the solution of thermal zones and thus support multi-criteria and multi-domain performance assessments. The choice of which approach to take is dependent on the stage of the design process, how much detail is needed to assess performance, how much information is available and available resources. Control based on system components tends to take longer to setup and can be more difficult to calibrate. This section focuses on ideal zone controls. Networks of system components will be covered in Chapter 13 and controls for flow networks is covered in Chapter 11.

6.1 Introduction

As we saw in Chapter 1, one important use of simulation is to test the *beliefs of the design team*. For example:

- assumptions that buildings constantly require mechanical intervention,
- that a focus on extreme conditions is sufficient to establish robust environmental controls,
- that *value engineering* has little or no impact on systems and control response or comfort.

> Conventional approaches force us to be specific before we have reached an understanding of supply and demand patterns. Delaying details until we can see the patterns of demand and control interactions supports *informed choices* of system type and components, a better match of building and control and earlier feedback to the design team.

6.1.1 Delayed investment in detail

Often the best path is to *delay our investment in detail* until we have determined whether a design idea is worth pursuing. How many second rate designs persist simply because of sunk-costs and inertia? And how many possibly superior alternatives are not tested because of resource constraints?

Delayed detail approaches can be used in many tools, for example, EnergyPlus offers the *ZoneHVAC:IdealLoadsAirSystem*. This terminal VAV unit controls a room without the need for descriptions of the central plant. An abstract heating control in EneregyPlus might also be accomplished via a *ZoneHVAC:Baseboard:Convective:Electric* component.

To explore delayed detail approaches, the first step is to decode tool jargon. Firstly, in ESP-r the term *ideal zone control* stems from the absence of time lags in thermostats, transport in ducts and pipes, or the action time for dampers. Secondly, you are not presented with a list of entities such as *perimeter trench floor heating* but requests (as in Figure 6.1) for:

- what is sensed, e.g. temperature, humidity, radiation, flux
- where the sensor is, e.g. zone air node, within a construction, within a component
- what control logic is applied to the sensor signal at different times of the day
- what action is taken, e.g. flux injection or extraction,
- where the point of interaction is, e.g. zone air node, within wall, within a system component
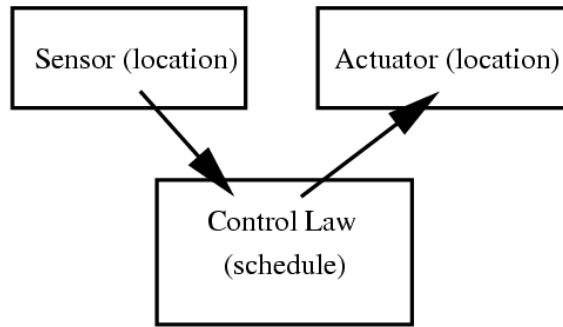
Figure 6.1 sensor - law - actuator.

The combination of *sensor, schedule of control laws and actuator* form what is termed *a control loop* in ESP-r. For example, a hospital ward might have a simple schedule (wards are constantly in use) and pre-scribed performance characteristics so that one control loop might be applied to a number of rooms of this type in a hospital. A residence in North America might have one thermostat and thus the control would be a classic *Master-Slave* controller with most rooms supplied based on conditions sensed elsewhere. This would require the definition of a master control loop and slave control loops for each of the other rooms.

In terms of sensors, the user can be either general or pedantic about the location of the sensor. If a thermo-couple is buried 10mm into a wall or attached to its surface it is possible to replicate this. A thermostatic radiator valve (TRV) which responds 35% to the room air temperature and 65% to the mean radiant tem-perature of the room can be specified as well as a shielded aspirated air temperature sensor.

In terms of the actuator the user can specify a location of the flux injection or extraction in the model e.g. the air node of the zone, a specific layer of a floor. By altering the radiant and convective split, one could approximate the heat distribution characteristics of a WCH radiator (which typically is 80% convective and 20% radiant) or an air based delivery by setting the convective fraction to 100%.

ESP-r users are asked to define characteristics which other tools infer from high level entity selections. Such inference can have implications - real thermostats sense a mix of the room air temperature and the radiant environment. Cold or hot surfaces thus result in a sensed condition which deviate from a pure-air sensor assumption. The radiant component of heating devices also changes the buildings response-to-control characteristics. Check if your simulation tool allows you to specify sensor attributes. Details of ESP-r sensors and actuators are listed in the *Entities Appendix*.

Control laws can be either abstract (e.g. the basic controller used in the example to follow) or realistic as with the PID controller which demonstrates the artefacts which would be observed in a poorly tuned PID control device. The *Entities Appendix* lists many of the available control laws and Section 19.6 provides a summary of control capabilities.

Some simulation tools provide auto-size functions. ESP-r has no such concept. Capacities for heating and cooling are specified by the user. A control loop, which is critically undersized can provide useful clues as to whether the building is capable of absorbing brief extremes in boundary conditions or building use pat-terns. Conversely, over capacity i.e. 20kW in a small bedroom can lead to erroneous response characteris-tics.

Control laws are also impacted by the time step of the assessment. An ON-OFF controller or PID con-troller used with a 15 minute time step assessment will exhibit characteristics of a *sticky controller*.

In buildings where air movement is important models may require a mix of ideal zone controls and air flow network component controls. This is especially true in buildings with hybrid ventilation systems. Control of components in mass flow networks is covered in a separate section.

6.2 Exploring building control issues

In this section we use example models included in the ESP-r distribution to explore environmental con-trols. One or more control issues will be outlined and then you will have the option to select models,

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study their documentation and then run assessments to characterize the temporal response of the building and controls at different times of the year.

Remember, such models are *one expression* of how environmental controls might be implemented. Attributes can be adjusted. Indeed, sometimes performance is best understood by altering the control description and looking at how predicted performance evolves.

> Explore controls via constrained models before implementing them in full scale models or using them in consulting or research projects.
> Adapt working practices which allow you to spend time with the results analysis module and check out a range of performance metrics and reports.

Experienced practitioners will be looking for confirmation of expectations and they will also have strategies for *what-else-do-I-look-at* to confirm the predicted thermophysical state. Those with experience will have many options beyond *the usual suspects* and some of these will be covered in Chapter 10.

6.2.1 Basic (ideal) control

To see what a sensor-law-actuator loop looks like let's explore an example model which uses a combination of free-float and basic controllers.

▶ **Exercise 6.1**   The exercise takes you through the interface path required to focus on environmental controls. The model used in Exercise 6.1 `cellular_bc/cfg/cellular_bc.cfg` is one of the many variants of the two cellular offices with a passage and the context of the basic control is shown in Figure 6.2.

This environmental control heats each of the rooms to 19°C during office hours and 15°C at other times of weekdays. On Saturday the timing is different and after 17h00 the temperature is allowed to free-float. On Sundays there is only a frost protection heating to maintain 10C and an overheat control which cools the room if the temperature goes over 30°C. There is 2500W of sensible heating capacity and 2500W of sensible cooling capacity and no humidity control.

The control loop that implements this is held in the model `ctl` folder. Both the interface and the model contents report use a standard reporting convention to describe control loops. The section of the model contents report focused on the environmental control is reproduced below:
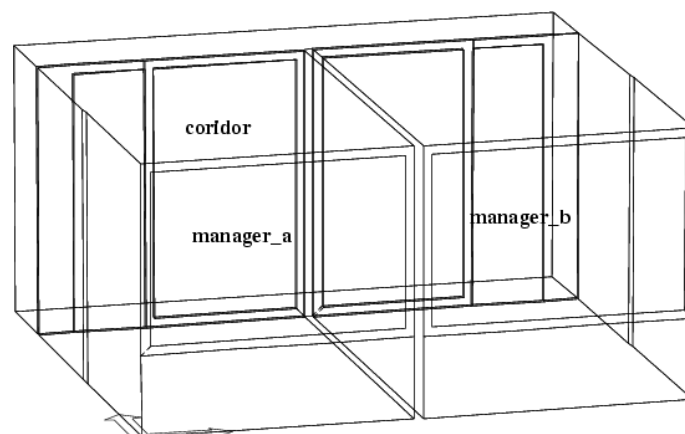
Project: base case model of two adjacent cellular offices

Figure 6.2 Context of basic controller example.

```
The model includes ideal controls as follows:
Control description:
Ideal control for dual office model. Weekdays normal office hours,
Saturday reduced occupied hours, Sunday stand-by only. One person per
office, 100W lighting and 150W small power.

Zones control includes  1 functions. this is a base case set of assumptions
 The sensor for function  1 senses the temperature of the current zone.
 The actuator for function  1 is air point of the current zone
 The function day types are Weekdays, Saturdays & Sundays
 Weekday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with  3 periods.
 Per|Start|Sensing  |Actuating  | Control law      | Data
   1  0.00 db temp   > flux        basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heating set-point 15.00C cooling 26.00C.
   2  6.00 db temp   > flux        basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heating set-point 19.00C cooling 24.00C.
   3 18.00 db temp   > flux        basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heating set-point 15.00C cooling 26.00C.
 Saturday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with  3 periods.
 Per|Start|Sensing  |Actuating  | Control law      | Data
   1  0.00 db temp   > flux        basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heating set-point 15.00C cooling 26.00C.
   2  9.00 db temp   > flux        basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heating set-point 19.00C cooling 24.00C.
   3 17.00 db temp   > flux        free floating
 Sunday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with  1 periods.
 Per|Start|Sensing  |Actuating  | Control law      | Data
   1  0.00 db temp   > flux        basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min heating capacity 0.0W. Heating set-point 10.00C cooling 30.00C.
  Zone to control loop linkages:
 zone ( 1) manager_a     << control  1
 zone ( 2) manager_b     << control  1
 zone ( 3) coridor       << control  1
```

As you can see, ESP-r parses the data associated with each control loop and expresses this as a brief statement (sorry about the abbreviations) about the sensor, actuator and the schedule and attributes of the control laws used. The *prj* interface the menu items associated with control are also space-constrained. You are confronted with sets of numbers and abbreviations from which the brief statement is derived. As you drill-down to individual control loops, periods and control laws the feedback becomes more explicit.

The interface for each control loop is divided into sections that describe the sensor and actuator as well as data for each period in each day type. What you might notice is that there is repetition of the capacity information at each period. The data structure allows *all attributes* to change at each period although most models only alter set-points. Notice that on Saturday, the last period of the day uses a different control law to signal a change from controlled to free floating conditions.

The last item in the report is the linkages between the defined control loops and the zones of the model. In this case one control loop is defined and *the pattern it represents* is used in all of the zones of the model.

As can be seen in the column in Figure 6.3 marked `day type` different control actions are enabled for each calendar *day type* defined in the model. To find out more about calendar day types check out Section 2 (e.g. a thursday day type was added to the standard set of day types) as well as the discussion in Section 5 and Exercise 5.1.

If you are following along in Exercise 6.1 the top-level menu for this basic control will look like Figure 6.3 (including those abbreviations and terse location indices). There are menu items for documenting the included controls, linking specific controls to zones, managing the list of controls (add/delete etc.), checking control syntax and saving the control definition to file. Procedures should enforce documentation to clarify the attributes of control loop definitions.

Figure 6.3 Top level zone control menu.

There is a centre section of the menu which allows access to the specifics of the each control loop. On first glance it is difficult to make sense of the numbers and abbreviations. The three numbers under the `sensor location` column and the `actuator location` columns define the specific location based on user selections. Selecting the control law brings up the choice of `sensor details`, `actuator details`, `period of validity` and `period data`.

Each control loop has one defined location for its sensor (although some control laws will supplement this definition) and one location for the actuator. Choices for a sensor are shown in Figure 6.4. There are two sensor choices `senses current zone db temp` which can be used if a control is referenced by many zones and `senses temp in a specific zone` which is used if conditions at a specific surface or if the sensed condition is mixed radiant and convective. Once you select the choice and answer some supplemental questions the indices shown in the high level control loop selection list of Figure 6.3 are generated.

Figure 6.4 Sensor choices (left) actuator choices (right).

There are fewer choices for the actuator of an ideal control. Unlike other domains, which might control two phase flow or a damper position, a zone control either adds or removes flux from a node within the simulation solution matrix as shown in the right of Figure 6.6.

Periods for a day type (Figure 6.5) are defined by their start time and the control law to use during the period. Control logic is used until there is a subsequent period statement or until the end of the day (which

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ever comes first).

If you select a period the attributes of the control law are available for review and editing (Figure 6.6). Some control laws have few attributes and other have upwards of twenty attributes.

Exercise 6.2 After exploring the interface exercise 6.2 will take you through the steps needed to run a standard assessment so that later in Chapter 10 you can use the results analysis module to answer some basic demand-supply questions:

- How often and when is the control actually used?
- How often are the room temperatures in the dead-band?
- How quickly do the room conditions deteriorate when the schedule switches to free-float?
- How often is heat being delivered at a fraction of the system capacity?

```
X  ESP-r Project Manager release 12.0.

two    Control periods

       control loop  1  (active on weekdays)
       number of periods:  3

       ----------------------------------------
       per|start|sensed  |actuated | control law   | data
       no.|time |property|property |               |
       a  1  0.00 db temp  > flux    basic control    2500.0 0.0 2500.0 0.0 15.0 26.0
       b  2  6.00 db temp  > flux    basic control    2500.0 0.0 2500.0 0.0 19.0 24.0
       c  3 18.00 db temp  > flux    basic control    2500.0 0.0 2500.0 0.0 15.0 26.0

       ----------------------------------------
       * add/ delete a period
       ? help
       - exit
```
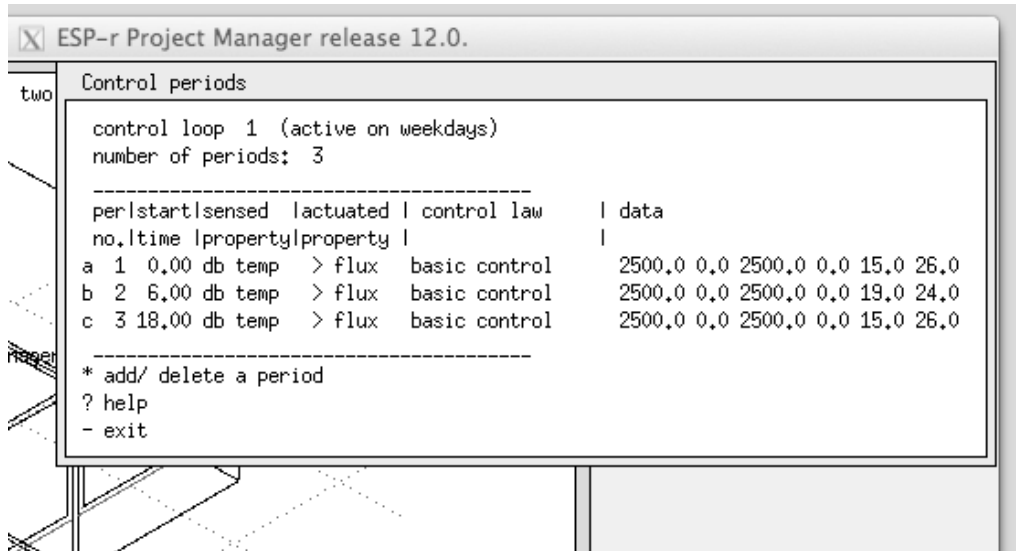
Figure 6.5 Control periods for weekday day type.

```
       Zone control period data

ef
es        Loop  1  day: Weekday  period:  2
          Sensed & actuated property is...
            db temp   > flux
cr
       ---------------------------------
       1 Starting at:  6.000
       2 Law: basic control
       a Choose parameter to edit:
       b Maximum heating capacity (W)    :    2500.0
       c Minimum heating capacity (W)    :       0.0
       d Maximum cooling capacity (W)    :    2500.0
       e Minimum cooling capacity (W)    :       0.0
       f Heating setpoint (C)            :    19.000
       g Cooling setpoint (C)            :    24.000
       h
       i
       j
       k
       l RH control >> OFF               :       0.0

       ---------------------------------
       + Shift to earlier or later period
       ! List details
       ? Help
       - Exit
```

Figure 6.6 Control law attributes for the current period.

6.2.2 Abstract floor heating example

Imagine it is early in the design process and the client mentions that they are considering an underfloor rather than a conventional radiator heating system but is worried about the response time and comfort.

Both floor heating and conventional radiator design options include a radiant component in the delivery of heat. Floor heating typically has substantial inertia. Is it possible to design a model which will reflect this inertia to deliver quick feedback to the client?

A component based approach is complicated by the dozens of possible combinations of boiler, pump and heating circuit layout and is burdened by the need to attribute each of the components. At an early design stage such details are *a distraction* from what is essentially a high level decision.

Exercise 6.3 Exercise 6.3 assumes that all you know is that the floor heating system is capable of injecting ˜40W/m2 within the screed of the floor slab during office hours based on the air temperature of the room. As you will see in the exercise, the exemplar model implements the floor heating via building-side entities (additional zones and heat transfer directives).

The challenge for controlling the floor heating is to sense conditions in one zone (the occupied space) and use that to impose a heat flux within another zone (the floor zone). As it happens there is a multi-sensor control law that supports this. Alternative representations of environmental controls are possible in many simulation tools if we *think out of the box*.

The placement of the sensor and actuator are shown in the left of Figure 6.7 and the adapted geometry of the model (there are two additional zones) is seen in the lower portion of Figure 6.7.

The control attributes required are shown in the right half of Figure 6.9. Exercise 6.2 explains the *thin zone* approach to representing the heat transfer layer of piping within the floor slab and ceiling structure.

During the simulation the core of the thin zone floor may rise to as much as 35°C in order to maintain a 21°C setpoint within the occupied space.

Although the heat injection is abstract, the resulting movement of heat through the floor structure and the subsequent radiant exchanges within the room are solved dynamically within the simulation. Figure 6.8 shows the temperature at the core of the floor and in the occupied space. On the fourth day the room temperature is excessive because there is a significant solar gain which boosts the floor temperature (and thermal inertia of the floor heating controller cannot respond quickly to this disturbance). If you have trouble linking this performance observation to the lines in the graph then section 6.4 will begin to give you clues as to the performance interpretation topics to be covered in Chapter 10.
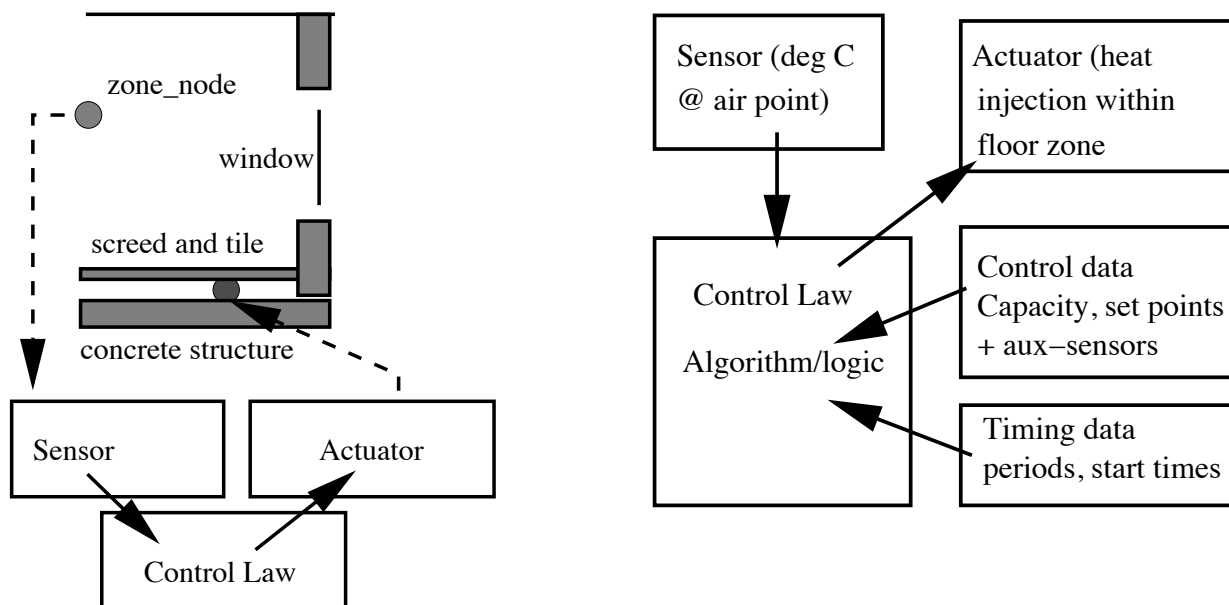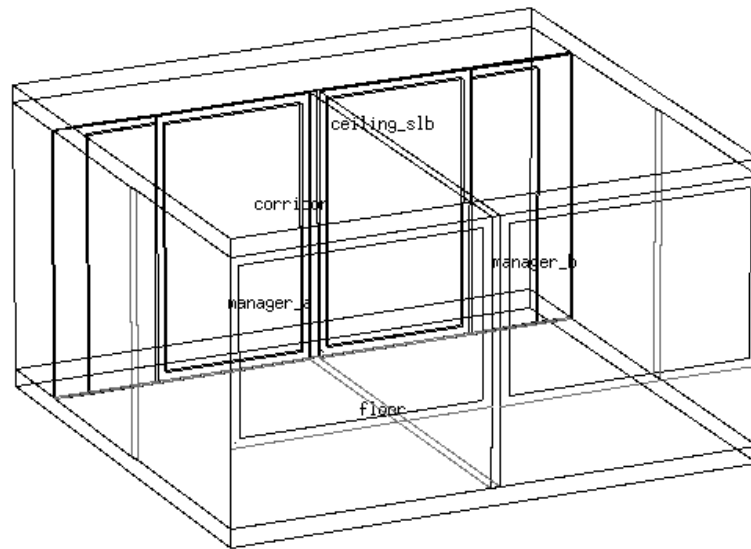
Figure 6.9 Abstract floor heating system and data requirements.

If you interpretation of the control response is *could do better* then altering the control attributes allows design variants to be tested. For example, if the response is slow, the position in the slab of the heat injection could be raised by re-defining the location of the actuator.

Once the required characteristics of the floor heating system have been assessed then these can be implemented as a network of components for use in the detailed design stage if the resources and goals of the project warrant it.
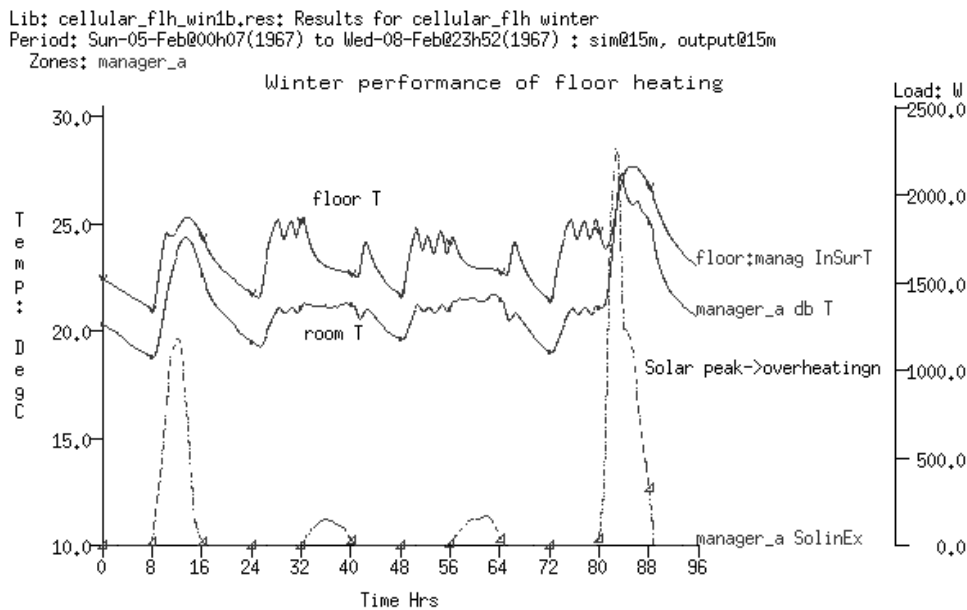
Figure 6.8: Temperatures at core of floor slab and in room above.

The downside of abstract approaches is that some performance criteria are not available (we do not know the return fluid temperature) and some aspects of the thermophysical response are simplified (variation of temperature in the slab due to tube spacing). Although it is not the case with a floor heating system, the minimum time-step for a zone control is one minute so systems that respond in the order of seconds are not well represented. Some control combinations found in BEMS are difficult, if not impossible to represent.

6.2.3 Controls implementing boundary zones

Focused models, which represent a portion of a building, are predicated on robust boundary conditions. A classic case is an office building with a suspended ceiling which acts as a return plenum and which has gains from ducts and pipes and lighting fittings. Below the occupied level is likely to be another such

ceiling plenum.

The temperature in the ceiling voids often deviate from the air temperature of the occupied space. Thus the standard boundary condition of `dynamic (similar)` which is offered by ESP-r is less accurate than the boundary conditions provided by a fully described zone.

Indeed, if the design question focused on whether a night purge of the ceiling void might provide useful structural cooling, the boundary condition above the suspended ceiling is critical.

Exercise 6.3 As we saw in Section 6.3.2 thermal zones can be used to define boundary conditions for occupied spaces. Bounding zones used to define ceiling and floor voids can also make use of selectively abstract representations as in Figure 6.9. This model `cellular_bounded.cfg` is featured in Exercise 6.4.

If the occupied space and the ceiling void above it are *well represented* we can use a control law to force the abstractly represented lower ceiling void to follow the predicted temperature of the *well represented* ceiling void. We can define another control which takes the mean temperature of the `manager_a` and `manager_b` rooms and conditions the upper low-resolution occupied space to follow the predicted temperature of the defined occupied space. The approach to creating the controls for each of the rooms are covered in the exercise.

To demonstrate the temperature match, the temperature in `boundary_up` is show in Figure 6.10 as the mean of the current temperatures in `manager_a` and `manager_b`. The use of a mean temperature of several model zones for the boundary condition above the structural slab is one approach.
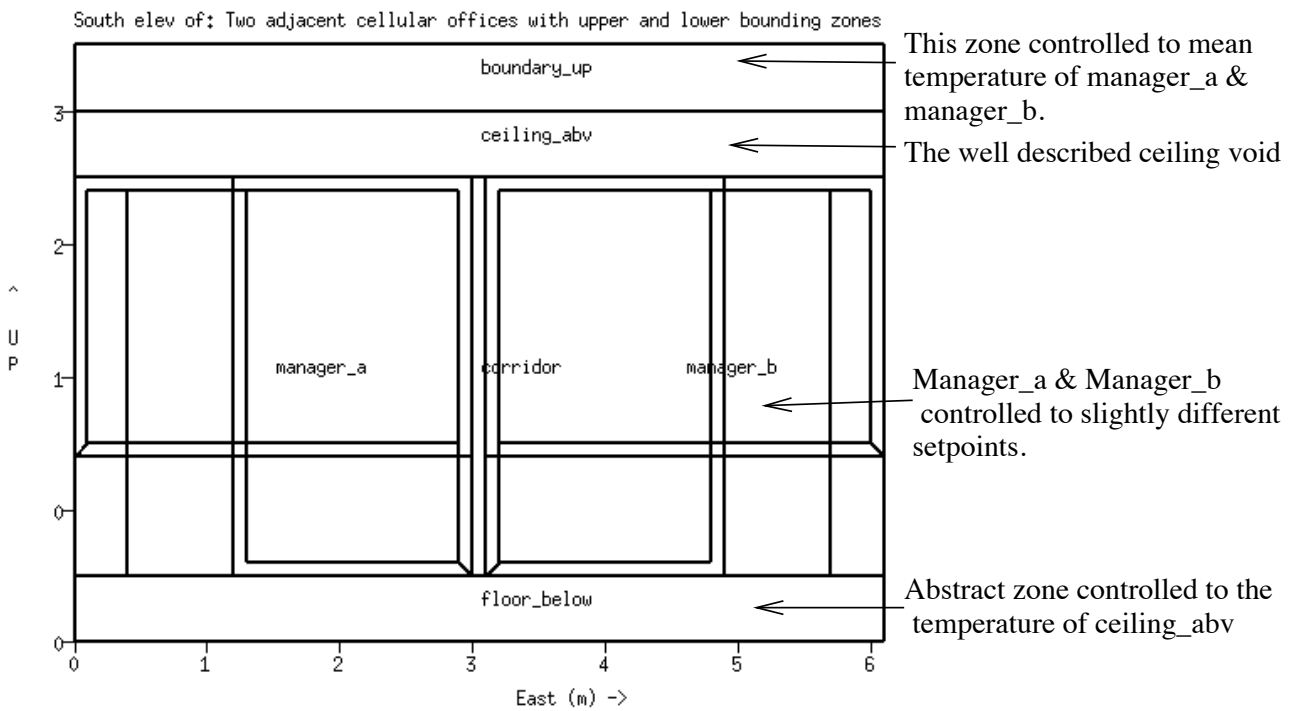
Classic issue in simulation: definition of dynamic boundary conditions while limiting model complexity.

Figure 6.9 Bounding control zones and logic.

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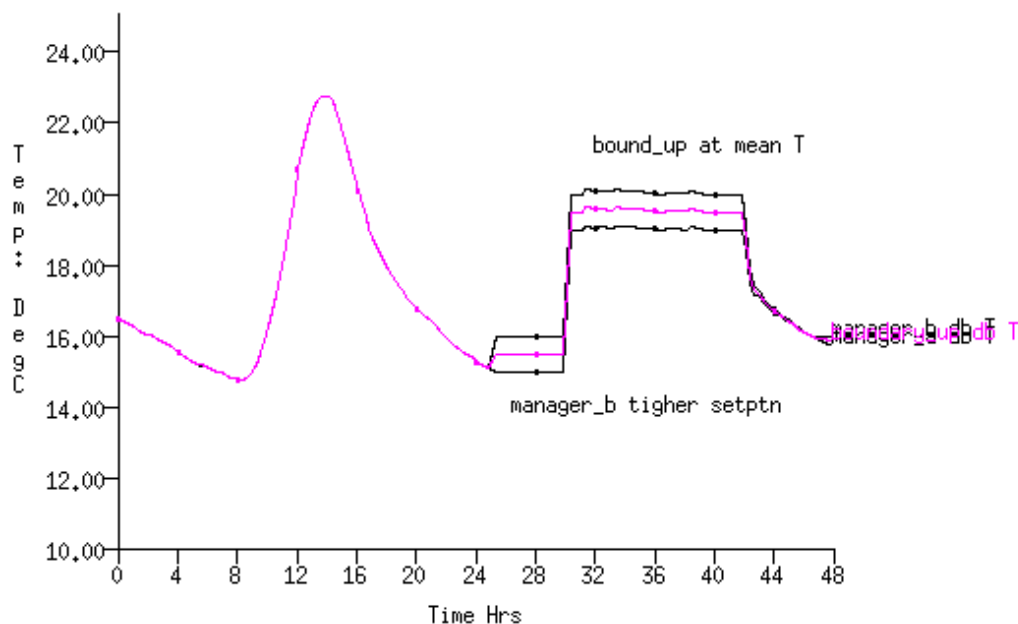
Figure 6.10 Mean temperature in boundary_up zone.

In summary, the flexibility of zone control loops has both costs and advantages. There are currently no *wizards* to automate the process so some tasks are tedious. Care and attention to detail is needed to ensure that the control logic is working well under a variety of operating regimes.

The advantage is that the facility can support the early exploration of novel design ideas. It may also reduce the complexity of other aspects of the model and support scaling of focused model predictions. And by delaying the requirement for specific details it may allow for a broader exploration of design ideas during the early design stages.

6.3 Interpreting control predictions

Do the controls that we implemented in our models perform as we expect? Gaining confidence in the response of controls draws on many skill sets:

- Setting up assessments with sufficient diversity of disturbance (control engineer jargon). Translation - a range of weather patterns and room uses that will exercise controls in ways that will help us to understand performance as well as identifying failure scenarios.

- Defining the frequency of the solution so that we capture the characteristics of the building and the environmental control (sensor response, actuator response and control logic switching). For example, an ON-OFF controller at a 10 minute time step is a rather *sticky controller*.

- Recognising that real control requires tuning and would act poorly as demands or boundary conditions changed. Detecting poor tuning in the virtual representation of a PID controller is not a universal skill for simulation users.

- Skills in navigating the various report and reporting formats within the ESP-r results analysis tool as well as pattern matching skills to identify faults and opportunities in the data.

Chapter 9 focuses on how we prepare for assessments - the period of the assessment, the frequency of solution. Chapter 10 focuses on the *res* module - the types of performance data as well as the forms of reporting. Once these topics have been covered it will be possible to explore the understanding of the example control models discussed in this chapter.

7 Flow

This Chapter focuses on flow modelling techniques. A number of simulation tools support the definition of flow nodes (within thermal zones and at boundary points) and flow components (openings, cracks, fans, pumps, conduits) and their linkage into networks which can then be solved dynamically along with other solution domains.

As elsewhere the discussion uses ESP-r to demonstrate the concepts and includes:

• differences between user imposed flow and dynamic approaches;

• overview of network flow modelling;

• the art of planning flow networks;

• defining and calibrating flow networks;

• control within flow networks;

• project management.

As with other simulation tools, air flow within an ESP-r model can be imposed via schedules of infiltration and ventilation. Scheduled flow is often used for engineering approximations, initial design studies and basic operational regimes. For example, a user might impose 0.5 air changes of infiltration for all day types and all hours or a schedules that change at each hour for each day type. These schedules may be subjected to control (e.g. increase infiltration to 1.5 air changes if zone temperature goes over 24° C).

Each tool has its own syntax for defining scheduled flows as well as jargon used to describe entities. In the context of ESP-r, the term *infiltration* relates air flows with ambient conditions and *ventilation* between thermal zones. There is no distinction between mechanically driven flow or naturally driven flow in energy balance reporting.

The critical word above is *imposed*. Schedules impose a flow regime which may have no basis in the *physics* of buildings. This is particularly true in the following cases:

• Where there is strong coupling between heat and air flow, e.g. stack and wind driven flow

• Where there are highly dynamic variations in ventilation rate, e.g. natural ventilation

• Where control strategies are important, e.g. opening or closing windows based on temperature and/or wind speed.

In these cases flow networks are better able to represent the dynamics of flow interactions.

7.1 Flow Networks

Flow networks offer considerable flexibility in describing a range of designs which are dependent on the movement of mass (air or liquids) within a model. A network describes possible flow paths, points where boundary conditions apply and locations where measurements of flow performance are required.

ESP-r's flow network solver dynamically calculates the pressure-driven flows within zones and/or environmental control systems that are associated with the network. The flows at nodes are a function of nodal pressures and the connected components' characteristics. The mass balance at each node is solved using a customized Newton-Raphson approach. The solution iterates until it converges and the pressure at each node and the mass flow through each connection are saved.

The solution takes into account the change in driving forces as conditions within the building and boundary conditions evolve. Information exchange between the domain solvers ensures that changes in flow will influence conditions in associated zones, controls, systems and CFD domains within a model. For example, opening a window on a cool day introduces cool air into a zone, which depresses the temperature of the walls which then alters the buoyancy forces driving the flow.

The solver is efficient and thus, even with scores of nodes and components, there is only a slight increase in computational time. Assessing thousands of time-steps of flow patterns in support of natural ventilation risk assessments is one use of flow networks. Flow networks are often used as pre-cursors to CFD studies. In ESP-r flow networks can be linked to domains for hybrid solutions.

Those who wish to know more about the solution technique should look at publications page on the ESRU web site. For example, *On the Conflation of Contaminant Behavior within Whole Building Performance Simulation* (A Samuel, 2006), *Energy Simulation in Building Design* (J A Clarke 2001), *The Adaptive Coupling of Heat and Air flow Modelling Within Dynamic Whole-Building Simulation* (I Beausoleil-Morrison 2000), *On the thermal interaction of building structure and heating and ventilating system* (J L M Hensen 1991) are books or PhD thesis which discuss some aspects of flow simulation.

An ESP-r model may have one or more de-coupled flow networks - some describing building air flow and others representing flow in a hot water heating system. In models which include separate buildings the flow network can include one or more of the buildings.

ESP-r differs from some other simulation tools in that it asks the user to define flow networks explicitly. An explicit description allows knowledgeable users to control the resolution of the network as well as the choice of flow components, their details as well as entity naming conventions.

This approach assumes that the user has opinions about flow paths as well as access to relevant information about the flow components used in the network. As with the geometric resolution of a model, creating flow networks is as much an art as it is a science.

The flexibility of flow networks brings both power and risk. The discussion that follows presents methodologies to help you decide when networks are called for, planing tips for flow networks and techniques for understanding the predicted patterns of flow within your model.

7.2 Building blocks

The building blocks we can use to define a mass flow network are flow nodes, flow components and flow connections. The least complex network that the solver will work with includes a zone node and two boundary nodes connected by two components (see Figure 7.1).
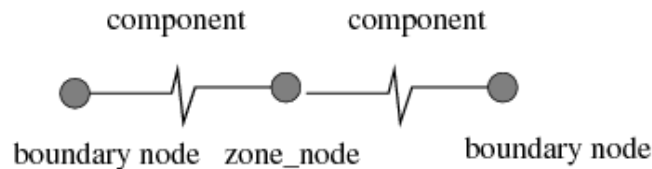
Figure 7.1: The least complex network.

Flow Nodes

Nodes in a flow network are measuring point for pressure, temperature and rate-of-flow. These bookkeeping entities are of four types:

- internal unknown pressure (air or liquid);
- internal known pressure (air or liquid, rarely used);
- boundary known pressure (air or liquid, example a 50PA blower door test);
- boundary with wind induced pressure (air nodes only).

A flow node has one temperature just as the volume of air associated with a thermal zone has one temperature. Typically there will be a one-to-one mapping between thermal zones and flow nodes. Internal nodes can either take their temperature from a thermal zone or they can be defined to track the temperature of another flow node. Let's call the former *real nodes* and the latter *extra* nodes. Extra nodes might be associated with a length of duct within a thermal zone.

Wind induced boundary nodes represent wind pressure at one point on the facade of a building. It is a function of the wind velocity, direction, terrain, building height, surface orientation and position within the facade. Typically, a flow network would include a boundary node for each location where air may flow into a building (height & orientation). If you follow this pattern the process of locating flow components representing the opening is simplified.

Pressure coefficients

The jargon we use to express changes in pressure due to changes in wind direction is a pressure coefficient Cp. In ESP-r, Cp values for standard angles of incidence (16 values to represent 360°) for a specific location are held as a set.

ESP-r has a common file of Cp coefficient sets for different types and orientations of surfaces derived from the literature. Let's be clear about this, one of the greatest points of uncertainty in flow simulation is in the derivation of pressure coefficient sets. Some groups reduce this uncertainty by undertaking wind tunnel tests or creating virtual wind tunnel tests via the use of third party CFD tools (ESP-r's in-built CFD solver does not yet support external domains).

Wind Speed Reduction Factors

The ratio of the wind velocity (usually at a standard height of 10m) and wind in the locality of the building is known as the wind speed wind reduction factor such that

`V = Vclim x Rf`

Rf is calculated from some assumed wind speed profile and accounts for differences between wind measurement height and surrounding terrain (urban, rural, city centre) and building height and surrounding terrain. Wind profiles can be calculated using three different models: power-law, LBL, logarithmic.

Caution is advised in the use of Rf values as the profiles they are derived from are invalid within the *urban canopy*. In such cases, it is advisable to use a small value for Rf in cooling/air quality studies and high values for infiltration heating studies to represent worst case conditions.

7.2.1 Flow components

Flow components (e.g. fans, pumps, ducts, cracks, valves, orifices etc.) describe the flow characteristics of entities which separate flow nodes. Flow is usually a non-linear function of the pressure difference across the component based on experimental and analytical studies taken from the literature.

ESP-r has a set of in-built flow components including ducts, pipes, fans and pumps as well as cracks, orifices and doors. Generic fixed volume or mass flow components as well as quadratic and power law resistance models are also included. Details of the methods used are included in the source code in the folder src/esrumfs. Some commonly used components (reference numbers in brackets) are:

- Power law volume flow (10) can be used where flow is well described by a power law
- Self regulating vent (11) is a European vent to embed in a window frame which moderates flow across a range of pressures
- Power law mass flow (15 & 17) can be used where flow follows a power law.
- Quadratic law volume (20) and mass (25) can be use where flow follows a quadratic fit.
- Constant volume flow (30) and mass flow (35) are abstract representations of a fan (can be controlled to approximate variable speeds).
- Common orifice (40) can be used for openings with a user defined discharge coefficient
- Specific air flow opening (110) has a fixed discharge coefficient and only requires an area.
- Specific air flow crack (120) is useful for openings up to 12mm wide.
- Bi-directional flow component (130) is useful for doors and windows which are door shaped where temperature and pressure differences can result in flow in two directions.
- Roof outlet/cowl (211) is based on measurements of typical ceramic units found in Europe.
- Conduit with converging 3-leg (220) and diverging 3-leg (230). There are lots of parameters needed to describe this and dragons live here.
- Conduit with converging 4-leg (240) and diverging 4-leg (250). There are lots of parameters needed to describe this and dragons have been sighted here.
- Compound component (500) points to two components e.g. an opening and a crack with parameters needed for control actions.

7.2.2 Flow connections

Flow connections link nodes and components via a descriptive syntax that takes the form: boundary node 'south' is linked to internal node 'office' via component 'door'. In the case of a flow inducer such as a fan the direction of flow is derived from how the connection is defined. For example 'office' to 'north' via 'fan' makes it an extract fan.

A connection also defines the spacial relationship between the node and the component e.g. that a floor grill is 1.5m below the node. If nodes and connections are at different heights, then the pressure difference across the connection will also include stack effects.

Good practice places a boundary node at the height of each opening to the outside. If you follow this pattern the delta height is zero for components from the point of view of the boundary node.

In the upper part of Figure 7.2 is a crack under a door that connects to zones (where the zone nodes are at different heights). In the lower part is a representation of a sash window (where there is one flow component representing the upper opening and another representing the lower opening. The sash window is associated with two separate boundary nodes.
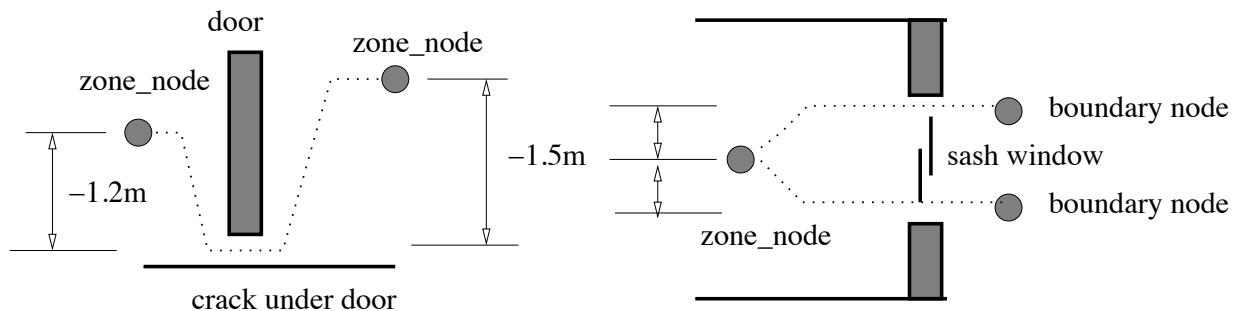
Figure 7.2: A crack under a door and a sash window.

Some people find the syntax used to describe the relationship between nodes and components a bit of a challenge. Here is one technique that works for quite a few users.

> Imagine yourself at the position of the flow node (e.g. in the centre of the zones air volume) and looking at the component. If you are looking horizontally then the height difference is zero. If you are looking up then the height difference is positive. If you are looking down (e.g. to the crack under the door) then the height difference is negative.

For example, if a zone node is at 1.5m above the ground and the lower sash window opening is at 1m above the ground and the upper sash window opening is at 2.1m above the ground. Look at the lower window opening from the point of view of the zone node it is 0.5m below the zone node and at the same height as the lower boundary node. The upper window opening is 0.6m above the zone node and at the same height as the upper boundary node.

Path to boundary

The other rule about creating networks is that every internal node must, somehow, have a path to a boundary node. The solver treats air as incompressible (for all practical purposes) and the solution is of the **mass** transfer within the network. When the temperature changes the volume must change and if the pressure has no point of relief then the solver breaks.

The design of the network must take this rule into account, especially if control applied to components would have the effect of totally isolating a node. The risk of breaking the rule increases with network complexity so we need procedures which are robust enough to scale with the complexity of the models we create.

Parallel and sequential connections

Figure 7.3 is a portion of a network which uses a common orifice to represent the window when it is opened as well as a parallel path with a crack. If the window is controlled and open then the crack has little or no impact on predictions. When the window is closed then the crack becomes the connection to the boundary node.

Recent versions of ESP-r support the concept of a compound component which is made up of, for example, an opening and a crack. The use of compound components can simplify flow networks by reducing

the need to parallel connections.
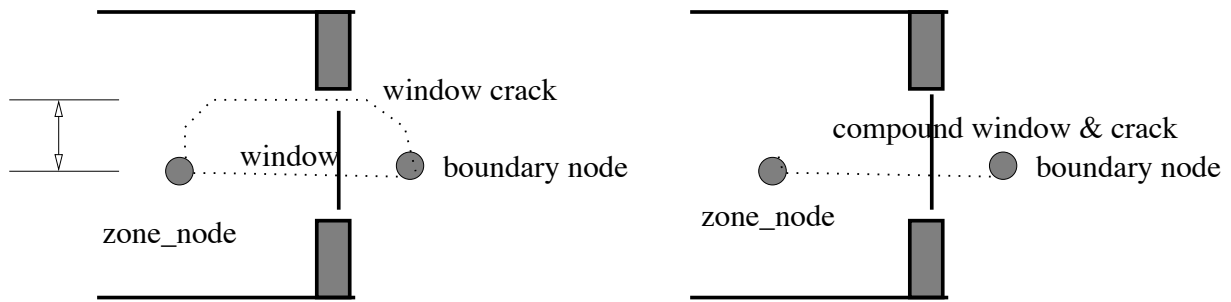
Figure 7.3: A crack & window and a compound component.

Up to this point the networks have been linked via a single component or components in parallel. Suppose we wanted to open a window if the temperature at the zone node was above 22°C AND the outside temperature was below 19°C. How might we implement the above AND logic? One technique is to use components in series.

If *zone_node* is linked to *boundary_node* by component *window* and we wish to insert a second component *control* it would be necessary to create *extra_node*, assign it to track the temperature of *zone_node*. The new flow component *control* should be of a type that would present little resistance to flow when open. The existing connection would be re-defined and the second connection in the sequence would be created as in Figure 7.4. The *window* component would take one control logic and the *control* component would take the second control. The original window crack connection would remain.
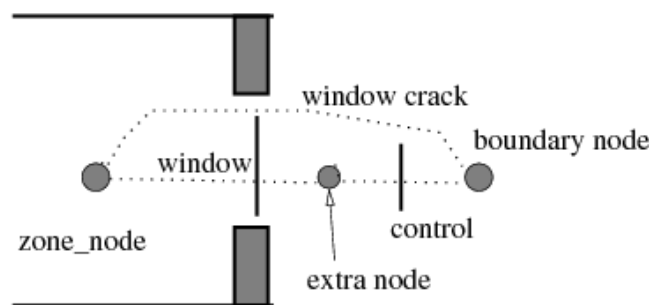
Figure 7.4: Use of additional nodes and components for control

The other technique is to use a `multi-sensor flow control` which tracks conditions at several nodes via AND and OR logic (see discussion later in this section).

When control is imposed, consideration should be given to adjusting the simulation time step to take into account the response of the sensor and flow actuator. If we observe flow rates oscillating it is usually in indicator that we need to shorten the simulation time step.

7.3 Steps in creating a network

When we plan a network we should account for how flow is induced or restricted, where control might be imposed as well as where we expect there to be differences in air temperature within a building.

For example, if you *believe* that a perimeter section of an office will often be at a different temperature consider creating a separate zone for the perimeter. Some practitioners include additional vertices in the model and subdivide floor and ceiling surfaces in their initial model so that it is easy to subdivide a zone at a later stage.

In deciding which components to use it helps to review the features of the available components and control options which can be applied to them as well as their data requirements. Browse existing models which include flow networks and run assessments and review predictions. A great way to understand how flow works is to systematically adapt the network and/or control description and observe the changed performance.

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A methodical approach to the creation of network ensure that networks of scores of nodes and components which work correctly the first time. Successful practitioners use the following set of rules:

Rule one   sketch out the network either as a 2D layout or as a 3D overly of the wireframe view of the model

Rule two   give informative names to the nodes and components on the sketch and use these same names when using the interface

Rule three   identify portions of the network where control will be applied

Rule four   if there are likely to be design variants, use overlays on the sketch to lay out alternatives and ensure that the sketch provides a summary of the intent of the overlay

Rule five   if there is room on the sketch include critical attributes of the components, if there is not ensure you separately record component attributes before you start on the interface

     A good sketch is worth hours of debugging - trust us on this!
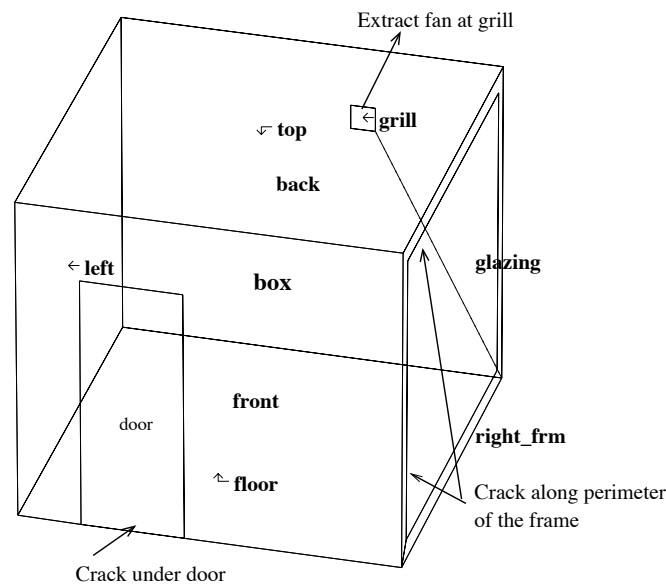
Figure 7.5: a simple network for a simple room

7.4 A simple network

To illustrate the process let's design a simple network for a room with a large west glazed facade with a slightly ill-fitting frame, an exterior door with a crack at the lower edge. Given the size of the glazing there might be significant solar gains and the need for a quick response to overheating conditions. If we want to know how often an extract fan on the back wall needs to run, and at what rate, the network should also include a component which induces flow and a control action if the room gets warm. This is shown in Figure 7.5.

Where could air flow

Air can flow under the door at the front facade. The undercut is 10mm x 800mm. This shape suggests a crack representation rather than an orifice. Air can also flow through the cracks at the frame on the right facade (2mm x 10m perimeter). Measuring the undercut at the door is straightforward, however, the length and width of the frame crack may not be apparent from a physical survey and there is some uncertainty.

Lets assume that the extract has a damper which limits leakage when the fan is off. Lets also assume that the grill in the back wall and the ducting does not particularly impact the volume of air flow via the fan. An abstract constant volume flow component is sufficient to test the *idea* of an exhaust fan. We will also want to test different magnitudes of extract and different turn-on set points. Later we can upgrade the representation to a polynomial pressure-volume relationship for a specific device.

Boundary nodes are needed - one just outside the crack in the door as well as just outside the grill in the back wall. The crack in the frame is around the perimeter so lets consider that the centre of the facade

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might represent the aggregate position of that crack. Flow through cracks typically is insensitive to buoyancy forces.

When we sketch out the network (Figure 7.6) lets also make a note of the names and attributes associated with each for reference during the creation process as well as to pass to the person checking the model. A model QA report will provide quite a bit of supporting information. The table below provides several of the relevant dimensions:

Component names and locations.

```
node name      type        height
room           internal    1.35m
south          boundary    0.0m
north          boundary    2.1m
east           boundary    1.35m


component name    type          data
crack-door        crack         10mm x 0.8m
crack-2mmx10      crack         2mm x 10.0m
extract           volume flow   ~1 air change


node - to - node      component
south to room         via crack-door
east  to room         via crack-2mmx10
room  to north        via extract


height differences:
crack-door is 1.35m below centre of room
crack-2mmx10 is at same height as room
extract is 0.75m above centre of room
```

Exercise 7.1

Our task is to record our decisions and attributes on the flow network sketch and then to use the interface to first define the nodes and then the components and then to link the network together.

ESP-r offers both graphical and non-graphical network definitions. Exercise 7.1 uses the graphical interface in the module **enet**.

There primary menu in the **enet** application can be toggled to focus on nodes, components or connections as in Figure 7.6.
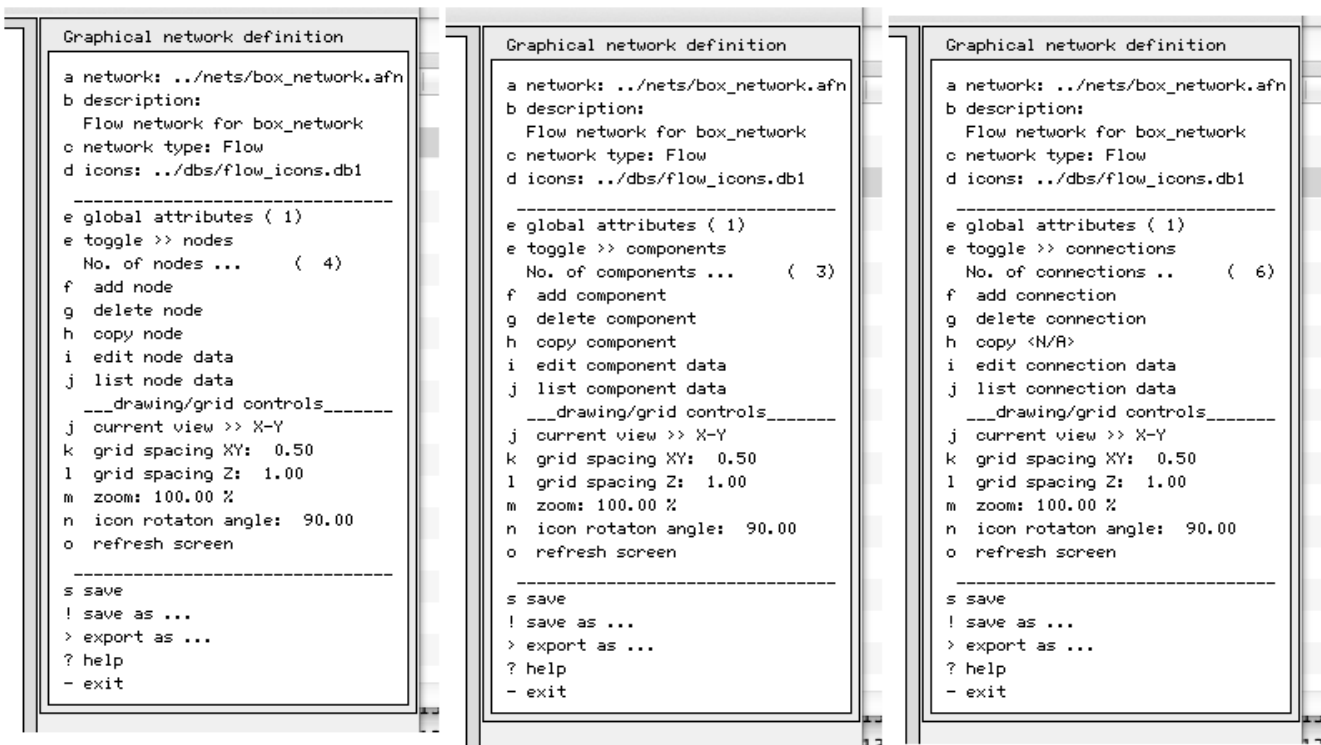
Figure 7.6: changing focus of main enet menu nodes, components, connections

At the end of the exercise the network and entities will look similar to Figure 7.7.
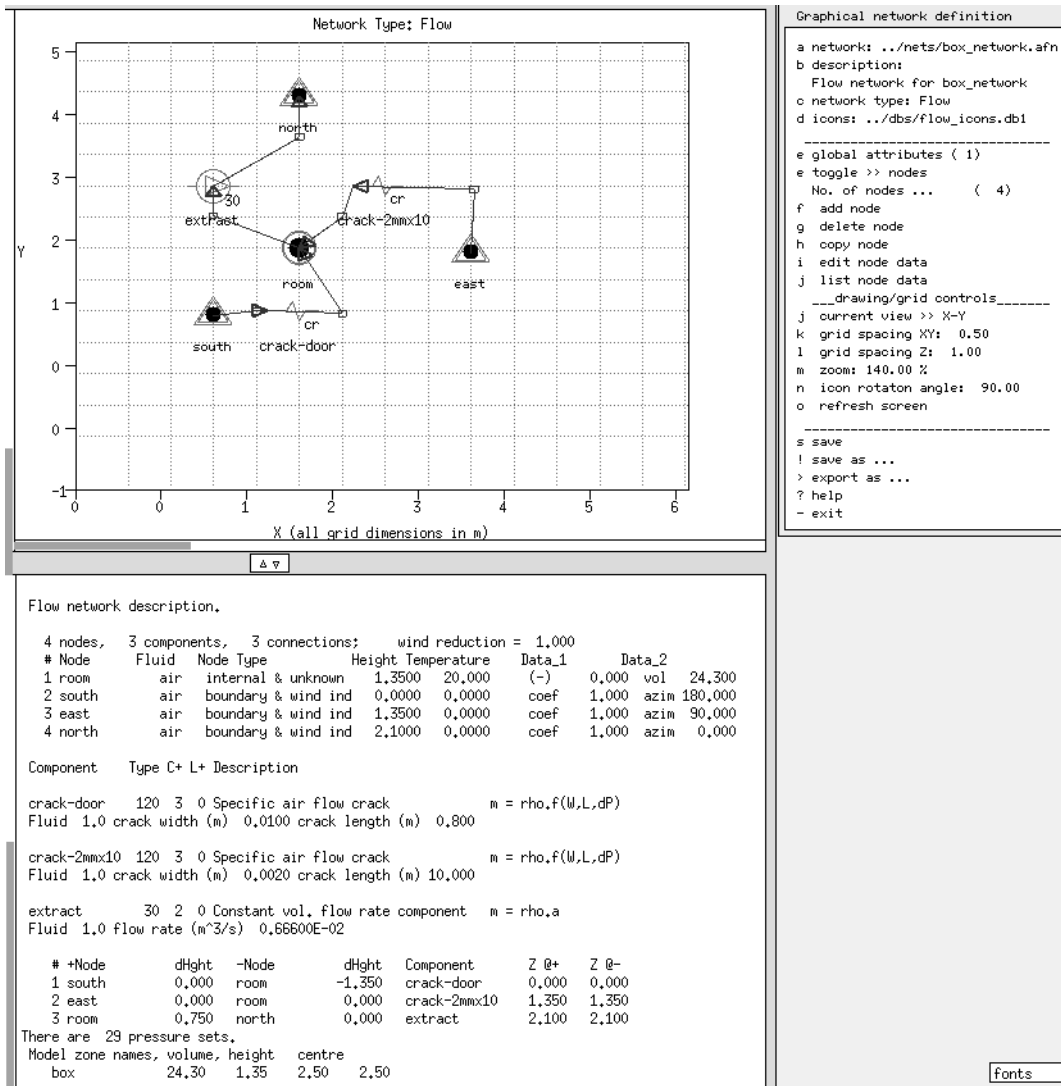
Figure 7.7: layout and entities of air flow in enet

```
   4     3     3    1.000     (nodes, components, connections, wind reduction)
Node          Fld. Type   Height       Temperature      Data_1          Data_2
room            1    0    1.3500          20.000          0.0000          24.300
south           1    3    0.0000           0.0000          1.0000          180.00
east            1    3    1.3500           0.0000          1.0000          90.000
north           1    3    2.1000           0.0000          1.0000          0.0000
Component    Type C+ L+ Description
crack-door    120  3  0 Specific air flow crack            m = rho.f(W,L,dP)
   1.00000000        9.99999978E-03  0.800000012
crack-2mm10m  120  3  0 Specific air flow crack            m = rho.f(W,L,dP)
   1.00000000        2.00000009E-03   10.0000000
extract        30  2  0 Constant vol. flow rate component  m = rho.a
   1.00000000        6.66659996E-02
+Node         dHght    -Node          dHght     via Component
south         0.000    room          -1.350     crack-door
east          0.000    room           0.000     crack-2mm10m
room          0.750    north          0.000     extract
```

Figure 7.8: the entities in the flow network.

Review Figure 7.8 with your planning documents and sketches. In a more complex network careful review is required to ensure that the network is both correct and complete.

Hint: as you create the connections, mark your sketch so that your progress is recorded. It is easy to duplicate a connection, or even worse, to miss out a connection.

This network includes an extract fan. Like other flow inducing components fans are nominally operational when included in the network. However, we only want the extract fan on under certain circumstances so we will need to apply control logic to the extract which is the subject of the next section.

7.5 Flow Control

As with ideal zone control, flow network control uses a *sensor > controller > actuator* structure to define flow control loops. A control loop senses a specific type of data at a specific location, the sensed value is evaluated by a control law and the control actuation is applied to the component associated with a specific flow network connection. A day can be sub-divided into several control periods with different laws or control law details. A number of control loops can be used in sequence or in parallel to implement complex control regimes.

At each simulation time step the flow solver takes the current conditions and predicts the flow. The flow predictions are passed to the zone solver which then generates a new set of conditions to be used by the flow solver at the next time step.

Control logic is tested at each time step. If we are approximating fast acting flow actuation devices then the simulation frequency should reflect this as far as is possible within the constraints of the project. Currently a one minute time step is the highest frequency that is supported by ESP-r for the zone and flow domains.

In terms of the room with the large east glazing, a 5 minute time step will enable the fan to be enabled soon after warm conditions are noticed and will prevent over-long running of the extract.

Flow sensors and actuators

In ESP-r a flow sensor is defined by its location and the values which it can sense. These include temperature, temperature difference, pressure, pressure difference, flow rates, humidity, etc. at nodes within the network. It is also possible to sense temperatures in zones or weather data.

Most flow components are able to be controlled. Control is expressed as a modification to an attribute of the component. For example, a control actuation value of 0.6 applied to a window with an area of 1.0m^2 would result in an opening area of 0.6m^2.

▶ Exercise 7.2

Exercise 7.2 sets up a flow control on the associated connection `room to north via extract.` At an early stage design and with a single speed fan and ON/OFF controller would be appropriate. We could start with ON above 23 degrees in the room.

7.6 Calibrating flow models

Having added a flow network to the model, let's see if the model will run and then if the predicted air flows make sense. What might we look for? We would expect low flow rates via the cracks as long as the room is comfortable with a jump in flow when the extract is enabled. On windy days the 'infiltration' rate might rise.

We might also wish to identify whether the control set point and the flow rate is consistent with maintaining comfort at different times of the year (the extract might be needed on a bright sunny winter day as well as in the spring and summer). Running assessment for one week in each season would give an early indicator.

For the initial assessment, select a summer simulation period and reset the simulation time step to 5 minutes. Figure 7.9 shows the room temperature, ambient temperature, direct solar radiation and the cooling equivalent of the air extract. Clearly on the 5th day the extract is not up to the combination of a warm day and solar radiation.
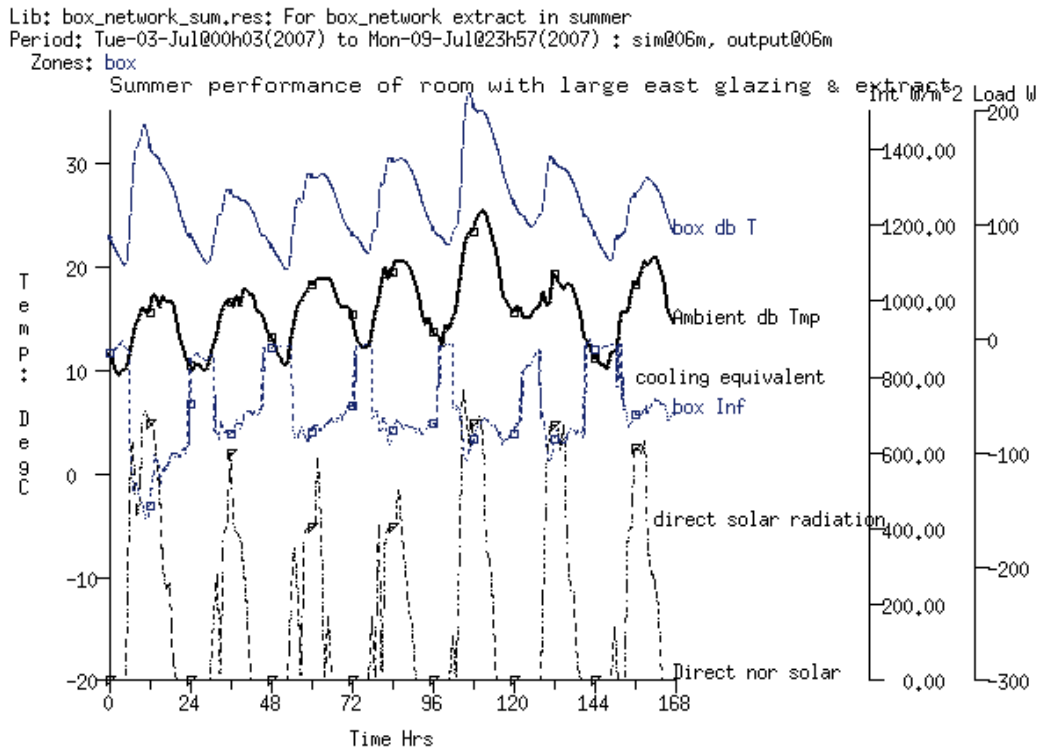
Figure 7.9: summer performance of room with extract

Another view of performance is to look at the volume of air entering the room via the openings. In Figure 7.10 the periods when the extract is operating coincide with the warm periods. The variations reflect wind effects.
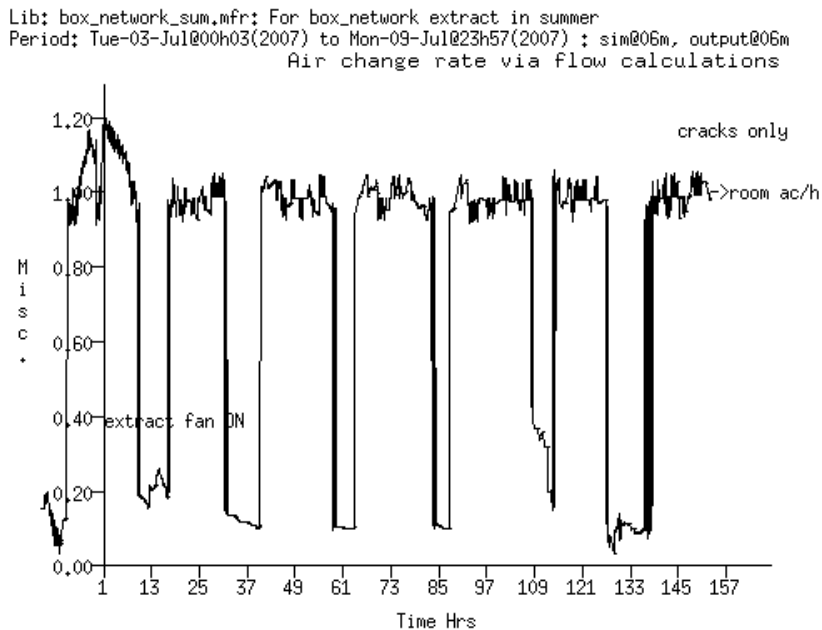
Figure 7.10: air entering the room (in air changes per hour)

Exercise 7.3

If you are interested in using the **res** module to generate multi-axis graphs then check out Exercise 7.3.

From that exercise it is clear that there environmental conditions are less than optimal. It is cool at times (after all there is no heating defined) and sometimes it is getting uncomfortably warm.

Clearly more extract fan volume or a lower setpoint is required to manage temperatures in the room. As an exercise on your own - try editing the volume flow rate of the extract component and then re-run the assessment.

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7.7 Flow control laws

The above example only looked at one kind of flow control. The range of control laws includes range based and proportional control as well as a multi-sensor control where the control law can include AND or OR logic from several sensed conditions.

An ON/OFF control has a single set point and attributes that determine if the control is direct-acting (ON above set point) or indirect (ON below set point) as well as the fraction of the nominal area to use when ON.

A multi-sensor flow control is an ON/OFF controller which includes the definition of more than one sensed location as well as and AND or OR logic to apply. In some cases a multi-sensor flow control can replace a series of individual controls (as described in Figure 7.4).

Range-based control in flow is similar to the range based control offered for scheduled flow. This allows for similar controls to be enacted after upgrading to a flow network. It uses the nominal area or flow rate of the component - but switches to an alternative rate/area as a function of the sensed condition - low rate if below low set point; mid rate if above a mid-range set point; high rate if above maximum set point as is shown in Figure 7.11.
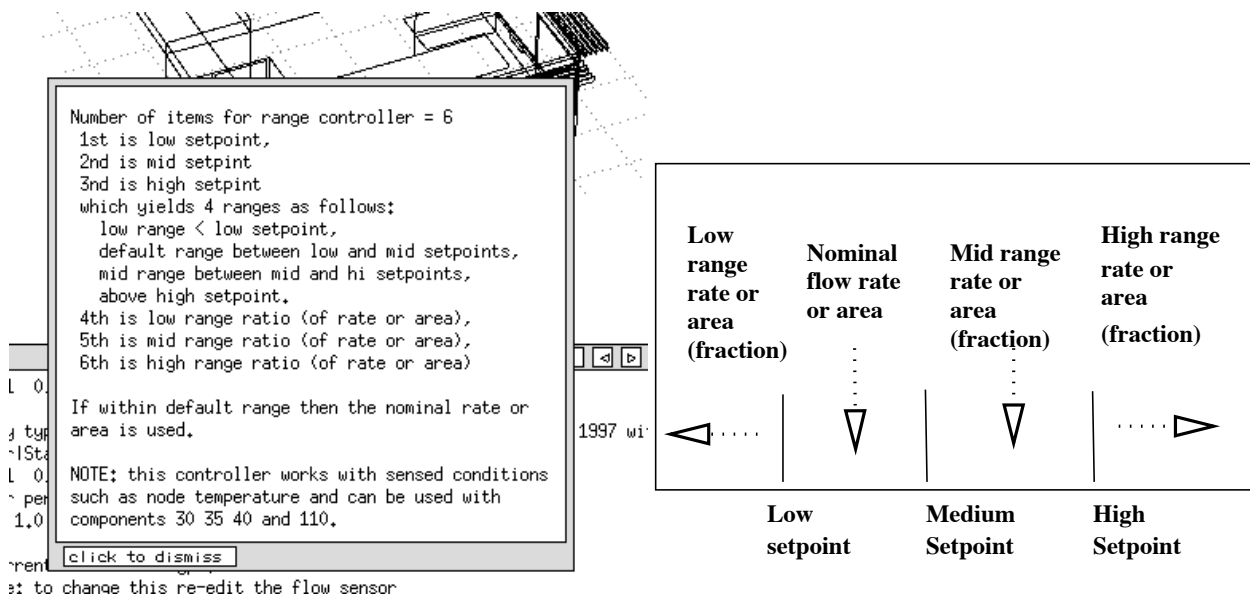
Figure 7.11: overview of range based control

Until control is applied the initial window components remain in a full-open state. In reality, occupants would probably open a window only as much as was necessary. Unlike automatic controls, occupants would tend to implement a sticky control (i.e. they delay adjustments). What types of control could approximate this?

- ON/OFF with ON expressed as a fraction of nominal opening area - this would be equivalent to closing the window below a set point value and open to X percent of nominal area above this value.

- Proportional control where the percentage opening area varies between two values. Some occupants would not exercise such fine (and continuous) control.

- Range based control could be used for a control that reduced the window opening area if the temperature in the room is close to the heating or cooling set points. In the dead-band between heating and cooling it would allow natural ventilation cooling by first using the nominal area of the window and then additional opening area if required. It would be necessary to re-define the nominal area of the window to represent slightly open rather than fully open.

- Multi-sensor control could be allow a window to open if the ambient temperature is within a certain range AND the inside temperature is within a temperature range as in Figure 7.12.

  sense dry bulb temperature actuate flow based on a multi-sensor law: normally closed with 3 sensors: For sensor 1 @ ambient T below setpoint 25.00 AND sensor 2 @ ambient T setpoint above 10.00 AND sensor 3 @ node manager_a setpoint above 21.00 starting @ 9h00.
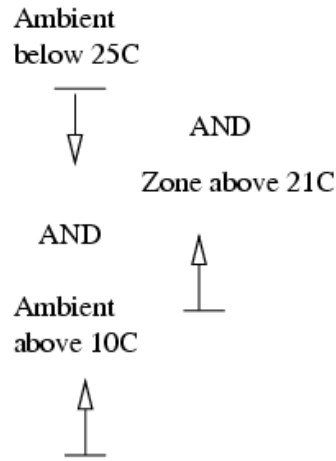
Figure 7.12: control via multiple states

If occupants are manipulating the windows then the control periods should match the occupied period with an alternative control law for the unoccupied period. Some building may operate a policy of limiting window opening after hours to limit the potential for rain damage. If automatic dampers are manipulating the openings then it would be necessary to find a combination of control law and simulation time step that reflected the regime.

Hint: once you specify a flow control loop it can be copied and then associated with other flow connections.

One of the exemplar models is a Surgery which includes a flow network with window which open in an attempt to provide comfort. This is shown in the following Figure 7.13.
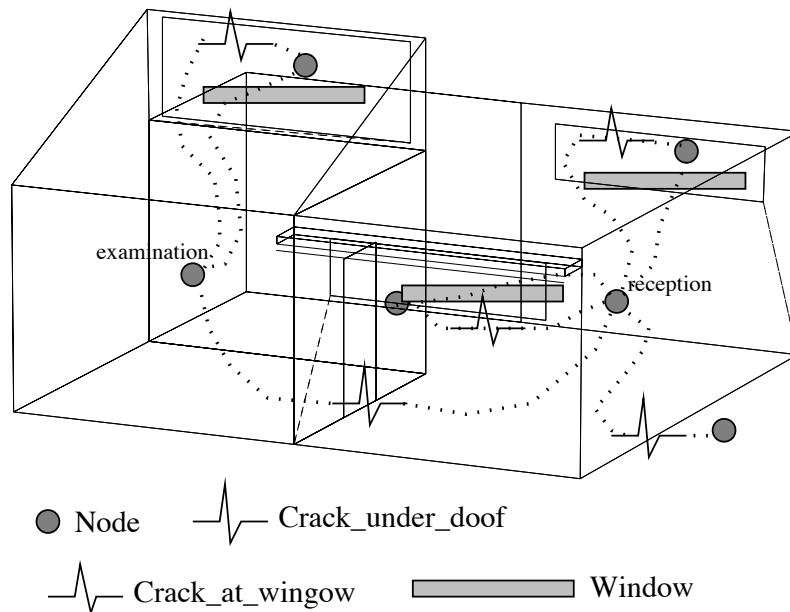
Figure 7.13: simple network for doctor's office

![Exercise 7.4 icon] **Exercise 7.4**

To explore flow control in windows, let's use an ON/OFF control for each of the windows allowing them to open 25% of their defined area if the temperature rises over 22°C. We will define the control once and then copy the control loop and associate it with the other windows.

And let's turn on the extract fan if the temperature in the Examination room goes over 24°C. At night we will keep the windows closed by setting the set point for the windows to 100°C. The steps to do this are included in Exercise 7.4.

7.8 Window representations

The Doctor's surgery used a simple representation of window openings. Many window types require that we adapt the flow paths and components. The following discussion uses a model with three adjacent zones (Figure 7.14) which differ only in the window details. The zone named manager has a simple window opening and component. The second zone has a sash window and uses an upper and lower connection to represent this. The third zone has a tall thin window where bi-directional flow is possible and a bi-directional component is used.

In this case we will create an initial model in which the windows are in their open position. Because we may later add control the network includes two connections per opening, one for the window and one for a crack that can act as a bypass in case the window is fully closed. These window and crack combinations are seen in many of the example models. As long as the window is open (even partially) the crack has almost no influence in the solution. If the window closes then the crack ensures that the closed state allows a constrained flow so the solver does not crash. And since windows which have no frame-related infiltration are rare the crack component is a better representation of the flow path than defining a very small orifice.

Basic network with windows
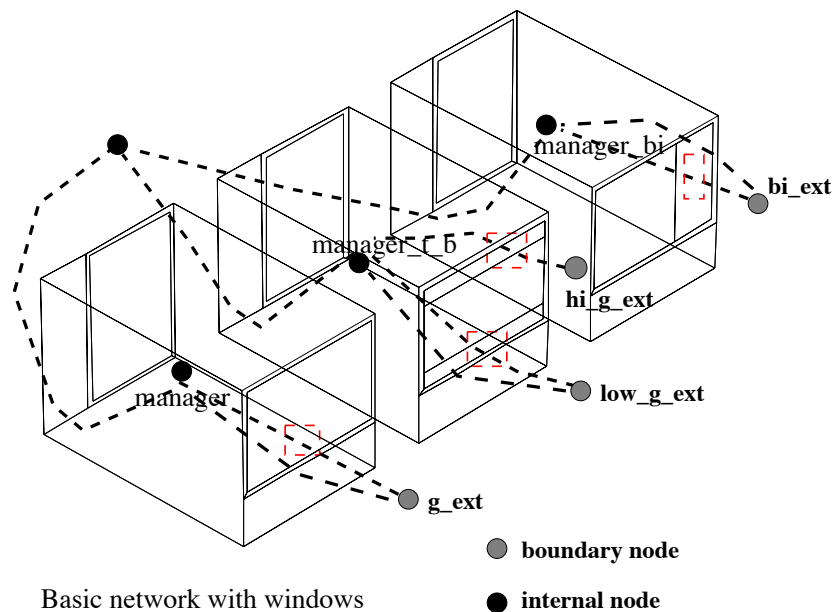
Figure 7.14: network in three test rooms

- Each zone has a window-crack connection to the outside. The crack component (window_crack) is 2.0m x 5mm and is used many times
- Each zone has a door-crack to an adjacent space (which is not geometrically defined). This crack component (door_crack) is 0.8m x 10mm and is used many times
- The adjacent space node should be defined as using the current temperature of the flow node in the manager.
- Manager has one window opening (window1.67) which is 1.67m2 is defined once and used once
- Manager_t_b (with upper and lower windows) needs 2 windows (win_up_.884 and win_low_.884) which are separately defined.
- Manager_bi (with a bi-directional flow opening). The component (win_bi) is Xm wide, Ym tall, has a discharge coefficient of 0.6 and the distance from its base to the adjacent node is X. Because the distance from the base of the door to the adjacent zone node may differ it is necessary to define bi-directional components for use in different contexts.
- Boundary nodes are defined at the specific height of the opening or crack they are associated with. This allows a zero difference in height between the boundary node and the component.

```
    8     6     7    1.000     (nodes, components, connections, wind reduction)
Node            Fld. Type   Height     Temperature     Data_1          Data_2
manager           1    0   1.5000       20.000          0.            40.501
manager_t_b       1    0   1.5000       20.000          0.            40.501
manager_bi        1    0   1.5000       20.000          0.            40.501
gl_ext            1    3   1.9500        0.            5.0000         180.00
low_glz_ext       1    3   1.1500        0.            5.0000         180.00
hi_glz_ext        1    3   2.7500        0.            5.0000         180.00
bi_glz            1    3   1.9500        0.            5.0000         180.00
adjacent          1    0   0.50000E-01    manager                0.        40.501
Comp     Type C+ L+ Description
door_crack       120  3  0 Specific air flow crack           m = rho.f(W,L,dP)
    1.00000    5.00000E-03    0.800000
win_1.68         110  2  0 Specific air flow opening         m = rho.f(A,dP)
    1.00000    1.68000
win_low.84       110  2  0 Specific air flow opening         m = rho.f(A,dP)
    1.00000    0.840000
hi_win.84        110  2  0 Specific air flow opening         m = rho.f(A,dP)
    1.00000    0.840000
bi_win           130  5  0 Specific air flow door            m = rho.f(W,H,dP)
    1.00000    0.880000    1.88000    0.600000    0.600000
win_crack        120  3  0 Specific air flow crack           m = rho.f(W,L,dP)
    1.00000    5.00000E-03    2.00000
+Node           dHght    -Node          dHght    Comp      Snod1  Snod2
gl_ext          0.000    manager         0.225    win_1.68
low_glz_ext     0.000    manager_t_b    -0.175    win_low.84
hi_glz_ext      0.000    manager_t_b     0.625    hi_win.84
bi_glz          0.000    manager_bi      0.225    bi_win
adjacent        0.000    manager        -0.725    door_crack
adjacent        0.000    manager_t_b    -0.725    door_crack
adjacent        0.000    manager_bi     -0.725    door_crack
```

Figure 7.15: ESP-r network file for window opening model

Nodes can be automatically generated for each zone; data is inferred from the zone (volume, reference height, etc). Internal nodes are usually at an unknown pressure. Define the boundary nodes to reflect the position of the openings in the facade.

Ensure your component names match the sketch! A component can be used several places. If control is to be applied - unique names of components and some duplication of components can be helpful (e.g. win_low.84 and hi_win.84).

Connections should tell a story! Parallel connections e.g. an opening and a crack - are useful if control is to be applied.

   Hint: mark you sketch as connections are made.

Figure 7.15 is a copy of the completed file which includes the attributes of the nodes and the components and connections. When you are working on the network refer back to this listing.

7.8.1 Component selection

Which window definition works best?

- an air flow opening does one-way flow only, so in cases of single-sided ventilation, flow can be restricted;

- a bi-directional component is intended for doors Ð care is needed in using it in locations such as windows;

- bi-directional flow can be approximated with a pair of air flow openings. Stack effects are accounted for if heights are correctly defined;

None of the available components takes into account high-frequency pressure changes which are one driving force in single-sided ventilation. When an assessment is carried out with this model, the simple window opening in the zone manager results in almost no flow. This is an artefact of this component type - flow is only supported in one direction at each time step. The limiting component is the opening under the door. The flow rates predicted for the sash window and the bi-directional flow component are more in line with expectations.

This does not imply that simple flow components should not be used. Only that they are a poor representation in the case of single sided ventilation.

7.9 Schedules vs networks

Now we turn to a practical application of a network within a portion of an office building (which includes a reception, conference room, general open-plan office and cellular office) in Figure 7.16. Except for the cellular office, each of the spaces are substantially open to each other (the conference room is only occasionally closed). The facade is an older design and is assumed to be somewhat leaky.

In terms of learning about air flow networks, the design is a good candidate for exploring options for conditioning of the space, including forced and natural ventilation.

The client observation that there are many hours when outside conditions are suitable for mechanical ventilation rather than air conditioning. Are these conditions also suitable for mechanical dampers embedded within the facade to allow fan-free ventilation?

The other feature of this design is the treatment of mixed open plan and cellular spaces. Many simulation teams and some simulation tools *pretend* that there is no air movement between perimeter and core spaces or across open plan spaces. This isolation of the perimeter discounts air transport which allows under heated spaces to borrow heat and spaces that are slightly under-capacity for cooling to borrow cooling from adjacent spaces.

In evaluating whether a flow network rather than a flow schedule is appropriate:

- there can be considerable differences between imposed infiltration and the predicted infiltration rates.
- in an open plan office there are large inter-zone flows, resulting in heating/cooling being 'borrowed' from adjacent spaces.

There are three stages to investigate

- the model with scheduled flows and the assumption that there is no intra-zone air movement
- a model variant with zone-to-zone linkages and infiltration paths (Figure 7.17)
- a model variant with zone-to-zone linkages, infiltration paths and controlled dampers on each facade orientation (Figure 7.18).

These three variants are included as example models (if you want. to explore flow issues). Review the model documentation, especially the sketches of the flow networks. Compare this with the contents of the flow network file and the interface.
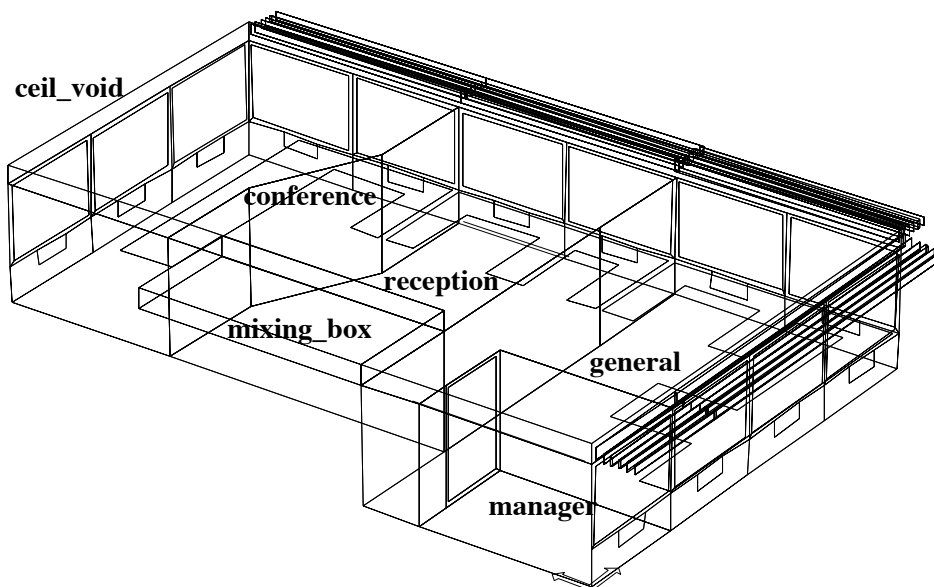
Figure 7.16: portion of an office building
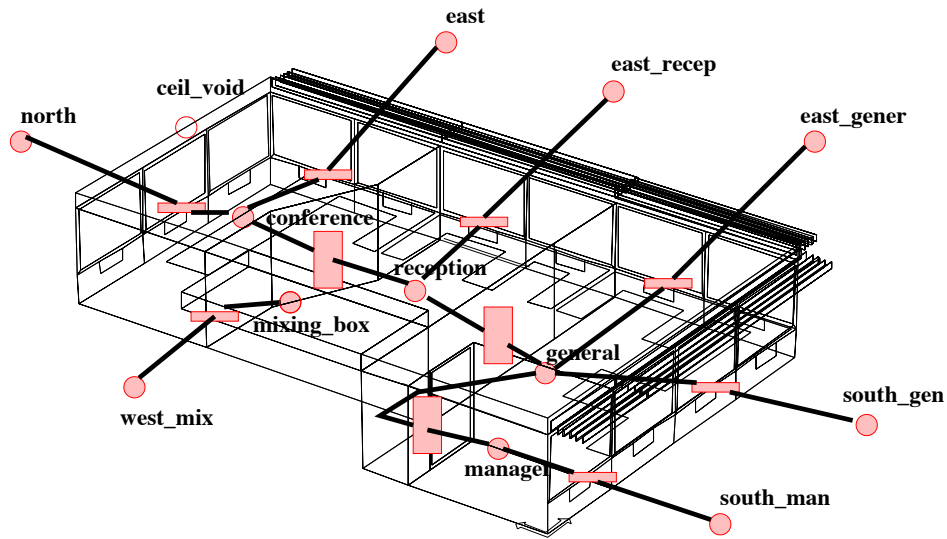
Project: Office model network for dynamic infiltration

○ Un−used node   ▭ Component − crack   ▧ Component − orifice

● Node   ▮ Component − door (bidirectional)

Figure 7.17: infiltration model within office building
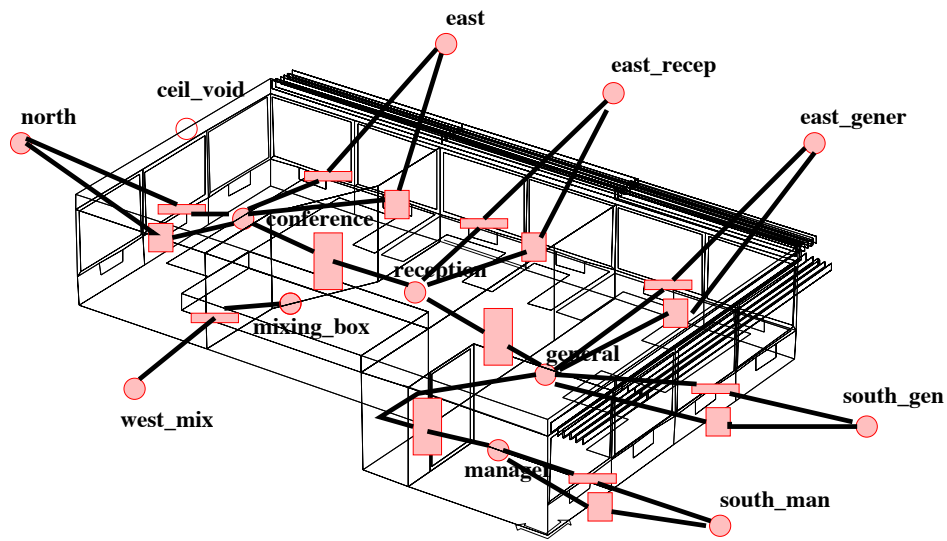
Project: Office model network for dynamic infiltration and facade vents

○ Un−used node   ▭ Component − crack   ▧ Component − orifice

● Node   ▮ Component − door (bidirectional)

Figure 7.18: vent model within office building

Scheduled flows in an open plan office

The version of the model with scheduled flows will yield predictions where the energy implication of infiltration is dependant on the temperature difference and independent of wind speed, wind direction and facade position. Predictions will follow the pattern seen in Figure 7.18.

Infiltration and inter-zone flow

The model variant with infiltration and flow between zones transforms the predictions in several ways (as seen in Figure 7.19): wind speed and direction are now taken into account and there is a moderation of

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demands as heating and cooling is distributed between zones.

Controlled vents and inter-zone flow

Using the model variant with controlled vents and flow between zones and running an assessment (as in Figure 7.19) indicates that the vents are open slightly longer than necessary and this has performance implications. The data also indicate that the conference room is over ventilated, perhaps because it has two facade orientations and the cross ventilation is more than is required.

Office model with "scheduled" infiltration – energy implications of imposed infiltration

Lib: office_ventapril.res: Results for office_vent (mid-april)
Period: Tue 8 Apr @00h45 to: Tue 15 Apr @23h45 Year:1997 ; sim@ 30m, output@ 30m
Zones: manager general conference reception ceil_void mixing_box
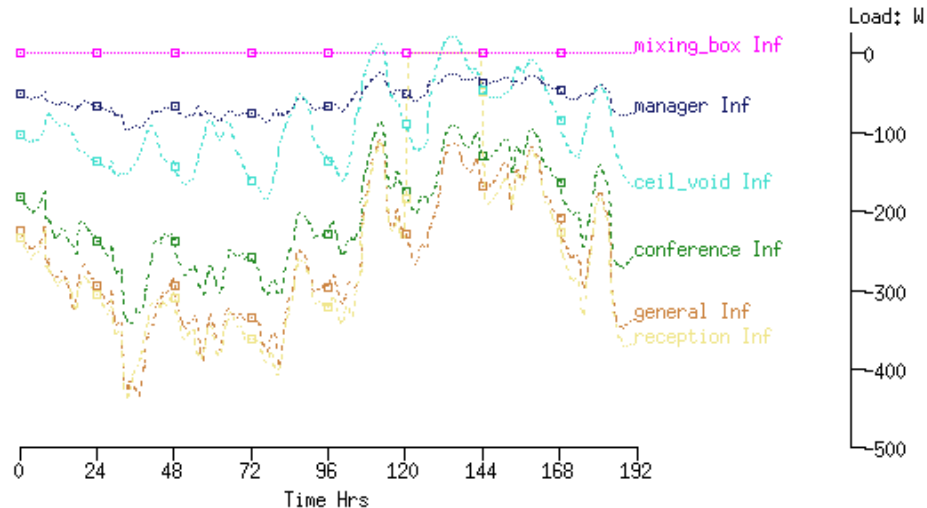
Heating and cooling demands and running hours (per zone and total)

Zone total sensible and latent plant used (kWhrs)

Zone		Sensible heating		Sensible cooling		Humidification		Dehumidification	
id	name	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd
1	manager	8.79	60.0	-14.93	51.0	0.00	0.0	0.00	0.0
2	general	22.00	44.5	-83.67	62.5	0.00	0.0	0.00	0.0
3	conference	26.87	54.5	-53.97	55.5	0.00	0.0	0.00	0.0
4	reception	16.95	44.5	-24.00	49.5	0.00	0.0	0.00	0.0
5	ceil_void	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
6	mixing_box	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
	All	74.61		-176.56		0.00		0.00	

Heating and cooling capacity for each zone and diversified totals

Lib: office_ventapril.res: Results for office_vent (mid-april)
Period: Tue 8 Apr @00h45 to: Tue 15 Apr @23h45 Year:1997 ; sim@ 30m, output@ 30m
Zone sensible load (kW)

Description	Maximum		Minimum		Mean	Standard
	value	occurrence	value	occurrence	value	deviation
manager	0.42	8 Apr@08h45	-0.65	12 Apr@14h15	-0.03	0.20
general	1.22	9 Apr@08h15	-2.92	15 Apr@14h15	-0.32	0.88
conference	1.38	9 Apr@08h15	-2.60	15 Apr@14h45	-0.14	0.68
reception	1.25	9 Apr@08h15	-1.34	15 Apr@14h15	-0.04	0.38
ceil_void	0.00	8 Apr@00h15	0.00	8 Apr@00h15	0.00	0.00
mixing_box	0.00	8 Apr@00h15	0.00	8 Apr@00h15	0.00	0.00
All	4.25	9 Apr@08h15	-7.34	15 Apr@14h45		

Figure 7.19: scheduled flow performance

Take your time when exploring flow results. Discovering approaches which yield clear indications of flow performance is an investment well worth making. The quantity of information can be large and there are several different *views* of the flow prediction data as well as reports on the energy implications of flow.

Office model with dynamic infiltration and interzone flows – energy implications of infiltration

Lib: office_vent_netinf_apr: Results for office_vent_netinf
Period: Tue 8 Apr @00h52 to: Tue 15 Apr @23h52 Year:1997 : sim@ 15m, output@ 15m
 Zones: manager general conference reception ceil_void mixing_box
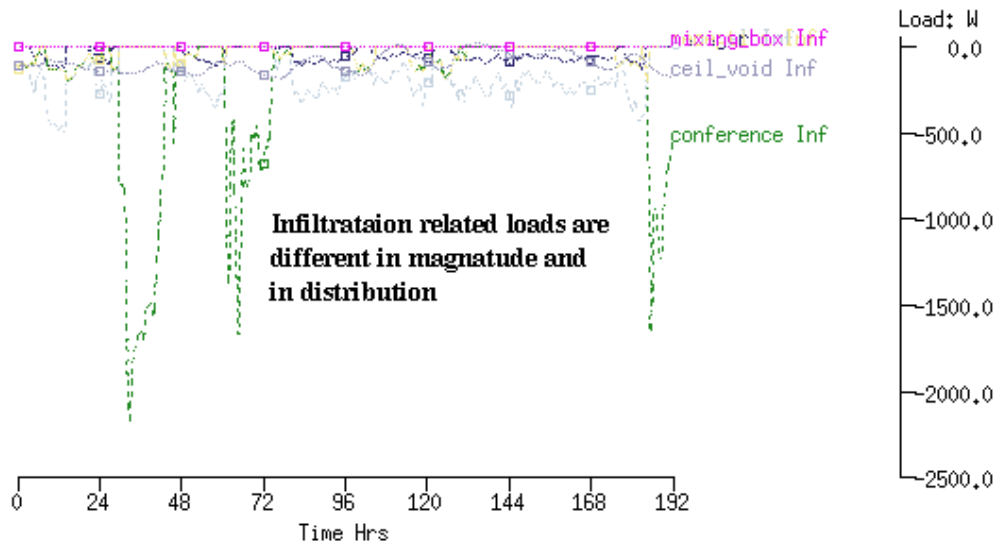
Heating use reduced, cooling slightly increased.

Period: Tue 8 Apr @00h52 to: Tue 15 Apr @23h52 Year:1997 : sim@ 15m, output@ 15m

Zone total sensible and latent plant used (kWhrs)

| Zone | | Sensible heating | | Sensible cooling | | Humidification | | Dehumidification | |
id name		Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd
1 manager		6.00	41.8	-15.27	53.0	0.00	0.0	0.00	0.0
2 general		15.09	32.2	-84.16	57.2	0.00	0.0	0.00	0.0
3 conference		24.09	41.8	-59.24	50.8	0.00	0.0	0.00	0.0
4 reception		6.43	26.0	-34.14	51.5	0.00	0.0	0.00	0.0
5 ceil_void		0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
6 mixing_box		0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
All		51.60		-192.81		0.00		0.00	

Heating capacity increased while cooling capacity the same

Lib: office_vent_netinf_apr: Results for office_vent_netinf
Period: Tue 8 Apr @00h52 to: Tue 15 Apr @23h52 Year:1997 : sim@ 15m, output@ 15m
Zone sensible load (kW)

| Description | Maximum | | Minimum | | Mean | Standard |
	value	occurrence	value	occurrence	value	deviation
manager	0.52	8 Apr@08h37	-0.66	12 Apr@14h22	-0.05	0.19
general	1.65	8 Apr@08h07	-2.81	14 Apr@14h22	-0.36	0.86
conference	2.89	9 Apr@08h22	-2.80	15 Apr@14h52	-0.18	0.77
reception	1.52	8 Apr@08h07	-1.54	15 Apr@14h52	-0.14	0.39
ceil_void	0.00	8 Apr@00h07	0.00	8 Apr@00h07	0.00	0.00
mixing_box	0.00	8 Apr@00h07	0.00	8 Apr@00h07	0.00	0.00
All	6.24	9 Apr@08h07	-7.51	15 Apr@14h37		

Figure 7.20: predicted infiltration performance

There is one substantial omission in the reporting of flow - there is no overview of what is happening throughout the network at a single point in time. Such a feature would speed up the discovery of patterns within a network. Currently users must manually collect this information.

Office model with controlled facade vents – classic on–off switching characteristics are (primarily) an artifact of the simulation timestep.

Lib: office_vent_netventc_a: Results for office_vent_netventc (ctld)
Period: Tue 8 Apr @00h52 to: Tue 15 Apr @23h52 Year:1997 ; sim@ 15m, output@ 15m
Zones: manager general conference reception ceil_void mixing_box
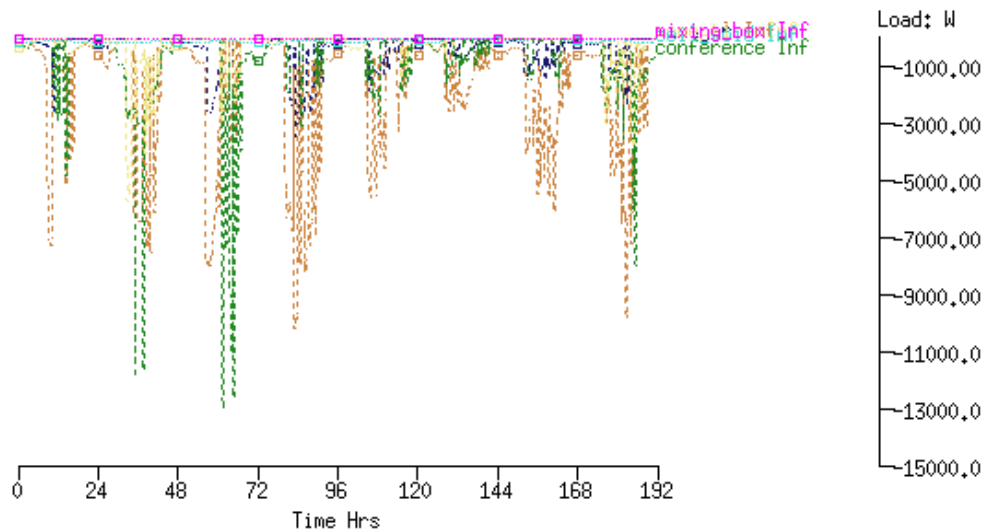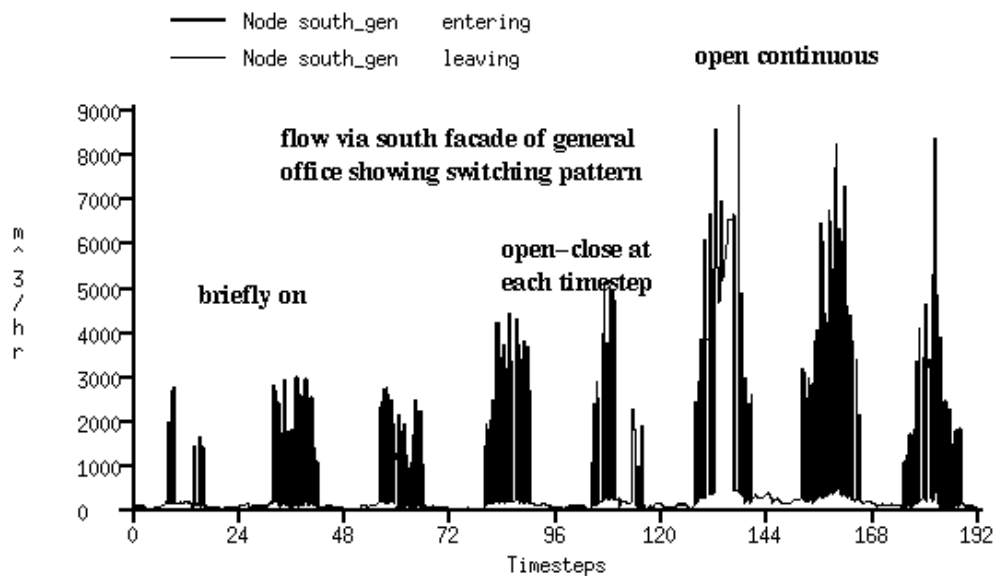
Figure 7.21: predicted facade vent performance

Although the flow of air in real building continually adapts to conditions and *self-balances*, simulation re-evaluates conditions at fixed intervals. Thus there is the possibility that differences in temperatures can build up during the simulation time step which would not be observed in real buildings. This results in exaggerated air flows, or oscillating flows, especially for large openings between thermal zones. Thus the choice of simulation time step is a topic worthy of discussion.

Flows that oscillate at each time step are sometimes an artefact of the simulation process. If the magnitude of the oscillation is likely to decrease, but there is not time (or disk space) to run assessments at a shorter time step, some users choose to integrate the results when running the simulation. This removes the oscillation but preserves the general trend of flow.

7.10 Hybrid ventilation

In 2000 the Chartered Institute of Building Services Engineers published *Mixed mode ventilation CIBSE AM13* (ISBN 1 903287 01 4). This publication defined several types of mixed mode ventilation e.g. contingency mixed mode, complementary mixed mode and zoned mixed mode systems. At the time, there were few options for numerically assessing how mixed mode ventilation worked. The publication was also geared towards regions of the world where there was a tradition of natural ventilation as well as an economic incentive to create buildings which were *future proof*.

One of the critical limitations to the simulation of designs which transition between natural ventilation, mechanical ventilation and full HVAC is the definition of air flow controls.

- Approximating the response of occupants to discomfort or changes in conditions is potentially complex.

- The response frequency of dampers and window actuation devices suggests that control logic needs to be tested at a relatively high frequency.

- Some people open windows while the environmental control systems are active in other buildings there is better coordination. Ideally, systems should be controlled differently if windows are open.

- Some ventilation regimes may need to sense indoor air quality.

In theory, almost any control logic that can be defined via a network of parallel or sequential decision points (see Figure 7.4) can be implemented. The need for additional bookkeeping nodes to define such logic paths limits how well such controls can be scaled. Extending flow networks to accommodate such logic was more than a linear function of the number of openings and fans to be controlled.

Simulating the transition between the *modes* defined in CIBSE AM13 places considerable demands on the facilities of simulation tools. Until 2008 it was difficult to switch off fans if windows opened, especially if the logic opening the windows was based on both inside and outside conditions.

Let's say there was a variant of the two cellular offices side-by-side that included two additional zones representing HVAC mixing boxes (one for the left zone and one for the right zone) as in Figure 7.22. Both mixing boxes are controlled to 16°C and there is a flow network that can deliver 5 air changes to the office if required. This approximates a CV HVAC system in cooling mode.

The left zone includes an upper and lower window opening which is controlled based on the logic shown in Figure 7.21. The fan associated with the mixing box uses an inverse description of the window control logic so that the fan turns on if conditions are not suitable for window opening. The right zone uses the mixing box during office hours. The return for the mixing boxes is via the corridor.

If the left zone is able to open its windows there is a potential savings in fan power as well as cooling. Heat and humidity picked up by the return air stream is represented in this model. Unfortunantly, ESp-r does not report the electrical energy used by the fan flow component so some post-processing is required.

The listing of the model control description below (Listing 7.23) shows the zone control used with the mixing box zones as well as the hybrid vent flow control.

Looking at the performance of the left zone for one day in Figure 7.24 the time between 8h00 and 15h00 is ok for window opening and there is 300-400W of cooling equivalent associated with the air flow. The delta T between inside and outside is less than 5°C so there is not much cooling from air movement. At 15h00 the outside temperature goes over 25°C and the windows close and the mixing box is used for a few hours until the outside temperature drops and the windows open again until the un-occupied period starts and both the fans and windows are reset to closed.

Looking at the performance of the right zone in Figure 7.25, the CV representation controls the zone in the range of 24-25°C. The dotted blue line is the amount of cooling in the mixing box. the dotted brown line is the cooling delivered to the zone.

The difference in the cooling demand for the two mixing boxes is shown in Figure 7.26. The reduction in cooling for the left zone clearly indicates that a hybrid ventilation scheme has the potential to save running costs under some conditions.
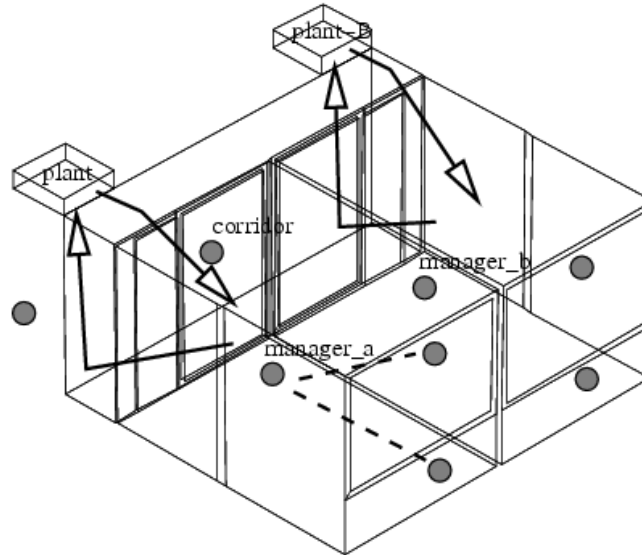
Manager_a using hybrid vent – switches to HVAC
Manager_b using HVAC during office hours
Both return via corridor to mixing boxes.

Figure 7.22: offices for hybrid vent and conventional HVAC

Listing 7.23: control descriptions

```
Zones control strictly controls plant and plant-B temperature to 16degC

The sensor for function  1 senses the temperature of the current zone.
The actuator for function  1 is air point of the current zone
There have been  1 day types defined.
 Day type  1 is valid Mon-01-Jan to Mon-31-Dec, 2001 with  3 periods.
 Per|Start|Sensing |Actuating | Control law     | Data
   1  0.00 db temp   > flux       free floating
   2  6.00 db temp   > flux       basic control
basic control: max heating capacity 99999.0W min heating capacity 0.0W max cooling
capacity 99999.0W min cooling cap 0.0W. Heat set-point 16.00C cool set-point 16.10C.
   3 18.00 db temp   > flux       free floating

 Zone to control loop linkages:
 zone ( 1) manager_a     << control  0
 zone ( 2) manager_b     << control  0
 zone ( 3) coridor       << control  0
 zone ( 4) plant         << control  1
 zone ( 5) plant-B       << control  1

Flow control Windows open and fan shuts down for manager_a when ambient temp is between
10 and 21 degC and room temp is more than 21degC .

 The sensor for function  1 senses node (1) manager_a
 The actuator for function  1 is flow connection:   1 man_alow - manager_a via low_win
 There have been  1 day types defined.
 Day type  1 is valid Mon-01-Jan to Mon-31-Dec, 2001 with  3 periods.
 Per|Start|Sensing |Actuating | Control law     | Data
   1  0.00 dry bulb > flow        on/off set-point 100.00 direct action ON fraction 0.000.
   2  8.00 dry bulb > flow        multi sensor on/off
multi-sensor: normally closed with 3 sensors: For sensor 1 ambient T set-point 25.00
inverse action AND sensor 2 ambient T set-point 10.00 direct action AND sensor 3 sense
node manager_a set-point 21.00 direct action.
   3 17.00 dry bulb > flow        on/off set-point 100.00 direct action ON fraction 0.000.

 The sensor for function  2 senses node (1) manager_a
 The actuator for function  2 is flow connection:   2 man_ahi - manager_a via high_win
 There have been  1 day types defined.
 Day type  1 is valid Mon-01-Jan to Mon-31-Dec, 2001 with  3 periods.
 Per|Start|Sensing |Actuating | Control law     | Data
   1  0.00 dry bulb > flow        on/off set-point 100.00 direct action ON fraction 0.000.
   2  8.00 dry bulb > flow        multi sensor on/off
```

```
multi-sensor: normally closed with 3 sensors: For sensor 1 ambient T set-point 25.00
inverse action AND sensor 2 ambient T set-point 10.00 direct action AND sensor 3 sense
node manager_a set-point 21.00 direct action.
    3 17.00 dry bulb > flow        on/off set-point 100.00 direct action ON fraction 0.000.

 The sensor for function  3 senses node (1) manager_a
 The actuator for function  3 is flow connection:   9 plant - manager_a via fan
 There have been  1 day types defined.
 Day type  1 is valid Mon-01-Jan to Mon-31-Dec, 2001 with  3 periods.
 Per|Start|Sensing  |Actuating  | Control law      | Data
    1  0.00 dry bulb > flow        on/off set-point 100.00 direct action ON fraction 0.000.
    2  8.00 dry bulb > flow        multi sensor on/off
multi-sensor: normally open with 3 sensors: For sensor 1 ambient T set-point 25.00
inverse action AND sensor 2 ambient T set-point 10.00 direct action AND sensor 3 sense
node manager_a set-point 21.00 direct action.
    3 17.00 dry bulb > flow        on/off set-point 100.00 direct action ON fraction 0.000.
 . . .
```


Figure 7.24: hybrid vent performance

Lib: annual.res: single day run
Period: Mon-06-Aug@00h05(2001) to Mon-06-Aug@20h54(2001) : sim@10m, output@10m
Zones: manager_b plant-B
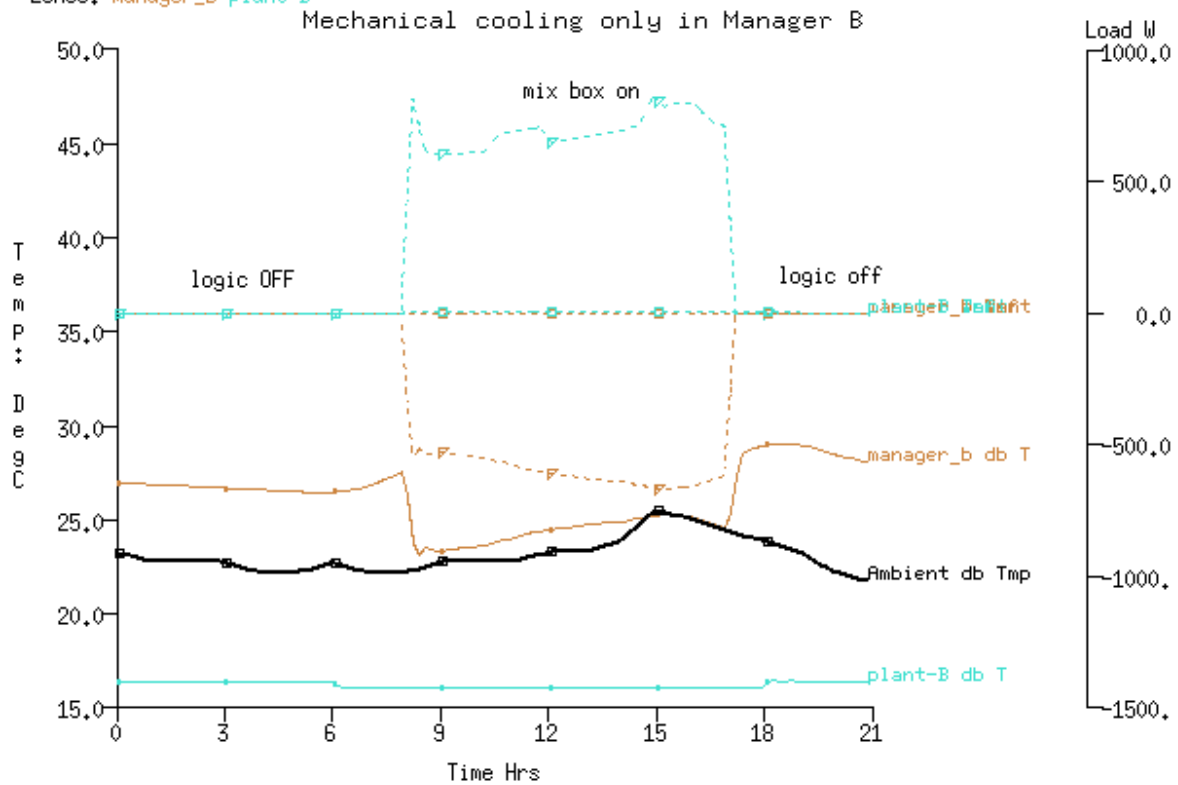
Figure 7.25: CV performance

Zone total sensible and latent plant used (kWhrs)

Zone id	name	Sensible heating		Sensible cooling		Humidification		Dehumidification	
		Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd
4	plant	0.00	0.0	-1.23	12.2	0.00	0.0	0.00	0.0
5	plant-B	0.00	0.0	-6.28	12.2	0.00	0.0	0.00	0.0
	All	0.00	0.0	-7.51	24.3	0.00	0.0	0.00	0.0

Figure 7.26: CV performance

7.11 Limitations of Network Airflow Models

Although network flow models are useful, they are limited for some applications:

- Large volumes represented by a single node, implying well-mixed conditions.
- Temperature distributions within air volumes cannot be determined (e.g. stratification).
- Momentum effects neglected.
- Insufficient resolution for local surface convection determination.

8 Detailed flow via CFD

ESP-r also supports higher levels of air flow resolution by incorporating a CFD domain solver. Although a mature field of research, its implementation in building models poses a number of classic problems. First, flow velocities in buildings are low (in comparison to traditional applications of CFD) and likely to be within the transition range between flow that is considered turbulent and that which is considered laminar.

The second issue is that boundary conditions such as surface temperatures and air temperatures and driving forces change over time. In buildings the movement of air influences surface temperatures which, in turn, change the driving forces for air flow. Many numerical approaches (including some stand-alone CFD tools) do not represent these evolving relationships.

Conversely, the building solver typically makes rough assumptions about the flow field within the zone which impacts heat transfer at surfaces. Even in models which include a mass flow network we can only make crude guesses at the velocity that is implied by a given mass transfer. Clearly, both whole building solvers and CFD solvers would have much to gain by enabling the exchange of information as the simulation progresses.

What has been implemented in ESP-r are CFD solvers as part of the multi-domain simulator **bps** supporting *coupled* solution with the zone solver as well as the mass flow solver (if there is a flow network in the model). The options for coupled solution include:

- one way adaptive coupling (wall functions are reselected based on a trial run at each timestep) or non-adaptive where specified wall functions are always used,

- two way adaptive coupling (as above but with heat transfer coefficients passed back to the zone solver)

- allow or disallow iteration between the CFD and mass flow solvers

These options address several limitations of conventional numerical approaches so that:

- CFD boundary conditions can be updated at each time-step,

- the domain is transient rather than static (unless you instruct it differently),

- initial directives about *wall functions* may not be appropriate when conditions change and the solver can re-evaluate the flow field to determine if different *wall functions* should be used.

New directives which best represent conditions at the current timestep are generated and used to drive the domain solution. The CFD results are passed back to the building solver to use in evaluating, for example, heat transfer at the surfaces in the zone. This results in new boundary conditions for the domain at the next timestep.

This sequence of first pass evaluation and adapted solutions is shown in Figure 8.1. Whereas the solution for a static timestep takes roughly 1900 iterations, within the multi-domain solution the prior conditions in the domain are used at the start of the next timestep and far fewer iterations are typically required.

The solution also takes into account connections between the domain and a mass flow network. Indeed, mass flow connections are used to pass information between adjacent domains. Thus changes in pressure or mass flow in other zones of the model become driving forces for the CFD solver. And because mass flow networks also include boundary nodes the CFD domain also has information on changes in weather patterns.

In additional, time-varying heat sources within rooms from the zone operations schedules which have been associated with volumes in the domain are also noticed by the CFD solver. As one might expect, models with a single domain solves much more quickly than models with multiple domains or multiple domains and a mass flow network (more iteration is required).
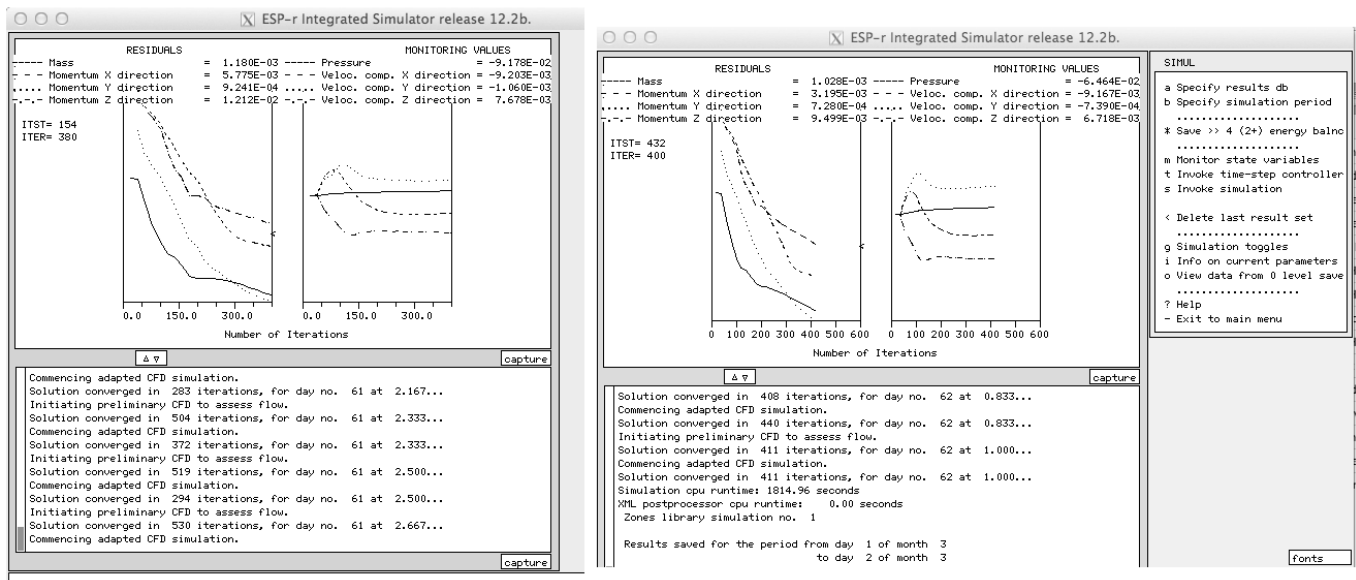
Figure 8.1: multi-domain solution process

For experts, ESP-r offers a stand-alone CFD solution module for testing of solution parameters and to support steady state 2D and 3D CFD assessments. Both the stand-alone and coupled approaches will be discussed.

> CFD is powerful stuff. And also wrapped up in jargon which sounds like English. It is a place where dragons live. The interface to CFD has a steep learning curve. Without a solid background, inclusion of CFD in models will absorb both computing and mental resources at an painful rate.
> You have been warned.
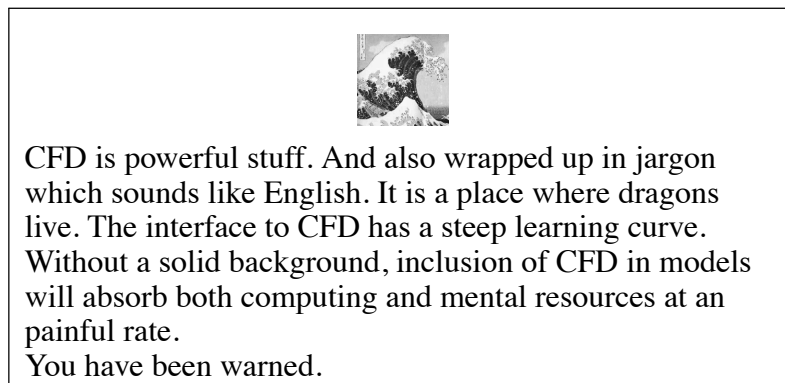
This chapter is not a tutorial on theory or solution techniques. There are PhD thesis written on these topics which are available for download on the ESRU web site publications page at <<http://www.esru.strath.ac.uk>>. And there are any number of books on the subject. The associated source code is (often) heavily commented and can provide a number of useful clues.

The discussion that follows includes an overview of the entities used to define domains, methods for designing domains, what to look for in the performance predictions and here-be-dragon boxes where particular care should be exercised.

8.1 CFD overview

Each domain is composed of a number of directives which define the *gridding of the domain*, the *boundary conditions* applicable, *groups* of cells at the boundary which represent inlets or extracts, *blocks* within the domain representing solid objects, sources of heat and/or contaminants. There are also directives that describe interactions between domains and thermal zones as well as solution directives. The creation and evolution of domains are based on interactions within the *Project manager*. Unless you are an expert resist the temptation to *hack the zone_name.dfd* files.

ESP-r supports one domain per thermal zone. And while it is possible to have a thermal zone fully contained within another thermal zone, it is not possible to have nested domains. It is also not yet possible to represent the site (outwith thermal zones) via a domain.

In ESP-r, domains and the cells within them are rectilinear in the X and Y axis and normally rectilinear in the Z axis. This also applies to internal blockages, heat sources, flow inlets and flow extracts which are defined with reference to the cells in the domain.

Of course, ESP-r thermal zones can be composed of polygons of arbitrary complexity so any zones which need to contain a domain should generally stick to rectilinear forms and, at least initially, be oriented along cardinal coordinates.

An auto-generate function in the ESP-r interface scans the zone geometry looking for unique points along each axis in order to define regions along each axis which begin and end at these points (more on this later in the discussion).

The maximum number of cells in each axis are based on parameters in place when ESP-r is compiled. For constrained versions of ESP-r the cell limit is ˜18x18x18, the standard is ˜32x32x32 and for the large ˜102x102x102. As one would expect, higher resolution domains impose a computational cost. ESP-r does not currently run multiple domain solvers in parallel.

8.1.1 CFD entities

The entities associated with CFD are detailed in the *Entities Appendix* and are summarised below:

- The grid of cells within a domain is formed within an orthogonal coordinate system with the domain X axis along the *South* face, the domain Y axis along the *West* face,

- The extents of each domain are set via four user specified zone coordinates and assumes that the zone geometry is rectilinear and using a cardinal orientation. Subsequently, zone geometries can be transformed and rotated as required,

- Each domain axis can include a number of regions. Regions are useful for ensuring cell boundaries align with zone surfaces. Each region is attributed in terms of the number of cells, its length and a power law coefficient (1.0 is even spacing).

The definition of the axis, regions and cells are found in the initial portion of the zone dfd file:

```
*thermal_geom
*vrts     1   2   4   5
# Ze is 0 if orthogonal
*regions    3   3   3   0  # regions in X Y Zw Ze directions
# Negative cell number enables symetrical gridding.
*xregion
 -10   3.750   1.100 # no cells, length, power law coeff
   1   0.200   1.000 # no cells, length, power law coeff
   1   0.250   1.000 # no cells, length, power law coeff
*yregion
  -4   1.650   1.100 # no cells, length, power law coeff
   1   0.300   1.000 # no cells, length, power law coeff
  -4   1.650   1.100 # no cells, length, power law coeff
*zwregion
  -6   2.050   1.100 # no cells, length, power law coeff
   1   0.200   1.000 # no cells, length, power law coeff
  -3   0.750   1.000 # no cells, length, power law coeff
```

- Domains include *volumes* which have attributes of name, type (keywords South, East, West, High, Low, Source, Block) and pairs of cell indices along the X axis (Ii If), Y axis (Ji Jf) and Z axis (Ki Kf). For example, West_low is one cell wide, 9 cells deep and 6 cells high at the left side of the domain (West) :

```
# Define the volumes for the domain.
*volumes   17
# name   type   Ii If Ji Jf Ki Kf
Inlet          West     1   1   5   5   7   7
Outlet         High    11  11   5   5  10  10
West_low       West     1   1   1   9   1   6
West_mid1      West     1   1   1   4   7   7
West_mid2      West     1   1   6   9   7   7
West_top       West     1   1   1   9   8  10
South          South    1  12   1   1   1  10
North          North    1  12   9   9   1  10
East           East    12  12   1   9   1  10
Floor          Low      1  12   1   9   1   1
Ceiling1       High     1  10   1   9  10  10
Ceiling2       High    11  11   1   4  10  10
Ceiling3       High    11  11   6   9  10  10
Ceiling4       High    12  12   1   9  10  10
CO2            Source   3   3   5   5   4   4
Source16       Source   8   8   5   5   4   4
Block          Block    1   2   5   5   4   4
```

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These named volumes are referenced in subsequent sections of the model file to provide additional attributes. The definition of volumes will be covered in Exercise 8.2.

- Domains include *solid boundary conditions* at which heat may be injected for example a volume named Wall3 as a solid with no heat (see below) or linked to a surface in a zone e.g. volume West_low is linked to surface west in the thermal zone.

```
# Solid boundary conditions.
*solids
Wall3        Heat    0.00
Wall4        Heat    0.00
  . . .
# Solid boundary conditions.
*solids
West_low     Temp   20.00 | Confl   2 west
West_mid1    Temp   20.00 | Confl   2 west
West_mid2    Temp   20.00 | Confl   2 west
West_top     Temp   20.00 | Confl   2 west
South        Temp   20.00 | Confl   2 south
North        Temp   20.00 | Confl   2 north
East         Temp   20.00 | Confl   2 east
Floor        Temp   20.00 | Confl   2 floor
Ceiling1     Temp   20.00 | Confl   2 ceiling
Ceiling2     Temp   20.00 | Confl   2 ceiling
Ceiling3     Temp   20.00 | Confl   2 ceiling
Ceiling4     Temp   20.00 | Confl   2 ceiling
  . . .
```

- Domains may include *air flow boundary conditions* and in the example below the volume Inlet is given a fixed velocity and temperature via:

```
# Air flow boundary conditions.
*air_flow
Inlet        Velocity  0.010 Temp 18.000 Hum  0.000 Area  0.000 Ang  0.000  0.000
Outlet       Velocity -0.010 Temp 20.000 Hum  0.000 Area  0.000 Ang  0.000  0.000
  . . .
```

- Domains may include *internal sources of contaminants*, for example CO2 and humidity sources (the interface is slightly less opaque than the data fields in the dfd file):

```
# Internal sources.
*contaminants(   2 contaminants, humdity is contaminant number   2 )
CO_2           0    1.0000
H2O            0    0.5900
*volume name,heat source,cas gain index and fraction, CO_2 H2O
CO2            0.0    0 0.00  0.0000153737 none         0.00 none
Source016      0.0    0 0.00  0.00 none          1.0 none
```

- Domains may include *blockages* which obstruct air flow, in the example below the volume Block has been set to zero heat gain via:

```
# Blockages.
*blockages
Block        Heat        0.000
  . . .
```

Each domain includes solution directives in the form of key words followed by data, an example is shown below:

```
*solution_methods
Turbulence 1 # k-e model
Buoyancy 1 1.0000 # full calc, density lin relax fac
# Equations to be solved:
*solution_equations
#  Type   Initial value  Relaxation type and factors
Pressure    0.000 Linear  1.000  0.500
Vel U  0.100E-02 Linear  0.500  0.050
Vel V  0.100E-02 Linear  0.500  0.050
Vel W  0.100E-02 Linear  0.500  0.050
Temp   20.000 Linear  1.000  0.250
Ted  0.100E-11 Linear   0.5       0.05
Epd  0.100E-11 Linear   0.5       0.05
```

Each domain also has directives about how much to iterate to arrive at an acceptable answer and the cell to monitor for convergence. Conventionally, we expect the solver to gradually evolve towards a stable solution and use a convergence criteria at a monitored point to judge this. Figure 8.1 is a classic expression of this process.

```
# Iteration control.
*iteration
   1000  0.1000E-01 No
*monitor    6   4   5  CFD.mon
*reint  NO
*svf  1  # frequency of results writing
```

8.2 Planning domains

Opinionated users with a background in CFD are confronted by an initial task of equivalencing the conventions used in ESP-r as well as acquiring familiarity with the menu structure and reporting used. ESP-r uses the *usual CFD jargon* for entities. It may also take some time to adapt to the requirement for rectilinear entities, the avoidance of small dimensions and the need to locate air flow inlets and outlets at the boundaries of the domain.

The requirements of domains should also be taken into account during the initial planning of zones. Inheriting the coordinates of a domain from the zone geometry aides the creation of domains if certain rules are followed:

- rotate the zone to cardinal directions prior to creating the domain,
- ensure surface junctions along an axis (e.g. on the front and back walls) are aligned rather than slightly offset,
- avoid thin window and door frames in the zone geometry and create such frames as rectangular head, sill and jamb surfaces rather than wrapping a single frame surface around the glass,
- avoid sloped surfaces and edges,
- include as zone surfaces flow inlets and flow extracts to speed up initial gridding tasks,
- identify instances where air flow inlets or extracts are required in locations other than the domain boundary (these will require blockages to channel the inlet or extract at the boundary of the domain to its actual location),
- if casual gains are to be included in the domain, ensure that the relevant gain is associated with a specific CFD source volume .

Although flow networks can include cracks a few mm wide, describing the form of a crack in a domain would probably *wake the dragons*. And while it is possible to create zone surfaces with small dimensions this may exceed the limits of some gridding regimes in ESP-r.

Models which have surfaces slightly offset can result in regions which are difficult to grid. For example, Figure 8.2 shows unhelpful zone coordinates on the left (the inlets are 50mm offset in the Y axis and is it really necessary to have a point at 610mm rather than 600mm? Easier-to-grid coordinates are shown on the right.
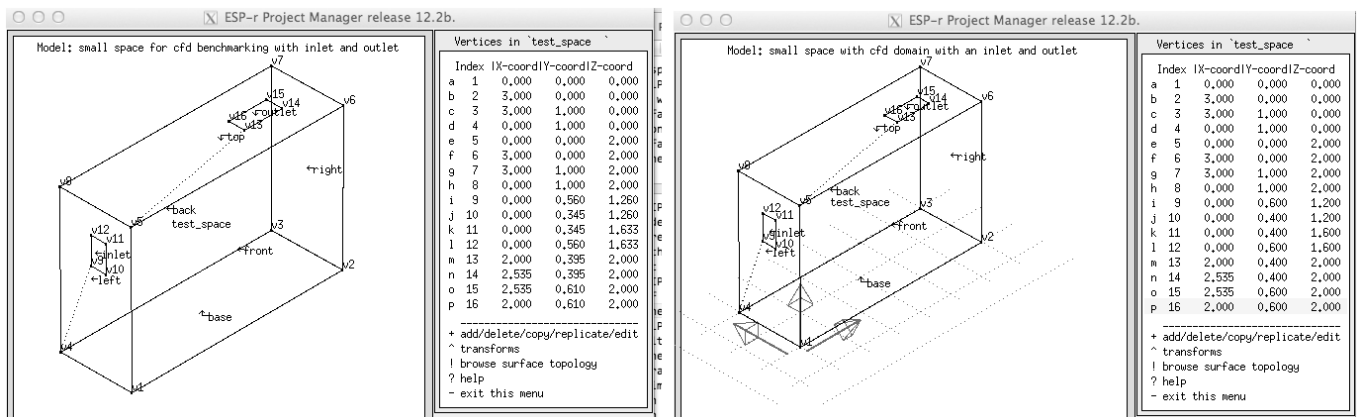
Figure 8.2: unhelpful and revised zone coordinates

ESP-r offers the option to scan the zone geometry and create one or more regions in each axis aligned to the coordinates in the zone. Consider the small space shown in Figure 8.3 which has an inlet on the left and an extract in the ceiling.
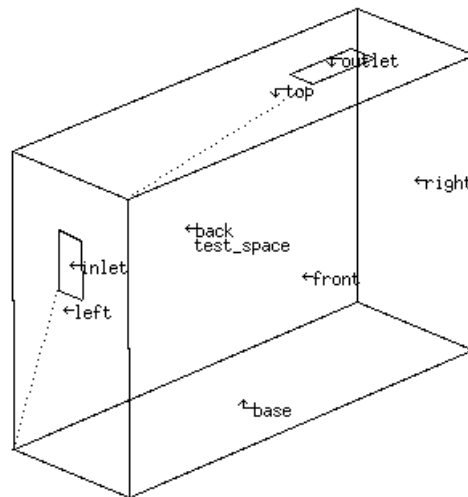
Figure 8.3: small space to be gridded

If we apply this facility we would expect three regions in each axis to coincide with the edges of the zone and the edges of the inlet and outlet. We also need to consider the number of cells required in each region needed to understand patterns of air movement. In the upper left of Figure 8.4 is an initial layout of 11 x 7 x 8 cells, in the upper right this has been refined for cells which are closer to square. The lower left grid is a higher resolution and the lower right grid implements ~100mm cells in all directions.
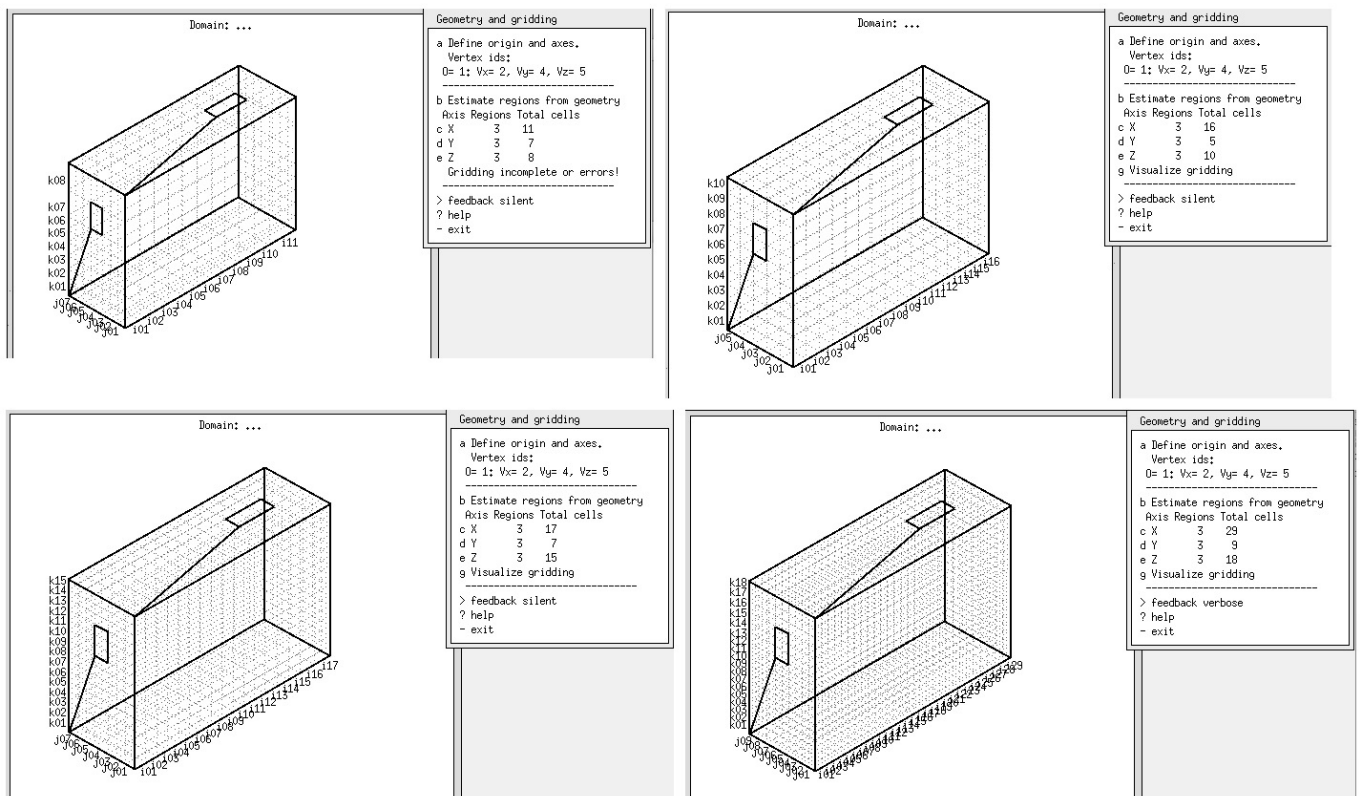
Figure 8.4: regions based on auto-generation and fine tuning

Exercise 8.1   Auto-grid facilities of ESP-r are explored in Exercise 8.1 which grids the space shown in Figure 8.3

After the initial cells have been defined, we must create named volumes which are cells or groups of cells and attribute them as to their purpose. Initial choices are:

- *Air flow opening* for either a mass flow network connection, a specified flow (kg/s) or a fixed pressure (Pa). These must be located at the boundary of the domain,

- *Solid surface* to link to a zone surface or as a fixed temperature or heat flux boundary condition, again, these must be located at the boundary of the domain and must be one cell thick,

- *Source* a source might be associated with a casual gain the the zone, a source of contaminant or humidity and is typically not at a boundary,

- *Blockage* interior blockage which air must flow around.

Well chosen names help model checking as does planning each volume on paper prior to using the interface.

▶ Exercise 8.2   Explore volume creation and attribution within a domain via Exercise 8.2.

8.3 Domain directives

After volumes have been created and attributed the solution parameters for the domain are defined. The domain can be treated as stand alone via the `CFD coupling >> Off` setting which allows it to be solved for one timestep via the **dfs** module. If you select `CFD coupling >> ON` then most likely you will need to associate each of the solid boundary volumes with a surface in the zone and specify the *handshaking* to be done between the CFD solution and the building solver.

By default velocity is solved. In addition the following can be solved:

- Temperature is solved or not

- Turbulence is solved via k-e model, fixed eddy viscosity, MIT zero-equation or fixed eddy initially switching to k-e at a defined iteration. Or turbulence can be turned off for laminar flow.

- Mean age of air is optional to solve.

- If contaminants are defined the distribution of these is optional to solve.

Depending on these high level directives there are a number of values for relaxation factors and convergence criteria. Its is an art as well as a science to set these attributes optimally. The Figure 8.5 below shows the detailed attributes for a stand-alone assessment on the left and a coupled assessment on the right.

The relaxation factors are slightly larger numbers for the stand-alone assessment. The coupled assessment benefits from being able to start from the state of the previous time-step rather than from an arbitrary initial condition.
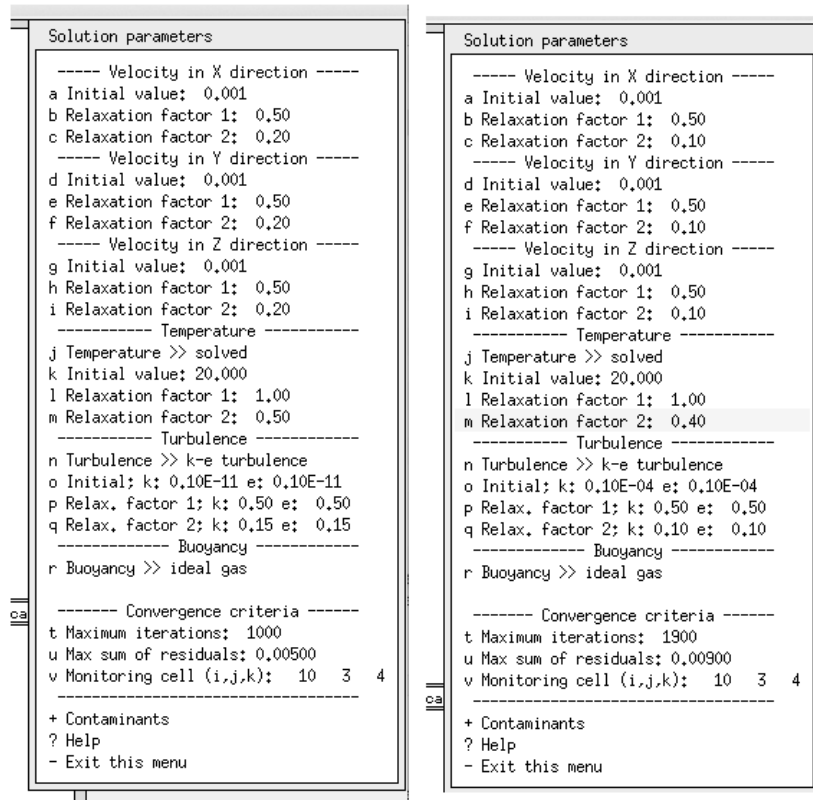
Figure 8.5: Detailed parameters for decoupled and coupled assessments.

Prior to running a multiple-domain assessments we want to check that the domain is syntactically and semantically correct. The stand-alone **dfs** module is designed for this task.

 Exercise 8.3   Explore the stand-alone **dfs** module via Exercise 8.3. This uses a version of the training model with solution directives included.

The result of the stand-alone assessment are indications of how air flows within the domain. In Figure 8.6 the air entering at the left is colder than the room and drops to the floor and then rises along the right wall edge. The point of extract at the ceiling does not seem to induce a particular concentration of arrows.
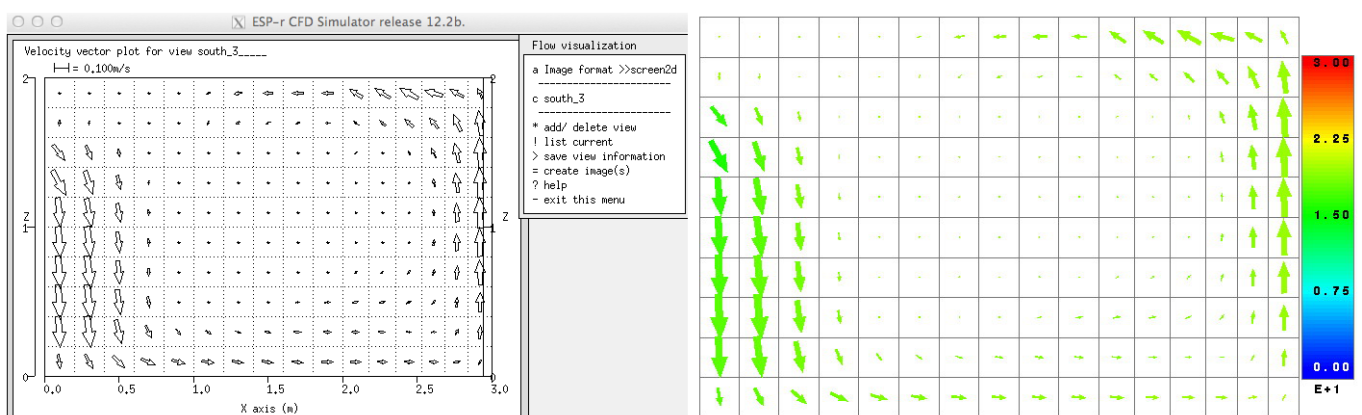
Figure 8.6: Examples of visualisation from stand-alone assessment.

8.3.1 Exploring performance

In Exercise 8.3 the in-built visualisation facilities were used. It is also possible to export the domian predictions to third party applications such as Paraview (www.paraview.org). This can generate a number of outputs such as the slice at the 3rd cell from the South boundary shown in Figure 8.7.

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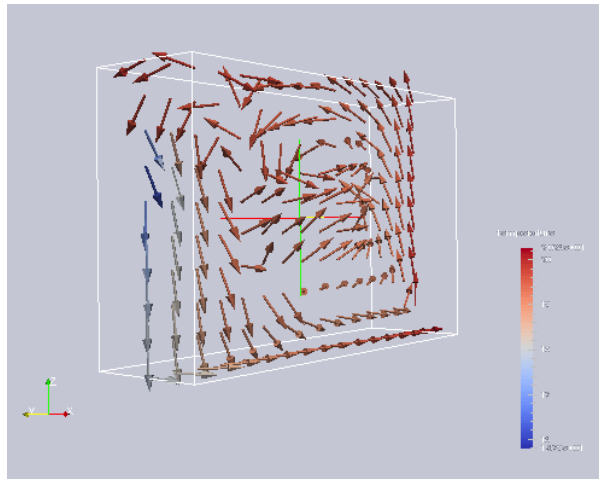
Figure 8.6: Using Paraview with exported performance data.

Exercise 8.4

If you have Paraview, you can take the predictions from Exercise 8.3 and export them to generate a range of image types. Explore this via Exercise 8.4.

8.4 Coupled assessments

Up to this point we have looked at steady-state assessments of air flow, where CFD in ESP-r really begins to deliver information into the design process is when it joins all the other solvers in a multi-domain assessment.

As mentioned at the start of the Chapter, several of the deficiencies in the evaluation of changing patterns of air movement begin to be addressed in *coupled assessments*. It should be possible, with access to moderate computing power, a solid background in the theory of CFD and an understanding of relaxation factors to carry out assessments involving hundreds, if not thousands of time steps. This is made possible, in part by the simulation engines ability to take the converged state of the domain as the starting point for subsequent time steps.

Looking closely at the text feedback in Figure 8.1, notice that for each time step there are two CFD passes. The first characterises the flow field in order to decide the most appropriate *wall function* to use at each of the boundary volumes. This is then used to invoke a second pass *adapted CFD assessment* making use of the current zone boundary conditions and pressure inputs from any associated mass flow network.

Paint sometimes dries faster than CFD. And waiting for 50, 100, 500 timesteps of building-CFD solutions introduces a considerable delay for feedback on evolving flow patterns. It is possible to ask the simulator to invoke a pre-view of the just-solved CFD domain at each timestep. The figure below is a capture of several timesteps.
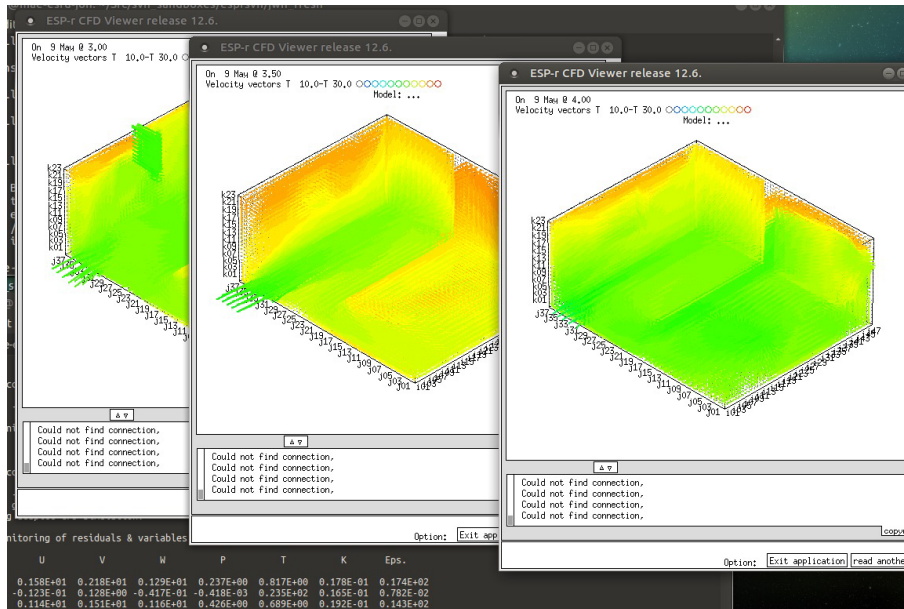
Figure 8.7: Preview of CFD domain as simulation progresses.

▶ Exercise 8.5

Want to explore how to adapt a stand-alone domain to work with a coupled assessment or open up an already-coupled model jump to Exercise 8.5!

There are, of course, many further steps which can be taken to, for example, associate a casual gain in a room with a heat source within the domain. And in a coupled assessment when the casual gain magnitude changes, so does the heat added to the domain.

Mass flow networks are great sources of wind pressure data that evolves with changes in the weather data that the simulation is using. The fixed inlet and exhaust directives can be replaced with links to nodes and components of a mass flow network to look at natural ventilation over time.

Exercises related to these advanced topics are in the TODO list.

9 Plant

In ESP-r environmental control systems can be represented as either so-called idealized zone/flow controls or as a network of system components which is often called a plant system. Other tools may create networks of components via templates of common system layouts. In the latter case the user supplies critical parameters and the layout is created, typically including control attributes.

For ESP-r there are no templates, the user is charged with the design of the component network and control applied to the components. Some aspects of designing plant component networks are similar to designing flow networks. And there are differences which many practitioners find confusing. There are dragons lurking with this portion of ESP-r.

Networks of components offer the following facilities:

- the psychrometric state within components and at points in the network is explicitly computed and is available for inspection
- interactions between components and/or controls are computed at sub-minutely or in extreme cases sub-second intervals and can be inspected in this time domain
- those who have an interest in fine-tuning the response of particular components or control devices within the network have many options for creating models which are close approximations of observed component response
- those interested in high resolution of both system components and mass flows can link both the system component solver and the mass flow solver (dragons tend to lurk here)

ESP-r provides feedback on the composition of such networks and a wealth of information about what is happening within and between components during simulations (via trace facilities) and different views of the *state variables* within the **res** module.

Those who master the use of system components are able to address a range of questions that are not possible with other approaches and have access to a rich store of performance indicators.

Tactical users of simulation do not rush to create networks of components until they have learned all they can from ideal controls. And they do this because creating networks of components:

- tends to take longer (more descriptive information and more linkages between components)
- such networks need tuning like real systems
- such networks fail in similar ways to real systems
- system interactions at the frequency of seconds increases the volume of performance data
- much performance data is in a form that it difficult for many users to interpret
- the facility requires you to assemble a network that is both syntactically correct and physically correct

In comparison with most of the ideal zone controls the use of networks of system components involves a steeper learning curve. Many tasks and much of the quality assurance in models with system components is the responsibility of the users. A methodical approach is essential.

- Rule one: start with zone and/or flow controls and learn as much as possible about the pattern of demands and the likely control logic that is appropriate for the design
- Rule two: planning and sketches are essential.
- Rule three: walk before you run - test out portions of the network and control options on a simple model before scaling the network.
- Rule four: document what you do.
- Rule five: leave plenty of time for testing.

For readers who are approaching the use of system networks in ESP-r with prior experience with component based analysis be aware that there is no concept of central plant and zone-side components. There is no conceptual difference between components representing a duct, a valve, or a cooling tower.

9.1 Using a network to represent mechanical ventilation

In prior sections air flow networks have been used to represent mechanical ventilation systems. Mechanical ventilation with a heater battery would require both a flow network and a means of heating the air. The heating could be done via a small thermal zone mixing box linked to an ideal control or all of the elements of the design could be defined via system components. In the discussion and exercises in this Chapter we will create several systems and explore how they respond to changing demands and boundary conditions.
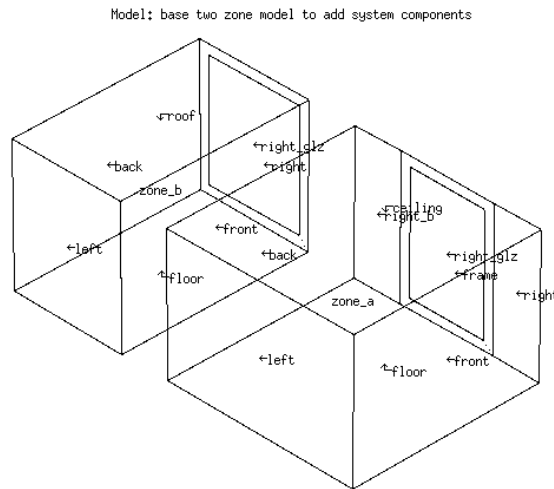
Figure 9.1: Two rooms with overheating potential.

▶️ Exercise 9.1

To demonstrate the use of system components let's add some to an existing model with two rooms, each with diversity of occupancy and east facing facades (Figure 9.1). Exercise 9.1 acquaints you with the base case model.

Figure 9.2 shows a standard mechanical ventilation system which we want to include in this model. It has a supply and an exhaust fan and a heater coil just up-stream from the supply fan. Two zones are supplied and the extracts from each zone are combined in a mixing box just before the exhaust fan.
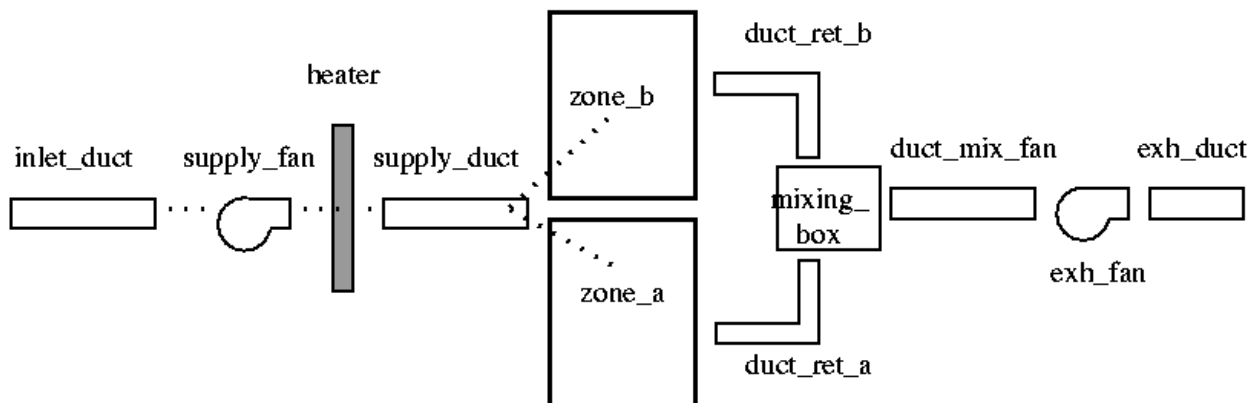
Figure 9.2 Basic mechanical ventilation system.

9.1.1 Planning networks

Planning is essential, even for a simple model. Sketch out your network first and decide on names for the components. Most of your work within the project manager will involve names of components and numbers representing component attributes and your sketch is essential for keeping track of your work, supporting QA tasks and communicating with clients.

After sketching the network gather the component information by first reviewing the available components within the plant component database. Database entries follow the form in Figure 9.3 and they are included in the model contents reporting as Listing 9.4. In addition to the *air conditioning* related components, there are many that relate to wet central heating systems, boilers, fans and pumps.

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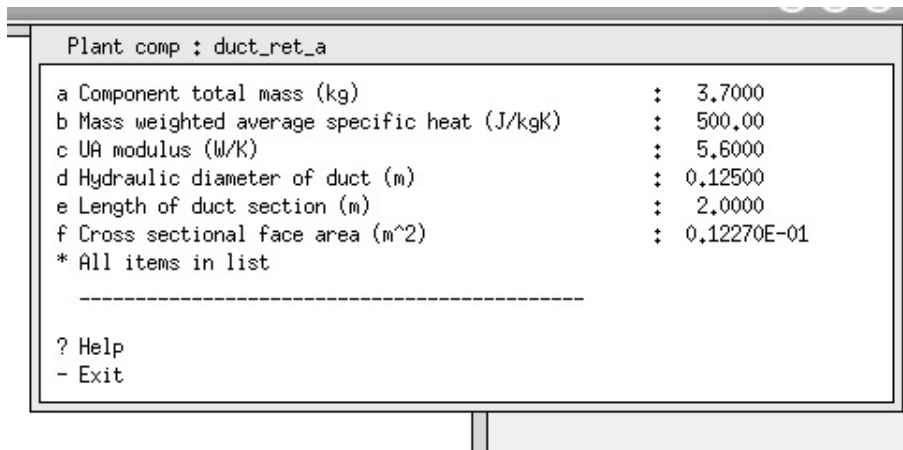
Figure 9.3 Typical component menu.

```
Component: duct_ret_a ( 1)  db reference  6
Modified parameters for duct_ret_a
Component total mass (kg)                : 3.7000
Mass weighted average specific heat (J/kgK): 500.00
UA modulus (W/K) :  5.6000
Hydraulic diameter of duct (m)           : 0.12500
Length of duct section (m)               : 2.0000
Cross sectional face area (m^2)      : 0.12270E-01
```

Listing 9.4 Typical component attribute reporting.

▶ **Exercise 9.2**

To explore available system components jump to Exercise 9.2. Locate examples of each of the entities in Figure 9.2 within the utility module which manages the plant components database.

9.1.2 Component sequencing

Although in theory you could define the components in your network in any order, some patterns make subsequent tasks much easier. For example, starting the definition with components downstream from the zones to the exhaust and then describing the supply side to the zones, as in Figure 9.5, can make subsequent tasks easier. Later, try out different sequences to describing components to see what works best.
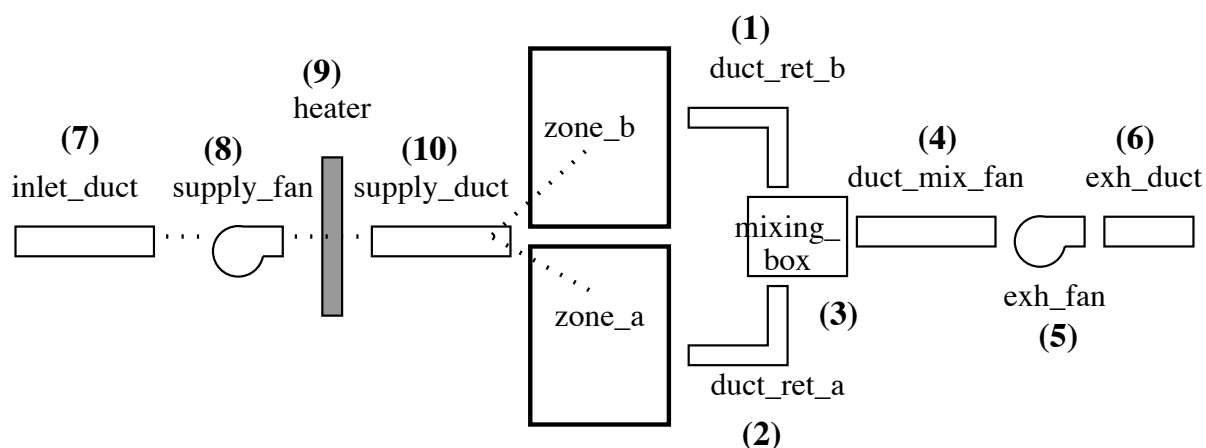
Figure 9.5 Order of components for ease of subsequent linking.

As components are added you are asked whether to accept their default attributes or if you want to edit them. Most components include an attribute for the total mass of the component. For the exercises this need not be exact. There is also a mass weighted average specific heat which tends to be either 500.00 or 1000.00. Each component also has a UA modulus. These parameters support calculations of how the casing of the component interacts with its surroundings.

Ducts have additional parameters, including the length of the duct, cross-sectional area and hydraulic diameter. If you pre-calculate these attributes it will speed up your descriptive tasks as well as reducing

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mistakes (see Rule two above).

If you want to explore the process of network creation then jump to Exercise 9.3. Otherwise select the exemplar list variant of the model which has the network already included.

When you have finished you should see something like Figure 9.6. Save your network and take a moment to review the components listed with your sketch to ensure they are consistent.

```
: 12.2a.

    Components

ive
        Name        Iref no.I      Type
      a duct_ret_a         6    air conditioning
      b duct_ret_b         6    air conditioning
      c mixing_box         1    air conditioning
      d duct_mix_fan       6    air conditioning
      e exh_fan            3    air conditioning
      f exh_duct           6    air conditioning
      g inlet_duct         6    air conditioning
      h supply_fan         3    air conditioning
      i heater             5    air conditioning
      j supply_duct        6    air conditioning

        ----------------
      + Add/Delete/Copy


      ? Help
      - Exit
```

Figure 9.6 Initial components.

9.1.3 Linking components

The next task is to link the components together. This is different from linking flow network components together. Clear your mind - the pattern is to begin your focus at a component that receives flow and note which component is sending the flow. Referring back to Figure 9.2 - the heater is supplied by the supply_fan so when you set up a link for the heater the first component request is the `heater` and the second component request is the `supply_fan`

Look again at the list in Figure 9.1. Notice that there is one supply duct feeding the rooms. We could have had two separate ducts, but to deal with a single duct supplying two rooms ESP-r uses the concept of a *mass diversion ratio*. If, when defining the linkages, we set the mass diversion for each path to 0.5 we send half the flow to each. Altering this ratio effectively changes the flow rates to the rooms. Except for the receiving component inlet_duct, which takes its supply from ambient air, each of the other connections is associated with another component. When the connections are complete save the network.

If you want to explore the process of linking components then jump to Exercise 9.4. Practice does help and you might find it straightforward once you have sorted out a good working pattern of interactions.

After linking the components the interface will be updated to that shown in Figure 9.7. Whether or not you did the exercise, compare the links in Figure 9.7 with the sketch in Figure 9.2
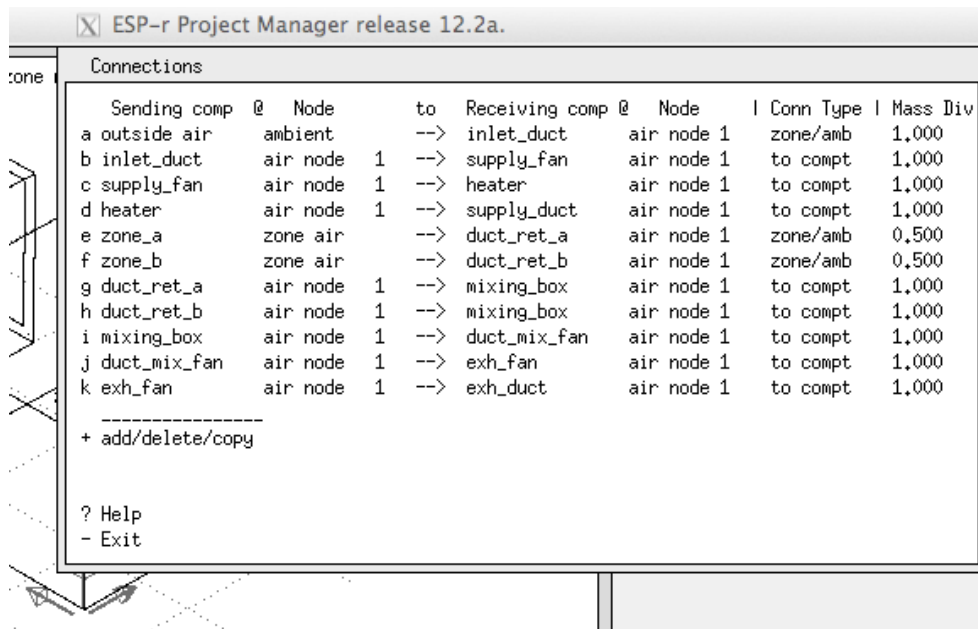
Figure 9.7 Connections after editing.

9.1.4 Defining containments

Components exist in a context (or containment), such as surrounded by a fixed or ambient temperatures or a zone temperature. Initially we might attribute each component with a fixed temperature of 20°C except for the inlet_duct which is associated with outside air. Later, if we knew if ducts were actually located within specific rooms we could update the containment to reflect this. Figure 9.8 shows what you should expect to see.
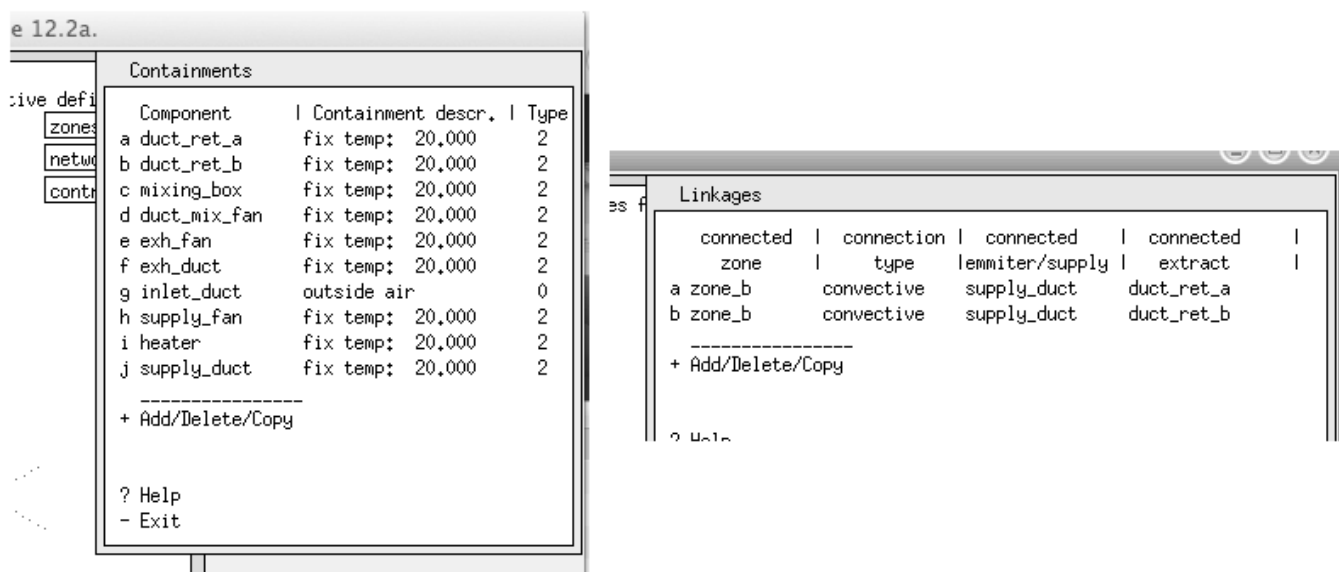
Figure 9.8 Containments for each component and zone links (right).

And before you do any further work, notice that there is a place for you to include notes (Rule 4) before you forget what this network is about!

Next we need to test the model to see if it is complete and syntactically correct. In the Project Manager generate a model contents report (see Exercise 15.1 to see how this is done). If there are problems extracting the report from the model files this indicates the syntax of the file is confused.

9.2 Links to zones and controls

At the bottom of the network definition menu there is an option link plant to zone. Before we can use this we must ensure that there is a zone control file associated with the model because ESP-r enables the link between thermal zones and plant components via a zone control law in addition to whatever control is

being applied within the components of the network. After you have used the interface to establish the zone-component links these zone control entries will have been created for you. Note that they will have high heating and cooling capacities, as long as they are larger than the actual capacity of the component nothing further needs to be done.

Since there are two thermal zones we need to add two entries. Because this is an air base system the link will be convective. For zone_a the associated component is `supply_duct` and the extract component is `duct_ret_a` and do the same for zone_b.

The interface will look like Figure 9.8 (right) when this is completed. This is a good time to save the network of components. You will be asked whether the zone controls should be updated to reflect the recent changes in the network of components (say yes).

Almost finished. The zone controls will have two additional control loops enabling communication between the plant and thermal zones (Figure 9.9). If you ever need to update these linking controls be aware that this portion of the interface will ask lots of questions before you are able to alter the capacity. Look at in the text feedback area for a synopsis of the current information in order to select the correct options.

Figure 9.9 Zone controls after auto-setup.

9.3 Plant controls

Up to this point we have used zone controls to establish the link between the thermal zone and network component domains. We now have to define the logic which will drive the heater component and for this we must define a so-called plant control. Plant controls include many of the attributes seen in ideal zone and mass flow controls - each control loop has a sensor definition and an actuator definition as well as one or more periods for each calendar day type.

In the mechanical ventilation network the item to control is the heater. The control loop, will sense node one within the duct_ret_a component and it will actuate node one within the heater component. The controller type `senses dry bulb actuates flux` (from within the list shown in Figure 9.10). The base case model included an ideal control law with multiple day types, lets follow that pattern but for the zone free-float we use `period switch off control`, and for the basic ideal control use an `on-off control` with a heating capacity of 3000W and a cooling capacity of 0W. The sensor is `senses output of a plant component` and the actuator is `node in plant component` and identify the heater (which happens to have one node).

The selection of control laws (see Figure 9.10) is somewhat terse, but the help message clarifies the relationship between the control law and the control type. These relationships are required because some components work on flux and some on flow and the actuation needs to reflect this.
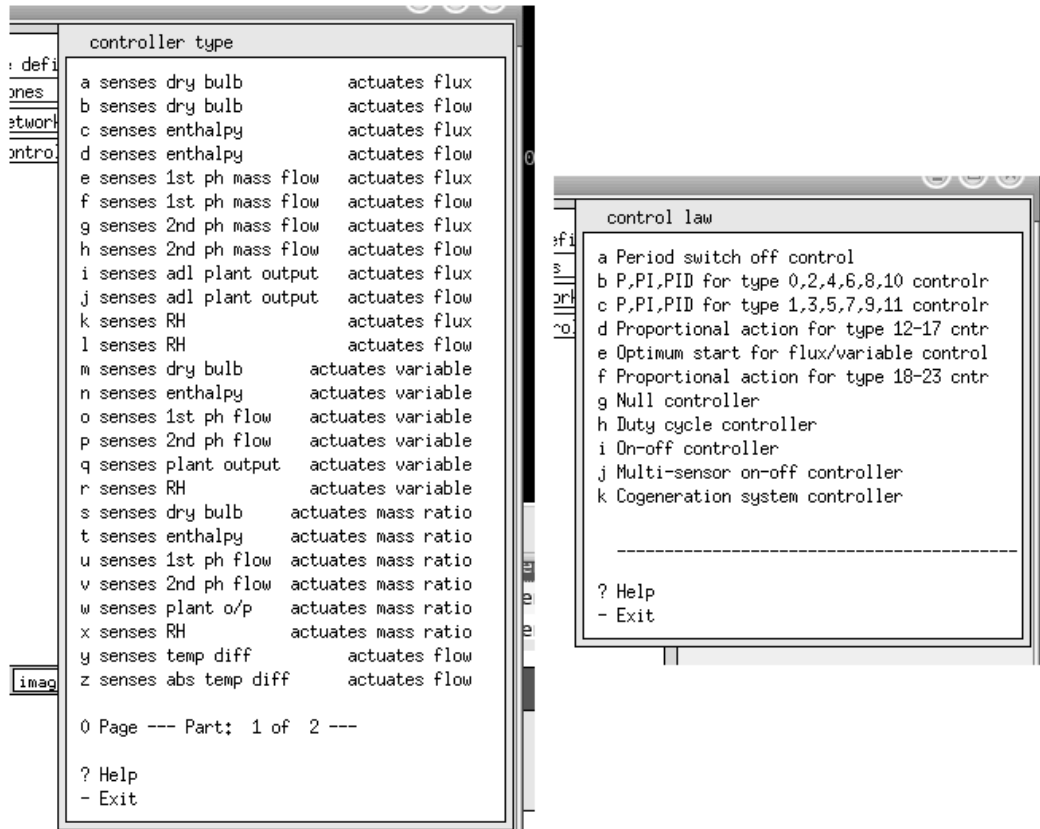
Figure 9.10 Component control types and laws (right).

A word about the data for the on-off control period. There are seven parameters:

- mode of operation (1.00)
- off set-point (23C)
- on set-point (19C)
- output at high (3000W)
- output at low (0W)
- sensor lag (zero) actuator lag (zero)

When the plant control is complete and saved it is a good idea to generate a fresh QA report for the model. This will provide additional feedback for checking that your model is consistent.

After you have reviewed the QA report adapt the simulation parameter sets. Use a 2 minute time-step for the zone solution with the plant simulation at 2 time-steps per building time-step and ensure that there are names for the zone and plant results files filled in.

Commission an interactive simulation. If all went well the simulation will take a minute to run (the plant is solving every minute). Figure 9.12 was captured while the assessment was underway. Temperatures fall off when control is not active with zone_b cooler at night. Sunday is cool (as expected). The occupied period is getting a bit warmer than the switch-off set point and not dropping below the switch-on set point.
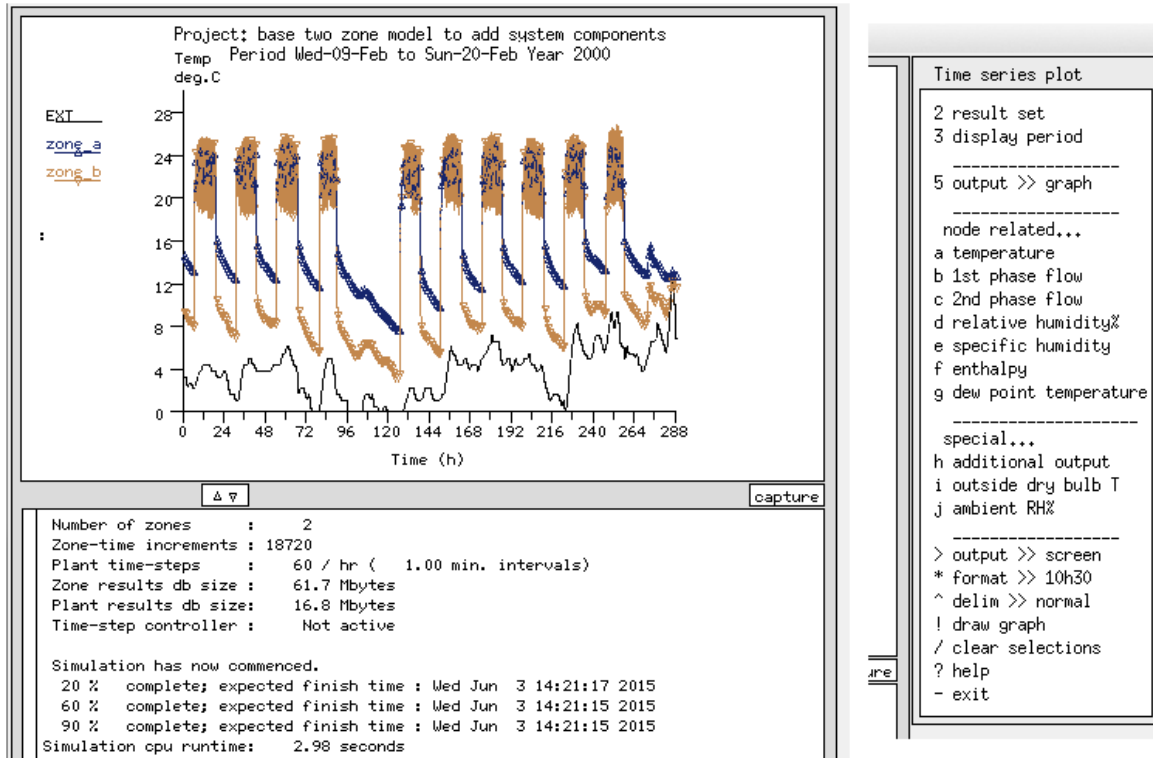
Figure 9.12 Monitoring of the assessment and results options (right).

The **res** module can be used to look at performance of both the zones and the system components. There are a number of choices for component reports (graphs over time, psychrometric graphs, timestep listings, statistics etc.). And, as shown in Figure 9.12 (right) there are a number of types of information that can be reported on.

To understand how well the mechanical ventilation system is working generate performance graphs such as in Figure 9.13. The ON-OFF control is clearly thrashing, when it is off the supply temperature drops to near ambient and a bit later the return air temperature drops below the switch-on level. It is also worth looking at the performance characteristics reports for the zones.

Figure 9.13 Supply temperature, return temperature, heater W.

One of the reasons one might need to use a network of components is to inquire into the internal state of the components so this is a good time to review what is on offer and, importantly, what information about the components are required to recover performance data.

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One way of discovering the performance sensitivity of networks of components to changes in control parameters is to run a series of simulations typically changing one aspect of a control or a component parameter at a time. This process works even better if a friendly control engineer takes part in the exploration. Certainly an on-off control will result in different performance characteristics to a PID controller, but remember to walk before you run when it comes to PID controllers!.

An existing variant of the model includes a PI controller and in Figure 9.14 below the temperature control is improved and the heater can be seen to be thrashing much less.

Period: Wed-09-Feb@00h00(2000) to Wed-09-Feb@08h59(2000) ; sim@01m, output@01m
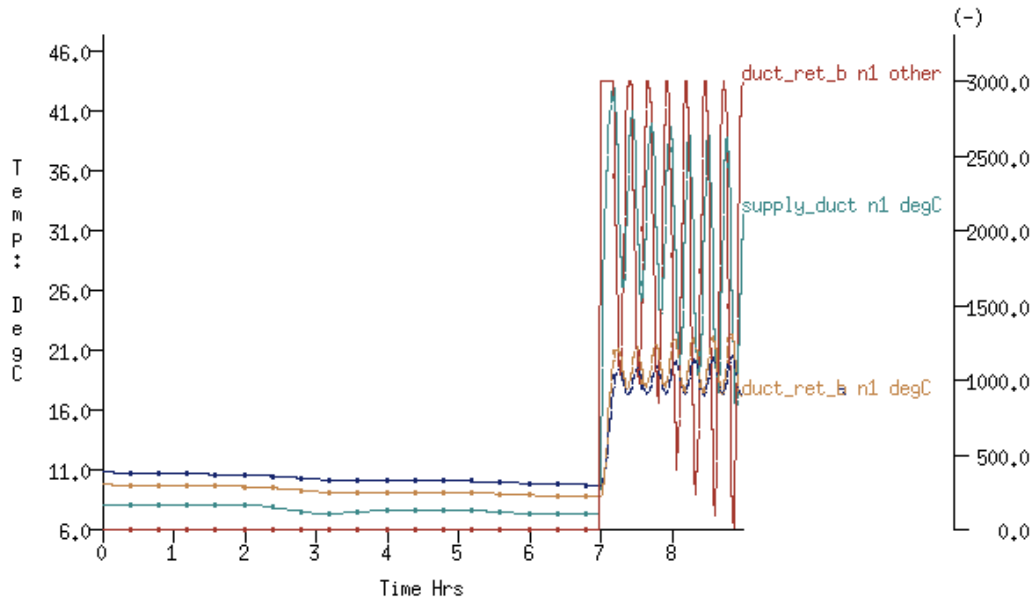
Figure 9.14 Performance predictions with proportional control.

Judging the additional resources needed in comparison with ideal zone controls is best done once you have defined a couple of component networks and developed some proficiency at the tasks involved. The goal is to employ the most appropriate approach to a given simulation project and only using complex facilities where a less complex approach does not support the requirements of the project.

10 Preparation for simulation

In ESP-r the model description can include a number of directives about the nature of the numerical assessments to be carried out as well as where to store the performance predictions for each of the analysis domains. There are a number of reasons to embed such information in the model:

- decisions made in the planning stage can be recorded

- procedures are made explicit

- support for subsequent automation and production tasks

- to allow performance predictions to be re-generated at a later date

- information embedded in a model is safer than scraps of paper

The idea of *simulation directive sets* came about because a highly competent user of ESP-r was asked by a client to re-run a historical project to extract some additional information. The archive of the model was found and the notes about the project were scanned and the simulation was re-run but the predictions had changed. A straightforward task became complicated and frustrating.

What had changed? Where did the fault lie? Had the model become corrupted? Had the numerical engine changed? Eventually the causal factor was found to be the number of *pre-simulation* days that were used. That particular value had not been recorded in the project notes.

Figure 10.1: Simulation parameter sets and IPV attributes (right).

And thus it became clear that the description of the model would be much more robust if it included a description of the specific assumptions and directives used by the simulation engine.

This simplifies the task of carrying out production runs and reduces the chances of errors. It also supports the idea of *implementing the plan*. If, at the planning stage, the team decide that specific weeks will be a good test of building performance the facility makes it *very easy* to implement the test. In the Project

Manager these preferences are managed in the `Browse/Edit/Simulate -> Actions -> Simulate -> simulation presets` menu. The current values for the active simulation preset are included in the upper portion of the `Simulation Controller` menu (left portion of Figure 10.1).

Menu options include:

- set name - identifying tag for the simulation e.g. winter, june or monsoon

- start-up days - each set includes the number of days in the pre-simulation period used to condition the model from its initial state. The initial value is based on a scan of the model composition. Users can increase it to improve model stability during the initial hours of an assessment or reduce it to improve run-times for the set.

- zone time-steps/h - each set includes the solution frequency and how often data are recorded.

- plant time-step/(bldg ts) - each set includes the system component solution frequency as a multiplier of the zone time-step. This should reflect the nature of the components and the control applied to them.

- result save level - each set includes directives for how much information is recorded (see discussion in section 10.2).

- period of simulation - start and end date of the simulation (one day to whole year)

- zone results - the file name to hold zone performance data

- flow results - the file name to hold mass flow performance data

- plant results - the file name to hold system component performance data

- moisture results - the file name to hold the moisture states

- electrical results - the file name to hold power performance data

- CFD results - the file name to hold CFD domain performance data

Simulation time-steps dictate the frequency of the numerical solution and in ESP-r this can range from one minute to one hour. Clearly your choices will have an impact on the time it takes to run the simulation, the size of the performance data files as well as the speed with which performance data can be extracted.

The frequency should also reflect the nature of the building composition, the control applied, as well as the types of system components used. If, for example, you use an ON/OFF controller which has a response time of around a minute then a 15 minute time-step is going to result in a *VERY STICKY CONTROL*. If you have an air flow network with large openings between rooms you would expect that the flow between the rooms will tend to moderate the temperature differences between the two zones. A simulation with a 30 minute time-step can result in un-natural differences in temperatures between adjacent rooms which are then resolved via the flow solution as a brief typhoon. It may be necessary to run assessments a different frequencies to find out an appropriate compromise.

File names for the result files are included in the simulation parameter sets so that each run generates known file names. This reduces confusion and is helpful for automation of simulation work. For example it is possible to issue a command in the form: `bps -file hospital.cfg -p monsoon silent` which will run the hospital model using the simulation parameters associated with the concept monsoon and create the specific results files and it will to this silently.

A group in Denmark once commented

we have two kinds of winter weather patterns that we always check - the cloudy windy (but not so cold) storm and the very cold but sunny.

For these observant users there is no single worst day and not even a single worst week and they want to embed this knowledge into their procedures and into their models so that it is really easy to ensure these checks are made.

10.1 Integrated performance views

Observant design teams also tend to have a checklist of performance indicators that they want to be continually reminded of as they evolve their designs so that the un-intended consequences of their latest brilliant ideas are exposed. Others would describe this as multi-criteria assessments and this is supported in ESP-r via a facility known as the Integrated Performance View (IPV).

IPV directives describe *what we want to measure* and *where we want to measure it* and *what assessment periods are required*. The right portion of Figure 10.1 is the main interface to the IPV facility. Note that it shares many of the attributes of the simulation parameter sets, indeed when you modify the IPV you will often find the simulation parameter sets are updated to match.

Directives are held in the model configuration file. These directives are similar to the *meters* implemented in other tools. The difference is in the information content and format of the requested data. Each request for a performance data type (e.g. zone resultant temperature, solar entering the zone in Figure 10.2) results in a statistical report, tabular data and a summary (because different users recognize patterns in different forms).

```
IPV metric sets

 ___metric_____zones_area_scaling_weight
a Resultant T (degC: 3   35.4  1.0  1.0
b Zone db T (degC) : 3   35.4  1.0  1.0
c Infiltration (W) : 3   35.4  1.0  1.0
+ add/delete metric set
! list metrics
? help
- exit this menu
```

```
IPV energy demand sets

 __set name zones area scaling__
a offices        2   27.0  1.0
b other          1    8.4  1.0
+ add/delete demand set
* timestep aggregate >> ON
! list demand sets
? help
- exit this menu
```
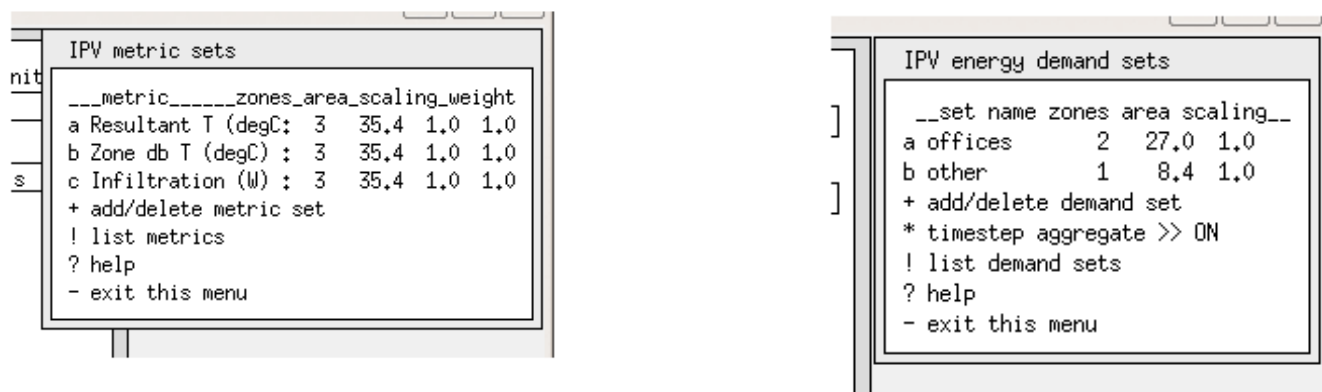
Figure 10.2: IPV performance metrics set and demands set interface.

The following performance metrics can be included in IPV directives:

- zone resultant temperature, dry bulb temperature, zone relative humidity
- zone infiltration load, zone ventilation (from other zones) load
- zone casual gains (all)
- zone solar radiation entering from outside, solar radiation absorbed in room

There is a separate selection process for requesting information on environmental systems demands (Figure 10.2 right). The facility allows you to identify sets of zones which you want to associate with a concept - for example *south_offices* might include 15 separate zones for which one aggregate report is requested.

It is also possible to specify a multiplier for environmental systems demands. For example, a specific perimeter office in your model might be representative of a dozen offices and a scale of 12 could be applied to the performance of the specific office when deriving the overall performance of the building. This is a particularly useful feature of an IPV.

After the performance metric sets and environmental demand sets have been defined the task turns to the nature of the assessments to be run. An IPV supports the following kinds of assessments:

- single annual (or use defined) assessment
- three assessments (winter, transition, summer) which can be a typical week in each season or all days in each season
- five assessments (winter starting 1 Jan, spring, summer, autumn, winter ending 31 Dec) which can be a typical week in each season or all days in each season

The IPV definition also supports the idea of scaling performance predictions. If you selected a typical week then you have the option to undertake the same kind of search-for-best-fit-weeks as is done in the ESP-r weather module.

Once the best-fit-weeks have been determined you have the option to use the HDD/CDD/solar ratios to determine an initial scaling for heating and cooling. The values for lights are scaled by the ratio of days in the short simulation to that of the whole season (right portion of Figure 10.1).

Once the IPV directives have been defined the information is saved to the model configuration file and the definition of simulation parameter sets are updated to match that of the IPV directives. You may then use the `Integrated Performance View` directive in the `Simulation` menu to automatically run the required assessments and, optionally to extract the requested performance metrics (and their statistics and

tabular and summary sub-reports) to a so-called IPV report.

These simulations will also generate the standard results files which can be interrogated interactively for information not available with the IPV report itself. Many users make use of the framework of the IPV to automate the production of simulation runs. It is also useful for large models where a single simulation would generate a results file greater than a couple of gigabytes.

If you ask to extract data then the results analysis module will be invoked with a command line that directs it to extract the requested data. If there are multiple assessments then the reports will be conflated and an overall summary will be produced. The overall summary takes the data from each season and the seasonal scaling factors included in the IPV definition in order to arrive at annual performance.

If your project involves energy demands that are not directly derived from the zone descriptions such as lifts and domestic hot water the IPV will scan a so-called demands file (also found in the `model context` menu and include it in the IPV report.

A sample of an IPV report for the collection of zones named offices is included in Figure 10.4. Diversified capacity is the instantaneous peak while the distributed capacity is the peak in each zone added together. And the integrated demand *does what it says on the tin*.

```
. . .
*assessment, 1,cellular_shd 1st winter run
*report,70,diversified,capacity,offices
*title,Diversified capacity,W
*format,table,1,7
*fields,Heating, Cooling, Lighting, Lighting (ctld), Fans, Small Power, Hot water
*data,1034.4,767.8,0.0,0.0,0.0,0.0,0.0
*end_report
 *report,70,diffuse,capacity,offices
*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating, Cooling, Lighting, Lighting (ctld), Fans, Small Power, Hot water
*data,1034.4,767.8,0.0,0.0,0.0,0.0,0.0
*end_report
 . . .
```

Figure 10.4: IPV data processed for display

Comfort reports are also embedded in the output. The data in Figure 10.6 is for a collection of rooms called ocup_zones. The format of the frequency report is not particularly human readable - it contains the same information as is found in the results analysis frequency bin reports.

```
*report, 6,distribution,comfort,ocup_zones
*title,Resultant temperature,degC
*format,frequency,12,5,12.0,2.0,30.0
*fields,range distribution percent cumulative_distrib cumulative_percent
*data
0,<12.0,0,0.0,0.0,0.0
1,12.0-14.0,0,0.00,0,0.00
2,14.0-16.0,4,1.96,4,1.96
3,16.0-18.0,19,9.31,23,11.27
4,18.0-20.0,91,44.61,114,55.88
5,20.0-22.0,43,21.08,157,76.96
6,22.0-24.0,27,13.24,184,90.20
7,24.0-26.0,20,9.80,204,100.00
8,26.0-28.0,0,0.00,204,100.00
9,28.0-30.0,0,0.00,204,100.00
10,30.0-32.0,0,0.00,204,100.00
11,>32.0,0,0.0,0.0,0.0
*end_report
*report, 6,stats,comfort,ocup_zones
*title,Resultant temperature,degC
*format,table,1,3
*fields,maximum,minimum,average
*data,25.727,14.552,20.266
*end_report
```

Figure 10.6: IPV comfort reports

Another metric that was requested was the infiltration into the set of zones named infil_zones (see Figure 10.7). This is typical of the data included for such metrics.

```
*report,11,stats,Infil,infil_zones
*title,Infiltration load,W
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max
        diversified_min,distributed_min
*data,-62.752,-88.499,-40.327,0.000,-62.752,-176.673,-178.132
*end_report
```

Figure 10.7: IPV report on infiltration

Another format of report is a time-step listing for a typical day in the season. Figure 10.8 is such a listing for the heating demand for the collection of zones named offices. The first column is the julian day of the year and the fraction of the day (12h00 equals 0.5).

```
*report,70,demand,per_unit_time,offices
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
38.0208,76.0,0.0,0.0,0.0,0.0,0.0
38.0625,365.7,0.0,0.0,0.0,0.0,0.0
38.1042,342.8,0.0,0.0,0.0,0.0,0.0
38.1458,299.6,0.0,0.0,0.0,0.0,0.0
 . . .
38.8542,54.8,0.0,0.0,0.0,0.0,0.0
38.8958,137.8,0.0,0.0,0.0,0.0,0.0
38.9375,196.7,0.0,0.0,0.0,0.0,0.0
38.9792,231.8,0.0,0.0,0.0,0.0,0.0
*end_report
```

Figure 10.8: IPV timestep report

At the end of the IPV report is a summary of performance which has been seasonally-scaled and zone-scaled and which include non-zone demands (see Figure 10.9) and is only available within the IPV.

```
*Summary
*report,98,energy,performance,aggregate
*title,Integrated demand,kWh/m^2.a
*format,table,1,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,20.796,26.027,10.385,0.000,0.000,0.000
*end_report
 . . .
*report,74,power,capacity,aggregate
*title,Maximum capacity,W/m^2
*format,table,1,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,32.718,37.636,2.379,0.000,0.000,0.000
*end_report

*report76,distribution,thermal_comfort,aggregate
*title,Resultant Temperature,degC
*format,frequency,9,6,16.0,2.0,30.0
*fields,range,winter_early,spring,summer,autumn,winter_late
*data
<16,0,0,0,0,0
16-18,0,0,0,0,0
18-20,4,2,0,0,4
20-22,19,2,0,0,24
22-24,91,30,0,16,109
24-26,43,25,10,16,59
26-28,27,62,23,45,2
28-30,20,83,158,126,6
>30,0,0,6,1,0
*end_report
*end
```

Figure 10.9: IPV report on infiltration

Note that the raw data is expected will be interpreted for display via a third party application (see Figure 10.10). Users should keep in mind that the IPV has similar risks to any prior-specification scheme. If it does not include a relevant range of topics for the current project it will fail as technique for enforcing

multi-criteria assessments. Many of the example models that come with the ESP-r distribution include IPV descriptions. Use them to explore the facility!
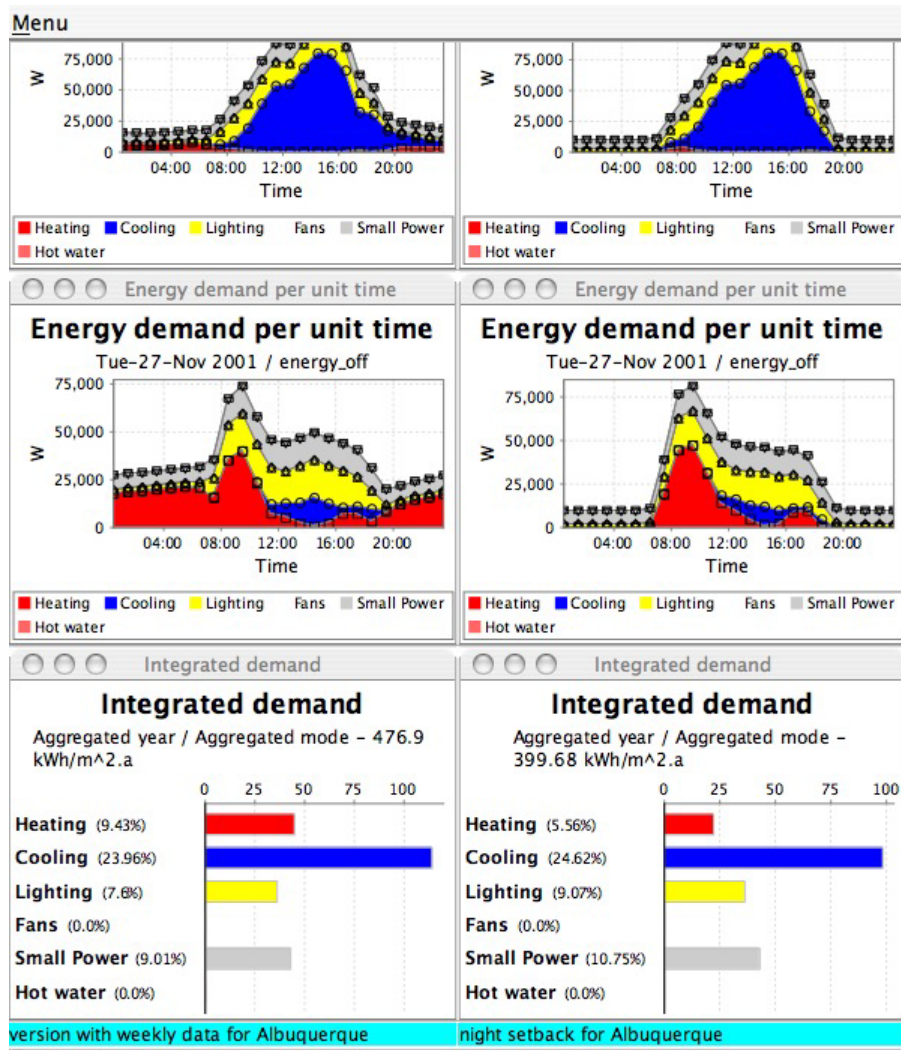
Figure 10.10: IPV data processed for display

10.2 Results libraries and reports

One of your choices prior to invoking a simulation is to select one of the pre-defined sets of performance data to be recorded in the results files as the simulation progresses. The following is a synopsis for each:

- Save level 0 - a text report is generated by the simulator if the user requests it after the assessment has been run. A sample of this report (for one of the example models and an annual simulation) is shown in Figure 10.11.

- Save level 1 - zone heating/cooling, zone control point temperature, zone dry bulb temperature into bespoke binary file. This is the smallest bespoke binary file and has minimal overhead when generated but is rarely used because of its limited contents.

- Save level 2 - zone heating/cooling, the zone dry bulb temperature, zone control point temperature, surface inside face temperatures, infiltration, ventilation, surface convective heat transfer at inside faces, casual gains (radiant, convective, latent), solar entering room, solar absorbed in zone, solar absorbed at inside face and outside face of each surface, relative humidity, latent load, linear thermal bridge flux. This file has somewhat higher overhead while it is being written and also results in a somewhat larger bespoke binary file. This save level is useful for general investigations that do not require nodal temperatures or energy balance reports.

- Save level 3 - in addition to save level 2 data fields this save level includes additional records which hold the temperatures at each node of each surface in the model. This is useful for ploting temperature profiles within constructions.

- Save level 4 - in addition to save level 2 data fields this save level includes additional records which hold the flux paths which represent the zone energy balance as well as surface energy balances. This is the default save level and although it generates a larger file it provides the most flexibility for ad-hoc investigations.

Save level 5 - no longer used.

Save level 6 - this is a relatively compact XML report which includes monthly data summaries. It is used by several third party tools to access predictions from ESP-r. It is also used when ESP-r is being used to run UK National Calculation Method assessments for code compliance purposes. Portions of a save level six file are shown in Figure 10.12.

The first token in each line is the model configuration file name, the second token is either the zone name or a key word (e.g. Total_DHW), the tokens such as MH1 stand for monthly heating january, MC2 would be monthly cooling february. Key words such as z_DHW_Month_1_MJ and z_DHW_Month_1_kWh are zone monthly kWh or MJ for a specific topic.

```
Performance assessment report
Results library cellular_bc_save0.txt
Standard climate file clm67
Configuration file cellular_bc0.cfg
Configuration descr base case model of two adjacent cellular offices
Period Sun-01-Jan to Sun-31-Dec Year 1967

 Zone          max air T  (occurrence)   min air T  (occurrence)
manager_a      30.00 Sun-14-May@14.75    10.00 Sun-01-Jan@ 4.25
manager_b      30.00 Sun-11-Jun@13.75    10.00 Sun-01-Jan@ 4.25
coridor        30.00 Sun-23-Jul@19.25    13.68 Sun-01-Jan@ 7.75

 Zone           max heat (kW)         max cool (kW)      heating (kWhr) cooling (kWhr)
manager_a       0.79 Mon-09-Jan@ 6.75  -1.76 Mon-21-Aug@12.75       271.9     -797.9
manager_b       0.79 Mon-09-Jan@ 6.75  -1.76 Mon-21-Aug@12.75       271.9     -797.9
coridor         0.32 Mon-09-Jan@ 7.25  -0.58 Mon-21-Aug@13.75        10.5     -480.9

All zones:
 Max_Temp   30.0  in manager_a on Sun-14-May@14.75
 Min_Temp   10.0  in manager_a on Sun-01-Jan@ 4.25
 Max_Heat    0.8  in manager_b on Mon-09-Jan@ 6.75
 Max_Cool   -1.8  in manager_a on Mon-21-Aug@12.75

Total heating requirements      554.3 (kWhr)      1995.6 (MJ)
Total cooling requirements   -2076.64 (kWhr)     -7475.9 (MJ)

Monthly metrics:
Month   Heating     Cooling     Heating     Cooling
Month    (kWhr)     (kwhr)       (MJ)        (MJ)
Jan      164.5      -11.4       592.1       -41.0
Feb       76.8      -38.7       276.4      -139.3
Mar       25.0     -179.1        90.0      -644.7
Apr       24.8     -118.2        89.1      -425.5
May        2.8     -274.8        10.1      -989.2
Jun        0.0     -323.3         0.0     -1163.9
Jul        0.0     -433.4         0.0     -1560.3
Aug        0.0     -409.6         0.0     -1474.7
Sep        2.4     -124.7         8.5      -448.9
Oct        9.1     -120.3        32.8      -432.9
Nov      101.4      -28.4       365.0      -102.1
Dec      147.6      -14.9       531.5       -53.5
```

Figure 10.11: Save level zero report

```
Case_ID,Zone_ID,key,Value
retail_unit_not.cfg,sales_area,z_DHW_Month_1_MJ,        205.723
retail_unit_not.cfg,sales_area,z_DHW_Month_1_kWh,        57.145
retail_unit_not.cfg,sales_area,z_Lights_Month_1_kWh,      11602.7
retail_unit_not.cfg,sales_area,z_DHW_Month_2_MJ,        185.815
retail_unit_not.cfg,sales_area,z_DHW_Month_2_kWh,        51.615
retail_unit_not.cfg,sales_area,z_Lights_Month_2_kWh,      10448.1
 . . .
retail_unit_not.cfg,sales_area,z_DHW_Month_12_MJ,        205.723
retail_unit_not.cfg,sales_area,z_DHW_Month_12_kWh,        57.145
retail_unit_not.cfg,sales_area,z_Lights_Month_12_kWh,      11541.0
retail_unit_not.cfg,sales_area,z_DHW_MJ,      2422.226
retail_unit_not.cfg,sales_area,z_DHW_kWh,        672.841
retail_unit_not.cfg,sales_area,z_DHWkWhperm2,        1.019
retail_unit_not.cfg,sales_area,z_ReqLight_kWhm2,        206.404
retail_unit_not.cfg,sales_area,z_Aux_Month_1_kWh,      1804.083
 . . .
retail_unit_not.cfg,sales_area,z_Aux_Month_12_kWh,      1804.083
retail_unit_not.cfg,sales_area,z_hrs_operation,  4200.000
retail_unit_not.cfg,sales_area,z_Auxiliary_kWhm2,      32.801
retail_unit_not.cfg,sales_area,Overh_PercentOcc_Above27, 18.223
retail_unit_not.cfg,storage,z_DHW_Month_1_MJ,        0.000
retail_unit_not.cfg,storage,z_DHW_Month_1_kWh,        0.000
retail_unit_not.cfg,storage,z_Lights_Month_1_kWh,        187.4
 . . .
retail_unit_not.cfg,storage,z_DHW_Month_12_MJ,        0.000
retail_unit_not.cfg,storage,z_DHW_Month_12_kWh,        0.000
retail_unit_not.cfg,storage,z_Lights_Month_12_kWh,        184.9
retail_unit_not.cfg,storage,z_DHW_MJ,        0.000
retail_unit_not.cfg,storage,z_DHW_kWh,        0.000
retail_unit_not.cfg,storage,z_DHWkWhperm2,        0.000
retail_unit_not.cfg,storage,z_ReqLight_kWhm2,        6.457
retail_unit_not.cfg,storage,z_Aux_Month_1_kWh,        287.556
 . . .
retail_unit_not.cfg,storage,z_Aux_Month_12_kWh,        285.897
retail_unit_not.cfg,storage,z_hrs_operation,  4140.000
retail_unit_not.cfg,storage,z_Auxiliary_kWhm2,        10.098
retail_unit_not.cfg,storage,Overh_PercentOcc_Above27,  5.045
retail_unit_not.cfg,Total_DHW,t_DHW_kWh,        672.841
retail_unit_not.cfg,Total_DHW_per_m^2,t_DHW_kWhperm2,        0.673
retail_unit_not.cfg,Total_lighting,t_light_kWh,  138422.000
retail_unit_not.cfg,Total_lighting_per_m^2,t_light_kWhperm2,      138.422
retail_unit_not.cfg,Total_Auxiliary_Energy,t_aux_kWh,      25082.238
retail_unit_not.cfg,Total_Auxiliary_per_m^2,t_auxiliary_kWhperm2,        25.082
retail_unit_not.cfg,sales_area,MH1,        4.334
retail_unit_not.cfg,sales_area,MC1,        0.000
 . . .
retail_unit_not.cfg,sales_area,MH12,        4.495
retail_unit_not.cfg,sales_area,MC12,        0.000
retail_unit_not.cfg,sales_area,integrZAHforFloorArea,      11686.840
retail_unit_not.cfg,sales_area,integrZACforFloorArea,     -56970.551
retail_unit_not.cfg,storage,MH1,        15.775
retail_unit_not.cfg,storage,MC1,        0.000
 . . .
retail_unit_not.cfg,storage,MH12,        15.576
retail_unit_not.cfg,storage,MC12,        0.000
retail_unit_not.cfg,storage,integrZAHforFloorArea,      23314.041
retail_unit_not.cfg,storage,integrZACforFloorArea,        0.000
```

Figure 10.12: Save level six report

Each option for recording building and system performance during a simulation must be matched by a procedure to extract useful information. For save levels two, three and four this will primarily be the results analysis module discussed in Chapter 10.

Having discussed the process of setting up a simulation to record what we want the next chapter focuses on how we might use the recorded information to understand how a design performs.

UNDERSTANDING PERFORMANCE PREDICTIONS

11 Understanding performance predictions

Essentially, we invest our time and energy in the creation of models in order to get to the point where we can explore the temperatures, flux and flow generated by the simulation engine. The better our skills at identifying patterns and looking at the chain of thermophysical dependencies within our virtual world the better we can reach that **AH!** moment that allows us to tell someone else a cracking good story about what we have found.

Recognition of patterns in data is, for some users, a existing skill set with existing preferences. For example, a frequency bin of temperatures may lead you to a clear understanding of discomfort much more quickly than viewing graphs of temperature vs time.

For others, patterns emerge in the relationships between different aspects of building performance. So, for example, if you notice surface temperature elevation and you suspect a causal relationship with, say, solar radiation entering the room or the radiant component of casual gains then a mix of data needs to be reviewed.

And patterns may only emerge if data is viewed from different *perspectives*. Thus elevated surface temperatures might have been noticed initially in a graph and coincidence with solar radiation identified when overlaid on the same graph but the magnitude of risk only clear in a frequency bin report and the relationship with other types of heat gain to the surface in the context of a surface energy balance.

ESP-r allows you to defer decisions until after assessments have been completed and interactively control of the scope, depth, order and format of your explorations via the *res* module.

11.1 The res module

Rather than rely on third party spreadsheets and graphing tools, ESP-r includes the *res* module which has a rich set of facilities for recovering and presenting data from the random access files created by the ESP-r simulator *bps*. Effective use of these facilities draws on pattern matching skills as well knowledge of the thermophysical relationships inherent in the design.

The extent of the data held in the random access files is described in the *Entities Appendix*. Review this before proceeding.

After commissioning an assessment, you can request a results analysis via `Model Management -> browse/edit/simulate -> results analysis` in the *project manager*. The *res* module top level choices are listed at the left in Figure 11.1. Item `a Graphs` expands to the list of options on the right.

There may be a number of assessment periods associate with a project e.g. typical winter, transition and summer weeks as well as whole season and annual assessments. These *sets* of predictions may be contained within a single results file or each period may be placed in a separate file. If there are multiple sets of results within a single file option `2 Select result set` in Figure 11.1 allows you to switch between them.

Many of the menus in *res* include an option to define the *output period* which is a sub-set of the whole period of the assessment. Selecting `3 Define output period` would cause graphs to zoom in or statistics to be generated for the selected days.

The primary choices for how you want to view the performance information are found in choices:

- Enquire about (see section 11.1.1).
- Time-step reports (see section 11.2)
- Graphs (see section 11.3) The choices *Plant results, Electrical results and CFD* results choices opens domain specific results files.

The option *IPV* is typically not selected by users because the Integrated Performance View facility is controlled from the project manager via a command line syntax when *res* is invoked.

```
results analysis:                      Graph facilities:
1 Select result file                   2 Select result set
2 Select result set                    3 Define output period
3 Define output period                 4 Select zones
4 Select zones                         ------------------
a Graphs                               a Time:var graph
c Time-step reports                    b Intra-fabric
d Enquire about                        c 3D profile
e Plant results                        d Frequency histogram
f Indoor env. quality                  e Var:Var graph
g Electrical results                   f Network air/wtr flow
h CFD                                  ------------------
i Sensitivity                          ? Help
j IPV                                  - Exit
r Report >> silent
* Preferences
? Help
- Quit
```

Figure 11.1: High level choices in res module

11.1.1 Enquire about

Several classes of statistical report are found in the *Enquire about* menu structure shown on the left of Figure 11.2. Options for the `a summary statistics` summary statistics performance metrics can be seen in the right of Figure 11.2. These same metrics are available as time-step reports and via graphs.

Summary statistics reports take the general form shown in Figure 11.3. The extreme values and time of occurrence are reported along with the mean and standard deviation for each item and the last line of the report is the overall peak and mean. The time of occurrence is a particularly valuable - a peak temperature of 27C during occupied hours is of greater concern than the same peak at 23h00. These reports can be generated for just about every type of data.

The sub-sections of the summary statistics are seen in Figure 11.4. Some of these directly match the data types set out in section 9.2 and others such as *Zone db T - ambient db T* and *Predicted Mean Vote (PMV)* are derived values. More information about the available data types are found in the *Entities Appendix*.

```
Enquire about:                         Summary statistics:
2 select result set                    2 Result set
3 define output period                 3 Display period
4 select zones                         4 Select zones
a summary statistics                   a Climate
b frequency table                      b Temperatures
c hours above a value                  c Comfort metrics
d hours below a value                  d Solar processes
f energy delivered                     f Zone flux
g casual gains distrib                 g Surface flux
h zone energy balance                  h Heat/cool/humidify
i surface energy balnc                 i Zone RH
j surface condensation                 j Casual gains
k intrstl condensation                 k Electrical demand
l monthly gains/losses                 m Renewables/adv. comp.
m monthly temp. stats                  n Network air/wtr flow
> output >> screen                     o CFD metrics
^ delim >> normal                      p Measured:temporal
? help                                 > Display to >> screen
- exit                                 & Data: as values
                                       + Filter >> none
                                       * Time >> 10h30
                                       ^ Delim >> normal
                                       ? Help
                                       - Exit
```

Figure 11.2: Enquire about and summary statistics choices

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```
Lib: cellular_bcwin.res: Results for cellular_bc
Period: Mon-09-Jan@00h15(1967) to Sun-15-Jan@23h45 : sim@30m, output@30m
Zone db temperature (degC)

Description        Maximum                  Minimum          Mean      Standard
               value   occurrence       value   occurrence    value    deviation
manager_a      23.979  14-Jan@14h15     10.000  09-Jan@00h15  16.598   2.6780
manager_b      23.979  14-Jan@14h15     10.000  09-Jan@00h15  16.598   2.6781
corridor       24.004  14-Jan@17h15     13.981  09-Jan@00h45  19.639   2.0037
    All        24.004    --             10.000    --          17.612     --
```

Figure 11.3: Typical summary statistics report

```
Climate choices::                            Temperature choices::
a Ambient temperature                        a Zone db T
b Solar Dir N                                b Zone db T - ambient db T
c Solar diffuse                              c Zone db T - other zone db T
d Wind speed                                 d Zone control point T
e Wind direction                             e Zone Resultant T
f Ambient RH                                 f Mean Radiant T (area wtd)
g Sky illumunance                            g Mean Radiant T (at sensor)
? help                                       h Dew point T
- exit this menu                             i Surf inside face T
                                             j Surf T - dewpoint T
                                             k Surf outside face T
                                             l Surf node T
                                             ? help
                                             - exit this menu


Comfort choices::                            Select a solar flux metric
a Predicted Mean Vote (PMV)                  Solar choices::
b PMV using SET                              a Solar entering from outside
c Percentage Dissatisfied (PPD)             b Solar entering from adj
d Local delta T head-foot                    c Solar absorbed in zone
e Dissatisfied due to floor T                ? help
f Diss. warm/ cool ceiling                   - exit this menu
g Diss. wall rad T asymmetry
? help
- exit this menu
```

Figure 11.4: Climate, temperature, comfort and solar choices

The second section of the *summary statistics* menu includes *zone flux* and *surface flux* and these expand to the constituent parts of the zone and surface energy balance which were written into the file store (Figure 11.5). Again they can also be listed as timestep data in columns or graphed. These zone and surface energy balance flux path reports complement the full zone and surface energy balance reports (see section 11.1.4).

```
Zone flux options::          Surface fluxes:              m long wave > buildings
a Infiltration (from outside) a conduction (inside)        n long wave > sky
b Ventilation (adj zones)     b convection (inside)        o long wave > ground
c Occupant casual gains (R+C) c LW radiation (inside)      p SW rad abs (other fc)
d Lighting casual gains (R+C) d SW radiation (inside)      q SW rad incid (other fc)
e Small power casual gains (R+C) e radiant casual occup    r heat storage (other fc)
f Controlled casual gains (R+C  f radiant casual light     ? help
g Opaq surf conv @extrn       g radiant casual equip       - exit this menu
h Opaq surf conv @partns      i heat storage (inside)
i Tran surf conv @extrn       j plant inj/extr (inside)
j Tran surf conv @partns      k conduction (other face)
k Total surface conv          l convection (other face)
? help
- exit this menu
```

Figure 11.5: Zone and surface energy balance choices

11.1.2 Environmental systems reporting

In the results analysis if you want to see the environment system *loads* you would use the *Heat/cool/humidify* option. If you used detailed components then additional information will be available

in the plant reporting. The current choices are shown in Figure 11.7.

```
Load choices::
a Sensible heating load
b Sensible cooling load
c Dehumidification load
d Humidification load
e Sensible H+C loads
f Latent H+C loads
g All Sensible + latent load
h Aggregate heating load
i Aggregate cooling load
j Aggregate dehumidification
k Aggregate humidification
? help
- exit this menu
```

Figure 11.7 Heat / Cool / Humidify options.

You can report on heating separately from cooling or conflated together. Although in any zone you would not get a controller to simultaneously provide heating and cooling at the same time-step, there could be heating on one zone and cooling in another zone at a point in time. The latent loads will be reported if you have specified humidity control, otherwise the latent loads are zero. The `Aggregate` items sum the data for the current set of zones in order to illustrate environmental controls at a larger scale.

11.1.3 Casual gains

The reporting of casual gains in zones takes many forms because casual gains are made up of sensible and latent components as well as convective and radiative fractions of the sensible gains and there are (currently) three types of casual gains that can be tracked in each zone. The selection list is shown in Figure 11.8. Again, if `Aggregate` options are selected values for the current set of zones will be included as single values rather than one per zone.

```
Casual sensible and latent:          m equipment (conv+rad)
a all sensible (conv+rad)            n equipment convective
b all sensible convective            o equipment radiant
c all sensible radiant               p equipment latent
d all latent                         q controlled fraction
e occupant (conv+rad)                r controlled (conv+rad)
f occupant convective                s controlled convective
g occupant radiant                   t controlled radiant
h occupant latent                    u aggregate occupant (c+r)
i lighting (conv+rad)                v aggregate lighting (c+r)
j lighting convective                w aggregate equipment(c+r)
k lighting radiant                   x aggregate lights+equip
l lighitng latent                    ? help
                                     - exit this menu
```

Figure 11.8 Casual gain options.

Currently it is possible to apply control to lighting casual gains by defining a lighting control regime, the details of which are held in a casual gain control file. The control fraction is supposed to match the output of the lighting control regime.

11.1.4 Zone energy balances

ESP-r provides a powerful analysis capability via zone air node energy balance reporting as well as surface energy balance reporting. If save level 4 is selected, for each time-step of the period for which a simulation is undertaken the individual flux paths which make up the air node and surface energy balances are recorded. A typical report is shown in Figure 11.9. Notice the TOTAL line which reports the sum of all gains and the sum of all losses and these should balance each other closely (to a Whr) if the model is correct.

An energy balance (from the point of view of the zone air node) of all of the flux entering & leaving the air node should balance at each time-step of the sim- ulation. The report is an integration of each of the above types of flux over the period of the assessment.

A flux is positive if it adds heat to the air node of the zone and is negative if it removes heat from the air node of the zone. For example, if exterior surfaces which are opaque are always colder than the air

temperature then the report will include losses for interior surfaces. The flux paths are documented in the *Entities Appendix*.

```
Zone energy balance (kWhrs) for manager_b
                        Gain       Loss
Infiltration air load   0.000   -10.600
Ventilation air load    0.000     0.000
Uncontr'd casual Occupt  2.430    0.000
Uncontr'd casual Lights  0.000    0.000
Uncontr'd casual Equipt  0.000    0.000
Thermal bridge (linear)  0.000    0.000
Storage at air point     0.616   -0.627
Opaque surf convec: ext  0.106   -1.406
Opaque surf convec: ptn  4.285   -8.522
Transp surf convec: ext  0.001  -10.344
Transp surf convec: ptn  1.132   -0.471
Convec portion of plant 23.411   -0.011
Totals                  31.981  -31.981
```

Figure 11.9: Zone energy balance report

Experts considering how to improve the performance of a design will often look at the zone energy balance for clues. For example to reduce heating in cold weather they would check to see what were the biggest losses and they would focus on the biggest gains in hot weather.

In the above report the losses from infiltration and via convection at transparent surfaces facing the outside are almost the same. Is it less expensive to make the facade more air tight or to put in better quality windows? The energy balance makes very clear that improvements to the opaque portions of the facade will have very little impact on the heating demands.

11.1.5 Surface energy balances

A surface energy balance (see Figure 11.10) reports flux gains & losses at the inside face of the surface. For surfaces which have an exterior boundary condition, the 'other-side' face energy balance is also reported.

An energy balance from the point of view of a surface of the flux entering and leaving at each face should balance at each time-step of the simulation. The constituents of the report are described in the *Entities Appendix* and are summed over the period of the assessment. Typically one would expect that gains and losses balance to within 1W.

A flux is positive if it adds heat to surface and is negative if it removes heat from the surface. For example, if exterior surfaces which are opaque are always colder than the air temp the the surface energy balance report will indicate gains at the inside face. There is a TOTAL line which reports the sum of all gains and the sum of all losses and these should balance each other closely if the model is correct.

```
Causal energy breakdown (Whrs) for part_glaz (10) in manager_a ( 1)
Surface is trnsp., area= 4.48m^2 & connects to surface 9 in zone 3

                    Facing manager_a
                    Gain        Loss
Conductive flux    4985.42     -59.43
Convective flux     470.62   -1132.32
Long-wave rad int    46.10   -4502.90
LW rad ext >bldg       --         --
LW rad ext >sky        --         --
LW rad ext >grnd       --         --
Shortwave rad.       59.00       0.00
Occupt casual gn    141.12       0.00
Lights casual gn      0.00       0.00
Equipt casual gn      0.00       0.00

Controlled casual     0.00       0.00
Heat stored         145.79    -153.39
Plant                 0.00       0.00
Totals             5848.05   -5848.04
```

For surfaces facing the outside the energy balance is reported as follows:

```
Period: Mon-09-Jan@00h15 to Sun-15-Jan@23h45(1967) : sim@30m, output@30m
 Causal energy breakdown (Whrs) for spandrel ( 7) in manager_a ( 1)
 Surface is opaque MLC, area=  2.70m^2 & connects to the outside

                    Facing manager_a          Facing outside
                    Gain       Loss          Gain       Loss
Conductive flux       0.27   -2853.92       3198.10    -354.00
Convective flux    1054.75     -80.06       2033.87   -3531.10
Long-wave rad int  1395.28    -209.51         --          --
LW rad ext >bldg      --         --          342.02     -87.26
LW rad ext >sky       --         --            0.00   -7315.40
LW rad ext >grnd      --         --           60.73   -1209.33
Shortwave rad.      612.81       0.00       6872.32       0.00
Occupt casual gn     84.03       0.00         --          --
Lights casual gn      0.00       0.00         --          --
Equipt casual gn      0.00       0.00         --          --
Controlled casual     0.00       0.00         --          --
Heat stored          87.40     -90.71        194.55    -203.53
Plant                 0.00       0.00          0.00       0.00
Totals             3234.53   -3234.20      12701.58  -12700.62
```

Figure 11.10: Surface energy balance reports

And experts would also check surface energy balances to determine what change might be appropriate. In the above case the primary loss in the spandrel is conductive so there is room for improvements in insulation levels. As expected the biggest loss for the inside partition glazing is via conduction (the convective exchanges are constrained by the low air velocity in the room).

11.1.6 Hours above and below

During performance evaluation sessions it is common to have questions in the form "how often is it warmer than X" or "how often is solar radiation on that surface more than Y Watts/m2". To answer such questions quickly for any of the standard performance metrics the *Enquire about* menus have an option for *hours above* and *hours below*. The choices are the same as on the right of Figure 11.2.

11.1.7 Energy delivered

Some performance questions relate to capacity and these are typically covered in the summary statistics reports. If the performance question is how often was heating or cooling required and how many kWhr were delivered during the assessment period then there are other choices such as the *Energy delivered* reports (Figure 11.12) which provide this information.

There are several items of interest in the energy delivered report. For each zone the sensible values for reported and the total for the included zones is written at the end of the report. The hours required may provide evidence of systems being used at low capacity for many hours.

Another report which includes the energy delivered is the monthly gains and losses report (Figure 11.13). Many users mistake this as a monthly energy balance report bit it only includes a subset of the information included in the zone energy balance report.

```
The energy delivered menu offers the following report:
Lib: cellular_bcwin.res: Results for cellular_bc
Period: Mon-09-Jan@00h15(1967) to Sun-15-Jan@23h45(1967) : sim@30m, output@30m

 Zone total sensible and latent plant used (kWhrs)
    Zone          Sensible heating  Sensible cooling  Humidification    Dehumidification
 id name          Energy   No. of   Energy   No. of   Energy   No. of   Energy   No. of
                  (kWhrs)  Hr rqd   (kWhrs)  Hr rqd   (kWhrs)  Hr rqd   (kWhrs)  Hr rqd
  1 manager_a     23.41   117.5     -0.01     1.0      0.00     0.0      0.00     0.0
  2 manager_b     23.41   117.5     -0.01     1.0      0.00     0.0      0.00     0.0
  3 coridor        1.95    22.0     -0.04     3.5      0.00     0.0      0.00     0.0

   All            48.78   257.0     -0.07     5.5      0.00     0.0      0.00     0.0
```

Figure 11.12: Energy delivered report

The monthly gains and losses report includes the following:

- convective exchanges at transparent surfaces which face the outside or something not-the-outside
- convective exchanges at opaque surfaces which face the outside or something not-the-outside
- sum of all casual sensible convective gains
- sum of all casual sensible radiant gains
- aggregate gains or losses associated with infiltration (air from the outside either natural or forced)
- aggregate gains or losses associated with ventilation (air exchanges with other thermal zones either natural or forced)
- heat delivered to the zone
- cooling extracted from the zone
- solar radiation absorbed at surfaces in the zone
- solar radiation entering the zone from the outside

```
Lib: cellular_bcwin.res: Results for cellular_bc
Period: Mon-09-Jan@00h15(1967) to Sun-15-Jan@23h45(1967) : sim@30m, output@30m
Monthly selection of gains & losses (to nearest 100Wh).


Zone        Period|Transp surf|Opaque surfs|Casual Gain|Infil|Vent|  Plant   |Solar radiation|
              in  |exter|other|extern|other|conv  radnt|     |    |Heat|Cool|absor |entering|
                  |facng|facng|facing|facng|           |     |    |    |    |inside|zone    |
manager_a   Jan    -39.   4.    -4.   -4.   11.   11.   -42.  0.   80.   -5.   52.      59.
            Feb    -29.   6.     0.   28.   10.   10.   -38.  0.   38.  -16.   96.     109.
            Mar    -22.  11.     8.   93.   11.   11.   -44.  0.   13.  -69.  210.     240.
            Apr    -20.   9.     5.   69.   10.   10.   -41.  0.   12.  -45.  159.     181.
            May     -9.  12.    11.  116.   11.   11.   -38.  0.    1. -105.  228.     259.
            Jun      2.  11.    12.  118.   11.   11.   -30.  0.    0. -124.  208.     237.
            Jul     12.  11.    15.  139.   11.   11.   -20.  0.    0. -169.  225.     256.
            Aug      8.  12.    15.  140.   11.   11.   -25.  0.    0. -161.  233.     266.
            Sep    -11.   7.     5.   56.   11.   11.   -25.  0.    1.  -43.  117.     133.
            Oct    -17.   9.     5.   64.   11.   11.   -33.  0.    5.  -43.  141.     161.
            Nov    -30.   6.    -1.   16.   11.   11.   -39.  0.   50.  -12.   66.      76.
            Dec    -37.   5.    -3.    2.   11.   11.   -43.  0.   72.   -6.   50.      57.
manager_b   Jan    -39.   4.    -4.   -4.   11.   11.   -42.  0.   80.   -5.   52.      59.
            Feb    -29.   6.     0.   28.   10.   10.   -38.  0.   38.  -16.   96.     109.
            Mar    -22.  11.     8.   93.   11.   11.   -44.  0.   13.  -69.  210.     240.
            Apr    -20.   9.     5.   69.   10.   10.   -41.  0.   12.  -45.  159.     181.
            May     -9.  12.    11.  116.   11.   11.   -38.  0.    1. -105.  228.     259.
            Jun      2.  11.    12.  118.   11.   11.   -30.  0.    0. -124.  208.     237.
            Jul     12.  11.    15.  139.   11.   11.   -20.  0.    0. -169.  225.     256.
            Aug      8.  12.    15.  140.   11.   11.   -25.  0.    0. -161.  233.     266.
            Sep    -11.   7.     5.   56.   11.   11.   -25.  0.    1.  -43.  117.     133.
            Oct    -17.   9.     5.   64.   11.   11.   -33.  0.    5.  -43.  141.     161.
            Nov    -30.   6.    -1.   16.   11.   11.   -39.  0.   50.  -12.   66.      76.
            Dec    -37.   5.    -3.    2.   11.   11.   -43.  0.   72.   -6.   50.      57.
coridor     Jan      0. -12.     0.  -25.   34.   34.     0.  0.    5.   -2.    7.       0.
            Feb      0.  -9.     0.  -15.   31.   31.     0.  0.    1.   -7.   13.       0.
            Mar      0.  -2.     0.    9.   34.   34.     0.  0.    0.  -41.   29.       0.
   . . . .
            Nov      0. -11.     0.  -20.   33.   33.     0.  0.    2.   -4.    9.       0.
            Dec      0. -12.     0.  -24.   34.   34.     0.  0.    3.   -2.    7.       0.
All zones   Jan    -78.  -4.    -8.  -34.   55.   55.   -85.  0. 164.  -11.  111.     118.
            Feb    -57.   4.     1.   40.   50.   50.   -76.  0.   77.  -39.  205.     218.
            Mar    -44.  20.    15.  195.   56.   56.   -89.  0.   25. -179.  450.     480.
            Apr    -40.  14.    11.  137.   53.   53.   -81.  0.   25. -118.  340.     361.
            May    -17.  27.    22.  260.   56.   56.   -76.  0.    3. -275.  487.     518.
            Jun      4.  28.    25.  271.   54.   54.   -59.  0.    0. -323.  446.     473.
            Jul     25.  34.    30.  330.   55.   55.   -40.  0.    0. -433.  481.     512.
            Aug     16.  34.    29.  325.   56.   56.   -50.  0.    0. -410.  498.     531.
            Sep    -21.  13.     9.  119.   54.   54.   -51.  0.    2. -125.  250.     266.
            Oct    -33.  14.    10.  132.   55.   55.   -66.  0.    9. -120.  302.     322.
            Nov    -60.   1.    -2.   12.   54.   54.   -78.  0. 101.  -28.  142.     151.
            Dec    -74.  -3.    -6.  -20.   55.   55.   -85.  0. 148.  -15.  107.     114.
  Annual         -381. 182.   135. 1766.  656.  656.  -836.  0. 554.-2077. 3820.    4066.
```

Figure 11.13: Monthly gains and losses report

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11.1.8 Condensation reports

If we know the air temperature and the humidity as well as the surface temperature it is possible to report how often condensation would form on surfaces in a room. The report does not say whether the condensation is a light misting or is severe enough to cause water droplets to form, simply that conditions exist for some degree of condensation. There are several options that can enhance the report. Firstly the actual humidity in the room can be used. For tests of sensitivity the user can also nominate a specific humidity and base the report on that.

The condensation report takes two forms - a summary that includes the number of hours of condensation for each of the surfaces and a detailed time-step-by-time-step listing of occurrences for each surface in the zone. These are shown in Figure 11.14.

```
Summary condensation report for: coridor      . . .
Surface   occurrences  hours              16h15 X X X X X X X X X X X X X X
right            170    85.00             16h45 X X X X X X X X X X X X X X
wall            167    83.50             17h15 X X X X X X X X X X X X X X
left            170    85.00             17h45 X X X X X X X X X X X X X X
ceiling         169    84.50             18h15 X X X X X X X X X X X X X X
floor           168    84.00             18h45 X X X X X X X X X X X X X X
door            325   162.50             19h15 X X X X X X X X X X X X X X
ptn_corid       318   159.00             19h45 X X X X X X X X X X X X X X
part_frame      273   136.50             20h15 X X X X X X X X X X X X X X
part_glaz       324   162.00             20h45 . . . . . X X . X . X X X .
part_frameb     278   139.00             21h15 . . . . . X X . X . X X X .
door_b          325   162.50             21h45 . . . . . X X X X X X X X .
ptn_coridb      318   159.00             22h15 . . . . . X X . X X X X X .
part_glazb      324   162.00             22h45 . . . . . X X X X X X X X .
filler          170    85.00             23h15 . . . . . X X X X X X X X .
Total occur & hours in coridor 327 163.50 23h45 . . . . . X X X X X X X X .
```

Figure 11.14 Summary and detailed condensation reports.

Condensation within a construction is also a topic of concern for some assessments. If save level 3 is used (nodal temperatures are recorded) then it is possible to plot temperature profiles over time as well as identify interstitial condensation.

11.2 Time-step reporting

Where graphs are good at indicating patterns they do not provide sufficient resolution to determine the specific values at a specific time.

For each item that is subject to a statistical report or might be included in a graph there is another option to view the item or a user defined collection of items in columns time-step-by-time-step. The interface options for time-step reporting are shown in Figure 11.15. The *performance metrics* options should look familiar!

```
Tabular Output:              Performance metrics:
 2 select result set           2 Result set          m Renewables/adv. comp.
 3 define period               3 Display period       n Network air/wtr flow
 4 select zones                4 Select zones         o CFD metrics
 g performance metrics         a Climate              p Measured:temporal
 h special material data       b Temperatures         > Display to >> screen
 i network air/wtr flow        c Comfort metrics      & Data: as values
 _____         d Solar processes      + Filter >> none
    formatting...              f Zone flux            * Time >> 10h30
 > output >> screen            g Surface flux         ^ Delim >> normal
 * time >> 10h30               h Heat/cool/humidify    ! List data
 * labels >> multiline         i Zone RH              ? Help
 ^ delim >> normal             j Casual gains         - Exit
 ? help                        k Electrical demand
 - exit                        m Renewables/adv. comp.
                               . . . . . . . . . . . . . .^
```

Figure 11.15 Time-step options.

The interactive display in *res* tends not to be presentation quality the process of data export to third party tools is enabled via the `> Display to >> file` options found in many of the command windows. Time-step listings are thus a common approach to exporting data into comma separated or tab separated

columns for processing in a third party application. At the bottom of the menu are options to redirect the output from the screen to a user nominated file. There is also a toggle for time to be written in an *10h30* form or as 0.4375 fraction of the day or the form of date and time most easily recognized by spreadsheet applications. The options for labels on one line (e.g. for inclusion in a spreadsheet) as well as for setting the delimiter from a space to a tab or a comma allow reports to be more easily accepted by 3rd party tools.

The listing in Figure 11.16 has the time in the first column, the outside ambient temperature in the 2nd column and each zone resultant temperatures in the remaining columns.

```
# Time-step performance metrics.
# Lib: cellular_bc_ann.res:
    Results for cellular_bc
# Period: Sun-15-Jan@00h15 to
    Mon-16-Jan@11h45(1967): sim@30m, output@30m
#Time AmbientdbTmp(degC) manager_aResT(degC)
    manager_bResT(degC) coridorResT(degC)
15.0104,3.15,15.27,15.26,19.85
15.0313,2.85,15.21,15.21,19.69
15.0521,2.70,15.05,15.05,19.54
15.0729,2.70,14.82,14.82,19.40
15.0938,2.70,14.66,14.66,19.27
15.1146,2.70,14.52,14.52,19.14
15.1354,2.58,14.35,14.35,19.01
15.1563,2.33,14.20,14.20,18.88
15.1771,2.20,14.05,14.05,18.75
15.1979,2.20,13.90,13.90,18.63
15.2188,2.20,13.76,13.76,18.50
15.2396,2.20,13.64,13.64,18.38
15.2604,2.20,13.51,13.51,18.26
15.2813,2.20,13.40,13.40,18.14
15.3021,2.20,13.29,13.29,18.02
15.3229,2.20,13.18,13.18,17.90
15.3438,2.20,13.09,13.09,18.15
15.3646,2.20,13.01,13.01,18.68
15.3854,2.20,12.97,12.97,18.85
15.4063,2.20,12.98,12.98,18.91
15.4271,2.05,13.03,13.03,19.03
 . . .
```

Figure 11.16 Time-step reports.

▶ Section   The time-step listing facility can, of course be scripted as can other text-based reporting if you invoke the results analysis application in text mode at the command line (see section 17.1).

11.3 Graphic reporting

ESP-r offers a number of forms of graphic display for data. The high level options are shown in Figure 11.17.

```
Graph facilities:
  2 Select result set
  3 Define output period
  4 Select zones
    -------------------
  a Time:var graph
  b Intra-fabric
  c 3D profile
  d Frequency histogram
  e Var:Var graph
  f Network air/wtr flow
    -------------------
  ? Help
  - Exit
```

Figure 11.17 Graphic report options.

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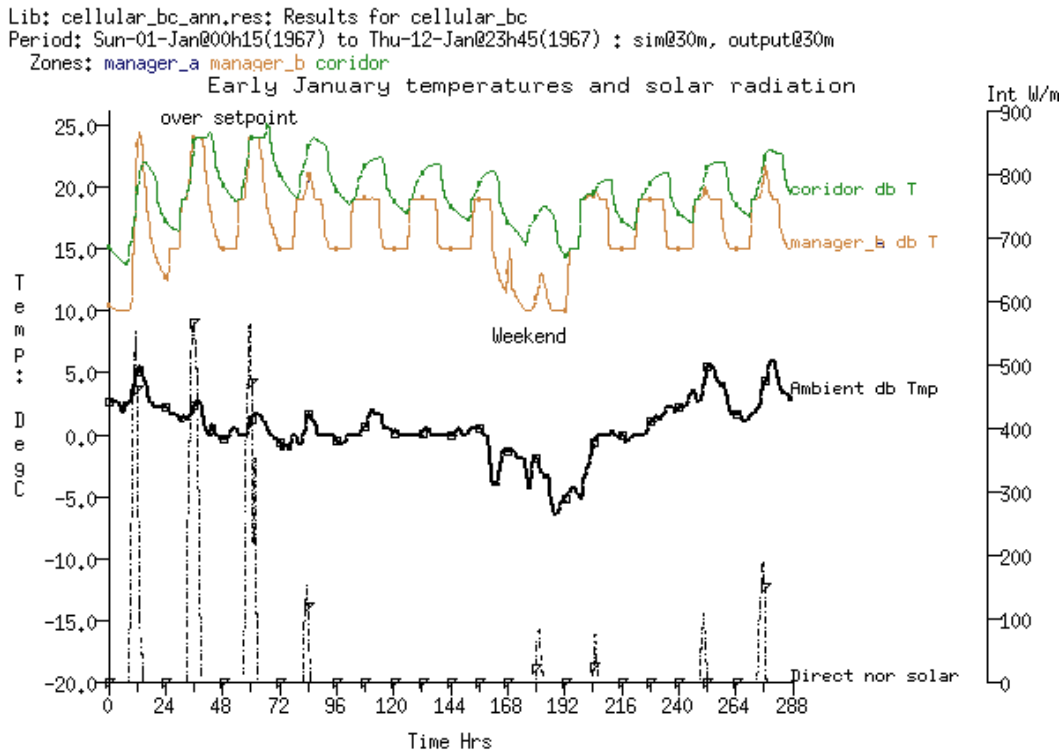
Figure 11.18 Example multi-axis graph.
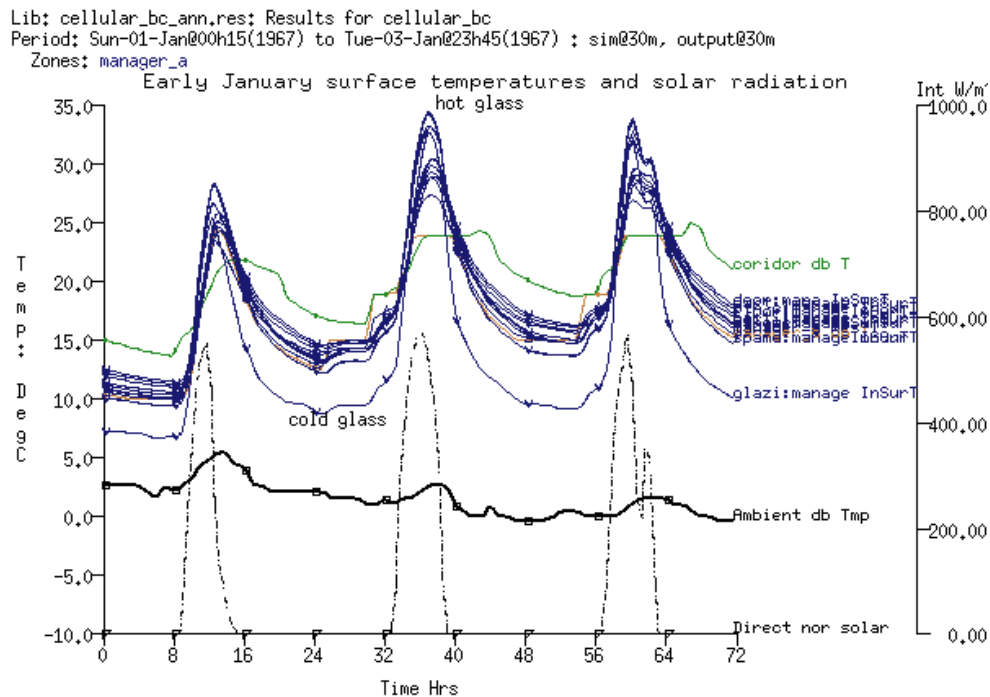
Figure 11.19 Example focused multi-axis graph.

11.3.1 Variables against time

The *Time:var graph* supports ad-hoc creation of graphs with multiple axis as seen in Figure 11.18. Here twelve days in January are graphed with the zone dry bulb temperatures of three zones shown along with the ambient outside temperature and the direct solar radiation.

It is clear in the graph that on weekday nights the temperature in the rooms falls to at 15°C night set-back temperature and at the weekends there is a frost protection setting at 10°C. On the initial days of the simulation the room temperature rises to the cooling set-point and to determine if this was due to solar radiation entering the rooms the solar radiation plot was added to the graph. For days where there is little direct solar radiation the un-conditioned corridor room is cooler when it is cooler outside and warmer

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when it is warmer outside.

In Figure 11.19 the user has focused the graph on the first three days of the assessment and restricted the graph to the manager_a zone and has added into the graph the inside face surface temperatures of all the surfaces in manager_a. Most of the surface temperatures track within a 3-4 degree range, except for the glazing which gets hottest at mid-day and coldest overnight.

And the graph is somewhat confusing in that the names of the lines for the surface temperatures overlap and it is not all that clear which one is the room dry bulb temperature. This might be a good reason for switching to the time-step listing report so that the specific temperatures can be seen or even to ask for statistics on surface temperatures.

11.3.2 Frequency bin

Earlier the discussion pointed out that the time of occurrence of extreme values can be important in assessments. Some users are also interested in the frequency distribution of values in rooms. For example, regulations might prescribe the number of hours in the summer that temperatures are allowed to go above 25°C. A frequency bin is a quick way to determine the rarity of extremes.

In Figure 11.20 is the annual distribution of dry bulb temperatures in the manager_a room. Because the data was not filtered by occupancy (e.g. for occupied hours) there is a range of 10 - 30 degrees with a bit over 20% of the time near 24 (the cooling set-point), 16% near 19 (the heating set-point) and about 10% of the time near 15°C (the night setback).

Often a frequency bin will demonstrate a recognizable normal distribution and the task becomes to choose points of significance at the upper and lower boundary of the range. For example, if there are 5% of delivered heating is above 15kW with a peak at 19kW then some users might explore the possibility of designing for 15kW with an adaptive control scheme.
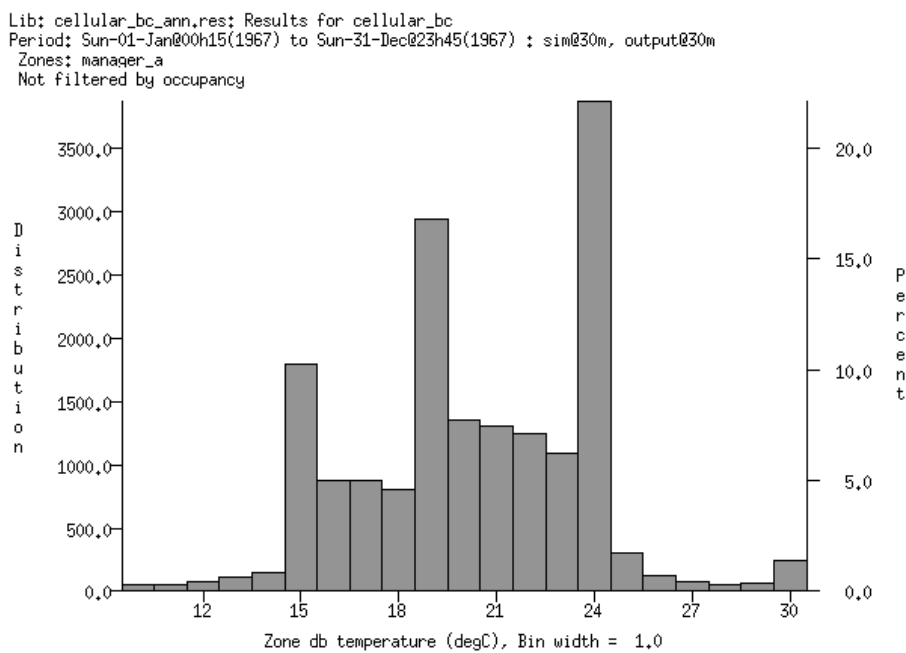
Figure 11.20 Example frequency bin.

11.3.3 3D surface plots

An alternative to a *flat graph* is a 3D surface plot where time is seen on the right axis, days are on the left axis and the value is shown as a height. Figure 11.21 shows the convective casual gains for the room manager_a. The dip at mid-day for lunch breaks can be seen as can the weekend breaks along the day axis. Great for checking the impact of lighting controls!

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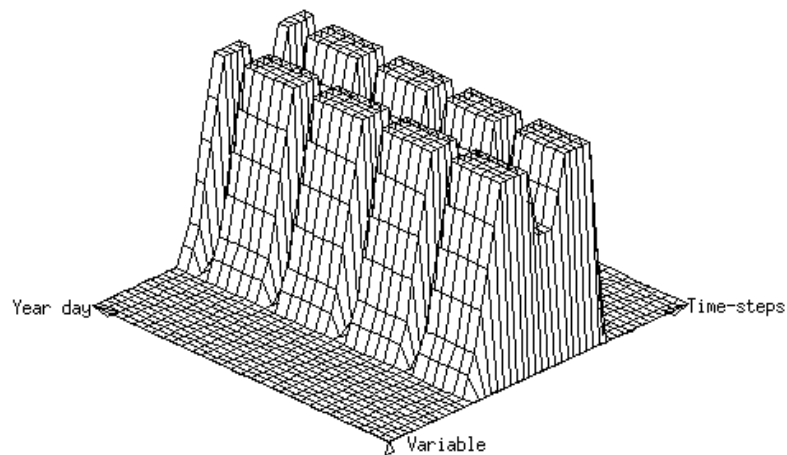
Figure 11.21 Example 3D plot of casual gains over time.

11.3.4 Variable vs variable graphs

The correlation between two variables can be visually explored if they are plotted with the first variable on one axis and the second variable on the other axis. In Figure 11.22 there would seem to be a fair correlation between the dry bulb temperature in the rooms and the resultant temperature in the rooms. There are occasional deviations near 15 and 19 degrees as might be expected because of the cycling of the heating in the rooms.
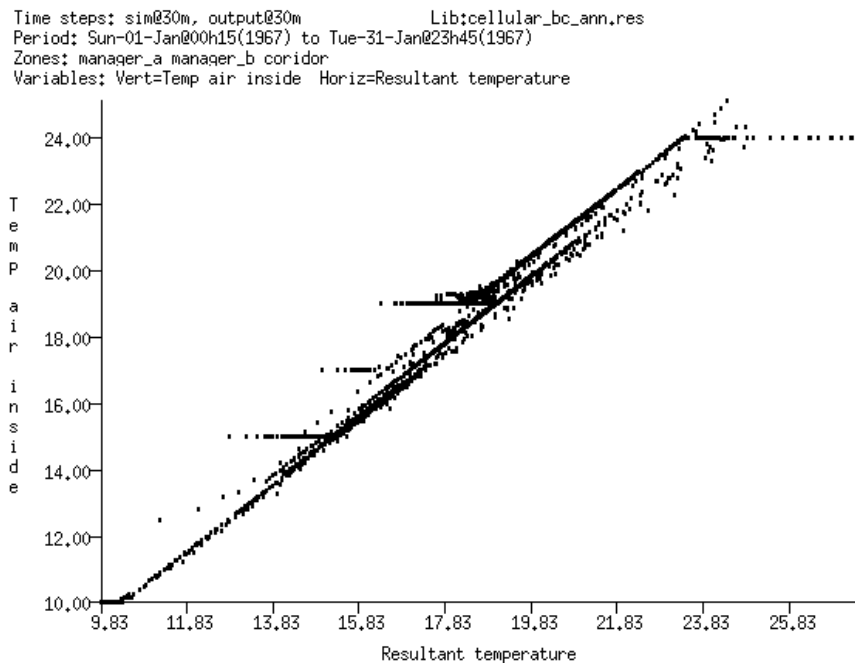
Figure 11.22 Example variable vs variable graph.

11.4 Methods for exploration of data sets

The discussion thus far has reviewed the types of information that can be accessed in the results analysis module of ESP-r and shown sample of many of the possible reports.

Those who deliver exceptional value into the design process tend to have exception pattern matching skills as well as a solid grounding in the underlying physics of buildings and systems. The ad-hoc nature of interactions in the results analysis module gives such users scope for identifying the underlying issues. So in Figure 11.19 the user initially plotted the room temperatures and then added the ambient temperature to confirm a sensitivity to the outside. The need for cooling in January was noticed and the question of 'what could make it warm' lead to a guess that solar radiation might be the core issue and so this was added to the graph. The next step was to look at the surface temperatures in a typical room to see what was getting warm. And one might also follow this with a quick review of the zone energy balances.

Pattern matching is a skill that can be acquired. With practice and guidance from experienced users novices (and even Architectural students) begin to recognize patterns and follow these to likely causal elements in their designs. It may take a number of iterations to accomplish this but it is one of the most important of simulation skills.

11.4.1 Exploring environmental control response

In section 6.3.1 the two cellular offices with passage training model with a basic control loop was used to explore the definition of controls which could be used to explore demand-supply matching issues such as:

- How often and when is the control actually used?
- How often are the room temperatures in the dead-band?
- How quickly do the room conditions deteriorate when the schedule switches to free-float?
- How often is heat being delivered at a fraction of the system capacity?

▶ **Exercise 6.2**   In the exercise 6.1 you were shown the steps for exploring the control law attributes. Exercise 6.2 involved invoking the standard winter assessment. If you have not done so, complete the winter assessment so that you can follow along with our exploration of the performance of this model.

The winter performance should indicate rooms are controlled during office hours and a set-back temperature is maintained overnight with a free float from late Saturday till early Monday. Most of these expectations are confirmed in the performance data included in Figure 11.23.

Note that the set-point in the two offices is maintained or slightly exceeded on most days and the night time temperature drifts down to the set-back. The corridor is warmer than the heating set-point and even reaches the cooling set-point for a few hours.

There are two deviations in the control which need to be explained. Why is Wednesday sufficiently warm in the room to reach the cooling set-point and should the free-float condition on Sunday coincide with the warmest predicted temperatures in addition to the expected coldest temperatures?

Strategies for *what-else-do-I-look-at* might begin with looking for *something* that is happening at the same time that might cause the thermophysical state that we are trying to explain. Those with experience will have opinions as to *the usual suspects*.

In the case of this model, the lightweight construction and the large area of glazing would suggest that one of *the usual suspects* for overheating is solar radiation. The graph in Figure 11.24 shows that there is a peak solar occurrence that coincides with Wednesday and Sunday. One might conclude that these offices are sensitive to solar gains.

If we want to evaluate the capacity required in these rooms we can use the `Summary Statistics -> heat/cool/humidify report` which is reproduced in Figure 11.24.

The information in this report should be used in conjunction with the graph in Figure 11.23 when considering the capacity needed. The statistics provide a value and a time of occurrence. As in most buildings the peak condition happens at different times in different rooms. The total is a *diversified* total which is based on the simultaneous peak rather than a summary of the individual peaks..
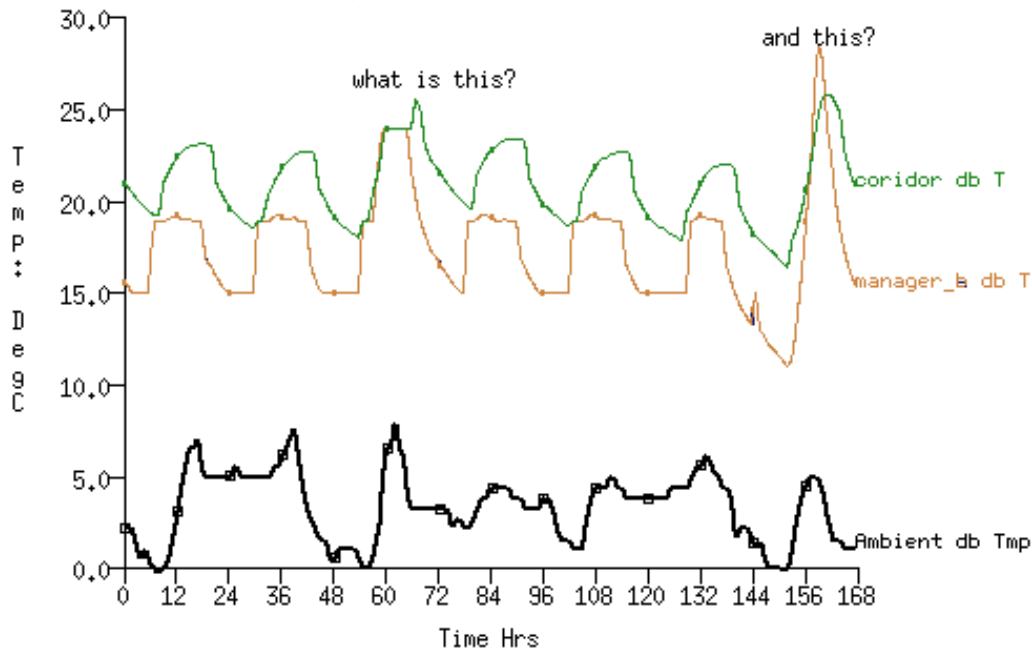
Figure 11.23 Winter temperature performance predictions.

The graph is important because the shape of the response of the environmental control allows us to better interpret the statistics as well as providing an early clue as to likely equipment choices or architectural interventions. The heating pattern is an early morning peak which rapidly decreases. The cooling demand is also a brief peak which decreases over several hours.

In this case there not a *sustained* demand for either heating or cooling. The graph indicates a classic pattern for which there are several classic solutions.
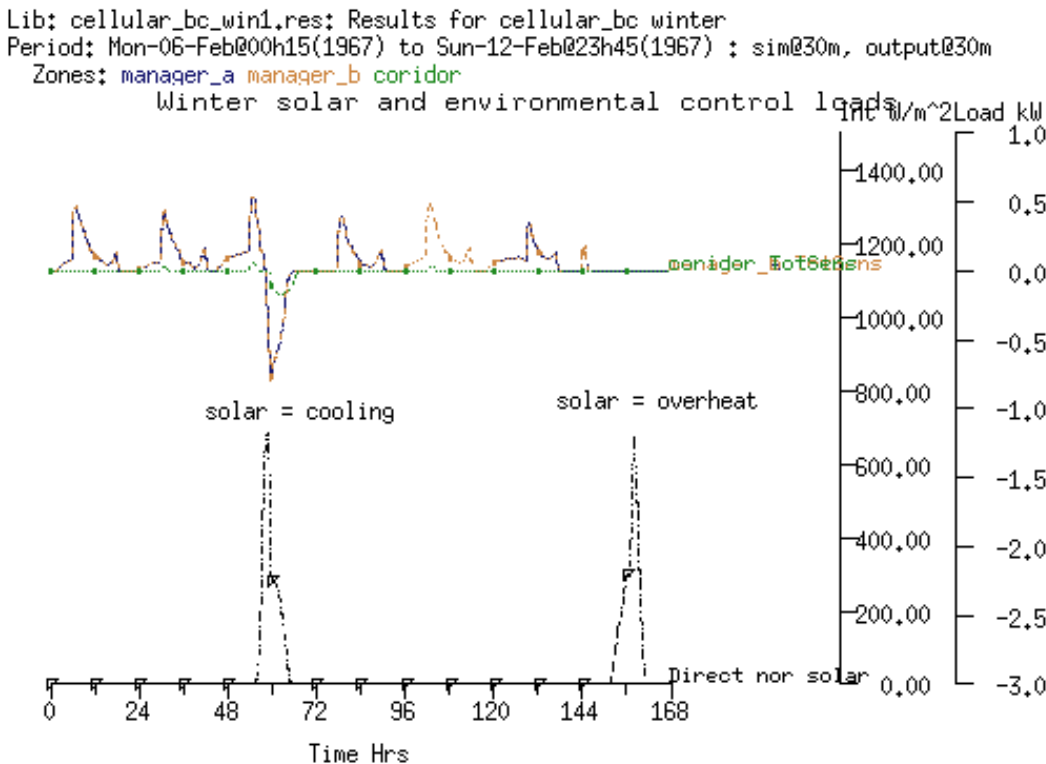
Figure 11.24 Winter environmental control use vs solar.

```
Lib: cellular_bc_win1.res: Results for cellular_bc winter
Period: Mon-06-Feb@00h15(1967) to Sun-12-Feb@23h45(1967) : sim@30m,
Zone sensible load (kW)

Description          Maximum                  Minimum
                 value    occurrence      value    occurrence
manager_a        0.52775  08-Feb@06h45    -0.79066  08-Feb@11h45
manager_b        0.52759  08-Feb@06h45    -0.79104  08-Feb@11h45
coridor          0.06318  08-Feb@07h15    -0.16820  08-Feb@14h15

    All          1.1181   08-Feb@06h45    -1.6361   08-Feb@11h45
```

Figure 11.25 Winter heating and cooling peak statistics.

The other report which may be of interest is the integrated energy demand which is found in the `Enquire about -> energy delivered` report (Figure 11.25).

In this report the heating and cooling is expressed in kWhrs and the number of hours that heating and cooling were active. Those with experience will be looking for options to deal with intermittent system use. There are stand-by costs and start-up costs which may need to be considered. Where the average rate of delivery is considerably different from the peak then there are a number of classic solutions which experienced practitioners will want to begin to consider.

```
Lib: cellular_bc_win1.res: Results for cellular_bc winter
Period: Mon-06-Feb@00h15(1967) to Sun-12-Feb@23h45(1967) : sim@30m, output

Zone total sensible and latent plant used (kWhrs)
    Zone        Sensible heating  Sensible cooling  Humidification
id name         Energy   No. of   Energy   No. of   Energy   No. of
                (kWhrs)  Hr rqd   (kWhrs)  Hr rqd   (kWhrs)  Hr rqd
1 manager_a     13.78    102.5    -2.93    7.0      0.00     0.0
2 manager_b     13.78    102.5    -2.93    7.0      0.00     0.0
3 coridor        0.23      7.5    -0.92    7.5      0.00     0.0

    All         27.79    212.5    -6.79   21.5      0.00     0.0
```

Figure 11.26 Winter heating and cooling energy delivered.

If we turn our attention to a typical spring week in Figure 11.26 we find that there are few hours that heating is required (briefly on Wednesday morning and Friday morning) and, depending on the temperature outside, quite a few hours when cooling is required in all rooms.

The graph in Figure 11.27 indicates that there are only brief requirements for heating and there is a short time between the demand for heating and the demand for cooling. This poses several issues for the design team. An experienced practitioner might consider several alternative scenarios for spring:

• disabling heating other than as a frost protection on days that start above 5C.
• altering the area of glazing to limit the solar radiation entering the room
• adding an outside shading device to moderate solar radiation falling on the facade
• adding internal mass to the room to reduce the rapid change in temperature.

The temperature pattern in the corridor is also instructive. The rise in temperature after the control period indicates that there is excess heat stored in the fabric of the corridor. On warm days (say above 15°C) the subsequent day finds the corridor temperature just below the cooling set-point. It is likely that this pattern will also be found in the summer and thus cooling will be required from the start of business.
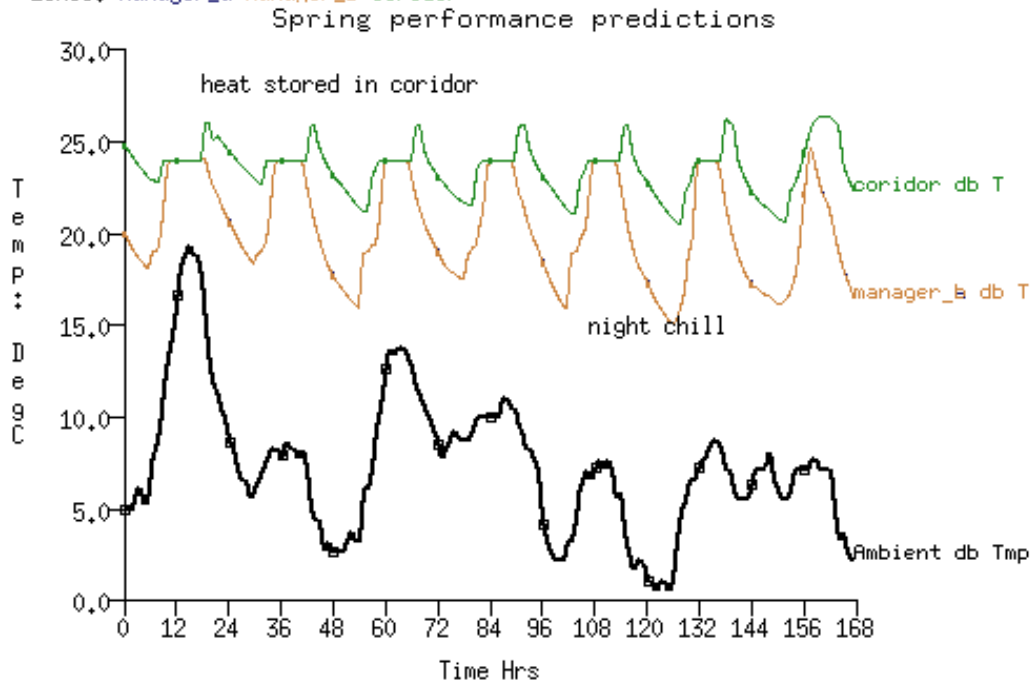
Figure 11.27 Spring performance predictions.
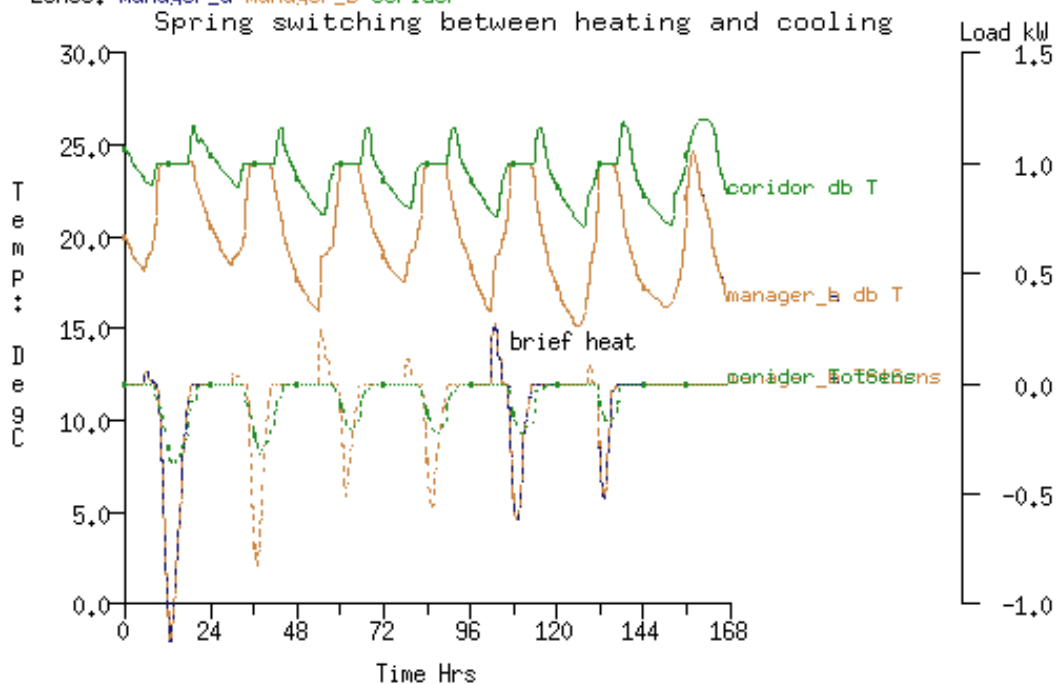
Figure 11.28 Spring switch from heating to cooling.

11.5 Marginal cost of testing ideas

Once a model exists the marginal cost of testing ideas tends to be low. It takes only moments to run focused simulations. It also only takes moments to use the results analysis module to generate and capture a sequence of graphs. Such patterns of performance can be valuable feedback to the design process.

In the early chapters the planning process included a review of weather patterns and if the selected periods are included in the model then it is easy to re-run assessments as the design and the model evolve. Experienced practitioners use such techniques to support interactive explorations.

11.6 Exploring uncertainty

Simulation models are abstractions of designs which, when processed by numerical engines, give rise to predictions which *appear to be precise*. Such reporting precision is probably unwarranted. Building are rarely implemented exactly as the construction documents specify, materials properties may differ between batches, thermostats may be poorly calibrated, ducts and fans may not have been properly comissioned. The way a building is used and the number of occupants may only roughly correspond to the assumptions used in the design process.

The abstraction needed when translating designs into the descriptive syntax of simulation tools introduces risk in the form of approximations and input errors. It is thus useful to explore whether variability in the form and fabric and use would lead to different design decisions or to the management of facilities. There are many approaches users can take to introduce uncertainty into models:

- Manual interventions - users can *hack* the model description files. This is often deceptively easy and just as often difficult to manage. It presumes a knowledge of the location and syntax of model entities as well as numerical skills needed if the aim is to implement a formal uncertainty regime. The user then comissions assessments, extracts performance data and then repeats the exercise (perhaps with some automation).

- Bespoke agent-based interventions - software agents with an embedeed knowledge of the location and syntax of model entitie and drivers for uncertainty regimes are used to automate the process of peturbing the model, invoking the required assessments and undertaking performance data extraction. Here the agent is bespoke (i.e. designed to implement specific uncertainty regimes on a specific model).

- General agent-based interventions - as above but with uncertainty directives supplied from an external source so that a variety of uncertainty regimes can be applied to simulation models.

- Embedded formal interventions - uncertainty directives are part of the model description and acted upon by the simulation engine, perhaps with a managing agent that is also taking its instructions from the formal uncertainty directives found in the model.

There are, of course, any number of ways to impose changes within a simulation model - a) users can manually drive the simulation tool interface (this does not scale well), b) a pattern matching language such as grep can be used to search and replace tokens in the model files, c) scripts can *drive* the tool interface to carry out specific editing tasks.

Uncertainty explorations may involve the creation of scores, if not hundreds, of model variants. Proving that the process is robust is one of many challenges. Few simulation tools were initially designed to accommodate large numbers of models and the skills used to support normal simulation use differ from those needed to manage a diversity of models.

Any of the above approaches can be used with ESP-r but we will focus on the *embedded formal intervention* approach within ESP-r. It uses a formal description of uncertainty which takes the general form of named lists of *what attributes of the model are uncertain* and named lists defining *where (temporal scope or location)*. These *What/Where* defintions are paired as needed. The attributes of a model which can be uncertain include thermophysical properties, surface properties, zone casual gains, ideal controls and weather data:

- thermophysical properties of a material - conductivity, density, specific heat, surface emissivity and absorptivity and diffusion resistance
- layer thickness within construction,
- zone air volume or a surface area,
- weather data - dry-bulb temperature, direct normal & diffuse solar radiation, wind speed and wind direction, relative humidity
- zone operations attributes for scheduled air flow - infiltration, ventilation, ventilation source temperature
- zone operations attributes for casual gains - sensible or latent magnitude, radiant or convective fraction, period start time

- ideal zone controls attributes e.g. heating and cooling magnitudes, period start times,

The attributes of *what-is-uncertain*, for example [wall_insul_thick] and [roof_insul_thick] might identify a layer of insulation in two different constructions which might be used in various locations in the model. Each such definition also includes a range and/or bound of uncertainty, either as a % of the nominal value of the attribute or a fixed offset i.e. 0.02m.

The *Where* definitions for construction uncertainties e.g. [facade_walls] and [the_roof] would include a list of associated surfaces. There are also options to define locations for all surfaces which use a specific MLC or material.

Topics such as weather or control are defined via time rather than location and so an [all_year] or [summer] could be created for these.

When bps starts it recognises that there are uncertainty defintions and ask the user whether a differential, factorial or Monti-Carlo assessment should be used and how many runs should be comissioned beyoned the base case model, typically 50-100. All runs are held in the same results file as separate [results sets].

At the start of each run the model details are scanned and the uncertainty description drives the modification of the model attributes in memory (no model files are changed). A random number is generated (a standard distribution between -2 and +2) which is applied to each uncertainty concept and its range/bounds directives.

An uncertainty definition for a casual gains is specific: the definition includes the zone, day type, period and gain type as well as a specific attribute i.e. sensible magnitude. Thus to impose a degree of diversity on casual gains a number of uncertainty definitions will need to be created.

An uncertainty definition for ideal control is also specific: the defintion includes the control loop and the day type and period in the day as well as a specific attribute. To approximate diversity may also require a number of uncertainty definitions to be created.

In the case of weather or control uncertainties the changed attribute is applied throughout the period defined by the temporal scope. For example, if the wind speed uncertainty change is 1.5m/s this is applied to the weather file wind speed hourly value at each timestep of the assessment. The next invocation might result in a change of 0.6m/s etc.

The results analysis facility recognises the uncertainty sets and enable a [sensitivity] menu which allows analysis within the full range of [results sets] or between specific sets.

Procedure

Before you enter into the uncertainty facility create a model contents report to aide identifying model entities that are of interest and plan the uncertainty defintions and a naming scheme.

You may need to adapt your model to support explorations of uncertainty. For example, if you are curious about the impact of insulation thickness in the facade, check which constructions are used and ensure they are not also attributes of internal partitions. If casual gains i.e. occupancy patterns are uncertain consider what casual gain attribute, or more likely, sets of casual gain attributes should be included. A complex schedule with many periods may not be a good fit for an uncertainty with period start times.

Once the model is fully attributed uncertainty can be selected via the [Browse/Edit/Simulate] menu option [p]. The password is 101 and you are asked to confirm the name of the uncertainty file (based on the model root name and ends with .ual). In the figures below is the top level menu, categories of distributions and the topical default ranges.
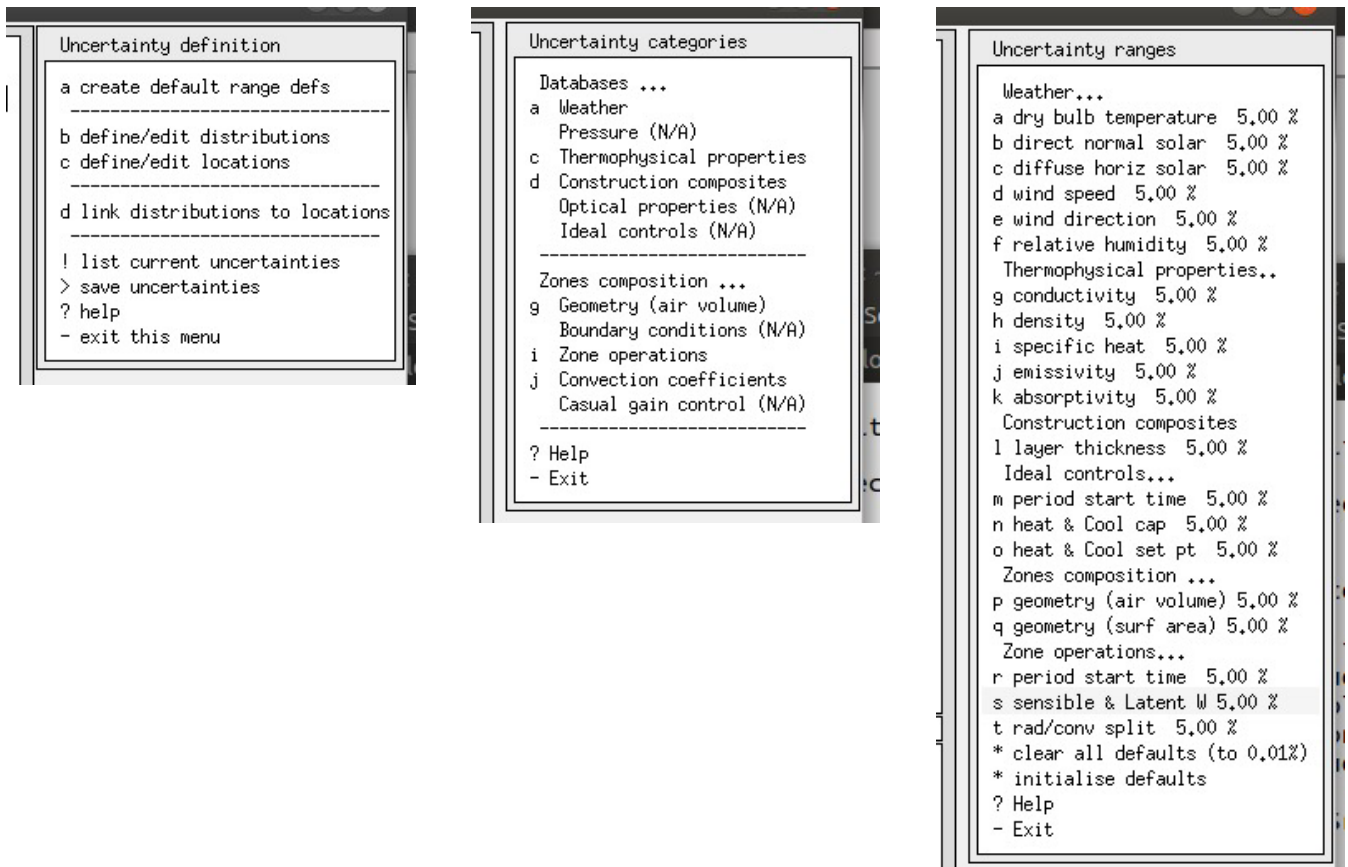
Figure 11.29 Uncertainty menu, distributions and locations

Next we have three menus which are associated with the exemplar model *uncertain_opr.cfg*. The uncertainty topics focus on what is happening within a zone e.g. the rate of infiltration, the magnitude of occupant casual gains, the radiant/convective split for a casual gain and the start of the occupied period. The location is simply *the_zone*.

Figure 11.30 Uncertainty menu, distributions and locations

There is a 'create default definitions' option which brings up a list of uncertainty topics. For each you can set the bounds and whether these are based on a % of the entities current attributes i.e. conductivity or are a real-number offset i.e. 0.01m from the current thickness of a layer. There is no specific requirment to use this facility.

The 1st phase assigns a so-called [distribution] for a chosen model attribute (also known as a parameter). For each of the major groupings of model attributes i.e. thermophysical properties you are asked to select a material used in the model as well as what attribute e.g. conductivity, density, is uncertain. Lets say conductivity. The magnitude of uncertainty can be either a percentage of the materials current conductivity or an offset value. For example copper has a conductivity of ~200(W/(m-K) so an offset value of 20 could be used.

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The 2nd phase selects the location of what is uncertain (e.g. a zone or surface). There is an initial question about location via [spatial] or [temporal]. Choose spatial unless you are dealing with weather or control attribues. You are then presented with options for an automated search for surfaces matching specific criter or a manual selection of zones and surfaces. Lastly give the location a name.

The 3rd phase links the distributions and locations. Here you select from the list of distributions and locations. Remember to save the uncertainty definitions as you proceed.

When running an assessment you need to invoke the simulator in silent mode. You will then be asked whether you want to carry out a [Differential] or [Factorial] or [Monte-Carlo] assessment. It will ask how many assessments to run 70-100 is typical for a limited number of uncertainties.

After the assessment there will be a fort.36: file which will include entries such as:

```
 ...
 **
 ** Edits for changes in set:          2          4
 Uncertainty definition          1  altered by    1.03761053
 cav_ins_thick:facade

Entering subroutine UAE02
Focus zone:   1 room
Editing layer thickness..
Zone:   1 Surface:    1 layer 3
THRMLI:     0.0250
to:
THRMLI:     0.0328
Editing layer thickness..
Zone:   1 Surface:    2 layer 3
THRMLI:     0.0250
to:
THRMLI:     0.0328
Editing layer thickness..
 Uncertainty definition          2  altered by   -0.572989583
 roof_insul_thick:roof

Entering subroutine UAE02
Focus zone:   1 room
Editing layer thickness..
Zone:   1 Surface:    5 layer 4
THRMLI:     0.0800
to:
THRMLI:     0.0458
synopsis U01 1.04 U02-0.57
 . . .
```

Here is an example of changing thermophsical properties.

```
 . . .
 ** Edits for changes in set:          35          4
 Uncertainty definition          1  altered by    1.29964566

 Entering subroutine UAE01 Focus zone:            1
 Editing element:
 Zone:             1  Surface:            1  Element           1
    con      den      sht     emis(I,E) abs(I,E)
    0.770 1700.000 1000.000 0.91 0.90 0.50 0.70
 to:
    0.820 1700.000 1000.000 0.91 0.90 0.50 0.70
 Editing element:
 Zone:             1  Surface:            2  Element           1
    con      den      sht     emis(I,E) abs(I,E)
    0.770 1700.000 1000.000 0.91 0.90 0.50 0.70
 to:
    0.820 1700.000 1000.000 0.91 0.90 0.50 0.70
 Editing element:
 Zone:             1  Surface:            3  Element           1
    con      den      sht     emis(I,E) abs(I,E)
    0.770 1700.000 1000.000 0.91 0.90 0.50 0.70
 to:
    0.820 1700.000 1000.000 0.91 0.90 0.50 0.70
 Editing element:
 Zone:             1  Surface:            4  Element           1
     con      den      sht     emis(I,E) abs(I,E)
    0.770 1700.000 1000.000 0.91 0.90 0.50 0.70
```

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```
to:
   0.820 1700.000 1000.000 0.91 0.90 0.50 0.70
Uncertainty definition           2   altered by     1.30377197

Entering subroutine UAE01  Focus zone:              1
Editing element:
Zone:           1  Surface:           1  Element           3
   con     den      sht    emis(I,E) abs(I,E)
   0.040  105.000 1800.000 0.91 0.90 0.50 0.70
to:
   0.043  105.000 1800.000 0.91 0.90 0.50 0.70
Editing element:
Zone:           1  Surface:           2  Element           3
   con     den      sht    emis(I,E) abs(I,E)
   0.040  105.000 1800.000 0.91 0.90 0.50 0.70
to:
   0.043  105.000 1800.000 0.91 0.90 0.50 0.70
Editing element:
Zone:           1  Surface:           3  Element           3
   con     den      sht    emis(I,E) abs(I,E)
   0.040  105.000 1800.000 0.91 0.90 0.50 0.70
to:
   0.043  105.000 1800.000 0.91 0.90 0.50 0.70
Editing element:
Zone:           1  Surface:           4  Element           3
   con     den      sht    emis(I,E) abs(I,E)
   0.040  105.000 1800.000 0.91 0.90 0.50 0.70
to:
   0.043  105.000 1800.000 0.91 0.90 0.50 0.70
** Edits for changes in set:        35            4
** Edits for changes in set:        35            4
**
. . .
```

The 'altered by' is the random number generated at the start of the run. This is multipled by the value of the range directive to get the specific change in the attribute.

The dialog when res starts might look like:

```
The name (uncertain_ctl.res) will be used.
Opening file with record length 40
Databases scan (ok)

Number of result-sets held = 20

Set|Control      |Start |Finish| Time     | Save |Average|Pre|Aid memoire
no.| name        | day  | day  |steps/hr|option| Flag  |sim|(for this set)
 1 float until   1, 2  28, 2      4       4      0    21  U01 0.42 U02 0.23
 2 float until   1, 2  28, 2      4       4      0    21  U01 0.81 U02-1.07
 3 float until   1, 2  28, 2      4       4      0    21  U01 0.57 U02 2.25
 4 float until   1, 2  28, 2      4       4      0    21  U01-0.77 U02 1.64
 5 float until   1, 2  28, 2      4       4      0    21  U01-0.66 U02 0.07
 6 float until   1, 2  28, 2      4       4      0    21  U01 0.81 U02-0.04
 7 float until   1, 2  28, 2      4       4      0    21  U01-0.05 U02-0.90
 8 float until   1, 2  28, 2      4       4      0    21  U01-0.89 U02-0.21
 9 float until   1, 2  28, 2      4       4      0    21  U01-1.93 U02 1.37
10 float until   1, 2  28, 2      4       4      0    21  U01-1.23 U02 0.06
11 float until   1, 2  28, 2      4       4      0    21  U01 0.52 U02 0.17
12 float until   1, 2  28, 2      4       4      0    21  U01-1.20 U02-1.82
13 float until   1, 2  28, 2      4       4      0    21  U01-0.28 U02-0.01
14 float until   1, 2  28, 2      4       4      0    21  U01 1.75 U02 1.57
15 float until   1, 2  28, 2      4       4      0    21  U01-0.64 U02-1.08
16 float until   1, 2  28, 2      4       4      0    21  U01 0.52 U02-1.28
17 float until   1, 2  28, 2      4       4      0    21  U01 0.23 U02 1.06
18 float until   1, 2  28, 2      4       4      0    21  U01 0.64 U02-0.16
19 float until   1, 2  28, 2      4       4      0    21  U01-0.52 U02-0.50
20 float until   1, 2  28, 2      4       4      0    21  M-C run:   19
The current result library holds data from a monte carlo uncertainty analysis
 Do you wish to analyse:  a) the uncertainties, b) a particular set ?
. . .
```

Below is a tabular list of inter-set statistics:

```
Zone db temperature (degC) is focus
room is focus
  Hour      Maximum        Minimum         Mean          Standard
```

```
               value          value          value         deviation
    0.12      13.7494        12.8298        13.2896         0.4598
    0.38      13.6880        12.7798        13.2339         0.4541
    0.62      13.6325        12.7358        13.1842         0.4483
    0.88      13.5800        12.6946        13.1373         0.4427
    1.12      13.5243        12.6499        13.0871         0.4372
    1.38      13.4583        12.5944        13.0264         0.4319
    1.62      13.3858        12.5319        12.9589         0.4270
    1.88      13.3125        12.4682        12.8904         0.4222
    2.12      13.2418        12.4068        12.8243         0.4175
    2.38      13.1771        12.3514        12.7642         0.4128
    2.62      13.1166        12.3002        12.7084         0.4082
    2.88      13.0575        12.2503        12.6539         0.4036
    3.12      12.9997        12.2015        12.6006         0.3991
   . . .
```

Below are column lists for zone temperatures in each of the sensitivity runs:

```
Time "Base","U01 0.81","U01 0.05","U01-2.14","U01 0.30","U01 1.23","U01 0.80","U01...
32.00520,9.3777,9.3791,9.3823,9.3781,9.3654,9.3795,9.3847,9.3823,9.3803...
32.01562,9.3723,9.3738,9.3772,9.3727,9.3588,9.3742,9.3797,9.3772,9.3751...
32.02604,9.3712,9.3728,9.3765,9.3717,9.3566,9.3733,9.3792,9.3765,9.3742...
32.03645,9.3714,9.3730,9.3770,9.3718,9.3555,9.3735,9.3799,9.3770,9.3746...
32.04687,9.3666,9.3684,9.3726,9.3671,9.3495,9.3689,9.3757,9.3726,9.3700...
32.05729,9.3501,9.3520,9.3565,9.3506,9.3318,9.3526,9.3598,9.3565,9.3538...
32.06770,9.3260,9.3280,9.3328,9.3265,9.3065,9.3286,9.3363,9.3328,9.3299...
32.07812,9.3001,9.3023,9.3074,9.3007,9.2794,9.3029,9.3110,9.3074,9.3043...
32.08854,9.2757,9.2780,9.2834,9.2763,9.2539,9.2787,9.2872,9.2834,9.2801...
32.09895,9.2564,9.2588,9.2644,9.2570,9.2333,9.2595,9.2684,9.2644,9.2609...
32.10937,9.2403,9.2428,9.2487,9.2409,9.2159,9.2435,9.2529,9.2487,9.2451...
32.11979,9.2247,9.2273,9.2335,9.2254,9.1991,9.2281,9.2380,9.2335,9.2297...
32.13020,9.2094,9.2122,9.2187,9.2101,9.1827,9.2130,9.2233,9.2187,9.2147...
32.14062,9.1945,9.1974,9.2042,9.1952,9.1666,9.1982,9.2090,9.2041,9.2000...
32.15104,9.1797,9.1827,9.1898,9.1805,9.1506,9.1836,9.1949,9.1898,9.1855...
32.16145,9.1651,9.1682,9.1756,9.1659,9.1349,9.1692,9.1808,9.1756,9.1711...
   . . .
```

The res module can also display graphs on a topic-by-topic basis. For example if there were 50 sets it would draw the mean and the highest and lowest value at each timestep.
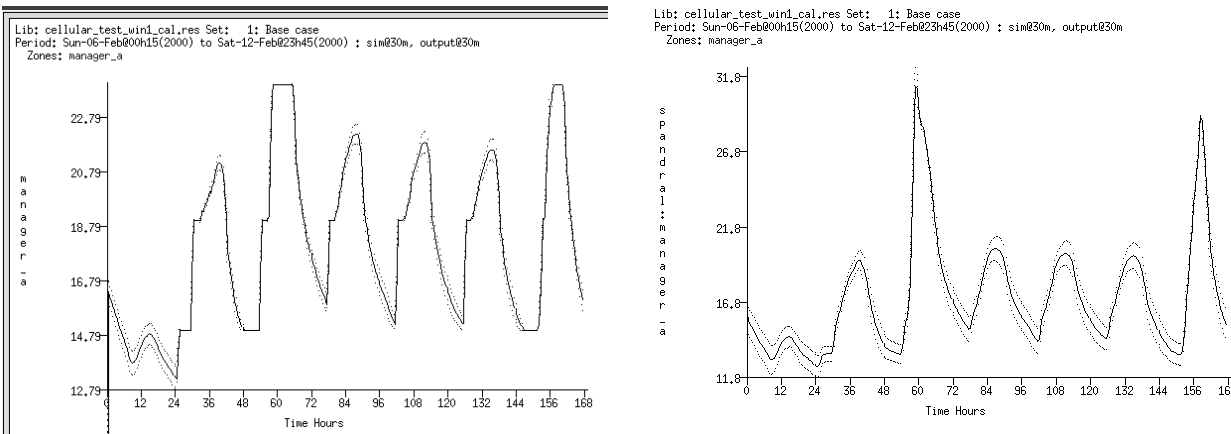
Figure 11.31 Uncertainty menu, distributions and locations

The uncertainty file

The description of uncertainties in a model are held in a tag-data text file. Below is an example where several attributes of zone operations have been defined. There is an [all_year] temporal scope as well as a [the_zone] location used by the various change definitions:

```
*Uncertainty analysis library
    4    2    4 # Changes, Locations, Actions
# Changes definitions follow...
*cng_def
infil_rate                 # Change id string
    4 # Change type: Scheduled operation
    0    1 # Operations parameter infiltration -
    2     0.200      0.000   # abs change infiltration
*cng_def
```

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```
people_watts              # Change id string
   4 # Change type: Scheduled operation
   1   1 # Operations parameter occupants sensible
   2   20.000     0.000   # abs change occupants
*cng_def
rad_frac                  # Change id string
   4 # Change type: Scheduled operation
   1   3 # Operations parameter occupants radiant frac
   2    0.100     0.000   # abs change occupants
*cng_def
occupant_start            # Change id string
   4 # Change type: Scheduled operation
   1   6 # Operations parameter occupants period start
   2    1.000     0.000   # abs change occupants
#
# Locations definitions follow...
*loc_def
all_year       # Location id string
   0 # Number of zones
   1   1 365  24 # Start day, hour, finish day, hour
*loc_def
the_zone        # Location id string
   1 # Number of zones
   1   1 # Zone number, Number of surfaces
   1
#
# Action definitions follow...
*act_def
   2 # Uncertanty ref: people_watts
   2 # Location ref: the_zone
*act_def
   1 # Uncertanty ref: infil_rate
   2 # Location ref: the_zone
*act_def
   3 # Uncertanty ref: rad_frac
   2 # Location ref: the_zone
*act_def
   4 # Uncertanty ref: occupant_start
   2 # Location ref: the_zone
```

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ORGANISATIONAL SUPPORT FOR SIMULATION

12 Organisational support for simulation

This chapter draws on two decades of observation of successful and less successful simulation groups. It expands ideas that the author and others contributed to *Building energy and environmental modelling: CIBSE Applications Manual AM11: 1998* The Chartered Institution of Building Services Engineers, London, April 1998 and the updated edition of 2015.

12.1 Classic mistakes

- confusing keyboard proficiency with the delivery of useful insights into the performance of a design
- the belief that *user friendly* software allows inexperienced staff to function with limited supervision and/or limited training and will have sufficient self-restraint to avoid complexity beyond their capabilities
- reliance on raw computing power rather than well-formed procedures and well-designed models
- equating the ability to generate reports and graphs with an understanding of the patterns within reports and graphs sufficient to add value to the project.

The stress of an approaching deadline and exhaustion is often associated with mistakes. A perfect storm for a simulation team is a manager who gives an inappropriate directive to a novice who does not have the background to recognize the directive is suspect or the confidence to request clarification. The novice thus works very hard at digging a hole for the team to fall into and lack of management attention ensures the pain is distributed.

Bluntly stated - errors and omissions in management can be as important than errors and omissions in technical execution. Simulation teams tend to underestimate the time required to develop procedures. Similar optimism pervades the task of maintaining and extending staff skills.

Simulation teams who thrive:

- have evolved procedures which limit errors and omissions,
- compensate for limitations within simulation tools and
- undertake reality-checks at regular intervals
- have discovered how to identify *opportunities for delivering additional value* to the design process.

12.2 Tool-specific procedures

Procedures need to adapt to the specific facilities of simulation tools:

- Simulation tools tend to be designed for individual use rather than team use. Distributed work groups remain largely unsupported.
- Optical illusions happen, e.g. the wireframe image looks correct but has reversed surfaces. Procedures should check non-visual attributes to enforce model quality.
- Tools can force users into tedious tasks. Procedures should identify alternative approaches.
- Constraints on in-model documentation force the use of external documentation (which is liable to get out of sync with the model as it evolves).
- Tools (including ESP-r) have limited 'undo' facilities. Procedures are needed to promote habits which compensate for such limitations.
- Simulation model files are surprisingly fragile. Manual editing (hacking) can lead to subtle faults as well as not-so-subtle faults.

    It is assumed that practitioners who deploy simulation are rather opinionated in what they want to achieve and are aware of the *rules and requirements* of the entities used to create models.

Users of other simulation suites will find much that is familiar in the discussion that follows.

12.3 Roles within simulation projects

Although there are successful independent simulationists, simulation is most powerfully deployed in a team environment. Why?

- Simulation demands a range of managerial, technical and communication skills.
- Projects can fail if errors in methods or model content are not identified. Self-checking is an invitation to risk that is difficult to overcome.
- There is a level of complexity beyond which models cannot be managed by individuals.

Setting up a simulation team is not a trivial task as can be seen in Appendix A of CIBSE AM11 2015. In simulation projects it is critical that someone considers the broad sweep of issues within the project as well as the client's goals. This *team manager* task tends to be taken by someone not tasked with creating the model (unless they can easily make mental jumps from detail to overview).

Someone who is not actively creating the model should also be tasked with ensuring its quality. Although it is *everybody's job* to notice opportunities to add value to the deliverables as well as errors and omissions, the *quality manager* should be the driving force.

There are dozens of points during a simulation project where *reality checks* are needed. Triggers might be:

- the time taken to accomplish a task is out of expected bounds
- predicted comfort (or other performance metric agreed for the project) went out-of-bounds
- similar zones, i.e. southwest corner offices on the fourth and fifth floors are performing differently
- the log of project assumptions has not been updated in a week.

There are points in a project wich *consultants* may be called in to advise on corrective actions or carry out specific modelling tasks. They may bring with them additional procedures which need to be integrated into the work-flow.

The most obvious role is, of course, that of using simulation tools (let's use the term *simulationist*) which includes a mix of semi-skilled and skilled tasks. Some simulation teams may call on *mentors* to consider how skills and procedures can be enhanced. And a range of *support staff* may interact with the team and need to be considered in procedures.

Individuals may rotate roles - in one project they may act as the team manager, in another they may carry out simulation tasks and for another they focus on quality issues. This has several benefits:

- it allows ad-hoc teams to be formed with the best available talent
- it ensures that staff develop a broader range of skills and have opportunities to exercise those skills
- it distributes knowledge of the resource requirements of specific simulation tasks
- it limits the isolation and dead-end horror stories that many simulation staff experience in some organisations.

For most projects, the challenge of working in a team is the inability of simulation software to cope with asynchronous manipulation of models, as well as our ability to maintain an audit trail of actions taken. The following sub-sections provide more information about each of these roles.

Team manager

The discussion of initial tactics in Table 1.1 of Section 1.2 is essentially a synopsis of issues addressed by a *team manager* role. When the discussion in Section 1.4 turned to the *client specification* the *core issues, related issues and actions table* were tasks for the *team manager* to champion.

Efficiency gains in planning and model generation should be directed at freeing up time to *live with the model and explore its performance* and thus better understand how it works. Time for exploration of value-added issues and speculative explorations is also a hall-mark of well run simulation groups.

Where a project requires skills not available within the team the *team manager* might retain the services of specialists such as an electrical engineer, CFD expert or air quality consultant who can do the work or assist staff to complete the work.

The quality manager

Just as the author of a book needs an editor to help focus the story, those who work on models find it difficult to recognize whether the model continues to be fit-for-purpose, whether the latest performance predictions are providing a consistent story or perhaps include a new pattern which needs attention.

One need not be an expert at simulation to carry out many of the tasks associated with ensuring model quality, but good pattern matching skills and an eye for detail are core competencies. Chapter 13 discusses many of the techniques used and Section 13.9 describes how to review model contents reports. It is quite possible to delegate a range of tasks to individuals who might not normally be considered part of a simulation team.

A traditional (reactive) approach is for quality managers to review reports generated by others. Those who are able to use simulation tools themselves to review models, generate model contents reports and review model predictions can turn this role into a proactive one.

The model planning rules in Section 1.6 tend to be based on an assumption that staff are working within their level of competence. Quality managers are in a position to track this as well as noticing risk as models are planned, implemented and maintained.

Another task is to establish criteria for the common data (such as material properties and component details) gathered by staff for use in simulation projects. How much uncertainty is acceptable in such entities? Where should assumptions and omissions be documented?

Typically the quality manager will have a list of questions and issues to explore as the project proceeds. The following table is illustrative:

Issues	Actions
Is the current project similar to a past project? Is there valuable information in historic notes and documentation?	Discuss findings with the team manager and staff. Identify issues to be tracked in the current project.
Are there design issues in this project which are new to the simulation team?	Review criteria and identify possible approachs. Find out who needs to work together to test these approaches.
What naming scheme will clarify the model to others in the design team? Is the client visually or number oriented?	Consider whether manufacturer's names for products are appropriate. Confirm which performance data presentation form matches client preferences.
What documentation has the client provided? Does it identify issues to be resolved prior to work starting?	Confirm what client documentation should be incorporated. Advise on who should embed this documentation.
Are staff keeping a log of actions, assumptions made and information sources used?	Carry out spot checks of information sources.
Does the model continue to reflect the initial plan? Are there resources available for value-added explorations?	Ensure updates to the model have been broadcast. Outline value-added issues that need to be discussed.
The model predictions indicate 15% less heating capacity is required - is this an error or is this an opportunity? What changed? And who made the change?	Identify performance data which could be influenced by this change. Is it time for some quick what-if studies?
During checking it was found that occupancy in several rooms was less than specified. When did this happen? What design decisions might be at risk?	Review how predictions change when the occupancy is updated.
The project is slightly ahead of schedule what do we do now? Where are opportunities for making the design work better? What is likely to be the next issue that the client will ask us to consider?	Revisit the assessments looking for performance improvements. Investigate modifications needed to explore new topics. Employ a focused model to check an alternative approach.

Simulation staff

Traditional deployment of staff often involves junior staff creating models, running assessments and extracting performance data. These can be valuable contributions if they have access to a mentor and there is frequent and close supervision. There are also times when it is cost-effective to involve senior staff in the creation and evolution of models as well as noticing patterns in performance predictions. And one of the best ways to pass on such skills is to ensure that others in the team are able to observe this *magic* happening.

The critical issue for successful deployment is to complement the *keyboard* skills of staff with domain knowledge, pattern matching skills and *risk recognition skills*.

Inexperienced staff are unlikely to appreciate the dependencies within the simulation tool (between different entity types and between different assessment domains).

Experienced staff must continually remember that:

- the knowledge about thermophysical relationships that guides their decisions about modelling and their use of simulation tools may not be known by others

- their use of simulation tool facilities relies on assumptions and relationships that others might not yet know

- their imagination of a time-line of tasks required to reach a particular simulation goal will probably require quite a bit of effort to translate into clear instructions which others can act on

The pattern matching which expert staff do unconsciously often involves the discovery of relationships - *if we see key word W in an error message then we forgot step X; if the shape of the heating demand profile looks like this then Z; if the largest heat loss path in the surface energy balance is north facing windows then investigate Y*. They might *assume that others will also notice such patterns* and conclude (inappropriately) that silence from junior staff is a sign that progress is as expected.

The following table (spanning to the next page) includes typical issues which confront simulation staff.

Issues	Actions
What preparation is needed for this project? Are we clear about the client's ideas? Have we done similar work in the past?	Review client requirements with manager. Sketch likely approaches to the model and review. Review past projects - can one be adapted? Review past models for use in testing ideas.
What analysis facilities are required? Running cost vs control? Comfort vs air quality? Frequency of occurrence?	For each domain identify what needs to be measured. Define the level of detail required. Identify likely interactions between assessment domains.
What model calibration approaches to use? Which best-practice performance indices? Can a previous project act as a benchmark? What operational regime and weather to test?	Review standard literature, past reports, working procedures for suggested tests. Identify weather pattern(s) and operational characteristics to use in tests. Embed simulation directives in the model.
How much time will it take to create the model? Is there a record from similar projects? Is this a crank-the-handle or exploratory model? Is the complexity within skills limits?	Review past projects with team manager. Plan a series of proof-of-concept models as a benchmark. Review with mentor. Review required tasks and time estimates.
What model variants might be needed? What other questions might the client pose? Is the current model at the edge of the tool facilities or staff skills? Are changes directed by new information or are they general parametric variations?	Discuss what other topics might be addressed with model variants. Estimate resources needed to alter model resolution. Review current model complexity in each domain. Use a test model to confirm automation facilities or scripts. Report findings to team.

Issues	Actions
How do we zone the model? What is the distribution and diversity of occupancy? What portions of the building are sensitive to facade changes? What variants of control logic might be used in different sections of the building? Is stratification an issue? Is cross-ventilation or air flow between rooms likely?	Using separate overlays sketch out regions for occupancy (density, schedules), control (logic, schedules), perimeter sensitivity, air flow connections, system types and control-ability. Unify the sketch overlays for initial ideas. Work out an alternative sketch of zones taking into account likely future issues. Sketch scenarios for air flow networks and revise zoning to accommodate.

Support staff

Contributions from technical and clerical staff should be included in the scope of working procedures. There are a number of tasks associated with acquiring and committing data (e.g. materials and components) to which support staff can make valuable contributions.

Other examples would be the production of an animated sequence of solar shading patterns on facades and internal spaces via a visual simulation tool such as Radiance. If done on an ad-hoc basis by simulation staff there is a risk that steps may be skipped or incorrect parameters entered. A well-trained technician who does such work regularly may be a better choice for such tasks.

Another acquired skill is the review of model contents reports in conjunction with the Quality Manager. For each simulation tool these reports tend to follow a fixed format and include recurring key words. It is reasonable to ask support staff to search to the inclusion or absence of specific words and phrases.

Delegating a task first requires someone to pay close attention to and document successful actions and assumptions. This is followed by an iterative process of testing and clarification of the procedure until it is fit for deployment. Support staff will need to be trained in the procedure and given sufficient time to fine-tune their skills. A good indicator of successful deployment is when support staff start suggesting improvements to the procedure.

Delegation also implies that the group work-flow is redesigned to merge support staff contributions into the design process. Both the Project Manager and Quality Manager will be involved in the merge.

The consultant

Sucess in using *consultants* to solve technical issues or provide a second opinion about predictions is as much about clear communication as it is about their skills. Friction points are:

- The consultant may insist that their method and their own software are the only possible ways to deal with a specific issue. Interactions with the expert can become complicated, for example, they may or may not provide information in support of their approach or let others vet their software.

- Another predictable point of confusion comes from the imbalance in information. The issue which led to the expert being called is so **normal and obvious** to the expert that they may stumble in their explanations to others who do not share this knowledge.

Having discussed the various roles in a simulation project it is time to turn our attention to simulation tool issues.

12.4 Common data stores

Simulation relies on access to a range of common descriptive data about entities in the built environment. These are typically held in files that the simulation tools access and which are composed of manufacturers' product data, test reports, site surveys, extracts from journals and reference books.

Much of the productivity of simulation experts comes from quick access to information as well as clear clues as to its fitness for purpose. Take away either speed or clarity and productivity suffers.

Typically, only a portion of this information comes packaged with the software. Much of the value-added for simulation groups is in extending the initial store of data. There is an up-front investment to

understand what is initially available, followed by populating these files with data relevant to future projects and then periodic updates and extensions.

In groups where multiple simulation tools are used the tasks associated with information management must take into consideration the degree of overlap between tools as well as tool-specific differences (which can be subtle). Consider whether there is a business case for minimizing differences between the common data used by different simulation tools.

The introduction of simulation into a business process or a research group thus requires initial decisions on how supporting data is acquired, evaluated, modified to fit group naming and documentation standards. Procedures for how data is committed and then managed on a long term basis must be agreed.

Thus, one of the initial points-of-discovery for a new simulation tool is the nature and extent of its in-built data-store. Commercial software tends to be well populated with entities. And these must still be subject to evaluation, adaptation and management.

12.5 Tool selection

While it may be possible to coerce your preferred tool to carry out a range of tasks, a lack of choice may impose a cost. Review the capabilities and cost-of-use of other simulation tools and develop selection criteria. The costs associated with acquiring and supporting multiple tools should take into account whether staff are able to cope with multiple tools or if additional staff are required.

Selection criteria are project specific as well as specific to the stage in the design process. Begin by carefully considering the nature of the project as well as the project goals. Answer the questions posted in Table 1.1 and sketch out (roughly) your ideas for a model. Here are some examples of assessment criteria:

- Site resolution (the form and scale of the site). Does the tool allow you to describe the impact of adjacent buildings and topography? Are weather data and local wind pressures available?

- Spacial resolution (the form and scale of the building and spaces inside). Does the tool support the complexity found in your sketch?

- Thermophysical resolution (the composition of the building and its response to changes in boundary and internal conditions). E.g. if the building has massive constructions or uses phase change materials does the solution technique support this?

- Environmental systems resolution (the composition of the systems and controls). Does the system(s) representation match the needs of the project? Is it possible to approximate the buildings control logic?

- Occupancy, lighting and small power resolution (the temporal distribution of internal gains). Is is possible to represent the interactions between occupants and the building e.g. manual controls?

- Computational support for the assessment domains required in the project e.g. if details of air movement is of interest is a CFD domain available, if comfort is of interest is there a built-in model of comfort?

- Do the computations produce the kinds of performance data (e.g. type of data, location of data, frequency of data) to allow the design team to judge project performance?

- Do you have the necessary supporting information (materials, constructions, optical properties, system components etc.) needed to represent the project in this simulation environment?

- During the life of the project what additional performance questions might arise? Does the tool support assessments for these issues and are staff skills appropriate?

- If other simulation environments or reporting tools are being used in the project are there established communication routes for information to pass between the tool suites?

- Are there sufficient resources in the project to allow this simulation suite to be used? Are staff skills appropriate for this mix of project requirements and simulation tool requirements?

One rapid approach to evaluating alternative simulation tools is to identify a recent project and explore one or two issues via the use of the current and alternative tools. Participants would then compare what simulation delivers with the prior findings in terms of resources required, skills needed as well as a comparison of predictions.

Recent projects are especially good if staff remember the approach they took and have access to the underlying project data. The mentor can both guide the simulation team and help them to understand the predictions from simulation.

12.5.1 Computational infrastructure

Simulation also relies on a computational infrastructure. And most groups assume that this is robust until it proves otherwise. The *otherwise* is sometimes random (e.g. a disk failure) and sometimes is predictable (someone did not keep a safe copy of their work). Both have antidotes.

Decide how many person-hours are acceptable as a loss at each stage of the design process and adapt the computational infrastructure and working practices (habits) to reflect this. Test this by staging a failure and notice how the group and its infrastructure recovers (or fails to recover).

One can be creative about the deployment of computational resources. Model creation tasks tend to be bound by the users speed of interaction rather than the power of the computer. A high quality monitor may be more important in model creation than computing power. A fast disk and extra memory is likely to be the critical factor during assessments and for data recovery tasks.

12.6 Training

Given the same simulation tool, the same computer type and the same brief, radically different times can be required to arrive at a completed model. What a novice can produce in a frustrating two days, seasoned staff can produce in ˜two hours with a computer which is half as fast.

Such differences in productivity are expected and should be factored into the staffing of a project. A tight time-schedule may be best supported by using more experienced staff whereas those with less experience will be more comfortable with a project with less challenging deadlines.

When two staff with roughly the same capabilities take radically different times for the same work then this should trigger a closer look. Maintaining and extending skills may be left to individuals, however some groups choose to actively support staff via:

- A person who has mastered the simulation software and helps staff to become comfortable with features which tend to be viewed as either *magic* or where *dragons live*.
- A person who has undertaken simulation projects of the scale, complexity and mix of domains which are being considered by the simulation group (to provide guidance).
- A domain expert (e.g. electrical engineer, air quality consultant) who works with a team to help define strategies and evaluation criteria.
- A person retained to carry out extended training within the simulation group, typically to assist the team to enter a new market or work with different types of clients.

Mentors may be part of the team or consultants who are retained by the team via a support agreement. At-risk projects may use mentors with elevated authority to take over tasks being carried out by staff if that is what is required to guarantee deliverables. In other cases a mentor may be on-call for brief consultations because their experience supports quick answers or to demonstrate an unfamiliar technique. This could be done in person or via a video conference.

Model quality is part of everyone's job and the pattern matching skills needed to support this may be acquired by careful study of documents such as Chapter 13 as well as by working with more experienced staff or a mentor. The following are examples of what might be noticed:

- There is a surface labeled fire-door which is made of the same construction as an interior glazed partition - is this possible?
- The operational documentation mentions a computer server but the schedule indicates considerable off hours - which one is correct?
- Shading patterns were calculated for all offices on the west facade except for floor three. Did we miss something?
- The heating demand peak during startup is four times the value during the rest of the occupied period. Is this expected? Are there alternatives we should explore?

If possible, the quality manager should devise task sequences to confirm the skills level, strategies and *inventive resources* of staff.

It is a challenge to match resources *actually used* with assumptions made in initial planning. One major contribution of simulation staff to the planning process is to provide realistic estimates of time and computational resources. Keeping notes about the time actually taken for specific tasks should be included in working procedures. Frequent updates to estimates as real data becomes available can help in the

management of staff resources.

What about time estimates for new (to the group) tasks? One could guess and risk under or over bidding. Or the simulation team can devote some of its resources to anticipating new topics and tasks by compiling background documents, creating exploratory models and undertaking mock projects. Remember, it is just as valuable to report a tool facility that is *not ready* for use as it is to discover an additional measurement which can be included in reports.

12.7 Summary

A well formed working procedure will ensure that staff are working at a pace that does not exhaust their mental reserves. This suggests that all members of the team should be clear about their own level of competence and how much reserve capacity they have.

It is a challenge to match resources used for generating and testing models with assumptions used in initial planning. With experience, simulation staff, mentors and quality managers can give close estimates of the amount of time they expect to take.

Well formed working procedures will ensure that before a bid is given to the client there is an evaluation as to the fitness of the suite of software tools available vis-a-vis the likely demands of the project. There will also be an evaluation of the current skills level in case preparatory work is required.

13 Model Quality

Simulation teams who are attempting to deal with real designs in real time are confronted by the need to ensure that their models are syntactically correct as well as semantically appropriate for the project.

Simulation teams who thrive invest considerable passion in ensuring the quality of their models. They do so to limit risk (a traditional reason for QA and QC). Such working practices are also likely to provide early *evidence of opportunities* to deliver additional value to clients.

Model quality involves both the facilities of the simulation tool and the skills of the simulation team. Among the most important issues are:

* designing models that the simulation team can understand
* designing models that clients recognize
* identifying faults in models that syntax checks fail to recognize
* working practices that ensure inbuilt tool checks are used regularly
* working practices that keep the quality manager in-the-loop
* working practices that ensure calibration checks
* understanding model contents reports

Semantic checking is related to the *design of the model* - how it includes and excludes thermophysical aspects of the design. Because it is an art as much as a science it is more difficult to establish rule sets for model design. Here the issues are:

* models (or tools) that are *not quite fit* for purpose
* models which continue to be used after entropy has set in
* models which are stuck in an unusable state

13.1 How can the vendor help?

The quality of models **begins** with the facilities offered by the software vendor e.g. QA reports, documentation, training and in-built software checks. Vendors decisions about in-built facilities have a substantial impact on the resources that simulation teams invest in model checking.

Some vendors believe *what you see is what you get*. Unfortunately, what you see on screen is only one of many possible views of the contents of a model. Here are some examples of optical illusions:

* A wireframe view can look correct but have reversed surfaces or missing surfaces
* A clever interface may decide to merge adjacent surfaces together - so what is reported is not the same as the user defined.
* Interfaces may decide to subdivide surfaces or components so that the model includes entities that the user did not ask for.
* The user may define a compact description which the tool expands into hundreds of entities which are difficult to understand and even more difficult to adapt.

Some software (including ESP-r) provides both information on the screen and model contents reports. Multiple views of a model allows those with graphic interpretation skills and those with report interpretation skills to work together to spot inconsistencies.

A good model contents report is a) human readable and b) reflect *any change* to *any entity* within the model. Simulation tools are imperfect and thus some entities may not be reported, some reports may be opaque or include a insufficient detail. Ideally, tools should allow the user to define the level of detail for various reported entities as well as which topics to include.

As mentioned earlier, independent actions by multiple users cause clashes which are difficult to resolve. If a model is working and some action by another person causes a fault, confidence can be badly affected.

Of course tools may be imperfect in their implementation of this concept:

- Some interfaces (like ESP-r) constrain the length of entity names. Terse names are a frustration and occasional source of error.
- Some interfaces assign names automatically and do not allow them to be changed - unique but arbitrary names can be opaque to the user.
- Some interfaces do not allow users to name entities within their models - this is unforgivable in terms of the resources required for model checking.

Knowing that simulation tools limit our ability to create self-documenting models it is for the community of users to evolve working practices which compensate for such limitations.

13.2 Responsibilities within simulation teams

Consider what simulation looks like from the clients perspective and choose, if possible, design the model to limit their confusion. Decisions made by team members as they plan and build models can influence the resources needed by others to understand both the intent and the composition of models. Some models *tell a good story* allowing design teams and clients to move on to substantive issues. Other decisions result in models with impose a considerable burden on the design team, puzzled expressions when clients view the model, and meetings hijacked by explanations of how the image on the screen represents their design. Making clients work hard is a questionable business strategy.

This is not an argument for a literal translation of CAD data into a thermal model. Much that is included in CAD drawings is simply noise in the thermal domain. A client who saw a simulation model with fifty thousand surfaces would be justified in asking for the methodology behind this approach to abstraction just as if they were told a box represented the Guggenheim in Bilbao.

Second quote of the day:

Self-administered QA brings great joy to someone else's lawyer.

Make it standard practice to outsource the task to another team member after initial checks are made by simulation staff.

Changes in staffing can require that models be passed to others in the team for completion. Opaque models increase risk during handover as well as the resources required.

The task of taking another persons model and understanding it well enough to make modifications to it is a classic test of working procedures. Projects go quiet for weeks at a time. If a substantial resource is given over to getting back to speed on a dormant project this could lessen the resources available for other tasks. It does not help that the design of simulation software rarely takes into account that many teams are working on several projects simultaneously.

Team manager

The team manager has in interest in ensuring that models are fit-for-purpose and that staff are working within their limits (and the limits of the tool). A model which tells a good story is one which the manager can more easily browse. And managers who regularly review models can anticipate possibilities as well as notice deadlines slipping.

Quality manager

Just as the author of a book needs an editor to help complete the story, a quality manager helps ensure that the model continues to be fit for purpose. Quality managers quickly recognise models which tell a good story and ensure that simulation staff get this feedback regularly.

Even with good working practices errors become embedded within models. Some typographic errors that get past tool checks will evidence themselves in the predictions of performance *if we are paying attention*. A 10KW casual gain in a room which is supposed to have 2KW may not show up as a temperature difference if the environmental control has an oversized capacity. The review would have to notice the reaction of the environmental control for this zone differed from other similar spaces. If the only report generated was a total for the building then this change might not be noticed.

Some errors can be subtle - selecting the wrong type of glazing for one window out of a dozen windows might alter performance of the room only slightly. The logic of a control which fails for an infrequent combination of sensed conditions may be difficult to spot.

Failure to check for site orientation prior to undertaking shading analysis can waste valuable time just as failure to notice that fire doors may be installed with fail-safe closing mechanisms (that allow mixing between zones) can alter assumptions about ventilation in buildings.

The simulation team should consider the frequency and types of error can exist without altering the patterns of performance to the point where a different design decision is made. Checks by simulation staff are likely to spot some types of errors but others only become apparent by their impact on predictions.

There are benefits in the quality manager being pro-active in the project and using simulation tool facilities to review models, generate model contents reports and review performance predictions. A pro-active quality manager can be a champion in identifying opportunities by reserving project resources for the exploration of value added issues.

Another pro-active task is to ensure that model quality is a continuous part of the model planning and creation process. The quality manager might also devise task sequences to confirm the skills level, strategies and *inventive resources* of simulation staff.

Simulation staff

The traditional deployment of staff involves junior staff *primarily working* to create models, run assessments and extract performance data. The critical issue for model quality is self restraint. Accepting default names for entities saves a few seconds but requires that others expend effort each time they browse through the model or look at performance reports.

Simulation staff are continuously making decisions and assumptions. For example - a quick decision to go with a standard concrete floor thickness rather than confirming the actual thickness in the model might be valid approach at the time. It becomes problematic if it persists and the decision is forgotten.

Unconstrained keyboard skills of novices can wreck havoc. Novices need active support from others who have more evolved opinions about the thermophysical nature of buildings and systems. If those with opinions take the time to pass on ideas then novices will be better placed co-operate when they start their work.

Topics that experienced users may forget that novices do not know are:

- Information required from the client at different phases of the work
- Benefits and drawbacks of different tools, time and computational resources for different tools.
- Ideas about how design issues might be represented
- Ideas about zoning strategies and level of detail
- Ideas about past models to review

Spending 2-3 hours a week exploring new working practices or generating scripts to automate processes is an investment that may result in better procedures and better models.

Domain experts and mentors

The domain expert will likely have strong opinions about they see in performance prediction graphs or reports. Subtle patterns may be easy for them to recognize.

The trick is to get the domain expert to also look at the model and the performance predictions with a view of further tweaks that could be made to improve performance or to confirm that the prediction is in line with expectations.

Mentors can play a pivotal role in enabling staff productivity and fine tuning working practices that ensure clarity in models. Prior experience with similar projects may allow the mentor to be among the first to identify where models are providing unexpected results.

Musical chairs

Rotation of quality assurance tasks has several benefits:

- A *fresh pair of eyes* can notice in seconds what has been evading others for hours.
- Conversations needed to confirm *what is this* are instructive for both participants.
- An appreciation how different designs of models impacts model checking tasks can result in better models.

13.3 Model planning

The thermophysical nature of a space which is *reasonably represented* by one hundred surfaces is not ten times better if a thousand surfaces are used. And because increasing complexity requires more than a linear increase in resources much thought is required to arrive at an appropriate model resolution.

This said, a small increment in model complexity may provide sufficient visual clues so as to reduce the effort needed to understand a model. Models that clients recognize help them to buy into the process and it often simplifies reporting requirements. This might be as simple as including visual place holders for columns and desks or including a crude block representation of adjacent buildings.

▶ Section   Other aspects of model design are covered in sections 1.4, 2.3, 3.1 and 4.1. In each of these sections the emphasis is on the planning stage and working out ideas in sketches rather than on the keyboard.

Entity names

A tool might be just clever enough to name the 27th surface in the zone which is vertical *Wall-27*. The author of the model knows the surface is the *partition_to_corridor* and probably knows several other attributes of the surface. The interface presents the initial guess for editing, five seconds of typing would *make this clear*. Accepting the default forces everyone else to work hard to understand what *Wall-27* is each time it is selected from a list or included in a report. It also slows down their use of selection lists and reduces the time delay and error if the wrong item is selected (or deleted).

Quote of the day:

Names are the first step to understanding and essential to owning ideas.

Names like hmeintflrt_1 might be derived from *horizontal mass element intermediate floor type instance one* but almost no one else will appreciate this baggage. If a client talks about room 1.12b then use that name in the model.

The second quote of the day is:

attribute names first and follow consistent patterns

Recording assumptions

As we create and evolve simulation models we make dozens of seemingly trivial decisions and assumptions which soon pass from our memory. If these are not recorded there can be adverse impacts. One of the driving forces for the author's software development has been to ensure that the internal data model of the simulation tool has space available to record decisions and assumptions.

The existence of a *slot* for explaining the intent of an occupancy profile does not ensure that it is used. The quality manager has an interest in self-documenting models and working practices should set standards for how decisions and assumptions are recorded.

Placeholders

Entities in simulation models require lots of attribution and the information required may not be available when required. The use of place holders for data not yet confirmed (e.g. creation of an approximate construction) is a valid way of continuing to get work done. Working procedures are needed to ensure that such pragmatic actions are followed up and the model is updated as better information becomes available.

Who does such updates, the frequency of reviews, and decisions about who needs to know that changes have been made are all items to include in a well-ordered working procedure.

13.4 Complexity

The evolution of software now allows simulation teams to create models which are closer approximations to the built environment and these models often involve a level of complexity which would not have been contemplated a few years ago. Our attempts to create better models is constrained by our ability to manage such models.

One of the unexpected problems with software which is designed to be both user friendly and over-functional is the level of self-restraint needed to create models which match the needs of the project. Facilities intended as productivity aids can easily seduce the user into an overly complex models.

Those who are unprepared for complexity multiply their workload as well as the risk that errors and omissions will go undetected. Some working practices are not fit for complex projects in part because staff been not been allowed to gain confidence in projects of increasing complexity.

Ensuring that the model is correct is, for many practitioners, the critical limit on the complexity of their models. Reviewing a hospital complex with hundreds of rooms to certify the correctness of thousands of entities is an iterative task. Each iteration focuses on a different aspect of the model and/or its performance.

Spot checks are one *useful step* in ensuring the quality of models. Quality managers will develop techniques for scanning model contents reports as well as techniques for reviewing the model form and composition with the tool interface.

A classic point of failure is to allocate time for reviewing model contents but not for commissioning assessments designed to identify semantic errors. Techniques that hi-light semantic errors tend to focus on short period assessments where patterns in the operational regime and boundary conditions should result in expected patterns of response.

Finding expected patterns is usually cause for celebration. The risk is in cutting short our multi-criteria assessments because we are in a good mood rather than concluding the assessments when we have reached a holistic understanding of the design.

Successful simulation teams also are able to recognize when complexity can be avoided. There are cases where a fully explicit representation is required - for example in a naturally ventilated building where air flow patterns are widely distributed. In many buildings there is considerable repetition and little to be gained by describing all rooms. The technique requires that a constrained model embody both the typical and exceptional elements of the design. Selecting what can be omitted from a model is a critical step in the planning process. The benefits can be considerable and many simulation groups use such techniques to conserve the resources needed to create, run and extract data from their models.

Another technique to re-allocate resources for semantic checking is to employ limited duration assessments (e.g. typical fortnights in each season along with extreme weeks) which are carefully scaled can result in predictions that are very close to predictions of brute-force annual simulations. This technique is especially important for simulation tools such as ESP-r which are disk intensive during the simulation and data extraction phases.

13.5 Multi-criteria assessments

Time gained by good working practices can provide a reserve of time to explore model performance. The more complex the model the more multi-criteria assessments are essential for discovering unintended consequences of design decisions as well as errors and omissions within the model.

So where might one begin the process of gaining confidence in a model? Well founded opinions as to what should be happening within the building (or access to such opinions) is a first step. This may take the form of information from similar projects, tabular data in handbooks, access to a mentor or expert or to measurements in this or similar buildings.

The next step is familiarity with tools and techniques for extracting performance data in forms which clarify what is happening within the virtual physics. In workshops for ESP-r, the time allocated for exploring model performance tends to be at least as long as for the model creation tasks. Both interactive investigative skills and the automation of data extraction are part of the process. The following list includes some useful indicators:

- the range of dry bulb temperatures in each zone and the time of the maximum and minimum AND frequency bins to confirm the number of extreme occurrences
- the difference between dry bulb and mean radiant temperature and if extreme do further checks for surface temperatures
- the range of heating and cooling demands and time of peak occurrence AND a frequency distribution of demand
- the number of hours heating and cooling is required AND the number of hours when zones are floating in the dead-band
- casual gains in each zone either as statistics and as a plot to confirm if lighting is switching as expected

- graphs of zone temperatures and zone environmental controls to see if an optimal start or stop might be useful, if there is heat stored in the building overnight or if a modular system might be appropriate
- statistics and graphs of solar entering the zones to confirm that windows that look like they are facing north actually do face north
- when a zone catches your attention check its energy balance for the type of heat transfer associated with big gains and losses

The time of occurrence is mentioned above because a peak temperature when no one is in the building might not be an issue. Frequency bins are mentioned because a peak demands for a dozen hours in a season may not be a good indicator of system capacity and extreme temperatures that are rare may be amenable to demand-side management.

Experts will also re-run transition season assessments without environmental controls or with reduced capacity for environmental controls. Why? Because buildings can often be comfortable with little or no mechanical intervention. The traditional focus on system capacity tends to ignore performance during the hundreds of hours of mild conditions that happen in most regions. A few moments to create a model variant to confirm this can result in significant value to the client.

Another trick of the experts is to gather statistics for the occupied period as well as at all hours. Why? Because attention to after-hours performance provides clues for improving the design of the building and its operating regime.

Some simulation tools such as ESP-r can be driven by scripts to automate the recovery of the data mentioned above. There are two common approaches:

- recording the keystrokes used during an interactive session into a scripts to automate subsequent checks
- defining an Integrated Performance View (IPV) for the model and using this to invoke specific assessments and recover the multi-criteria data.

▶ Section The use of scripts is covered in Section 17.1 as well as in the *Automation* section of this chapter. Setting up an IPV is included in Section 13.8.

Working at the edge

Most experts plan their work and their models to avoid the computational and complexity limits of their tools. A failure to anticipate the likely course of the project is a classic way to run short on options.

ESP-r is compiled with specific limits of model complexity and it is worth checking what the current limits are during the planning stages. It may be necessary to re-compile ESP-r if you want different limits (there are alternative header files available for different model resolutions that have been tested). The *Install Appendix* provides information about this. Other simulation tools are written to allow models to grow in complexity without having to re-compile, and there are still limits that knowledgeable users avoid.

Models which have been extended towards the limits of the simulation tool reach a point where productivity can suffer. There are many possible vectors for this, some involve actions by the user and some can be gaps in the logic of the software.

Caution and paranoia are useful attitudes. Archiving the working model as a first step. Generate a full model contents report and extract a range of performance data for use in comparisons with the revised model. Talk to others about their experiences of managing complex models and for advise on where simplifications can be made *before altering* the model. Plan the sequence of tasks, make frequent backups, carry out calibration runs on the revised model and check these against the initial performance predictions.

Each simulation tool and data extraction technique tends to have a point where the burden becomes noticeable. For example, ESP-r can be disk intensive. Data extraction gets progressively slower as result files grow. This can be managed if the design of the model and the design of the assessments and data recovery tasks are considered in the planning stages of the project.

Entropy is a word that begins to describe parametric studies. So much is invested in setting up a base case model that can be adjusted to reflect the various design variants. If after testing and running the scripts the whole edifice can be destroyed by demands to alter the base case and re-run the assessments.

ESP-r has the flexibility to be used for parametric work but the distributed file structure can make it difficult to make global changes to dozens of models and the potentially hundreds of files that support such models. Other tools also have constraints related to parametric studies which need to be understood.

Automation

Using a simulation tool interface to apply multiple changes to a model can be frustrating. Some users *hack* their model files and some use scripts to perform parametric changes to models. While such actions can save time they are also a potential source of subtle errors if dependencies are not resolved.

The author noticed that some practitioners make fewer errors than others when creating model variants. A critical review of the order of the tasks and the checks that were done to limit errors resulted in a *create model variant* facility within ESP-r. This manages model files to ensure that subsequent changes by the user to create new variants do not impact the original model. Other tools may provide facilities to manage model variants and working practices should be design to manage the use of such facilities.

ESP-r and other tools include functions to search and replace instances of a specific construction within the model as well as to rotate or transform the model. Other global changes to models may require editing of model files by a sequence of manual tasks or the use of scripts. Experts test their scripts. Working procedures should insure that the altered model is scanned by the tool to see if errors are detected and a fresh model contents report is generated and compared with the initial model.

Some parametric changes require more than a substitution of key words and names in model files. For example, removing a surface requires that many relationships within the model be re-established (e.g. shading patterns and surface-to-surface view factors be recalculated. Ideally, simulation tools are designed track these dependencies and attempt to resolve them.

Unfortunately, scripts can be fragile and difficult to maintain. It is worth checking with the software vendor to see if it is possible to revise the tool to support parametric excursions and the handling of model variants.

13.6 Semantic checks

Ideally we design models to be no more and no less complex that is required to answer the current design question. If we are clever our model will also be designed to answer the next question the client will ask. A model which is overly simple may fail to represent the thermophysical nature of the design. A model which is overly complex absorbs resources which may not be sustainable.

Thus we need to design tests to determine whether the model represents the essential characteristics of the design and is likely to deliver information at acceptable confidence levels. One form of question follows the pattern: *buildings of this type tend to XX when YY happens*

- If heating stops at 10h00 on a sunny cold winter day we expect to see the little immediate change but perhaps a gradual drop in temperature until 15h00 when solar radiation levels drop.
- If cooling stops at 15h00 on a hot day we expect an immediate rise of 3°C and then a slow rise until about 20h00.
- During a Monday morning startup after a cold weekend we expect to see full demand for 2.5 hours followed by a drop to about 40% of capacity when the set-point has been reached.
- If we double occupancy in the conference room we expect the cooling system to cope for one hour and then the heat absorbed in the walls should cause comfort to degrade.
- If we constrain heating capacity by 15% we expect a half hour longer to warm up and to find eight hours below the heating set-point during the month.

These questions are based on expectations of a specific circumstance. The expectations might be in the form of a pattern description, a statistic or a frequency of occurrence. Whether we are able to write down an expectation in advance or are able to construct an opinion as we look at the performance predictions or are unable to make a semantic judgement is largely a function of background and experience.

This points to one of the reasons that simulation is difficult for students. They are only beginning to form their ideas about how buildings and systems work and their pattern matching skills are also in development. Conversely, well designed virtual experiments can be an excellent learning tool for students. They have access to the thermophysical state of everything at each moment of time and by changing a few numbers they can undertake another experiment and look at the differences.

Guidance for students is essential (and a critical weakness in the provision of simulation). It is also fiendishly difficult to design a good virtual experiment. The good news is that pattern matching skills can be acquired.

The typical form of question involves a scenario defined in terms of a few hours or days (one exception involves a month). A graph or report covering a short period is quick to produce and its density of data is more manageable and thus it is possible to overlay other performance data to see what else is happening at the same time or just before our point of interest.

Missing from the above list are questions ending with "we expect 29.5 kWhr/metre square/year heating". Why. Firstly, it implies an annual simulation. We want to delay computationally intensive checks until we have gained confidence in other aspects of the model. Secondly, what is being measured is derived from the performance of dozens if not hundreds of entities and their interactions. A reported value matching our expectations does not necessarily bestow confidence in the underlying entities. An unexpected value provides few clues as to the underlying cause but does present us with a massive pile of data to sift through. Again, let's first focus on performance indicators with fewer dependencies.

The task for the simulationists is to design a virtual experiment which will allow us to see if predictions match expectations. Some of the questions require a step change to be introduced into the model and some questions imply a base case assessment and a second assessment run with some aspect of the model changed. Of course we will keep a copy of the unaltered model so that we can continue with standard assessments after the semantic checks have been run! Of course we will remember to include in our models labels that will remind us of which semantic check we are working on and to clearly identify which graph or report fragments are associated with that test!

Some semantic checks can be carried out by reviewing the client's questions and considering the underlying physics involved. If, for example, the design is sensitive to the distribution of solar radiation within rooms then a review would usefully look at the pattern of surface temperatures during the day vis-a-vis the distribution of radiation.

A design goal to make best use of solar energy for heating while controlling summer overheating will likely require careful attention to geometric resolution and the constructions which are used. To find out if additional geometric resolution (e.g. subdividing walls and floors) yields better predictions then the same room can be represented by three zones at different resolutions. What is learned from this exercise can be applied to the full scale model.

If control of blinds was also included then switching patterns would also be checked. But in this case it may be necessary to compare against the same room without the blind control. Indeed, to clarify the impact of ideal zone controls or system component control a variant model without the control or with a simple control is often the most efficient approach and working procedures should ensure that such model variants can be quickly created or are maintained as the work progresses.

The result of a semantic test might be that the model is predicting a pattern of performance for that scenario that is a good match with out expectations. Brilliant. Do other parts of the building exhibit this same pattern? Is this something to tell the client about? With each scenario is increasing confidence in the model, adding to our understanding of how the design performs and if that performance is in line with the initial ideas of the design team. Because the issue is focused it is possible to convert our newly acquired understanding into a story which is easy to deciminate to others.

The result of a semantic test might also be confusion. What was see is not what we expected and the task evolves into determining if our expectations were ill-founded, the model does not, in fact, support this kind of assessment, the model includes errors, or if our virtual experiment has yielded some new information and a new pattern for the design team to understand. Methods for dealing with this are covered in Chapter X. Clearly the resource required will be some function of the complexity of the model.

If a simulation team is confronted with a new kind of building or system and anticipates the need for rigorous syntactic and semantic checks then there is a business case to be made for working procedures that highlight expected or unexpected performance as early as possible and with the least resources consumed as possible. Focused initail models and focused semantic checks are one way to conserve project resources.

With a general tool such as ESP-r there are usually several possible designs of the model. In the planning stage a series of constrained models of different approaches can be created to identify the most promising approach. Some simulation teams will have a range of test models available or will have procedures for setting up test models. The *working practices* chapter recommends that simulation groups invest in

exploratory approaches and in the creation of models for testing future design process issues.

An example enabling a suite of models to test sensitivity is the sequence of models in the *technical features* group of example models distributed with ESP-r. These represent the same pair of cellular offices and a corridor at different levels of resolution and with different simulation facilities enabled.

A semantic check may also be triggered by an unexpected performance prediction.

- Why is this room several degrees warmer than expected?
- What is the largest heat gain to the space? When is it happening?
- What else is happening at the same time or just before this?

Professor Joe Clarke introduced the idea of *causal chaining of energy balances* in the early 1990's. It involves identifying the dependencies implied by a thermal event and working back down the dependency tree to isolate the form of energy transfer, which if corrected, will alter the initially noticed thermal event.

Models which have evolved many times in response to changes in design focus may include details which are no longer relevant or at an in appropriate level of detail. A critical review may be in order to determine if a fresh start will be more productive than further revisions. Another classic point to evaluate a fresh start is when the client poses a new what-if question.

The resources required to carry on with a not-quite-fit-for-purpose model should be judged against the cost of designing and implementing a model for the new design question or parametric study.

An example is the quality of light in rooms. Generating daylight factors to roughly assess whether the back of a room will be perceived as dark is a very different question than *is there glare at the head of the conference table*. Daylight factors are much less sensitive to the geometry of the facade than the requirements of a glare assessment. One is essentially independent of time and the other is both position and time dependant.

Hardware and human gremlins

> Think of simulation models as prisoners of war which have a duty to escape (or at least ruin your weekend).

There are countless ways for models to be rendered unusable because of corruption, inconsistencies or lost files. Phrases like - *I was going to backup this evening* compete with *I was only trying to make the model work better* and *there was a power spike* become part of the folk history of every simulation group. The intensity and duration of the disruption which follows is determined by the robustness of our working practices.

Making backups is not rocket science. It is amazing how a delayed holiday brought on by a disk crash can change work habits to the point where the loss of a half hours work is considered a failure within the group.

For every type of computer and operating system that ESP-r runs on there are utility applications available to create archives of model folders. In Unix/Linux/OS X systems commands like `tar cf broxburgh_18_apr_contol_a.tar broxburgh` will put all the files and sub-folders of broxburgh into an archive file. On Windows it is usually a matter of a right click on the model folder to create a zip file. Each simulation group will have its own naming scheme for such files as well as rules as to where these files are stored.

The frequency of backup depends partly on the imagined hassle of repeating a particular set of actions as well as the state of the model. The following are classic trigger points for making backups:

- when a zone becomes fully attributed
- prior to making a model variant
- prior to a search and replace operation
- prior to a transform or rotation
- prior to a change in control strategy
- to record the current state of the model prior to a review
- when someone with electrical test gear is seen in the building

And backups can be focused on one or two files which are related to an issue being tested. A quick test of reducing the cooling capacity in one zone of the building would start with making a backup of the current control, altering a few values in the control definition, running a test and then recovering the initial state

of the control. Different groups adopt different styles of file naming conventions and the logs of the actions taken and reverted.

One issue which is much debated is whether model archives should include results files. Some groups include these, some compress such files prior to archiving and some groups include in the archive scripts and directives needed to re-generate results files. ESP-r models can include pre-defined *simulation parameter sets* and many groups build their working procedures around such facilities.

13.7 Team Checklists

The following table includes some of the issues to notice when working with simulation models. Roughly, the order begins at the start of the work. Clearly there are scores of topics which could be added to this table.

The form of the table is to pose a general issue in the left column and provide a list of associated topics or questions in the middle column and related actions in the right column. Consider this as a starting point and extend the topics as new situations arise and as working procedures for speculative future work is contemplated.

Questions	Actions
What do we know about the site? Does the client realize the importance of the site? Is the north arrow on the site plan? How might site issues constrain the design? How might site layout be used to improve the design?	Check the site plan, area maps, site photographs and confirm orientation. Visit the site and make note of site solar and wind obstructions. Check principal wind direction and whether vernacular architecture takes this into account. Discuss with design team options for adjusting the building on the site. If orientations may vary ensure naming regime avoids confusion (e.g. avoid north_entrance).
What weather data is available near the site? What patterns of weather will impact the building design? How have other buildings adapted to the local weather? What are the design teams ideas about the influence of weather?	Review weather data to establish seasons, typical periods, extreme periods and periods for failure test sequences. Discuss with design team the results from initial review of weather.
Is the design evolving or static? What drawings or sketches can we access? Are there plans, sections and elevations available to review? Are the drawings likely to change? What is the design team debating now and what are likely future topics?	Review drawings or CAD files and gather comments from simulation staff and quality manager. Check that the drawing scale is reasonable and if details might influence the design of the model. Discuss the level of detail required within the team. Arrange a meeting with the design team and present sketches of planned model and likely approaches.
What is the composition of the building? Are the goals of the project consistent with these constructions? Are construction details known? What what-if questions relate to constructions? Do we have sources for missing data? What criteria for rejection of constructions?	Review common data files for matching constructions and/or SIMILAR constructions. Create place holder constructions and document. Review sections and discuss with design team. Discuss support for selecting appropriate constructions.
Does the client have an well-formed opinion about the building use? Is the building for a known tenant or is it speculative? Is building occupancy an issue for future-proofing?	Check the assumptions made by the client. Quantify likely scenarios. Consider diversity, holidays and peak use occurrences. Check past models for similar patterns.

Questions	Actions
What is the clients big idea? What performance issues are related to the big idea(s)? What kind of model would confirm this? What analysis domains and metrics of performance will confirm this? Can beliefs held by the design team be confirmed?	Listen to the language used and review sketches to identify beliefs behind the big idea(s). Identify issues and determine if they can be assessed. Review available tools to check for matches in numerical capabilities and reporting facilities.

In-built Tool checklists

The internal checks which simulation tool interfaces support typically include issues such as *is this polygon flat* and *does the construction attribute point to a correct entity in the common file* and *does the boiler have a non-negative capacity*.

Tool checks are not likely to flag a surface named *door* which is composed of *150mm of concrete* or which is *horizontal*. It is unlikely that doors are horizontal or have a concrete construction attribute. Unlikely can happen and users are in the best position to notice this.

In addition to checks in the interface, further scanning of the model may be done by the simulation engine. If the simulation engine scan passes then it becomes possible to move from syntax checks to semantic checks based on predicted performance (see sections 13.6 and 13.8).

Criteria for frequency of syntax checks should be included in the working procedures. Typically these would happen during the evolution of the model as well as after simulations have been run.

There are techniques for reducing the time taken for checks. Incremental checks are well supported by looking at the differences against an earlier report and software for hi-lighting the differences between two files or between two folders is readily available. The use of pattern search tools (i.e. grep) can identify key words in model contents reports.

The table that follows illustrate some of the issues. Use this as a starting point for generating your own responses to issues as they arise and for planning future tasks.

Questions	Actions
What changed since version 1.3? Who is working on the model? What tasks are they involved in? Does this match the work plan?	Consult the work log. Generate a model contents report and see how this differs from the previous report. Check with the quality manager and simulation staff about current status.
The client wants to test a different roof type Which parts of the model are affected? Is information available on the new roof? What performance issues might change? What tasks are required and which staff should be involved? Is this a model variant or an edit of the existing model?	Update the common constructions if required. Generate a model contents report, archive the current model and performance predictions. Create model variant if required. Apply changes, generate model contents report, check against previous report, re-run calibration assessments and review. Archive the revised model and brief the client.
The interface says 'problem edges' in conference zone. Is there a missing surface? Are there edges which do not follow the rules used in the tool? Is there one or more reversed surface?	Look at the wire-frame for missing surface labels. Use the check vertex topology option for a report. Turn on surface normal arrows to review orientation of surfaces. Check for vertices linked to only one surface.

Questions	Actions
The ceiling void is warm and retaining sufficient heat to cause a morning cooling issue. Under what operating regimes and weather conditions is this happening? What are the primary gains within the ceiling void? Is it possible to remove heat from the ceiling void?	Carry out checks under different weather patterns. Review the energy balance in the ceiling void. Review how boundary conditions are represented. Test sensitivity of operating regimes. Force a brief purge of heat from the ceiling void and check the whether (and how long) it takes the condition to re-establish.

13.8 Simulation outputs

In simulation the time when the *fat lady sings* is most often after the simulation has been run and the team is exploring the performance predictions looking for *the story* to tell the rest of the design team.

Some simulation groups generate the same report irregardless of the project. Such poor value for money is largely the fault of the client for not making their needs clear or not having sufficient experience to know the variety of deliverables that a simulation team can provide.

It is only natural that simulation staff have their preferences for the graphs and tables that are included in reports. However, the goals of many projects are multi-criteria and working patterns need to be established to ensure that a range of performance issues are tested and taken into account in reports to the client.

Gremlins enjoy watching us find patterns we expect, declaring success and then having someone else discover the chaos. The risk of unintended consequences can be reduced by multi-criteria assessments and by different people with different agendas attempting to understand the predictions.

This is not a new issue. ESP-r has long included the concept of an Integrated Performance View (IPV) where a number of performance issues are identified at the planning stage and recorded in the model so that recovery of multi-criteria assessments can be automated. A typical range of metrics would be comfort, system capacity, energy use over time, emissions of carbon dioxide, distribution of light in rooms and the number of hours of system use. As implemented, the IPV is imperfect and further work is required to allow risk to the better managed and opportunities identified.

In other simulation tools this could be implemented by the inclusion of 'performance meters' for a range of issues. The critical step is taking the time early in the design process to identify issues which may arise as design options are tested.

Running well-designed calibration assessments should usually only take a few moments each so they will focus on typical weeks rather than whole seasons. For performance metrics which are not yet part of an IPV there are still options to automate assessments and data recovery. A library of standard scripts for extracting performance data on a range of topics is a useful complement to interactive explorations.

The table that follows is a sample of issues and questions and actions for staff attempting to understand performance predictions. Use this as a starting point for your own working practices.

Issues	Actions
Have calibration assessments been run? Were there enough measurements to understand performance?	Review the criteria for calibration assessments. Identify measurements which match expectations. Identify and investigate unexpected measurements.
Is performance tracking planning stage expectations? What issues were mentioned in recent meetings? What value added issues are under consideration? Do we have trigger values for failure? What other data views will complement standard reports and graphs?	Explore performance interactively, including a few tangent issues. Follow up issues by looking at dependant or related issues. Run test script to confirm data recovery logic and reporting format is ok. Do spot checks. Run the full script. Get someone else to do spot checks.

Issues	Actions
What if we altered the vision glass?	Establish what is available and the claimed benefits.
What products would be likely candidates?	Identify glazing-related improvements and where to apply.
Do we have thermophysical and optical data?	Archive model, establish base case performance, test substitution and data extraction procedures.
What criteria would signal better performance?	Implement one change at a time, compare against the base case and then rank order.
Is performance sensitive to the facade orientation?	

13.9 The model contents report

This section is a review of the ESP-r model contents report. What should you be looking for? What are key words to scan for? How much detail is available? Where is is information held? The reports generated by other tools will differ in detail but they will cover many of the same issues. Those of you who are constrained to screen captures of the tool interface can also create rules for interpreting entities shown in the interface.

Exercise 13.1

You can, of course, review the contents reports included in example models. These are typically found in the `doc` folder of models. Go through the steps in Exercise 13.1 to create your own report for your own model and see how the form, fabric and names that you supplied are included in the report.

The following listings are portions of the model contents report for the doctors office project. Prior to each section is a discussion of the contents of the report. After the report fragment is a discussion of key words and phrases to look for.

The user has the option to selected which topics are included in the report as well as the level of detail included for each topic. The example below used the verbose level for most topics.

As mentioned elsewhere, many quality managers will create a hard-copy of such reports and use them in conjunction with the interface when reviewing models. One common pattern is for simulation staff to generate the report and then insert additional notes and assumptions or highlight blocks of text that require further discussion and pass this to the quality manager along with the location of the model.

The header

The header of the model report focuses on site and high level project related information. Some of the text is based on user supplied phrases and other parts are generated from model data and file names.

The key words for this section are the date that the report was printed and the name of the model log file (which may contain useful additions by the user).

The first two lines of the report also are the place to identify what is *different about this model*. These phrases are used in many places in the interface and in reports.

The year mentioned in the summary will have been initially set to match that of the weather file. One reason to alter the year is to shift the day of the week - for example, in 2001 the first of January is a Monday.

```
Synopsis

This is a synopsis of the model for training session on Thursday defined in
office_for_doctor.cfg generated on Fri Jul 30 11:13:01 2010. Notes associated
with the model are in office_for_doctor.log

The model is located at latitude   55.90 with a longitude difference of   -4.10
from the local time meridian. The year used in simulations is 2007 and
weekends occur on Saturday and Sunday.
The site exposure is typical city centre and the ground reflectance is 0.20.

Simulationist name: not yet defined
Simulationist telephone: not yet defined
Simulationist address: not yet defined
Simulationist city: not yet defined
```

```
Simulationist postcode: not yet defined

The climate is: ESP test climate and is held in: /usr/esru/esp-r/climate/clm67
with hour centred solar data.
```

What to look for in header

The summary of the site location and the climate should be checked to see if they match the project. Default values here may be indicative of a lack of attention.

In the report below the lines identifying the building, the building owner and the simulation team have not yet been filled out.

If the project requires model variants then its is *really important* to consider naming schemes and titles - users in a hurry can easily select the wrong model! If you create a model variant check that the tiles and documentation have been updated to reflect this.

The log file for the model is a text document which is initially filled in by the interface when the model is created. Some groups use this file as a place to document progress on the model. Imagine reviewing a model after several months. What kind of notes would you like to find in order to come back to speed on this project?

The databases

The next section of the report focuses on common data stores associated with the model. Some of these are standard databases - the <std> indicator in the menu or the report indicates that it is a standard file. Data stores can also be model specific - a path ../dbs. And they might be located in a non-standard location with a full path give - /home/fred/databases.

Files in the standard esp-r/databases folder are initially supplied with the software. The example and validation models distributed with ESP-r reference these files as will many user created models. Thus is it important that these files are secure and are only altered with due care and attention. Other files can be added to the standard databases folder as required or added to a non-standard location if that is more convenient.

It is up to the group to manage and document common data. Entries in the fies should be reviewed and the contents *should* be of a know quality and kept up to date by the quality manager. The file read and write permissions on Unix and Linux and OSX computers can be used to ensure that these so-called corporate files are protected from corruption or casual modifications. Groups working within a Windows infrastructure will have to implement their own procedures because it is difficult to prevent corruption or casual modification by users.

```
Databases associated with the model:
standard pressure distr: pressc.db1
materials              : ../dbs/office_for_doctor.materiald
constructions          : ../dbs/office_for_doctor.constrdb

standard plant comp    : plantc.db1
standard event profiles: profiles.db2.a
standard optical prop  : optics.db2
  . . .
   sections skipped
  . . .
Multi-layer constructions used:

Details of opaque construction: extern_wall

Layer|Matr|Thick|Conduc-|Density|Specif|IR  |Solr|Diffu| R    |Descr
     |db  |(mm) |tivity |       |heat  |emis|abs |resis|m^2K/W
Ext     6  100.0    0.960  2000.    650. 0.90 0.70     25.  0.10 lt brown brick : Light brown brick
    2 291  150.0    0.040    12.   1000. 0.90 0.70     30.  3.75 Min wool quilt : Insulation (Min wool
    3   0   50.0    0.000     0.      0. 0.99 0.99      1.  0.17 air  0.17 0.17 0.17
Int     2  100.0    0.440  1500.    650. 0.90 0.65     15.  0.23 breeze block : Breeze block
ISO 6946 U values (horiz/upward/downward heat flow)=  0.226  0.228  0.224 (partition)  0.222
Total area of extern_wall is      78.45

Details of opaque construction: int_doors

Layer|Matr|Thick|Conduc-|Density|Specif|IR  |Solr|Diffu| R    |Descr
     |db  |(mm) |tivity |       |heat  |emis|abs |resis|m^2K/W
```

```
    1   69  25.0      0.190    700. 2390. 0.90 0.65    12.  0.13 oak : Oak (radial cut)
ISO 6946 U values (horiz/upward/downward heat flow)=  3.316  3.682  2.928 (ptn)  2.554
Total area of int_doors is       4.20
  . . .


Details of transparent construction: dbl_glz      with DCF7671_06nb optics.

Layer|Matr|Thick|Conduc-|Density|Specif|IR   |Solr|Diffu|  R     |Descr
     |db  |(mm) |tivity |       |heat  |emis |abs |resis|m^2K/W
Ext   242    6.0    0.760  2710.   837. 0.83 0.05 19200.   0.01 plate glass : Plate glass
  2     0   12.0    0.000     0.     0. 0.99 0.99     1.   0.17 air  0.17 0.17 0.17
Int   242    6.0    0.760  2710.   837. 0.83 0.05 19200.   0.01 plate glass : Plate glass
ISO 6946 U values (horiz/upward/downward heat flow)=  2.811  3.069  2.527 (ptn)  2.243


Clear float 76/71,     6mm, no blind: with id of: DCF7671_06nb
with 3 layers [including air gaps] and visible trn: 0.76
Direct transmission @ 0, 40, 55, 70, 80 deg
  0.611 0.583 0.534 0.384 0.170
Layer| absorption @ 0, 40, 55, 70, 80 deg
   1  0.157 0.172 0.185 0.201 0.202
   2  0.001 0.002 0.003 0.004 0.005
   3  0.117 0.124 0.127 0.112 0.077
Total area of dbl_glz is      11.55
```

Common data files associated with the model may or may not be derived from a standard file. Typically they will include items specific to the model. Such entities may eventually migrate to the corporate common data folder (a task for the quality manager). ESP-r does however have limitations on the internal model documentation. It falls to the simulation team to supplement this so that they conform to group policies.

Each common data file differs slightly in implementation. Currently the constructions contents are the core of the report. The constructions make reference to materials and if transparent to the associated optical properties. The layout of the report is similar to that used in the interface.

The constructions part of the report is a combination of numbers and short labels. It follows an older format which lacks clarity for some users. For example, name of the construction is restricted to twelve characters and there are no categories.

Until the data structure is revised it is up the user to compensate for the limitations in the tool (other tools will have different limitations to compensate for).

What to look for in common data files

When reading the report remember the layers go from 'other-side' to room side. Make a point of comparing the reported U values with other data sources to ensure that the construction is properly defined. In the case of ESP-r, a U value is a *derived value* and not part of the calculation process. It is also up to the user to correctly account for the changes in heat transfer between the centre of glazing and sections near the frame. There are several approaches such as using averaged values and using separate surfaces for the centre and edge of glass but little consensus in the community.

Constructions which are transparent have additional entries in the report for optical properties. This part of the report includes jargon and a not particularly human readable format. The data used by ESP-r is more detailed that that provided by some manufacturers. And it does not include some data generated by optical analysis tools such as Window 5.2 and WIS. ESP-r is not unique in simplifying some aspects of diffusing glass and advanced light re-directing glazing products.

Other potential errors might include reference to the wrong file or confusion about its contents. Several of the example models include local copies of common files and maintain the same name as the standard database. Updates to the standard database will not be reflected in these derived files. Conversely if new entities have been added to a local file care and attention are required when incorporating this into the corporate common data to avoid name clashes.

Updates to standard files also require care and attention. For example, an ISO standard recommended that foundation constructions include at least 500mm of earth. Two standard constructions were identified for upgrading but it was also necessary to scan for references to these constructions in the models distributed with ESP-r. For one of the constructions a dozen models required updating and the update needed to include not only refreshing the zone construction files but also remembering to update the model contents reports. A similar procedure would apply to simulation groups and their own archives of models.

Another relationship to check in the common constructions is between the construction and optical property. A three layer double glazed windows construction can only be matched to a three layer optical property set. For a window with a low-e coating the improved performance is represented as an increased resistance in the air gap in the construction definition.

An internal (between the glass) blind is often represented by glass air metal air glass in the construction with optical property sets that allow some radiation to pass through the metal layer. Thus the metal layer mass is used in the construction definition and the optical property tells the simulator what portion of the solar radiation passing through the construction is absorbed at the metal layer. An operable blind is usually implemented by altering only the optical properties (the mass does not move).

The thickness of a layer in a construction is often the same as the physical entity. And there are instances where this in not appropriate and where a given construction may need to be represented in different ways. For example, a sandstone wall in a castle is 700mm thick and ESP-r will complain about this as it stresses the underlying numerical method and limits our knowledge of the temperatures within the wall. A better representation would be four layers e.g. 150mm 200mm 200mm and 150mm (assuming the 400mm in the centre are rubble and the outer 150mm is faced stone). A similar approach would apply to insulation products. Layers of insulation of 100mm are preferred.

The idea that constructions are composed of layers is thermophysically defensible for homogeneous constructions but requires adaptation for non-homogeneous constructions. A given layer (parallel with the face of the construction) may be composed of one or two repeating materials perpendicular to the face of the construction e.g. insulation and structure. In this case the properties of the parallel layer is derived from the weighted contributions of the insulation and structure. If such composite materials are to be included then it must be clear what materials were used and the percentages of each.

Zone controls

The next section of the model report is extracted from the controls defined for zones and/or flow or system networks. The documentation phrases are provided by the user. Next there is a short synopsis of what is being sensed and what is actuated. This is followed by an automatically generated synopsis for each period in the control schedule.

The control section of the report is a compromise. The space available for translating the parameters of each period's control law is limited and abbreviations are necessary. Some controls include jargon used by control engineers. There are a few controls which have almost no translation of the control parameters. Some controls which have parameters which include auxiliary sensor definitions can be confusing because the standard report of sensor and actuator locations does not know that it has been superseded.

Invest time in understanding to how ESP-r represents and reports on controls so you can spot errors and omissions before you run assessments. The reports may also provide clues if you find the model is not working as expected.

The control portion of the QA report below indicates that the model is probably at an early stage. There is, for example, no mention of why 2KW capacity was specified for heating and cooling during office hours and 1KW during the setback periods.

Documentation is important for ideal controls because the sensor actuator control law pattern used by ESP-r can approximate any number of physical devices. It may be that a later version of the model shifts from ideal representations to component based representations of environmental controls and initial statements can assist this transition.

What to look for in controls

Words and numbers must be backed up with a clear description and an initial check should evaluate whether the description given is a good synopsis for the controls that have been implemented. The software does not force you to update the description when you are working with control loops so find a way to make this a habit!

ESP-r allows control loops to be defined which are not yet referenced in the model. Users are also responsible for assigning links between control loops and thermal zones. Thus is it possible that this association is not correct. It is possible that an incorrect link will result the the *appearance* that the zone is controlled and so it is necessary to be pedantic in inspections of the control listing to ensure that the correct control is used.

Control logic is separated into different periods in the day. This allows for considerable flexibility in environmental controls and it also complicates the process of proving that controls are working as intended. Control logic may also differ on different day types - one typical error is to update controls for one day type and not check further.

```
The model includes ideal controls as follows:
Control description:
to work with reception occupant 80W with diversity during the day max to
400W. Lighting at 150 W during occupied period. 60W equipment during
occupied period

Zones control includes  1 functions.
1kW heating overnight during setback, 2kW office hours to reach 20C set-point
during office hours. Weekend setback to 10C.

 The sensor for function  1 senses the temperature of the current zone.
 The actuator for function  1 is air point of the current zone
 The function day types are Weekdays, Saturdays & Sundays
 Weekday control is valid Mon-01-Jan to Mon-31-Dec, 2007 with  6 periods.
 Per|Start|Sensing  |Actuating | Control law    | Data
   1  0.00 db temp   > flux      basic control     1000.0 0.0 1000.0 0.0 10.0 24.0 0.0
basic control: max heating capacity 1000.0W min heating capacity 0.0W max cooling
capacity 1000.0W min cooling capacity 0.0W. Heating set-point 10.00C cooling set-point
24.00C.
   2  7.00 db temp   > flux      basic control     1000.0 0.0 1000.0 0.0 20.0 24.0 0.0
basic control: max heating capacity 1000.0W min heating capacity 0.0W max cooling
capacity 1000.0W min cooling capacity 0.0W. Heating set-point 20.00C cooling set-point
24.00C.
   3  8.00 db temp   > flux      basic control     2000.0 0.0 1000.0 0.0 21.0 24.0 0.0
basic control: max heating capacity 2000.0W min heating capacity 0.0W max cooling
capacity 1000.0W min cooling capacity 0.0W. Heating set-point 21.00C cooling set-point
24.00C.
   4  9.00 db temp   > flux      basic control     2000.0 0.0 1000.0 0.0 21.0 24.0 0.0
basic control: max heating capacity 2000.0W min heating capacity 0.0W max cooling
capacity 1000.0W min cooling capacity 0.0W. Heating set-point 21.00C cooling set-point
24.00C.
   5 17.00 db temp   > flux      basic control     1000.0 0.0 1000.0 0.0 20.0 24.0 0.0
basic control: max heating capacity 1000.0W min heating capacity 0.0W max cooling
capacity 1000.0W min cooling capacity 0.0W. Heating set-point 20.00C cooling set-point
24.00C.
   6 21.00 db temp   > flux      free floating
 Saturday control is valid Mon-01-Jan to Mon-31-Dec, 2007 with  3 periods.
 Per|Start|Sensing  |Actuating | Control law    | Data
   1  0.00 db temp   > flux      free floating
   2  8.00 db temp   > flux      basic control     1000.0 0.0 1000.0 0.0 10.0 24.0 0.0
basic control: max heating capacity 1000.0W min heating capacity 0.0W max cooling
capacity 1000.0W min cooling capacity 0.0W. Heating set-point 10.00C cooling set-point
24.00C.
   3 19.00 db temp   > flux      free floating
 Sunday control is valid Mon-01-Jan to Mon-31-Dec, 2007 with  3 periods.
 Per|Start|Sensing  |Actuating | Control law    | Data
   1  0.00 db temp   > flux      free floating
   2  8.00 db temp   > flux      basic control      500.0 0.0 1000.0 0.0 10.0 24.0 0.0
basic control: max heating capacity 500.0W min heating capacity 0.0W max cooling
capacity 1000.0W min cooling capacity 0.0W. Heating set-point 10.00C cooling set-point
24.00C.
   3 19.00 db temp   > flux      free floating

 Zone to contol loop linkages:
 zone ( 1) reception     << control  1
 zone ( 2) examination   << control  1
```

Dead-bands and heating and cooling set-points can be used to fine tune control logic to match the response of physical devices. There are caveats - ESP-r is implementing ideal controls so the time-lags in physical devices is absent. We might think we know what is happening in a room thermostat but most of the time we are guessing.

ESP-r does not support auto-sizing so it is up to the user to define heating and cooling capacity. Sometimes we have this information but many users just stick in a big number. Imagine what a big number represents to a numerical engine - a small room with a hundred thousand Watts of heat dumped into it not something that we would do in reality so it is probably best not to go there in a virtual world either.

Some controls in real life are unstable if not properly tuned and an un-tuned PI or PID controller in ESP-r will exhibit the same patterns. Reserve time for virtual tuning and be aware that the same controller may not perform well in different seasons without re-tuning.

Minimal capacity is a concept embedded in a number of ideal controls. The idea is that some wet central heating systems tend to have poorly lagged pipes that are exposed in the room and even if a valve turns off the radiator there is still some heat released from the piping.

Zone composition

The next section of the model report provides both summary and detailed reports of zone composition. If the attribution in a zone is incomplete the summary will reflect this.

The report for each zone reflects the verbosity selected before the report was generated. Much of the report is based on information derived from scanning the form and composition of the zone. If the zone is fully attributed then U-values and UA values are reported for a quick reality check.

Note that the derived values may be a bit confusing if the zone shape is complex - for example if portions of the facade are horizontal and facing up then they will be included in the roof area. Transparent surface that are not vertical may be reported as skylights.

```
ID Zone          Volume|          Surface
   Name          m^3   | No. Opaque Transp ~Floor
 1 reception     120.0  12  165.5    4.5   40.0  reception has one staff and up to 4 visitors
 2 examination    60.0  11   86.0    7.0   25.9  examination for one doctor and one visitor
   all           180.   23  252.    12.    66.
```

```
Zone reception ( 1) is composed of 12 surfaces and 26 vertices.
It encloses a volume of 120.m^3 of space, with a total surface
area of 170.m^2 & approx floor area of 40.0m^2
reception has one staff and up to 4 visitors
There is 94.000m2 of exposed surface area, 54.000m2 of which is vertical.
Outside walls are 123.75 % of floor area & avg U of 0.226 & UA of 11.195
Flat roof is 100.00 % of floor area & avg U of 0.924 & UA of 36.965
Glazing is 11.250 % of floor & 8.3333 % facade with avg U of 2.811 & UA of 12.648
```

```
A summary of the surfaces in reception( 1) follows:
```

```
Sur| Area |Azim|Elev| surface   |    geometry       | construction |environment
   | m^2  |deg |deg | name      |optical|locat| use | name         |other side
 1  12.0  180.   0. partn_a     OPAQUE   VERT -     mass_part    ||< partn_a:examination
 2  9.90  270.   0. partn_b     OPAQUE   VERT -     mass_part    ||< partn_b:examination
 3  9.75  180.   0. south_wall  OPAQUE   VERT WALL  extern_wall  ||< external
 4  21.0   90.   0. east_wall   OPAQUE   VERT WALL  extern_wall  ||< external
 5  9.75    0.   0. north_wall  OPAQUE   VERT WALL  extern_wall  ||< external
 6  12.0    0.   0. partn_c     OPAQUE   VERT -     mass_part    ||< identical environment
 7  9.00  270.   0. west_wall   OPAQUE   VERT WALL  extern_wall  ||< external
 8  40.0    0.  90. ceiling     OPAQUE   CEIL ROOF  roof_1       ||< external
 9  40.0    0. -90. floor       OPAQUE   FLOR -     grnd_floor   ||< ground profile  1
10  2.25  180.   0. south_glz   DCF7671_ VERT C-WIN dbl_glz      ||< external
11  2.25    0.   0. north_glz   DCF7671_ VERT C-WIN dbl_glz      ||< external
12  2.10  270.   0. door        OPAQUE   VERT -     int_doors    ||< door:examination
```

```
An hourly solar radiation distribution is used for this zone.
Insolation sources (all applicable):
 south_glz north_glz
```

```
Explicit viewfactors have been derived for this zone.
Shading patterns have been calculated for this zone.
```

The list of surface attributes is probably best viewed in conjunction with a wire-frame image of the zone. This is one of the places where a well designed naming regime will allow inconsistencies to be identified quickly.

After the surfaces attributes have been listed there may be additional lines which identify optional attributes of the zone. In the example above is a notice that shading patterns have been pre-calculated for the zone as well as radiation viewfactors calculated.

Details of the polygons which make up the surfaces of the zone are not included. Users interested in this level of detail will either have to look at the interface (where co-ordinates and edge lists are found) or look at the model descriptive files.

Quality managers will scan this report for 'UNKNOWN' attributes. One might expect some 'UNKNOWN' early in the model composition. Some users tend to address attributes one at a time - for example, they might make a pass through the model assigning construction attributes, and then make a second pass attributing the ground connection details for foundation surfaces. Frequent re-freshes of the model contents report will clearly show where such progress has been made.

Another check that is part of many group's work flows is to look for names that do not match the entity. For example, a wall named south_wall might actually be facing West. Is this because the zone was rotated after the surfaces were named? If so a better naming scheme might be *front*, *back*, *left*, *right*. Differences in names and wire-frame views might also indicate that a surface has been inverted. In this case one would look at the numerical value of the azimuth and elevation reported as well as the wire-frame view of the zone and turn on the *draw surface normal* option.

In the column of surface names look for duplicate names - this can cause havoc with some functions in ESP-r. Check also that the surface names are following the general rules for naming agreed by the group.

The column of optical tags will either include the key words *OPAQUE* or *TRAN* or the initial part of the optical property name. If ESP-r becomes confused or the user is forgetful then surfaces which you intended to be transparent might show up with an *OPAQUE* tag. To correct this go to the menu for the attributes of this surface and re-select the construction and also, if necessary set the optical property toggle. If the problem persists then it might be that the entry in the common constructions does not have the correct optical property.

The column of location tags are based on the orientation of each polygon and are used by some methods within ESP-r. For example, a polygon which is approximately vertical uses a specific heat transfer regime so it is useful to pre-calculate this attribute of the surface. The tag also can be useful tag for quick visual scans of the model.

The column of surface uses supports building code compliance rules which need to identify specific types of facade entities. As a form of documentation surface use tags are also useful. In the future these tags may help automate the creation of flow networks. Currently surface use attributes are optional so you will often find this column filled with '-' entries.

The column of construction names should be read in the context of the optical property name as well as the surface name. Some users also check the location tag. In a well designed and well composed model these attributes should reinforce each other and a key pattern matching skill is to learn to quickly recognize discontinuities in these attributes.

The right-most column described boundary conditions. For partitions this report is more specific than the 'ANOTHER' tag that occurs in the geometry file or the higher level menus. Be aware that there are space limitations and longer zone and surface names may have been truncated.

After the columns of surface attributes the report (if generated in verbose mode) should tell you about extensions to the zone definitions. In the example above there is a note that explicit viewfactors have been calculated. The report does not include the actual view-factors and it is not clear from the report whether or not the view-factors are up to date. To get more information one must go to the interface for view-factors.

Zone schedules

The next section of the report focuses on the schedules of air flow and casual gains defined for the zone. First there is the user supplied documentation and then the data for each of the schedule types.

The format of the report is similar to that supplied in the interface and thus it is somewhat terse. In the example below there is no control imposed on the air flow schedule and so no information on the control logic is included.

The current version of ESP-r supports a minimum period of one hour so there can be up to 24 periods in a day. Periods should be in sequence and include the whole of each day type.

Working procedures that minimize errors typically enforce matching documentation and data. Numbers may be correct without being clear as to what they represent.

The user documentation includes a brief note about the casual gains. There is some diversity included in the casual gains for occupants. Lights are a fixed wattage as are small power loads. The documentation says computer all the time but the data is only on during office hours. Which is correct? A quality

manager would notice that the radiant and convective split is 50 50 for occupants and lights and ask for clarification.

```
 Air schedule notes:
one air change all day. reception - up to 3 people, one computer all the time
 Control: no control of air flow

Number of air change periods for daytype weekdays     :    1
  Period   Infiltration    Ventilation      From Source
  id Hours Rate ac/h m3/s Rate ac/h m3/s   Zone Temp.
  1  0 - 24     1.00  0.0333    0.00  0.0000   0     0.00

Number of air change periods for daytype saturday     :    1
  Period   Infiltration    Ventilation      From Source
  id Hours Rate ac/h m3/s Rate ac/h m3/s   Zone Temp.
  1  0 - 24     1.00  0.0333    0.00  0.0000   0     0.00

Number of air change periods for daytype sunday       :    1
  Period   Infiltration    Ventilation      From Source
  id Hours Rate ac/h m3/s Rate ac/h m3/s   Zone Temp.
  1  0 - 24     1.00  0.0333    0.00  0.0000   0     0.00


Notes:
reception - up to 3 people, one computer all the time
Number of weekdays      casual gains= 14
Day Gain Type        Period Sensible  Latent      Radiant     Convec
    No.  label       Hours  Magn.(W)  Magn. (W)   Frac        Frac
weekd  1 OccuptW      0- 7     0.0       0.0        0.50        0.50
weekd  2 OccuptW      7- 8    80.0      40.0        0.50        0.50
weekd  3 OccuptW      8- 9   240.0     120.0        0.50        0.50
weekd  4 OccuptW      9-12   400.0     200.0        0.50        0.50
weekd  5 OccuptW     12-14   240.0     120.0        0.50        0.50
weekd  6 OccuptW     14-17   400.0     200.0        0.50        0.50
weekd  7 OccuptW     17-21    40.0      20.0        0.50        0.50
weekd  8 OccuptW     21-24     0.0       0.0        0.50        0.50
weekd  9 LightsW      0- 8     0.0       0.0        0.50        0.50
weekd 10 LightsW      8-19   150.0       0.0        0.50        0.50
weekd 11 LightsW     19-24     0.0       0.0        0.50        0.50
weekd 12 EquiptW      0- 8     0.0       0.0        0.40        0.60
weekd 13 EquiptW      8-19    60.0       0.0        0.40        0.60
weekd 14 EquiptW     19-24     0.0       0.0        0.40        0.60
Number of saturday      casual gains=  3
Day Gain Type        Period Sensible  Latent      Radiant     Convec
    No.  label       Hours  Magn.(W)  Magn. (W)   Frac        Frac
satur  1 OccuptW      0-24     0.0       0.0        0.50        0.50
satur  2 LightsW      0-24     0.0       0.0        0.50        0.50
satur  3 EquiptW      0-24     0.0       0.0        0.40        0.60
Number of sunday        casual gains=  3
Day Gain Type        Period Sensible  Latent      Radiant     Convec
    No.  label       Hours  Magn.(W)  Magn. (W)   Frac        Frac
sunda  1 OccuptW      0-24     0.0       0.0        0.50        0.50
sunda  2 LightsW      0-24     0.0       0.0        0.50        0.50
sunda  3 EquiptW      0-24     0.0       0.0        0.40        0.60
```

What to look for in zone schedules

As with controls the documentation of zone schedules should match the values and an update to the schedule should (by habit) include a revision to the documentation. A review of the model contents report should ensure that the documentation is both clear and consistent.

The section on infiltration and ventilation provides both air changes per hour and m^3/second values. The latter is derived from the volume of the zone and thus should change if the room volume changes. Another thing to look for in the ventilation section is that the volume given for ventilation between rooms is in terms of the current zone, not the supply zone. It is the users responsibility to derive the correct volume for ventilation.

The example above indicates eight periods for occupants on weekdays and it is implied that the changes in values are to introduce some diversity into the schedule. The 400W periods are clearly the peak and the peak lasts three or four hours. There is also a ramp-up and ramp-down at the start and end of office hours. It is assumed that this is used to represent brief occupancy of cleaning staff but it is not explicitly stated in the documentation.

Another pattern to observe is the radiant and convective split. It is likely that default values have been used and it may be worthwhile to fine tune these values. Note that ESP-r uses fixed representations of sensible and latent values for occupants but in reality they are sensitive to the temperature of the room and the metabolic rate. Those doing analysis in temperate climates without air conditioning should adapt values accordingly.

There is also a summary section in the QA report which provides a range of derived data which have proved to be of use to practitioners. For example there are UA values for different portions of the building fabric which provide a quick reality check.

```
Project floor area is 65.900m2, wall area is 78.450m2, window area is 11.550m2.
Sloped roof area is 17.088m2, flat roof area is 40.000m2, skylight area is 0.00m2.
There is 147.09m2 of outside surface area, 90.000m2 of which is vertical.

Outside walls are 119.04 % of floor area & avg U of 0.226 & UA of 17.743
Sloped roof is 25.930 % of floor area & avg U of 0.924 & UA of 15.791
Flat roof is 60.698 % of floor area & avg U of 0.924 & UA of 36.965
Glazing is 17.527 % of floor & 12.833 % facade with avg U of 2.811 & UA of 32.463
```

What to look for in the project summary

The reported floor area is based on the list of surfaces associated with the base of each zone. Occasionally errors occur in this if surfaces have been added or removed or the floor is sloped. Check the values in each zone report.

The summary report makes assumptions when allocating surfaces to particular categories. It is possible that complex zones may not be accurately reported. An example is a facade which includes horizontal elements.

The reported UA values are based on standard assumptions and might also be mis-allocated if their location is mis-interpreted. The intent is to provide a guide for practitioners who also work with software that uses UA based calculations or include quick UA evaluations as part of their model quality checks.

13.10 Summary

Well-formed working procedures will ensure that models tell a clear story to the design team and that performance predictions have been reviewed to ensure that predictions are within normal expectations and options for better than expected performance are delivered to the design team.

It is a challenge to ensure resources used for generating and testing models is within the project budget and that sufficient time and attention is available for exploring value-added issues. A pro-active quality manager is needed to champion such issues.

The quality of models is a result of decisions made during the planning stage, the design of the model, actions by members of the simulation team and the facilities included within the simulation tool.

The increasing complexity of models is partly driven by new questions from design teams and by productivity features in simulation tools but is constrained by our ability to confirm that models are both syntactically and semantically correct.

The discussions and tables included in this chapter are intended to be a starting point for simulation teams to generate robust working procedures and provide ideas for skills which may be useful to acquire.

14 Interactions between tools

Simulation tools are often called upon to interact with other tools. For example ESP-r has options for exporting model entities in file formats used by other numerical assessment tools such as ESP-r, visualisation tools such as Radiance, as well as a few CAD tools. Simulation tools often hold a *super-set data model* of their virtual worlds which allows them to act as repositories for information which might be useful to other tools.

There are also a options for acquiring information generated by other tools, some of which are robust and some not-so-robust. Managing the process of exchanging information is a topic which will be elaborated in a future edition.

WORKING WITH EXPERIMENTS

15 Working with experiments

Simulation tools are often used to design experiments because it is far easier to explore opportunities and omissions in a virtual experiment than to re-configure a physical experiment.

Simulation tools also take part in validation exercises which require them to be used in an extremely pedantic context with is rarely demanded in commercial practice. As validation exercises evolve simulation tools need to evolve as well as the working practices that support experiments and validation work. There is much to discuss and this throws down the gauntlet for inclusion in the next edition.

16 Install Appendix

ESP-r is available on a number of computing platforms and this section provides information on how to acquire ESP-r and manage the distribution folders and supporting files.

ESP-r was initially a suite of tools running on Sun workstations and then the code was adapted to also run on Linux as well as OSX and a number of ARM based low cost systems. It has also been ported to compile and run as native Windows graphic executables and console applications via MSYS/MSYS2 or within a Cygwin emulation environment on Windows.

ESP-r implicitly assumes a range of operating system services. For example, that common data files and example models are held in folders where normal users can read but not overwrite such files. For operating systems where such protections are differently enforced or absent teams should exercise care with corporate resources.

ESP-r requires the computer environment is using a locale where **real numbers use a period as a decimal point and that a comma, tab or space is a separator between data**. A USA or UK locale works. Other locals may result in model corruption.
ESP-r works better *without spaces* in the path to a file and also has limits on the length of path.
There is also a restriction that names of entities use the ASCII character set rather than an extended character set.

These dependencies are related to the underlying Fortran source code read and write statements. ESP-r has been observed to have problems with some, but not all Asian keyboards and locales.

All of the distributions of ESP-r are based on the use of the GNU compiler collection (gcc g++ gfortran). Implementations are available for all Linux variants, OSX, Cygwin emulation and Windows native compiles (via MSYS/MinGW or MSYS2).

Linux is the primary development and deployment platform for ESP-r. Not only does it support a robust tool chain for building the executables, it enforces strict file permissions (to protect corporate databases), it multi-tasks well and scales simulation from low resource ARM computers to compute servers. Instructions for building from scratch are found in src/manual/OS/Linux.

Whereas Linux tends to place users home folders in /home OSX places them in /Users, otherwise the use of ESP-r is essentially the same as Linux. Because the interface has a Linux look-and-feel and some OSX users may find this confusing.

OSX supports the GNU compiler collection as well as X11 libraries and source code conventions. For development work it is necessary to install either the so-called *MacPorts* or *Homebrew* facilities as well as X11 support. A full list of requirements can be found in the source distribution folder src/manual/OS/Apple along with instructions for building ESP-r from scratch.

One approach to ESP-r running on Windows computers has been to use an emulation environment called Cygwin. Cygwin provides the compilation environment required by ESP-r as well as translating operating system requests and providing a similar command line interpreter (shell scripting) as one would find on a Linux machine. Instructions for building from scratch are found in src/manual/OS/Cygwin.

Again there few code differences required for development and use of ESP-r on Cygwin. In terms of user experience, ESP-r thinks it is running on a Linux box and the same user interactions apply.

Cygwin supports the usual GNU compiler collection and X11/GTK graphics libraries and the development tasks are essentially the same as on Linux. File permissions are less strict than Linux and thus care should be exercised to avoid overwriting files that ESP-r assumes have strict permissions.

The native Windows implementation of ESP-r interface works on Windows W7, W8, W10 computers. The build process relies on the MSYS or MSYS2 environment required by the GNU gcc g++ gfortran compilers. Instructions for building from scratch are found in src/manual/OS/Native_windows. The standard distribution folder layout is shown in Figure 16.1
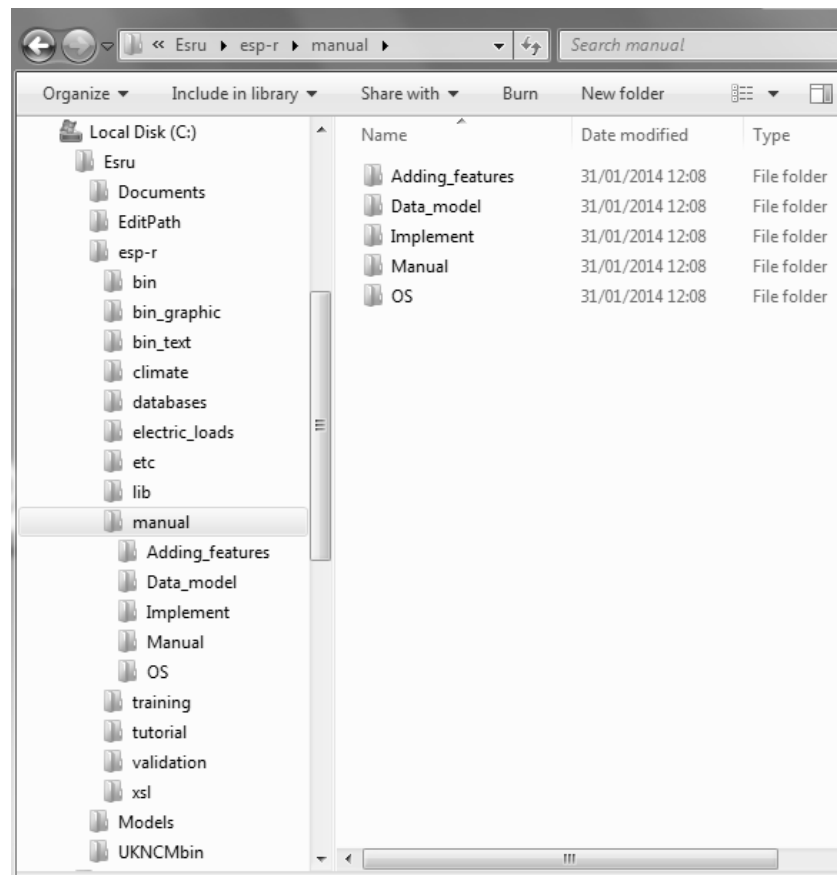
Figure 16.1 ESP-r distribution on W7 computer.

Native Windows ESP-r executables are either a graphic interface or a pure-text set of executables which can be used for scripted production work or as the engine for other user interfaces. MSYS/MSYS2 includes a bash shell and thus the same automation scripts used in OSX and Linux are possible from within MSYS/MSYS2. For computers without MSYS users will normally be using the graphic version of ESP-r executables, however, the console version of ESP-r executables can be used with *bat* files to support some automation tasks.

See the *Interface Appendix* for a discussion of the different interfaces to ESP-.r Below is the general layout with the selection menus on the right, text feedback at the lower left, wire-frame feedback at the upper left and a number of tabs at the top for viewing controls.
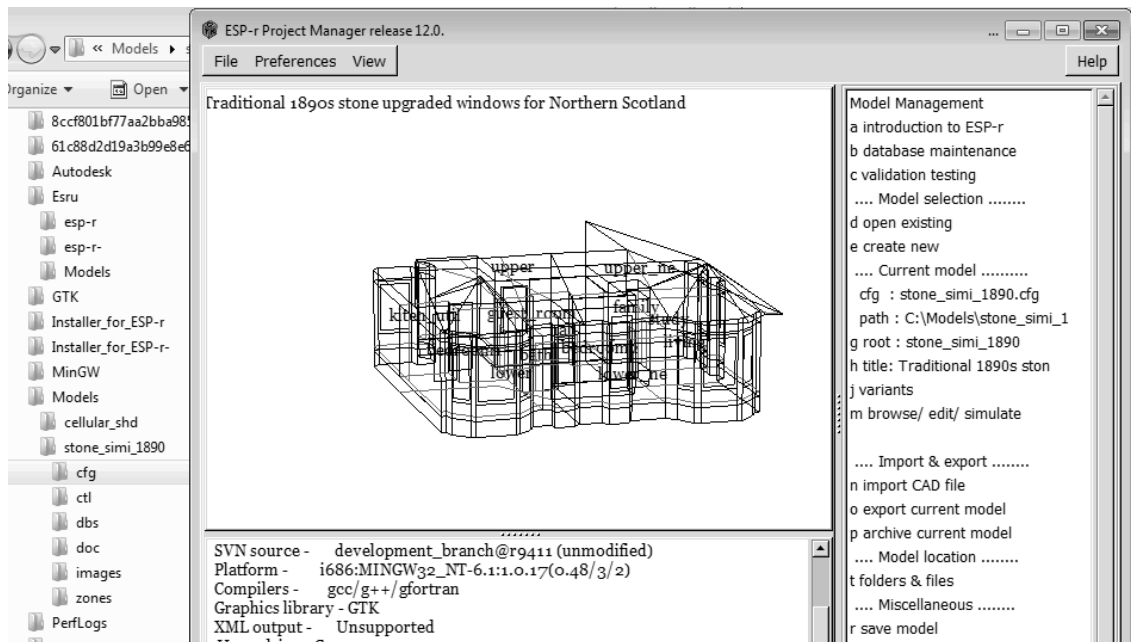
Figure 16.2 Project manager interface on Windows 7.

Differences are found in the facilities and uderlying security of the operating system and in the layout and conventions of the file system. For example, ESP-r currently has a limited ability to cope with spaces in file names and it also has limits on the length of file names. These limit where ESP-r can be installed as well as how deeply nested model folders can be before file names become truncated. For this reason, pre-compiled versions of ESP-r are designed to be in `C:\Esru\esp-r` rather than in `C:\Program Files\Esru.`   ESP-r models work best in `C:\Esru\Models` or at the top level of the users folder e.g. `C:\Users\Fred\Models\`

Acquiring source distribution

ESP-r is hosted on github <https://github.com/ESP-rCommunity>. To grab the full source distribution you need to use git to checkout the ESP-rSource.git, ESP-rDatabases.git, ESP-rModels.git and ESP-rDoc.git as follows:

```
mkdir ESPrgit
cd ESPrgit
git clone --recursive https://github.com/ESP-rCommunity/ESP-rSource.git
git clone --recursive https://github.com/ESP-rCommunity/ESP-rDatabases.git
git clone --recursive https://github.com/ESP-rCommunity/ESP-rModels.git
git clone --recursive https://github.com/ESP-rCommunity/ESP-rDoc.git
```

Now use a utility called rsync to merge the repositories into ESPr_Master:

```
mkdir ESP-rMaster
rsync -av ESP-rSource/ ESP-rMaster/
rsync -av ESP-rDatabases/ ESPrMaster/data/
rsync -av ESP-rDoc/ ESPrMaster/doc/
rsync -av ESP-rModels/ ESPrMaster/models/
```

Typically one would place these files and run such commands in a location that you have control of e.g. /home/fred/Src/esru_distribution.

In the top level folder you will find `Install` which controls the build process. There are command line options different levels of optimisation `--opt0 --opt1 --opt2 --opt3` the first for debug and development and the last for distribution (it might run more than twice as fast) `Install --opt1` is good for Windows MSYS and Cygwin builds and `Install --opt3` for ARM processors and OSX. A typical command line invocation for development work on Linux (assuming that the folder /opt/esru exists and can be written to) would be:

```
cd Src/esru_distribution
./Install -d /opt/esru --gcc4 --debug --opt1
```

Questions about installing databases and example models would be answered `YES` so that dependencies are satisfied. You are also asked about which type of interface you want to build (see the *Interface*

Appendix for details of the implications of this choice) as well as how to host multiple interface versions of ESP-r on a computer. And you can build ESP-r to support different levels of model complexity (constrained executables can run in less memory). There are a number of options which can be passed to `Install` and these can be found via as well as in the `src/doc/manual` folders.

Environment variables and files

When ESP-r is initially compiled several types of information are embedded in the executables (e.g. where ESP-r is installed) and other types of information (e.g. where to find example models and what common files to initially load) is scanned in from text files. One of these text files is called `esprc` and the standard version is assumed to be in the installation sub-folder `esp-r`. Its contents are listed in Figure X and the meaning of the tokens is presented below.

The file is in tag - data, data format. Typically the first token is a label and the second token is either an executable to be invoked or the name of a file to be used. To alter this initial specification use a text editor and change the relevant token as required. Look in the `preferences` menu of the Project Manager to access the details of this file.

The initially created version of the *esprc* file is held in the ESP-r installation folder. If a user wants a custom version of this file to use they should copy it to their *home* folder with the name *.esprc*.

- *ESPRC - this is the file type tag. It must be the first line
- *gprn - commands associate with capturing a rectangular section of the screen. The 2nd token **import** is the executable which captures a section of the screen. In this case the esprc file was created with a Linux computer and the executable name would be different for a different computer operating system.
- *tprn - commands associated with dumping the current text feedback buffer to file will write to the file identified in the second token.
- *gxwd - a variant of *gprn but which captures the whole screen.
- *cad - instructions for a CAD tool to invoke. The second token is the executable and the third token is a key word describing the type of file it creates.
- *image_display - commands related to the display of model-associated images. The second token is a key word identifying the format of the file and the third token is the name of the executable to invoke to display that type of image. There can be several *image_display lines in the *esprc* file.
- *journal - turns on a time-stamp facility which logs user actions and the key words are ON and OFF.
- *editor - which ASCII text editor to invoke if an external application is required.
- *report_gen - not used
- *exemplars - the name of the file to read which includes a list of models which can be accessed and where they are stored. The initial contents of the *exemplars* file is for use in ESP-r workshops but the contents can be edited to include other models.
- *validation_stds - the name of a file to read with information needed to commission standard tests
- *db_defaults - the name of a *default* file which holds a list of initial common data files. If you want to use an alternative list edit this file.
- *db_climates - the name of a *climatelist* file which holds a list of weather data sets and their location. If you want to use an alternative list edit the file or provide the name of an alternative file.

Default file assumptions

The second file which is commonly scanned when ESP-r modules start is the *default* file. The name of this file is included in the *esprc* file. The file is a tag - data format and is typically found in the installation folder. An example of this file is listed in Figure 16.2. Note that the paths in this file are to the standard installed location of ESP-r. If ESP-r is located in a different path then this file will reflect this.

As with the previous files the name of the file is associated with a specific topic and/or dialogue within the user interface. These dialogues associated with specific types of model files require a default name and the default file names are scanned in via the *default* file rather than being hard-coded into the interface. The name of the file can be altered by editing the file.

- *ESP-r Defaults - this must be the initial line of the file.

- *ipth - this is the path to where ESP-r has been installed based on the specific commands given during the installation process
- *cfg - this is a default file name for a model configuration file (useful for demonstration purposes)
- *ctl - this is a default file name for control loop definitions
- *mfn - this is a default file name for an air flow network
- *dfd - this is a default file name for the domain description
- *res - this is a default file name for a zone predictions (results) file. This file should be created during the install process so that it is easy to demonstrate ESP-r.
- *mfr - this is a default file name for mass flow predictions
- *clm - this is a default file name for weather data. This weather file should be created during the install process.
- *prs *mat *mlc *opt *evn *pdb - these are default file names of common files (in case the user request a default). Many users will change the name of the common files to suite the needs of their work. This file can be accessed via the `preferences` menu of the Project Manger.

```
*ESPRC
*gprn,rectangular dump,import
*tprn,Text dump,/tmp/tx_dump
*gxwd,screen dump,import -window root
*cad,CAD package,xzip,ZIP
*image_display,TIF,display
*image_display,XBMP,display
*image_display,GIF,display
*image_display,XWD,display
*journal,OFF
*editor,editor,nedit
*report_gen,Reporting tool,xfs
*exemplars,Exemplars,/usr/esru/esp-r/training/exemplars
*validation_stds,Validation standards,/usr/esru/esp-r/validation/stds_list
*db_defaults,Defaults,/usr/esru/esp-r/default
*db_climates,climatelist,/usr/esru/esp-r/climate/climatelist
*end
```

Figure 16.3 A typical esprc file.

```
*ESP-r Defaults
*ipth /usr/esru/esp-r
*cfg /usr/esru/esp-r/training/basic/cfg/bld_basic.cfg
*ctl /usr/esru/esp-r/training/basic/ctl/bld_basic.ctl
*mfn /usr/esru/esp-r/training/basic/nets/bld_basic_af1.afn
*dfd /usr/esru/esp-r/training/cfd/template.dfd
*pnf /usr/esru/esp-r/training/plant/vent_simple/cfg/vent.cfg
*res /usr/esru/esp-r/databases/test.res
*mfr /usr/esru/esp-r/databases/test.mfr
*clm /usr/esru/esp-r/climate/clm67
*prs /usr/esru/esp-r/databases/pressc.db1
*prm /usr/esru/esp-r/databases/material.db4.a
*mlc /usr/esru/esp-r/databases/multicon.db5
*opt /usr/esru/esp-r/databases/optics.db2
*evn /usr/esru/esp-r/databases/profiles.db2.a
*pdb /usr/esru/esp-r/databases/plantc.db1
*ecdb /usr/esru/esp-r/databases/elcomp.db1
*mcdb /usr/esru/esp-r/databases/mscomp.db1
*icdb /usr/esru/esp-r/databases/icons.db1
*mldb /usr/esru/esp-r/databases/mould.db1
*sbem /usr/esru/esp-r/databases/SBEM.db1
*end
```

Figure 16.2 A typical default file.

```
*CLIMATE_LIST
*group  ESRU standard climates
# WARNING: Keep this file up to date with current directory structure !
*item
*name   Default UK clm Climate
*aide   Climate data as distributed with ESP-r for testing purposes.
*dbfl   /usr/esru/esp-r/climate/clm67
*winter_s 2  1  12  3  30  10  31 12
*spring_s 13 3  14  5   4   9  29 10
```

```
*summer_s 15 5    3  9
*winter_t 6   2  12  2   20 11 26 11
*spring_t 17 4  23   4    2 10  8 10
*summer_t 3   7   9  7
*avail   ONLINE
*help_start
Location is 52.0N and 0.0E. The solar radiation is Direct Normal.
 Month       Minimum  Time           Maximum  Time          Mean
 Jan          -6.4 @20h00 Sun  8    12.7 @14h00 Sun 29      3.8
 Feb          -1.9 @ 5h00 Tue 14    12.2 @13h00 Thu  2      5.2
 Mar          -0.8 @24h00 Fri 31    16.1 @15h00 Tue 21      6.8
 Apr          -1.9 @ 2h00 Sat  1    19.4 @15h00 Mon 17      7.1
 May           0.0 @ 3h00 Wed  3    22.7 @14h00 Thu 11     10.4
 Jun           5.0 @ 2h00 Fri  9    21.1 @15h00 Tue  6     13.6
 Jul           9.4 @ 3h00 Mon  3    27.7 @12h00 Mon 17     18.0
 Aug           7.7 @ 4h00 Sat  5    24.4 @12h00 Tue  1     15.6
 Sep           5.0 @ 6h00 Thu 21    22.2 @12h00 Tue 26     13.5
 Oct           2.2 @ 5h00 Mon 30    19.4 @13h00 Sat  7     10.8
 Nov          -0.8 @ 5h00 Mon 27    14.4 @14h00 Sat 11      5.2
 Dec          -4.2 @ 1h00 Sat  9    12.7 @ 9h00 Sat 23      3.8
 All   -6.4 @20h00 Sun  8 Jan  27.7 @12h00 Mon 17 Jul   9.5
 Typical winter week begins Monday 6 Feb,
 Typical spring week begins Monday 17 April,
 Typical summer week begins Monday 3 July.
 Typical autumn week begins Monday 2 October.
 Typical winter week begins Monday 20 November,
*help_end
*item
*name    ALBUQUERQUE NM USA iwec 723650
*aide    ALBUQUERQUE NM USA iwec 723650 was sourced from US DoE web Sep 2005
*dbfl    /usr/esru/esp-r/climate/USA_NM_Albuquerque_iwec
 . . .
```

Figure 16.3 A typical section of a climatelist file.

The list of available weather files

The last ASCII file which is used by ESP-r modules on a regular basis is the so-called *climatelist* file. This file is referenced by the *esprc* file (see above discussion) and includes a list of the weather data sets that were installed on the computer. When the interface of one of the ESP-r modules presents a list of available weather data it scans this file.

Each time you want to add weather data to your computer you should edit this file with a text editor so that the listing will include the new file. There is a detailed discussion of how to use **clm** to add new weather files in Chapter 6. A portion of this file is shown in Figure 16.3.

The *climatelist* file includes the following types of information:

- a display name for the weather data (as seen the the interface list)

- a brief documentation about the weather data

- its location on the computer

- the start and end dates of each of five seasons (winter from 1 Jan, spring, summer, autumn, winter ending 31 Dec). These dates typically were supplied by a person who knows the weather of the region and the social customs of the region.

- the start and end dates of a typical week in each season. There is an facility in the **clm** module which searches for typical weeks based on heating and cooling degree days and solar radiation patterns.

- a block of text up to 60 lines which provides a summary of the weather. This block is auto-generated within **clm** and you can edit it and extend it if required.

17 Interface Appendix

In addition to its multi-platform capabilities, ESP-r has three styles of interaction: pure-text, the legacy X11 graphic interface and a GTK graphic interface (see the Table below). Pure-text is a separate executable for Windows, otherwise it is a command line option.

Graphic interfaces have separate regions for graphic feedback, text feedback, menu selections and user dialogues for editing entities and selecting files. User interactions are uniform and each of the ESP-r modules follows the same layout.

Operating System	X11	GTK	Pure-text
Windows	-	X	X*
Cygwin	X	X	X
OSX	X	X	X
Linux	X	X	X

Pure-text is the most *geeky* on offer. It is driven either by user supplied keystrokes or commands included in a script (see Section 17.1). An example of the X11 interface is seen in Figure 17.1.
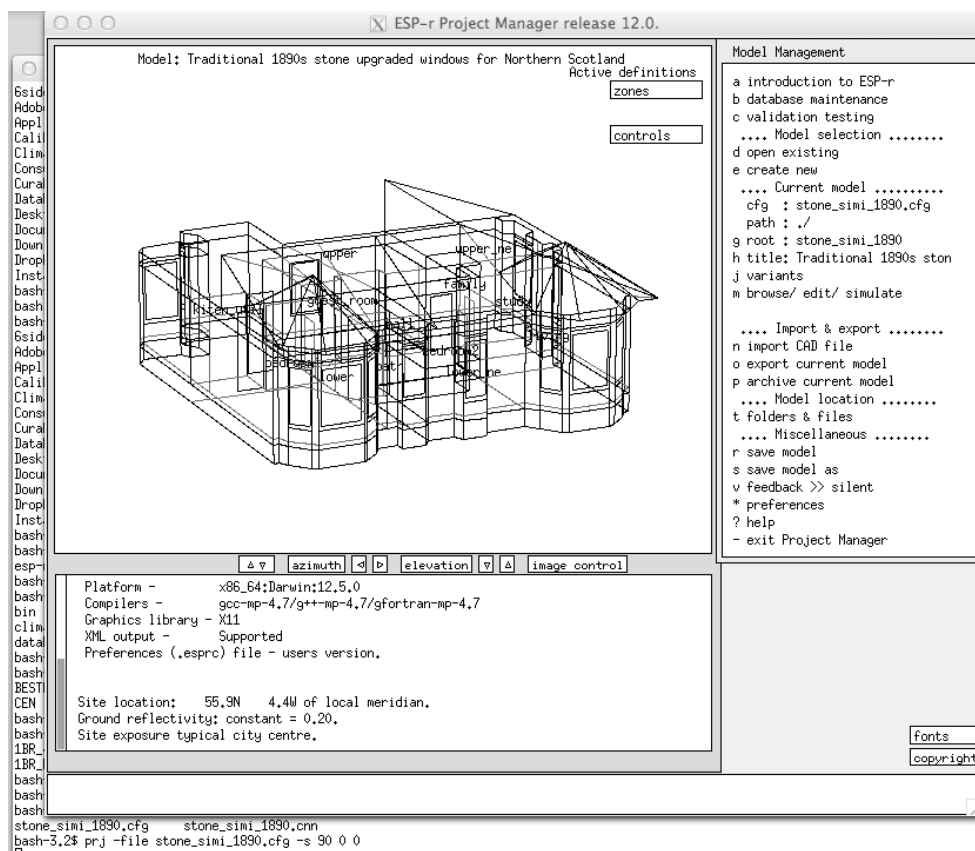

Figure 17.1 An example of invoking the project manager X11 interface.

GTK+ libraries can be deployed across a range of operating systems, including Windows. GTK has a number of in-built features, such as file browsing, that are not standard in X11. Figure 16.2 is an example of the GTK interface.

The order and naming of dialogs and command menu selections are the same in each of the interfaces. Differences are listed in the bullet points and table below:

- Scripts (see section 17.1) and keystroke selection are not supported in graphic mode GTK.
- Control of wire-frame images of the model (adjusting viewing direction and the level of detail) are equivalent but implemented differently in X11 and GTK.
- Some choices of fonts for the graphic feedback and text feedback and menus are available for size as well as switching serif to mono-space so that columns in reports can be aligned.
- Images associated with models are displayed in pop-up windows, however the X11 version uses a 3rd party tool to carry out the task. The name of the 3rd party executable is defined in the environment variables file *.esprc* in your $HOME folder or the *esprc* file in the ESP-r distribution folder.
- File browsing facilities are limited in the X11 and pure-text interfaces to folders within the model or the distribution databases. The list of files are presented in the command window. In GTK a general pop-up file browser is used which is not limited to the model folders.
- In the X11 and pure-text interfaces items in control menus which start with a character can be selected by typing that character. Menu entries that start with a blank in the first column are not keyboard selectable are usually reporting derived values or acting as labels. Menu items in the GTK interface are selected via mouse actions and do not respond to keyboard actions.

Interaction	X11	GTK	Pure-text
menu select via keystroke	X	-	X
menu select via mouse	X	X	-
control via script	X	-	X
click-on-bitmap	X	-	-
click-on-vertex	X	-	-
wire-frame of model	X	X	-
wire-frame view control via buttons	X	-	-
wire-frame view control via pull-down	-	X	-
font selection via button	X	-	-
font selection via pull-down	-	X	-
graphic feedback font sizing	X	X	-
text feedback font sizing	X	X	-
text feedback font type	-	X	-
image display via pop-up	-	X	-
image display via 3rd party app	X	-	-
drag menu to resize width	-	X	-
text feedback cut-and-paste	-	X	-
text feedback scroll back	X	X	-
general folder/file browser	-	X	-
model file browser	X	X	X
pure-text interface via command line option	X	X	-

17.1 Text mode & scripting

Text mode operation is available as a command line option `-mode text` however on Native Windows ESP-r must be compiled without graphics and invoked via the DOS command shell to run in pure-text. To acommodate two versions of ESP-r the executables need to be located in separate folders with the PATH environment variable pointing to one or the other folder.

In Figure 17.2, the project manager has been invoked from a command window (the same command syntax applies in Linux, OSX and Cygwin). The list of user options is shown in a double column (options which start with a character or number are activated by typing that character). The prompt is seen at the bottom of the figure.

```
MacBook-Pro-7:cfg jon$ prj -mode text -file stone_simi_1890_frames.cfg
ESP-r Project Manager
This is a development copy of prj, based on ESP-r release 12.7.

Copyright resides with the member organisations of the ESP-r
development consortium as listed at:
http://www.esru.strath.ac.uk/Programs/ESP-r_central.htm.
```

```
and https://github.com/ESP-rCommunity.

Build information:
  SVN source -         @rRevision: 1536 (locally modified)
  Platform -           x86_64:Darwin:14.5.0
  Compilers -          gcc-mp-5/g++-mp-5/gfortran-mp-5
  Graphics library - X11
  XML output -         Supported
  Preferences (.esprc) file - users version.

 Site location:     55.9N    4.4W of local meridian.
 Ground reflectivity: constant = 0.20.
 Site exposure typical city centre.
Model Management:
  a introduction to ESP-r
  b database maintenance              .... Import & export ........
  c validation testing              n use CAD tool or parse gbxml file
   .... Model selection ........     o export current model
  d open existing                   p archive current model
  e create new                       .... Model location ........
   .... Current model ..........    t folders & files
    cfg  : stone_simi_1890_frames    .... Miscellaneous ........
    path : ./                       r save model
  g root : stone_simi_1890_frames   s save model as
  h title: Traditional 1890s 4tsp   v feedback >> silent
  j variants                        * preferences
  m browse/ edit/ simulate          ? help
  - exit Project Manager
 Model Management:?>
```

Figure 17.2 An example of invoking the project manager in text mode.

Production work often requires a specific sequence of tasks e.g. running a standard set of assessments followed by commands to extract a standard report. Such sequences are often codified within automation scripts. To create such a script use one command window to invoke the relevant ESP-r module with −mode text and in a text editor record the keystrokes (one per line) which you use to carry out the tasks. Usually a script includes a header which defines which command interpreter to use.

Below is a portion of a script called *SIMULATE.wc* is used to run a standard assessment (with ideal controls active). The script is invoked with two parameters. The first $CONFIG is the name of the model configuration file and the second is $VERSION which specifies the path to the executable. The sequence of keystrokes used by the ESP-r module is terminated by XXX after which the script terminates.

```
#!/bin/csh -fb
set CONFIG=$1
set VERSION=$2
$VERSION/bps -file $CONFIG -mode text <<XXX

c
$CONFIG.wc_res
9 1
15 1
3
1
s
y
ESRU Standard test: $CONFIG
y
y
-
-
XXX
```

Having run the assessment, a second script in the source code validation/benchmark/QA/model/cfg folder named ANALYSE_4 is invoked to start up the results analysis module and cause a sequence of reports to be generated.

```
#!/bin/csh -fb
set RESF=$1
set VER=$2
$VER/res -file $RESF -mode text<<XXX

d # enquire about
>
$RESFILE.data
$RESFILE results
a # summary statistics
h # sensible
a # heating
h
b # cooling
b # temperatures
a # zone db
b
e # zone resultant
b
d # zone control pt
-
-
d # enquire
a # summary statistics
f # zone flux
a # infiltration
f
b # ventilation
m
a # real power
m
b # reactive power
j
b # convective casual gains
-
j
c # radiant casual gains
-
d # solar processes
a # entering from outside
d
c # solar absorbed
i # zone rh
j # casual gains
a # all
-
j
b # convective portion
-
j
c # radiant portion
-
j
```

```
e # total occupant gain
-
j
i # total lighting gain
-
j
m # total small power
-
-
-
c # timestep reports
g # perf metrics
j # casual
e # total occupant
-
j
i # total lighting
-
j
m # total small power
-
! # list data
-
-
d
f # energy delivered
g # casual gains distrib
h # zone energy balance
b
b
i # surface energy balance
b
b
* # all surf in reception
-
* # all surf in office
-
* # all surf in roof
-
l # monthly
a
b # frequency
b # of temperatures
a # zone db
y
>
-
-
-
XXX
```

Figure 17.3: A script for performance data recovery

It is also possible to script the use of ESP-r on Windows platforms, however this requires ESP-r modules compiled as console applications rather than graphic applications.

There are two broad approaches, first to use a Windows cmd console with interactions in the form:

```
clm.exe -mode text -file XX <actions
```

Where `actions` is a text file holding the command keystrokes to be carried out. This does not work for graphic versions of ESP-r because menu commands respond to mouse clicks rather than keyboard commands.

The second approach is to run the console application within a MSYS bash shell. This provides roughly the same functionality as a bash shell in Cygwin or Linux. There are subtle differences, especially when specifying paths to files.

Seasoned users of ESP-r often use the Perl language to compose a sequence of assessments and data recovery tasks. Indeed, it is possible to use a script to modify the shape and or composition of a model.

Anything that can be done via an interactive session in text model can be included in a script.
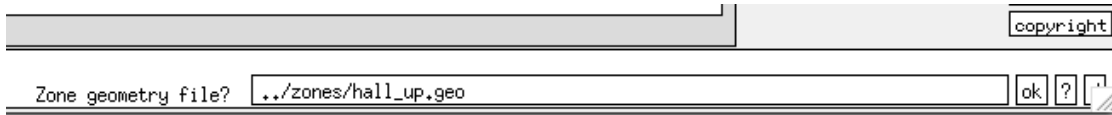
17.2 X11 graphics

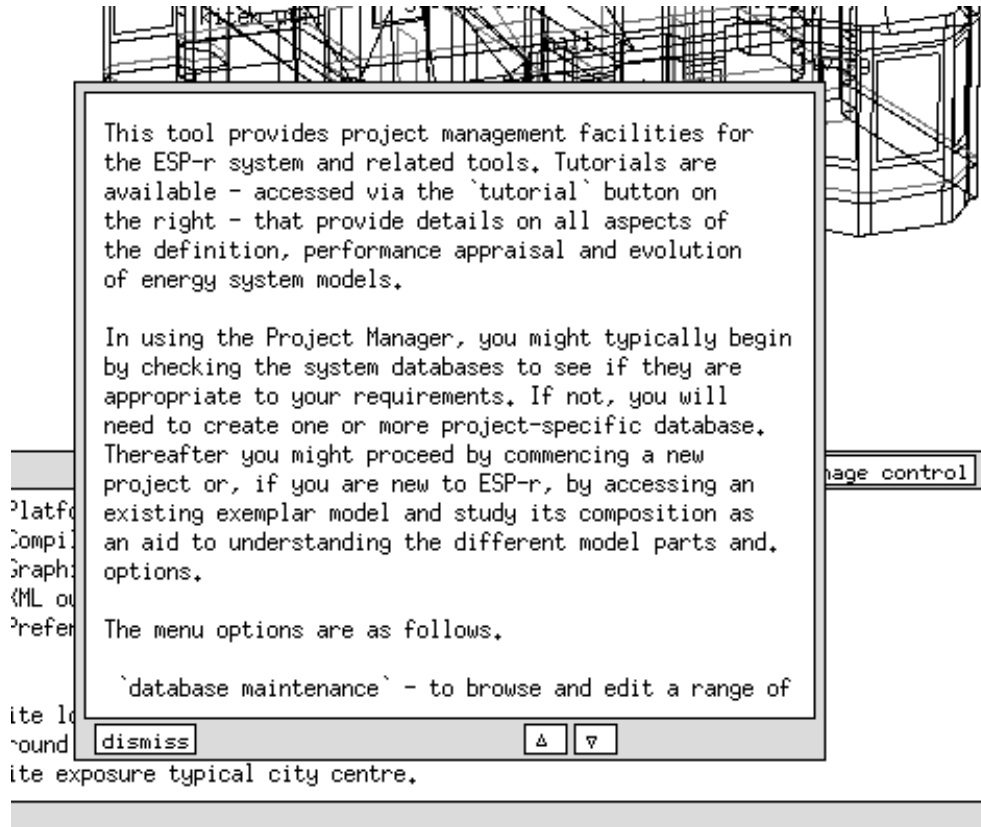Figure 17.4 Specifying a file name.

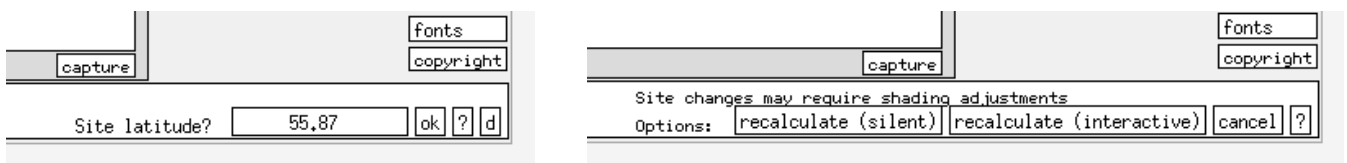
Figure 17.5 Pop-up help for a dialog.

Figure 17.6 Real number & X11 radio button dialog.

This style of interaction supports the most complete graphics input functionality but has limited file browsing facilities.

```
Image Control

a eye point: 168.3 -62.2  56.5
b view point:   8.9  10.6   2.5
c angle of view:  40.0
d display >> perspective
  ----------------------------
e display >> surfaces & obstruct
f highlight >> normal
g view bounds >> optimum
  ----------------------------
h zone names      >> display
i surface names   >> hidden
j vertex number   >> hidden
k site origin     >> hidden
l site grid       >> hidden
m grid distance      optimum
n surface normals >> hidden

  ----------------------------
* zones to include in image
! refresh image
1 hidden line view
2 views from sun
? help
- exit this menu
```

```
? help
- exit
```

```
△ ▽ | azimuth | ◁ ▷ | elevation | ▽ △ | image control | | capture |
ity: constant = 0.20.
ical city centre.
```

```
fonts
```

Figure 17.7 X11 wire-frame control menu and buttons.

```
Available files

a CFClayers.db1.a
b SBEM.db1
c UK_notional.constrdb
d ccht-optics.db1
e ccht_constr.db1
f ccht_material.ascii
g ccht_na_constr.db1
h cellular.materialdb
i components.db1
j flow_icons.db6
k icons.db1
l material.db3.a
m material.db4.a
n mould.db1
o mscomp.db1
p mscomp.db2
q multicon.db3
r multicon.db4
s multicon.db5
t north_american.constrdb
u north_american.materialdb
v north_american.materialdb.a
w optics.db2
x optics.db3
y plantc.db1
z plantc.db2

0 Page part:  1 of  2

? help
- exit this menu
```

```
Model Management    zone list

a introduction      a orch_pit     *
b database maint     b stage_low    *
c validation tes     c stage_high   *
  .... Model sele    d grnd_bkstg   *
d open existing      e L1_bkstg_off *
e create new         f L1_bkstg_cor *
  .... Current m     g L2_bkstg_off
  cfg : summer        h L2_bkstg_cor
  path : ./           i L3_bkstg_cor
g root : theatre     j L3_bkstg_off
h title: Theatr      k grnd_foyer
j variants           l L2_foyer
m browse/ edit/      m gr_fr_seat_s
                     n grnd_seat_s
  .... Import &      o grnd_seat_n
n import CAD fil     p stage_low_re
o export current     q abv_orch_pit
p archive curre      r gr_fr_seat_n
  .... Model loc     s low_gall_s
t folders & file     t low_gall_n
  .... Miscellane    u high_gallery
r save model         v top_air
s save model as      w L3_air
v feedback >> si     x aux_roofs
* preferences        y main_roof
? help               z towers
- exit Project
                     * All items
                     0 Page:  1: 2

                     ? help
                     - exit this menu
```

```
Surface name

a ptn_br2      *
b angle_a      *
c sill_b       *
d column_c     *
e sill_d       *
f column_e
g sill_f
h angle_g
i ne_corner
j north
k ptn_study
l ptn_halla
m ptn_hallb
n ceiling_liv
o floor_liv
p skirt_a
q skirt_b
r skirt_c
s skirt_d
t skirt_e
u skirt_f
v skirt_g
w skirt_h
x skirt_i
y frame_b
z head_b

* All items
0 Page:  1: 2

? help
- exit this menu
```

Figure 17.8 Browsing databases folder (left) zones and entity selections (right).

Figure 17.3 is an example of a text dialogue (confirming a model file name). The layout is similar to all X11 dialogues - there is a prompt above and/or to the left of the editing box. On the right is an **ok** box, a **?** box and a **default** box. In menus or dislogs, clicking on the **?** produces a pop-up dialogue (see Figure

17.4). Up and down arrows are included to support scrolling. Figure 17.5 is a dialog requesting a real number. Such dialogues usually have range checking included and you might be asked to re-specify the number. Figure 17.6 is the X11 equivalent of a radi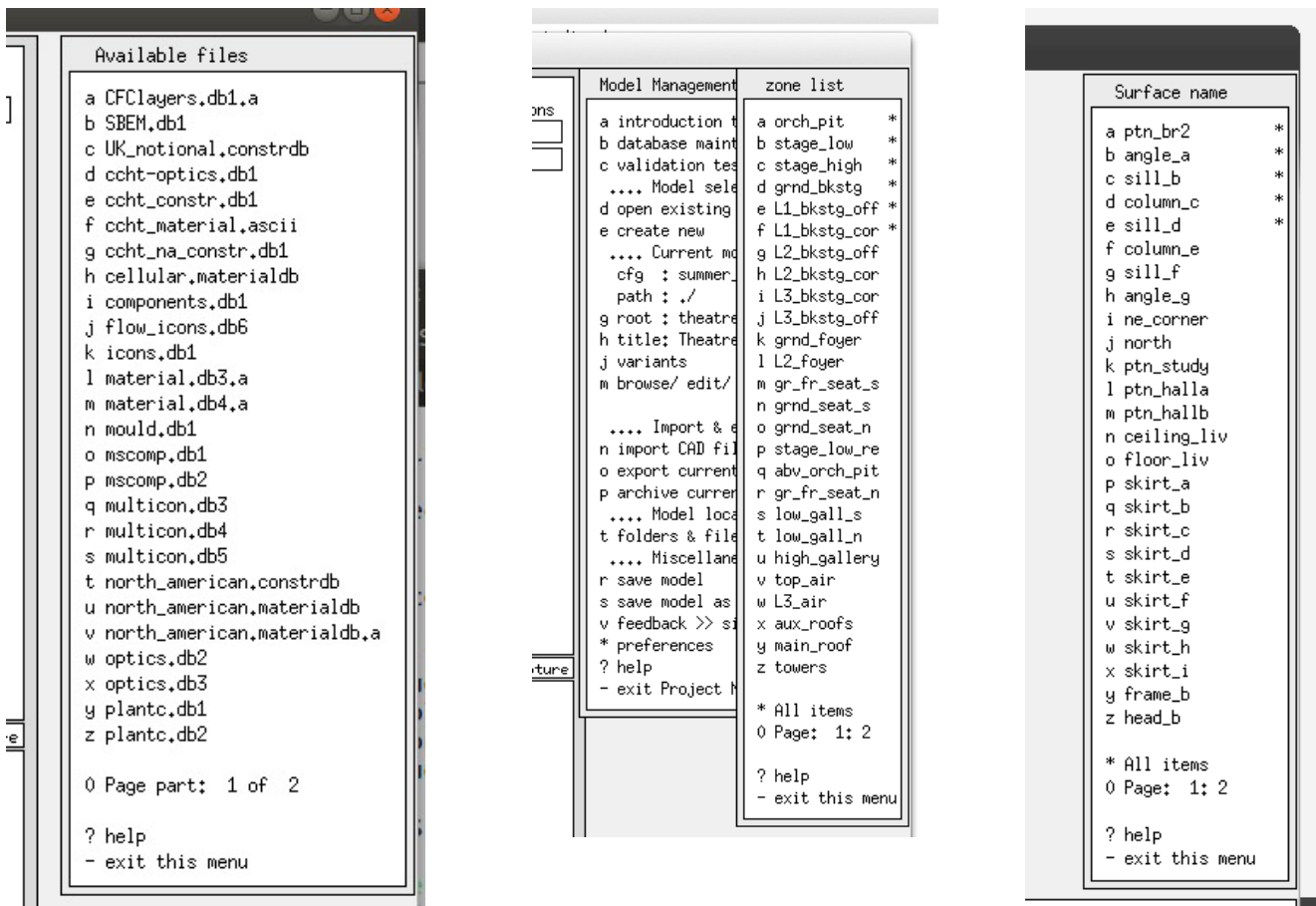o button (only one item can be selected). Figure 17.7 shows the X11 control of a wire-frame view and Figure 17.10 is for the GTK interface. In this case a menu dialogue has been used to approximate a pro-forma. Figure 17.8 (left) is an example of browsing for files within a folder, in this case the databases folder for the ESP-r distribution.

Selection lists where you are able to select more than one entity e.g. Figure 17.8 (right) shows a list of surfaces in a zone that have been selected and the selected items have a * in the right column. There is an `* All items` option which will select the whole list. If you want to remove and item from the selection then select it and the * will be removed. Notice also that there is a

`0 Page: 1:2` which signals that surfaces continue to a second page.

17.3 GTK+ graphics
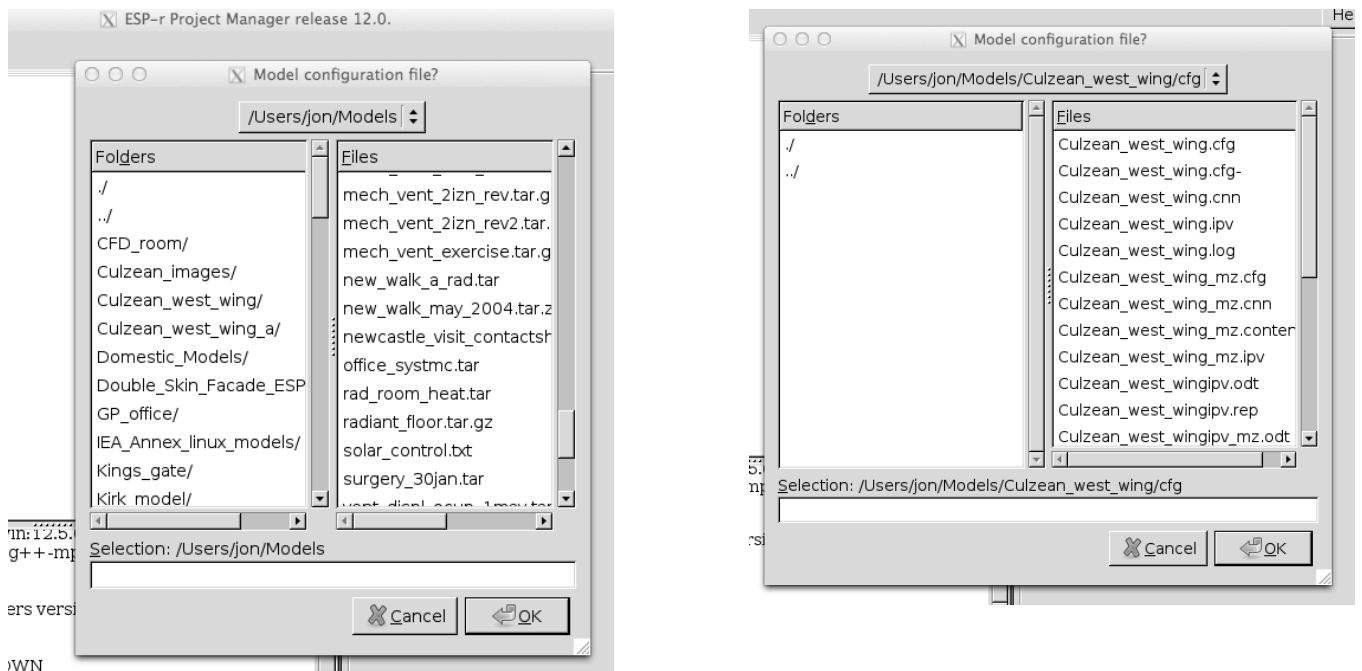
Figure 17.10 GTK file browsing dialog.
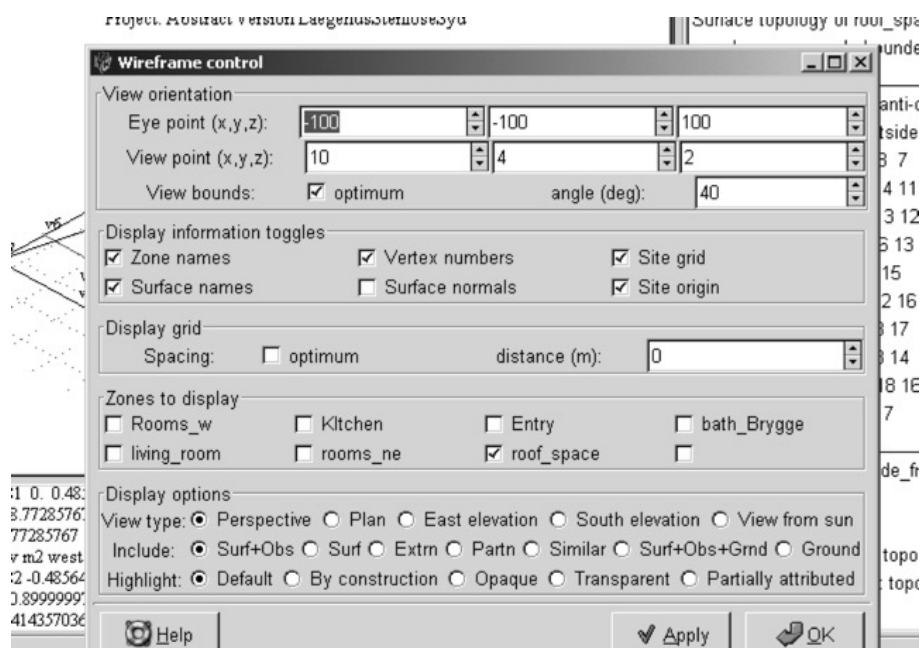
Figure 17.11: GTK wire frame control dialogue.

225

The following Figures are the GTK equivalents to the file specification dialogue, pop-up help message, real number dialogue and a radio button dialogue.
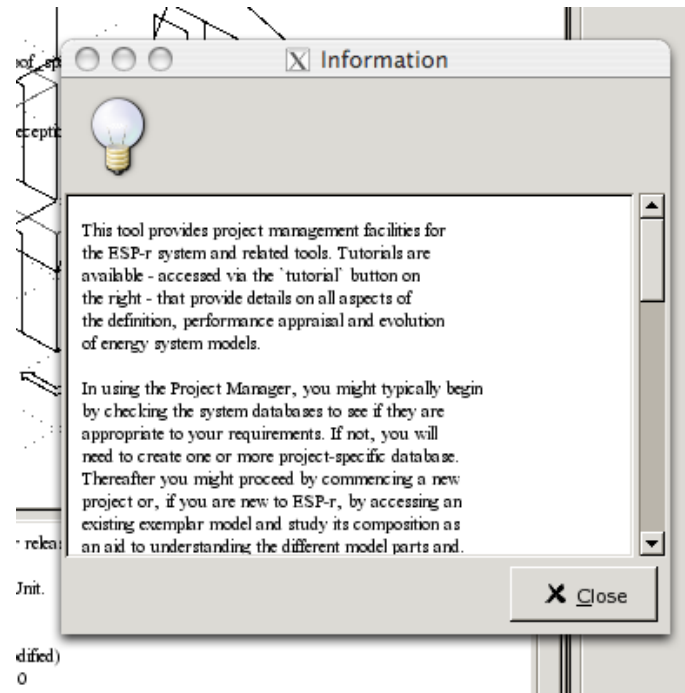
Figure 17.12 GTK popup help.
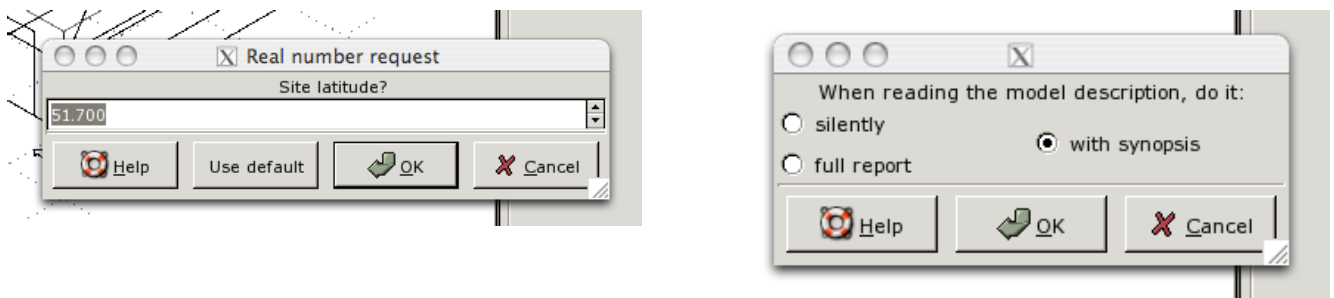
Figure 17.13 GTK real number and radio button dialogues.

ESP-r dialogues normally use English, however GTK does support locale specific text in buttons that are used in some dialogues. Support multiple languages is not yet implemented in the menus and dialogs.

18 Entities Appendix

The art of creating models fit for purpose draws on our ability to select appropriate entities from within the simulation tool. And the task of understanding the performance of these entities draws on our ability to traverse the many kinds of performance data generated by the simulation engine. This chapter is focused on ESP-r entities.

18.1 High level entities

Weather.

Building and system performance can be dependant on changes in weather data. Weather data from files in the *Climate* folder is hourly based. Alternatively, short time-step weather data can be held in a temporal file. If assessments were run at shorter time-steps then the weather data source interpolated values are reported.

- Ambient temperature (degrees C)
- Direct normal solar radiation (converted from global horizontal depending on the radiation type in the weather file) (W/mˆ2)
- Diffuse solar radiation (W/mˆ2)
- Wind speed (m/2 typically at 10m)
- Wind direction (degrees from North clockwise)
- Ambient RH (%)
- Sky illumunance (lux) is a derived value.
- Sky temperature is derived from other weather data unless explicitly included via the temporal file facility.

Site.

Some model descriptions relate to the context of the model.

- A *model calendar* is composed of one or more *named day types*, each of which can be associated with one or more Julian days-of-the-year. Initially models are assumed to have Weekdays, Saturday, Sunday, Holidays (weekend days can be defined to match regional preferences). Zone ideal controls and zone schedules make reference to day types. Additional day types can be created as required. For example, summer working days and winter working days might differ in terms of occupancy patterns or control set points.
- Monthly ground temperatures profiles (either selected from in-built lists or supplied by the user) are referenced as surface boundary types. The surface temperature of the ground is derived via a separate energy balance solver which takes into account the sky and building surface temperatures. These temperatures are not reported, if you want additional site data invoke the *trace facility* in the simulator.

18.2 Building entities

Zones.

- A *thermal zone* represents a volume of air at a uniform temperature and which is fully bounded by surfaces (see below). Within the complexity constraints of ESP-r a zone can take an arbitrary form. A thermal zone might represent the casing of a thermostat, a portion of a physical room or a collection of physical rooms depending on the requirements of the project and the opinions of the user.

–   Within a thermal zone there is an air-node energy balance. Air movement with the outside and with other zones in the model is included in this energy balance. Casual gains from occupants, lights and small power are also included.

–   A CFD domain can be associated with a thermal zone and/or mass flow nodes can also be associated with a thermal zone.

–   Long wave radiant exchange is supported between all surfaces associated with a zone. The default treatment is weighted by area and emissivity and the *mrt* utility is able to calculate explicit view-factors for thermal zones of arbitrary complexity.

–   Direct and diffuse solar radiation is tracked within a zone. The default treatment is diffuse distribution of solar radiation entering the zone from the outside or adjacent spaces. The *ish* utility is able to calculate shading patterns on the facade as well as insolation patterns within a thermal zone of arbitrary complexity, including internal mass represented via surfaces.

–   Ideal environmental controls can sense and actuate at the zone air node. Sensors can reflect the current air temperature or a mix of air and MRT. Actuation can be a convective injection at the air node or a mix of convection and radiation to be absorbed in the zone surfaces on an area/emissivity basis.

–   As zones must be fully bounded by polygons, openings between thermal zones must be represented by a surface (typically composed of a construction which minimally restricts heat flow). Air movement (mixing) associated with such openings is a separate definition in ESP-r e.g. a scheduled zone ventilation or via cracks and bi-directional flow components within a mass flow network.

–   A thermal zone can be partly or fully bounded by another zone. For example, a kiln in a room might be represented as a separate thermal zone and its casing defined by surfaces which are also represented in the room (e.g. as partitions). This maintains the correct air volume in the room and heat lost from the kiln by convection and radiation is accounted for in the room.

Surfaces.

•   A *surface* is a polygon composed of vertices and edges with attributes of name, boundary condition, thermophysical composition, optical properties and use. Within the limits of complexity a surface polygon can be of arbitrary shape as long as it is flat.

–   During assessments a surface energy balance is maintained at each face of each surface. Each face of a surface has a single temperature at any moment in time and each constituent of the surface energy balance is consistent across the whole of the face of the surface.

–   For purposes of control, a sensor can be located at or within a surface (e.g. temperature, moisture) or it can be the point of actuation (e.g. an embedded pipe). Radiant heat injected into the zone via an environmental control is part of the energy balance of the surface.

–   One face of a surface is in contact with the zone air volume and it also participates in long-wave and short-wave radiant exchanges with other surfaces in the zone. Potentially short-wave diffuse radiation may pass to and from adjacent rooms. Convective heat transfer is evaluated at each time step at each face of each surface and can optionally follow specific correlations or values derived at that time step from the CFD solution.

–   Surfaces have a boundary condition attribute that specifies the nature of thermophysical interactions at the *other face* of the surface (see below).

•   a *door* or *glazing* or *frame* is simply a surface that is named and attributed as such by the user.

•   *Parent - child - grandchild* relationships between surfaces, e.g. a window within a frame within a wall are assessed (and reported) as the zone description evolves. There is no requirement that a door or a window or a frame be a child (sub-surface) of another surface.
Parent-child relationships are based on edge matching as well as inferences from user actions (e.g. inserting a door via the interface). Such information is used to assist in assigning boundary conditions - if a parent wall faces the outside then it is initially assumed that child surfaces inherit this attribute. And if a window is removed the shared edges and vertices of the parent surface can be more easily tested for removal.

•   *internal mass* is represented via pairs of surfaces which are thermally connected back-to-back and thus each presents two faces to the thermal zone for radiant and convective heat transfer. These surface pairs can be of arbitrary shape (as long as their edges match). ESP-r can work with dozens of pairs, often imported into zones via *pre-defined entities*. Usually the construction of each represents the

thickness of the actual mass.

If the position of thermal mass is not critical then a pair of surfaces can be sized to aggregate the total surfaces area of thermophysical clutter in the room. Otherwise thermal mass surface-pairs can be placed as required up to the limits of geometric complexity within the room and fully participate in the zone energy balance.

Model Topology.

Each surface in the model has one face that is in contact with a thermal zone as well as attributes which define the boundary-condition-at-the-other-side.

- A *surface boundary condition* is one of the following:
- external - in contact with ambient weather conditions can have direct and diffuse shading patterns calculated for each hour of a typical day in each month
- similar - the other face has the same temperature and radiant environment e.g. if it is hot in the room it is hot on the other side
- constant - a fixed temperature and radiant environment .e.g a cold store
- monthly ground temperature profile - direct contact with either a standard monthly temperature profile or user defined monthly temperature and with no solar radiation
- another surface - in this zone (internal thermal mass) or a surface in another zone (a partition). Both surfaces should be approximately the same size and composed of constructions with the same number of layers and their surface normals should be ˜180 degrees apart. In the interface and model zone files this type of boundary condition is expressed as *partn_cor in office* to be connected with *partn_off in corridor* and one would expect to find a similar specificion for *partn_off in corridor*. If an *another surface* boundary condition is not matched then a warning is triggered.
- adiabatic - no heat flux passes.
- BASESIMP - part of a basement definition using the BASESIMP ground heat transfer regime.
- CEN 13791 - used for validation tests. Direct sunlight falls on both sides of partitions equally.
- UNKNOWN - not yet defined

Other geometric entities.

- an *obstruction* is a rectangular or six-sided body which is recognised by the shading and insolation analysis application *ish* as well as the visualisation tool *Radiance*. An obstruction does not take part in the thermophysical solution other than to reduce the sunlight falling on other surfaces. An obstruction placed inside a room as a visual place holder for furniture or columns and will not take an active part in shading and insolation calculators or have thermophysical interactions with zone surfaces.
- an *MRT sensor* one or more rectangular bodies within a room at which radiant asymmetry can be measured. These bodies do not take part in thermophysical interactions with other zone surfaces or the zone air node.
- a *visual entity* rectangular or six-sided bodies within a room which are seen in the wire-frame view and are exported for use within Radiance. These are often included when pre-defined objects are imported into zones.

Zone operational attributes.

- *zone casual gains* are user defined profiles for each day type in the calendar. There is an overall description of the gains in the room (essential for checking models). Casual gains comprise a name e.g. fluorescent, teacher, photocopier and a type (e.g. people, lighting, equipment, other) and a profile of one or more periods covering the whole day.
  ESP-r includes several representations of *dynamic persons*. The first is a polynomial equation based on ASHRAE tables, the second is a multi-node model taking into account thermoregulatory processes, clothing and activity levels as well as age and gender. The third method represents a body within a CFD domain as multiple segments, each with its own clothing level. Each of these takes into account the current air temperature and humidity in order to predict the sensible and latent contribution to the room. An exemplar model is available to allow you to explore these facilities.
  Each period has a start and end hour, casual gain identification, sensible watts, latent watts, sensible radiant and convective fraction and optionally electrical characteristics (real and reactive power,

voltage, phase and power factor).

- *zone scheduled infiltration* relates to air movement from ambient whether unintentional or mechanically forced. It includes a documentation attributes and user defined profiles for each day type in the calendar with the option to be controlled based on time, ambient or zone temperature as well as wind speed. If a mass flow network is defined, infiltration will be equated with the flow node associated with the zone.

- *zone scheduled ventilation* relates to air movement between thermal zones whether unintentional or mechanically forced. To represent mixing between zones there needs to be a matched definition of ventilation in each of the zones. It includes a documentation attribute and user defined profiles for each day type in the calendar with the option to be controlled based on time or zone temperature. If a mass flow network is defined, ventilation will be equated to the flow node associated with the zone.

18.3 Control entities

Ideal controls.

The following is a summary of the most often used control laws.

- *basic control* is an ideal controller which will exactly maintain a set-point if it has sufficient capacity. This is often used to identify demand patterns. The attributes are: maximum and minimum heating capacity, maximum and minimum cooling capacity, heating and cooling set-point. Humidity control is optional and is achieved via moisture injection or dehumidification at a maximum g/s rate. There is an option to relax temperature control in order to maintain humidity control.

- *free float* disables control for the period. There are no attributes for this controller.

- *fixed injection or extract* implements a control with a fixed heating or cooling rate if the logic requests an ON state. Many heating and cooling devices are not able to adjust their operation and respond to transient conditions with an ON/OFF control action. This controller is sensitive to the simulation time-step (which should be modified to represent the response of the device). The attributes of this control are heating injection, heating set-point, cooling extraction and cooling set-point.

- *basic proportional control* is a proportional controller which works within a throttling range and optionally implements PI control with an integral action time or a PD control (dangerous) with a derivative action time or a full PID specification. This control can be as unstable as a badly tuned real controller. The attributes are: maximum and minimum heating capacity, set-point and throttling range, maximum and minimum cooling capacity, cooling set-point and throttling range. Integral and derivative times are optional.

- *linkage with plant component* is a zone controller that is used in conjunction with a plant component network to identify interactions between the plant network and zones. The attributes of this control are the component in the network and the node of the component and the type of coupling. If the air stream of the system components interacts with a zone then the source component and down-stream components are identified.

- *multi-stage with hysteresis* implements a staged controller in which additional capacity is brought on-line if the set point is not reached. There are three stages for heating and three stages for cooling. The attributes include a heating and cooling set-point as well as a delta temperature for heating and cooling capacity changes.

- *separate ON/OFF flux* is a controller which implements a heating-on-below and heating-off-above logic as well as a cooling-on-above and cooling-off-below strategy. This approximates a classic thermostat response pattern. The attributes are heating and cooling capacity as well as two set-points for heating and two set-points for cooling.

- *temperature match (ideal)* implements a controller which will attempt to match the evolving temperature at another location or a weighted temperature at several locations. This is useful in validation or calibration studies where recorded boundary conditions need to be matched. To represent a well ventilated roof space, a control can heat or cool the roof space to match the current ambient temperature. Another example is to force an abstract boundary zone for a ceiling void to match the current temperature of a fully defined ceiling void found elsewhere in a model. The attributes are a maximum and minimum heating and cooling capacity, the number of sensors and their locations.

- *temperature match (ON/OFF)* implements a controller which will attempt to match a temperature at another location via an ON/OFF control action. Attributes are similar to the above control.

- *optimal start* implements an optimal start heating controller which attempts to reach a desired temperature at a specified time. This controller works by trying one scenario and if it fails it re-winds the simulation to the start of the day and then attempts a different scenario. It can be operated with a 4h00 start or a user defined start or a start time tested by iteration. The attributes are heating capacity and set-point, the desired time of arrival, minimal time difference and temperature difference for testing.

- *multi-sensor controller* is designed to implement a control in one location based on actions taken in another location. An example of this is to represent a HVAC system as a mixing box which is controlled between a range of temperatures in order to control conditions in another zone linked to it via an air flow network. Another use of this control is to abstractly represent a floor heating system as a geometrically thin thermal zone into which heat is injected in order to control the temperature of an occupied space. The attributes of this controller are minimum and maximum heating and cooling capacity, heating set-point, cooling set-point and number of auxiliary sensors and their locations.

- *slave capacity controller* implements a common residential control strategy where a thermostat in one part of a residence controls the operation of HVAC in other rooms. Typically such controls, if not carefully balanced, will result in poor control in some of the slave zones. Several control loops are required to implement a master-slave control in a building. One control loop represents the master control and there is one slave control loop for each of the slave zones. The attributes of the controller are the index of the control loop that represents the master controller and the slave heating capacity and slave cooling capacity.

- *variable supply temperature* implements a controller for a constant volume air supply rate which adjusts the supply temperature to maintain a room set-point. This controller is abstract (it is not part of an explicit air flow network). Details of the performance are available if the simulation trace option is invoked. The attributes are maximum supply temperature, minimum supply temperature, air flow rate, room heating set-point, room cooling set-point.

- *VAV with CAV heating* implements a controller which uses VAV for cooling and CAV for heating. This controller is abstract (it is not part of an explicit air flow network). The controller assumes a constant supply temperature and uses a terminal re-heat. It is intended for early design stage studies of VAV characteristics. Details of performance are available via simulation trace functions. The attributes are reheat capacity, air supply temperature, room set-point, maximum air flow rate, minimum air flow rate.

18.4 Performance Data

As simulations are invoked domain-specific *results* files are created which hold performance data which can subsequently accessed by the *res* module. Our understanding of buildings and environmental control systems can be enhanced by drawing on a range of performance data. Some, such as surface temperatures, are solved as the simulation progresses and others, such as the zone resultant temperatures are derived from the zone air temperature and the area and emissivity weighted temperature of the surfaces in the zone.

The *res* module entries such as `Enquire about -> summary statistics` or `Enquire about -> hours over` expand to a list of individual data as in the figure below. The bullet points following clarify the meaning of the `Temperature` and `Comfort` entries.

```
Summary statistics:          Temperature choices::        Comfort choices:
2 Result set                 a Zone db T                  a Predicted Mean Vote (PMV)
3 Display period             b Zone db T - ambient db T   b PMV using SET
4 Select zones               c Zone db T - other zone db T c Percentage Dissatisfied (PPD)
  ----------------           d Zone control point T       d Local delta T head-foot
a Climate                    e Zone Resultant T           e Dissatisfied due to floor T
b Temperatures               f Mean Radiant T (area wtd)  f Diss. warm/ cool ceiling
c Comfort metrics            g Mean Radiant T (at sensor) g Diss. wall rad T assymetry
d Solar processes            h Dew point T                _____
  ----------------           i Surf inside face T         ? help
f Zone flux                  j Surf T - dewpoint T        - exit this menu
g Surface flux               k Surf outside face T
h Heat/cool/humidify         l Surf node T
i Zone RH                    _____
j Casual gains               ? help
k Electrical demand          - exit this menu
  ------------------
m Renewables/adv. comp.
n Network air/wtr flow
o CFD metrics
p Measured:temporal
  ------------------
> Display to >> screen
 . . .
```

Figure 18.1: Summary statistics choices for temperature and comfort

Temperatures.

The ESP-r simulator records a number of temperatures and the results analysis offers additional derived values.

- Zone dry bulb temperature [Zone db T] is the temperature at the zone air node and is equivalent to a shielded air temperature (°C).

- Zone db T - ambient db T and Zone db T - other zone db T show the temperature difference between two locations. No need to open up a spreadsheet!

- Zone control point T - if an ideal zone control is associated with a zone this is the temperature that it is using.

- Zone resultant T - this is a 50-50 mix of the zone db T and the mean radiant temperature of the surfaces in the zone. This might also be known as *effective temperature*. Some practitioners might use this as a proxy for comfort.

- Mean radiant temperature (area wtd) - this is the area and emissivity weighted summary of surface temperatures within the zone. It is a general value for the zone rather than for a specific location in the room.

- Mean Radiant T (at sensor) is a location-specific radiant temperature reported from radiant sensor bodies which might have been included within the zone. It takes into account the angle of view between the sensor body and the surfaces of the room.

Comfort.

ESP-r reports on comfort via a series of measures derived from research by P.O. Fanger. It also includes position-specific indicators if sensor boides have been defined.

- Predicted mean vote (PMV) via the Fanger method is a dimensionless index -4 to +4, with zero indicating comfort, negative numbers representing a perception of cold and positive numbers representing warmth. It is based on room dry bulb temperature, mean radiant temperature, humidity, local air velocity, occupant metabolic rate and clothing level.

- Predicted mean vote (SET) an alternative PMV which based on standard effective temperature.

- Percentage dissatisfied (PPD) is expressed as a percentage of occupants who are not happy with conditions within the room. Although it is based on the same input parameters, PPD does not differentiate between hot and cold as a source of discomfort.

- Local delta T head-foot is PPD based on temperature difference of the air at head and feet.

- Dissatisfied due to floor T - PPD based on overly warm floors you are asked to identify floor surfaces in each room
- Dissatisfied due to ceiling radiant T asymmetry at radiant sensors (either warm or cold). ceiling.
- Dissatisfied due to wall radiant T asymmetry at radiant sensors

Solar in rooms.

ESP-r is able to account for solar radiation entering the building on a surface-by-surface basis via a surface energy balance. At a higher level it can report on solar radiation distribution in rooms via:

- solar radiation (direct+diffuse W) entering from all outside-facing glazing,
- solar radiation (diffuse W) entering from adjacent zones
- solar radiation absorbed by opaque surfaces within the zone

Note that in some zones the reflection of solar radiation will also result in losses to adjacent zones as well as to the outside but these are only available if you turn on the *trace* facilities in the simulator.

Zone air node energy balance.

The ESP-r simulator solves the energy balance at the air node at each time step and this is available directly as a report. The individual flux paths are also available separately.

- The infiltration air load is the kWhr gain or loss implied by the movement of air from the outside air and the zone. An integrated report will often include both gains and losses. Note that air which leaves the room and arrives at the outside is not counted in the zone energy balance. No energy balance is reported for the outside environment.
- The ventilation air load is the kWhr gain or loss implied by the movement of air from other zones of the model into the room. Air leaving the room to another zone is reported in the energy balance of the other zone.
- Convective gains from occupants, lights and small power devices are separately reported in the zone energy balance report. The radiant component is found in the surface energy balance report. In the `Summary statistics -> Zone flux option` reports you can also find reports on casual gains in terms of total sensible gains (radiant + convective).
- Linear thermal bridges defined in the zone are part of the zone energy balance. Although users are able to define a number of linear thermal bridges the aggregate gains or losses (in kWhr) are reported.
- Because the starting and ending temperature of the air over the period of the assessment may be different the energy balance includes a storage term for the air point.
- Convection at the inside face of surfaces of the zone can be significant flux paths and are reported in four separate lines - convection at opaque surfaces which have an exterior boundary condition, opaque surface which have any OTHER boundary condition (ground, similar, partition, constant, basesimp), transparent surface which have an ambient boundary condition and transparent surfaces which have any other boundary condition.

Surface energy balance.

The surface balance includes:

- conduction (heat moving through the construction) at a point just below the surface layer (halfway between the surface layer and the next node),
- convection (heat transfer to the air) at the face,
- long-wave radiation exchange with other surfaces in the room,
- long-wave radiation from the 'other-side' face of the surface to to other buildings/ the ground/ the sky (if the surface is facing the outside),
- radiant portion of casual gains from occupants/ lighting/ small power loads,
- heat stored in the construction
- solar radiation absorbed on the inside face as well as solar radiation absorbed on the other face along with solar radiation indicent on the other face.

- the radiant portion of casual gains at the inside face

Heating cooling and humidification.

Any environmental controls, whether via zone ideal controls or system components will have some performance attributes reported. The convective portion is part of the zone air energy balance while any radiant injections or extraction will be part of surface energy balances. In graphing, tabular, and statistics forms the following are available on a zone-by-zone basis except that *aggregate* values are summed for all of the currently selected zones:

- sensible heating load (kW)
- sensible cooling load (kW)
- dehumidifiacation load (kW latent)
- humidification load (kW latent)
- sensible heating + cooling (kW)
- latent heating + cooling (kW latent)
- all sensible and latent (kW)
- aggregate heating load (kW for all currently selected zones)
- aggregate cooling load (kW for all currently selected zones)
- aggregate dehumidification and/or humidification (kW latent for all currently selected zones)

Zone casual gains.

Currently ESP-r can keep track of three types of casual gains (typically labeled as occupant, lighting and equipment). Each casual gain comprises a sensible convective and sensible radiant portion as well as a latent portion (expressed as equivalent Watts) There are lots of combinations:

- all sensible (convective + radiant) comprises all of the casual gains that have been defined in the room
- all sensible convective (the convective portion of all of the casual gains that have been defined in the room)
- all sensible radiant (the radiant portion of all of the casual gains that have been defined in the room)
- all latent (the latent portion of all of the casual gains that have been defined in the room)
- occupant (convective + radiant), occupant convective, occupant radiant, occupant latent - combinations for the occupant type
- lighting (convective + radiant), lighting convective, lighting radiant, lighting latent (the latter is likely to be zero)
- equipment (convective + radiant), equipment convective, equipment radiant, equipment latent - combination for small power casual gains.
- if casual gain controls are active in a zone then it is also possible to report on the magnitude of which ever casual gain is being controlled
- there are aggregate reports for occupants, lighting, equipment which sum the convective and radiation values for all of the currently selected zones
- dispersed demands (lifts, pumps, DHW) are associated with the building as a whole and are typically defined as part of an Integrated Performance View. They do not take part in the thermal simulation, however they can be part of a *normalized performance report* of the whole building.

19 Capabilities

This Chapter is a review of the capabilities of ESP-r for representing the virtual physics of buildings and systems as well as what can be measured and reported. Some of the information is similar to the publication *Contrasting the Capabilities of Building Energy Performance Simulation Programs by Crawley, Hand, Kummert and Griffith of July 2005*.

In that publication the summary of ESP-r is:

ESP-r is a general purpose, multi-domain (building thermal, inter-zone air flow, intra-zone air movement, HVAC systems and electrical power flow) simulation environment which has been under development for more than 25 years. It follows the pattern of *simulation follows description* where additional technical domain solvers are invoked as the building and systems description evolves. Users have options to increase the geometric, environmental control and operational complexity of models to match the requirements of particular projects. It supports an explicit energy balance in each zone and at each surface and uses message passing between the solvers to support inter-domain interactions. It works with third party tools such as Radiance to support higher resolution assessments as well as interacting with supply and demand matching tools.

ESP-r is distributed as a suite of tools. A *project manager* controls the development of models and requests computational services from other modules in the suite as well as 3rd party tools. Support modules include: weather data display and analysis, an integrated (all domain) simulation engines, environmental impacts assessment, 2D-3D conduction grid definitions, shading/insolation calculations, view-factor calculations, short- time-step data definitions, mycotoxin analysis, model conversion (e.g. between CAD and ESP-r) and an interface to the visual simulation suite Radiance.

ESP-r is distributed under a GPL license through a web site which also includes an extensive publications list, example models, cross-referenced source code, tutorials and resources for developers. It runs on almost all computing platforms and under most operating systems.

Although ESP-r has a strong research heritage (e.g. it supports simultaneous building fabric/network mass flow and CFD domains), it is being used as a consulting tool by architects, engineers, and multi-discipline practices and as the engine for other simulation environments.

19.1 General modelling features

This section provides an overview of how ESP-r approaches the solution of the buildings and systems described in a user's model, the frequency of the solution, the geometric elements of which zones can be composed and exchange supported with other CAD and simulations tools.

- ESP-r employs a partitioned solution approach. Simultaneous loads, network air flow, CFD domain(s), electrical power and system component solution is via custom domain solvers. Interactions between domains are handled with message passing between the solvers at each time-step.

- The building solution is based on matrix partitioning and Gaussian elimination. Partitioning is by thermal zone and zone coupling is handled by message passing at each time-step. This approach conserves memory in the case of large models, but requires resources for message passing.

- Entities in ESP-r are represented as control-volume heat-balance nodes (finite volumes). Such nodes are distributed throughout the fabric and air volumes of the building and within system components. An explicit energy balance is maintained at each zone air volume, at each face of each surface and at each finite volume of used in system components.

- System components support temperature, two component (moist air and steam) flow, heat injection/extraction and electrical characteristics at each component node.

- Electrical power solution supports mixtures of DC as well as three phase power with real and reactive power. The electrical network can link to casual gains in zones and surfaces which include electrical characteristics as well as system components.

- The mass flow solution works with mixed air and water flow networks of nodes (at zones, system components and at boundary locations) as well as a range of flow components. Control logic can be applied to flow components to approximate mechanical or user interventions. The solver is highly optimized and can solve networks of hundreds of nodes with minimal computational overhead. It typically runs at the same frequency as the zone solver with the option to iterate (useful for models with large openings).

- Iteration supported in system component and network flow solution domains. Zone solver can be adjusted from fully implicit to fully explicit but defaults a Crank-Nicolson formulation. Conduction defaults to 1D and models can include 2D and 3D conduction (if additional data is supplied).

- Domain interactions supported e.g. mass flow solution feeds system component and zone solution at each time-step.

- Zones can be assessed with a mixture of environmental controls, including free float and user under-sized controls as well as supporting radiant gains and injection of heat into layers of a construction.

- Simulation frequency is one minute to one hour for zone and air flow domains. System and electrical components solved from one second to one hour. Time-step controller with support for rewind to start of day for exploring optimal start regimes.

- Zone geometry is based on 3D polygons of arbitrary complexity (including explicit representation of internal mass). Shading devices are block shapes. There are a number of geometric rules: a) zones must be fully bounded, b) surfaces must be flat, c) edge ordering defines outward face of surface, d) unbounded edges detected, e) internal mass requires back-to-back surfaces, f) zones can be embedded within other zones. All zone surfaces take part in the zone energy balance.

- Glazing is a surface with optical property attributes which supports solar transmission and absorption at each layer in addition to the convective, conductive and radiant exchanges of opaque surfaces. Optical properties can be subject to control action. Frames can be represented explicitly or via adapting the properties of the surface representing glazing.

- Surfaces can have attributes for phase change materials, temperature dependant conductivity, electrical characteristics (e.g. integrated PV), moisture adsorption, contaminate emission properties.

- Facility to import DXF files (V12) which confirm to specific standards of layer naming and use of 3D entities.

- Facility to export DXF files (V12), EnergyPlus (geometry, constructions, casual gains), VRML worlds, Radiance visual simulation models.

- Facility to import geometry and composition from EnergyPlus IDF files (V8.5). Schedules, systems and control are not yet imported.

- Measured data (one minute to one hour frequency) of temperatures, set-points, weather data, casual gains can be associated with a model.

- Ideal environmental control systems can be defined (in addition to component based system descriptions).

19.2 Zone Loads

This section is an overview of ESP-r's support for solving the thermophysical state of rooms: the heat balance underlying the calculations, how conduction and convection within rooms is solved, and how thermal comfort is assessed.

- An explicit energy balance is maintained at each zone air volume and at each face of each surface. The default treatment is to use three finite volumes for each layer of each construction. Typically, materials over about 200mm thick are subdivided into multiple layers to increase the efficiency of the solution as well as providing additional points for recording temperature.

- The minimum size of a zone is ˜1cm^3. Rooms with dimensions greater than 100m probably should be subdivided. Minimal surface dimensions are ˜1mm and there is no specific maximum size. Surfaces can include ˜24 edges but complex surfaces or surfaces with large dimensions may not be well represented by 1D conduction. Minimum thickness of a construction layer is ˜0.2mm although care should be taken when thin and thick layers are adjacent.

- A number of boundary condition types are supported in ESP-r: a) exterior, b) other side has similar temperature and radiation, c) other side has fixed temperature and radiation, d) other side is a surface in

this or another zone, e) standard or user defined monthly ground temperature profile or a 3D ground model, f) adiabatic (no flux crosses), g) other side is part of a BASESIMP foundation description, h) CEN 13791 partition.

- Air gaps are typically treated a resistance layers which are sensitive to surface orientation. Glazing using alternative gasses or with coatings must be approximated by altering the air gap resistance. Air gaps can be explicitly represented as thermal zones and optionally included in an air flow network (such explicit treatments do not scale well but do support explicit treatments of radiation and convection across air gaps).

- There are ~20 internal convection regimes and 25 external convection correlation's in addition to user defined heat transfer coefficients. Conditions at inside and outside face are evaluated at each time-step. Some outside regimes are sensitive to the angle of incidence of the wind as well as whether the surface is on the windward or leeward side. Heat transfer coefficients derived via a CFD solution can be applied at the next time-step.

- Internal mass can be explicitly represented and these surfaces take part in the full energy balance as well as solar insolation patterns and long wave radiant exchanges.

- Radiation view factors can be calculated for zones of arbitrary complexity and shape, including internal mass.

- Fanger thermal comfort as well as MRT and resultant temperature reported. If sensor bodies are defined then radiant asymmetry is also reported.

19.3 Building envelope and day-lighting

This sections is an overview of the treatment of solar radiation outside a building as well as its distribution within and between zones. Outside surface conduction is also discussed.

- The default treatment is to assume no shading and that insolation is diffusely distributed within a room. If there are external sources of shading these are represented as opaque non-reflective block shapes. Shading calculations (direct and diffuse) are done for each hour on a typical day of each month. Diffuse shading can be based on isotropic or anisotropic sky conditions.

- Insolation distribution (including radiation falling on internal mass surfaces) can also be predicted at each hour on a typical day of each month.

- Beam solar radiation is tracked to first absorption and then diffusely distributed. Solar radiation passing into adjacent zones is treated as a diffuse source. Solar radiation passing out through a facade is assessed.

- Optical data on transmission and absorption at five angles is typically used and can be imported from Window 5.1 or 5.2. Data from WIS requires additional editing. Bidirectional optical properties and control is supported for those with experimental data.

- Seasonal adaptation of shading devices requires separate models, each pointing to obstruction descriptions for that season.

- Optical properties can be switched based on a range of criteria (the number of layers is required to be constant). There is a facility to substitute an alternative construction as well as alternative optical properties. The requirement for a constant number of layers poses a challenge for the representation of movable blinds and shutters.

- Day-lighting control can be based on split-flux method, user defined daylight factors or time-step use of the Radiance visual simulation suite to compute lux on a sensor. Multiple circuits can be treated in each thermal zone.

- Some users choose to explicitly represent opaque blinds as sets of surfaces. In the case of blinds between glass this is often approached by treating the blind as a layer with the construction which has optical properties approximating the transmission through the slats and openings. If the optical properties of this layer are switched then the absorption characteristics of the blind layer change (as does the thermal state of the construction).

- Conduction is typically represented in 1D but can be switched to 2D and 3D (the input data requirements increase considerably).

19.4 Infiltration ventilation and multi-zone air flow

This section provides an overview of how air movement, either from the outside or between rooms or in conjunction with environmental systems is treated.

- The simple approach to air movement in ESP-r is to create schedules of infiltration (air movement from the outside either natural or forced) and ventilation (air movement between zones). Control can be applied to these scheduled flows based on a range of criteria e.g. increase infiltration to 2ach if room goes over 24°C.

- The intermediate approach to air movement is to create a network of flow nodes and components and solve the leakage distribution at each time-step based on the current boundary driving forces as well as stack and pressure distributions inside. Most of the underlying component representation are derived from the literature. In common with most other mass flow solution approaches there are some gaps in the provision of component types.

- Control can be applied to mass flow components to approximate occupant interactions or mechanical flow controls. Combinations of controls in sequence and in parallel are used to create complex regimes.

- The highest resolution approach is to define one or more computation fluid dynamics domains (optionally in addition to a flow network). The domain is in a rectangular co-ordinate system with optional blockages. Solution is typically transient 2D or 3D. There are a range of wall functions available as well as equation types.

- The CFD solution supports one way and two way coupling. Two way coupling takes its boundary conditions from the zone solution and returns heat transfer coefficients. There is an adaptive controller which re-forms each domain at each time-step based on changes in boundary conditions and the flow patterns predicted from an initial (coarse/fast) CFD assessment.

- The CFD solution can also use flow boundary conditions from an associated mass flow network. This allows wind pressures and flows with other zones to be assessed at each time-step. This linkage can also use one way or two way coupling; two way uses iteration to achieve mutual agreement on pressures and flow rates between the two domains, whereas with one way coupling flow rates from the mass flow network are simply imposed on the CFD domain. When multiple CFD domains are defined this coupling is limited to one way.

- The CFD solution can include cells which are heat and contaminant sources. The former can be associated with zone casual gain schedules so that there is a temporal aspect to such gains.

- Zone air volumes are assumed to be well mixed at one temperature. Stratification requires either the use of a CFD domain or subdivision of physical spaces into multiple thermal zones with a mass flow network used to assess air exchange.

- A mass flow network can include elements associated with natural ventilation and buoyancy driven flow as well as components within a mechanical system. Thus it is possible to create an air based solar collector from a collection of explicit zones and a flow network (as an alternative to a component based approach).

- For models of high resolution there is a post-processor which determines if specific species of mycotoxin will grow on surfaces of a model.

- Architectural elements such as Trombe-Michelle walls and double skin facades are usually composed of multiple zones with a mass flow network to support air movement assessments.

- ESP-r includes a common file of wind pressure coefficients (at 22.5 degree intervals) which can be associated with wind pressure boundary nodes in a flow network. Some users populate this file with data from wind tunnel tests or third party CFD runs (the in-built CFD does not support exterior domains).

19.5 Renewable energy systems and electrical systems

This section is an overview of options for representing renewable energy systems either as components within an ESP-r model or via 3rd party tools. Including an electrical power network in a model allows a number of issues related to renewable energy systems to be addressed.

- Some system components represent components of renewable energy systems such as generators, fuel cells and batteries. These can be tested independently or switched into the power grid. Mixtures of 1/2/3 phase AC and DC can be described.

- The electrical solver works at the same time-step as the system components and yields real and reactive power flows, power losses, current magnitudes and phase, voltage magnitudes and phase, phase loadings.
- ESP-r data can be exported for use with supply and demand matching tools such as MERIT (also available from ESRU).

19.6 Ideal environmental controls

This section is an overview of ESP-r's approach to ideal (from a control engineers perspective) zone controls.

- For early stage design issues ESP-r users tend to use ideal zone controls to represent environmental controls as loops of sensors and actuators with a range of control laws.
- Ideal zone controls can be combined with control of mass flow components to increase the resolution of models. Mass flow components can be used to represent some aspects of duct work in mechanical systems (ESP-r has not been designed to be used as a duct design tool).
- Sensors in ESP-r can be located at a number of positions within the building (the zone air volume, at or within a surface, at a flow node or outside of the building for use with weather data variables). Actuators in ESP-r can be located at the air node, at or within a surface, at a flow component etc.

Zone control loops include a schedule of control laws are applied as required to approximate many environmental control regimes. The zone controls include:

- basic ideal control with maximum and minimum heating and cooling capacity, heating set-point, cooling set-point and moisture injection.
- free floating control
- fixed injection/extraction with heating injection, cooling extraction, heating set-point and cooling set-point.
- basic proportional control with maximum and minimum heating injection, maximum and minimum cooling extraction, heating set-point, cooling set-point. There is a throttling range and optional integral action time and/or derivative action time.
- A multi-stage controller with hysteresis. There are three stages of heating and three stages of cooling. There are heating off and cooling off set-points as well as dead bands for heating and cooling and heating and cooling set-points.
- Variable supply controller with or without available cooling. It includes a maximum supply temperature, minimum supply temperature, air flow rate room heating and cooling set-points.
- Separate ON/OFF controller which includes heating and cooling capacity, heating on below, heating off above, cooling on above and cooling off below set-points.
- Ideal match temperature controller which is given a maximum heating and cooling capacity and a list of sensors and their weightings as well as scaling factors. A typical use is to control a boundary zone to a measured temperature or to match the temperature in another zone. There is also an ON/OFF controller which can be used to match measurements or other zone temperatures.
- Time proportioning control which includes heating and cooing capacity, heat on and off set-points, cooling on and off set-points, minimum on times and off times. Useful for equipment that has a slow cycle time.
- Optimal start logic with heating capacity, desired set-point, desired time of arrival, minimum time difference with optional start time. There is also an optimal stop controller.
- Slave capacity controller points to a common sensor and forces the zone actuator to act as the master actuator but with a user defined heating and cooling capacity.
- VAV approximation controller which includes a reheat capacity, supply temperature, room set-point, maximum and minimum flow rate

19.7 Component based systems

This section is an overview of ESP-r's component-based approach to describing environmental systems. There are a number of component types (some are listed below) which can be linked together to form a

range of environmental control systems. Some devices are represented by several components - for example there is a single node radiator as well as an eight node radiator - so the user has a choice of component resolution.

As with zone controls, system components can be included in system control loops. There are a number of control laws available depending on whether flux or flow is to be controlled.

- Air conditioning steam/spray humidifier, water/steam flow multiplier, water/steam flow converger and diverger
- Air conditioning cooling coils with flux control, a counterflow cooling coil with water mass flow rate control, a counterflow cooling coil fed by WCH system, a two node cooling coil with specific fin and tube details.
- Air conditioning heating coils with flux control, a counterflow heating coil with water mass flow rate control, a counterflow heating coil fed by WCH system
- Plate heat exchanger, air/air exchanger, heat exchanger segment, duct, duct damper
- Cooling tower
- Centrifugal fan
- Wet central heating boilers: non-condensing boiler, with on/off control, with aquastat control, calorifier, modulating boiler, TRNSYS type 6 WCH boiler storage water heater
- Wet central heating radiators: basic (one node), exponent model radiator, WCH thermostatic radiator valve, mechanical room thermostat.
- WCH pipes: pipe, converging 2-leg junction, converging multi-leg junction, heat transfer tube, heat transfer tube with transport delay, insulated pipe with transport delay, flow control valve
- WCH basic chiller or heat pump, water cooler, compressed gas cylinder
- WCH generic liquid/liquid heat exchanger and gas/liquid heat exchanger and water/air heat rejector
- Oil filled electric panel radiator
- CHP engine components: one node and three node representations.
- Hydrogen appliance (generic generator supplied by hydrogen source)

19.8 Environmental emissions

The emissions associated with the energy use of buildings can be tracked via user supplied conversion factors for heating and cooling and small power loads as well as loads which are not attributable to a particular zone.

There is a rarely used facility that allows users to define environmental impacts associated with the assembly and transport and disposal of building components.

19.9 Weather data

This section gives a summary of how ESP-r uses weather data and how users access and manipulate this data.

ESP-r holds the following weather data in both ASCII and binary file format. Solar data can be in two forms. The normal file formats support hourly data.

- Diffuse solar on the horizontal (W/m**2)
- External dry bulb temperature (Deg.C)
- Direct normal solar intensity or global horizontal (W/m**2)
- Prevailing wind speed (m/s)
- Wind direction (degrees clockwise deg from north)
- Relative humidity (Percent)
- Site description, latitude and longitude difference from the local time meridian.

There is a conversion utility which is able to read EnergyPlus EPW weather data and extract the required data fields. ESP-r also works with sub-hourly weather data via a so-called temporal file.

There is an facility that scans a weather data set to determine best fit weeks in each season based on heating and cooling degree days and radiation levels. It also reports initial scaling factors that can be used to convert from short period assessments to seasonal performance data.

19.10 Results reporting

This section is an overview of how building and systems performance data is accessed in ESP-r. The standard approach differs from many other simulation suites in that one or more custom binary databases are created depending on the number of domain solvers used in a particular model.

- The zone solver writes out a number of items at each time step which related to temperatures of the zone air and surfaces as well as fluxes associated with a zone air energy balance and surface energy balances.

- The plant component solver writes out the temperature, 1st phase and 2nd phase flows at each node of each component.

- The mass flow solver records the pressure and temperature at each node, pressure difference across each network connection as well as stack pressure and mass flows along each connection.

- The electrical power solver writes out the real and reactive power, power loss, current magnitude and phase, voltage magnitude and phase, phase loading for each node in the electrical network.

- The CFD solver records temperature, axial velocity components, contaminant concentration and mean age of air for each cell where applicable..LP ESP-r includes a results analysis module which is able to read these binary results files and, for any of the stored variables report on the data in various formats and undertake statistical analysis.

- Graphs of time vs variable with option of multiple vertical axis and support for combinations of data.

- Graphs of variable vs variable to look for trends and correlation's between data types

- Statistics with maximum value and time of occurrence, minimal value and time of occurrence, mean and standard deviation

- Statistics with number of hours over and under a specified value

- Time step listings in multiple columns with various separators as required by third party applications

- Frequency bins and cumulative frequency bins in tables and graphs.

- Zone and surface energy balances as well as individual reporting of all contributor variables in the energy balances.

- Energy demand over time including hours of use.

- Comfort in terms of PMV, PPD, radiant asymmetry, resultant temperature, MRT.

- Monthly gains and losses for a number of variables in each zone.

- The CFD results can be visualised within the interface in 2D or 3D (velocity only), used to generate standalone static visualisations (e.g. bitmaps) or exported to 3rd party visualisation software (e.g. ParaView).

There is a facility which generates XML files based on a description of variables to save during a simulation. The list of items to capture is typically generated by editing a separate specification file.

There is a facility which allows users to include a range of performance metrics for a model called an Integrated Performance View. This description is used by the results analysis module to generate a report based on information in one or more simulation files.

19.11 Validation

Testing of software has been an ongoing activity for the ESP-r development community and takes several forms: assuring the quality of the code in ESP-r, testing that the underlying computations are correct and detecting differences with the predictions of other tools. ESP-r has been involved in the following projects:

- IEA Annex 1 (1977-1980). Inter-program comparison of 19 different tools

- IEA Annex 4 (1979-1982). Inter-program comparison of a commercial office building with nine tools over four years.

- IEA Annex 10 (1984-1986). Inter-program comparison of HVAC systems.
- IEA Annex 21 (1988-1993). Inter-program and analytical comparison commonly known as BESTEST.
- SERC validation project (1988). Inter-program comparison undertaken by several Universities and research groups in the UK with extensive analytical tests.
- UK Energy Technology Support Unit Applicability study was carried out over seven years and focused on passive solar houses.
- EC PASSYS project (1986-1993) combined outdoor test facilities (in 14 locations) with model predictions.
- British Research Establishment/ Electricity de France empirical validation study of a BRE office building and a BRE house.
- BESTEST, RADTEST, Home Energy Rating System BESTEST were carried out at various times and by various teams and focused on radiant heating systems (RADTEST) and air conditioning systems and furnace models (HERS).
- CEN 13791 standard required a number of extensions to ESP-r to accommodate the unusual physics assumed in the standard.

20 Exercises Appendix

This Appendix includes exercises which are referenced in, and complement, the discussion in the earlier chapters. The exercises assume no particular proficiency with simulation tools, only basic operating system skills in working in folders, managing files and running applications.

> Note: the ESP-r interface is evolving - phrases used in the exercises may not exactly match the interface.

Prior to undertaking the exercises review the *Interface Appendix* and the *Install Appendix*. Read each exercise in full before you do the tasks in the exercises.

Time required: In training workshops, participants tend to complete the first dozen exercises on the first day. In a self-paced environment 12 hours (including reading time) should suffice.

Preparation: Have a notepad available to record assumptions and sketch paper for recording plans and dimensions as well as a calculator. The exercises ask that you grab images at specific points so ensure you know how to grab a section of the screen and save it to an image file.

About model files: Most ESP-r model files are ASCII text and should be viewed with a *text editor*. On Windows the free NotePad++ has a number of useful features. Otherwise use WordPad rather than Word. On Linux/Unix nedit or gedit and on OSX bbedit also works well. The text based editor nano is useful, especially if you are accessing files remotely.

Conventions used: Commands that you type in are shown in bold courier text `cd` while selections that you make in ESP-r menus are in italicised courier text *Model management ->Model management -> new model* where the first phrase is the menu title and the text after the *->* is the option to be selected.

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Exercise 1.1 - Setting up your Models folder (referenced by Section 1.1)

Overview: You need a working *Models* folder for the models that you will be browsing and creating.

Background: You should own this working folder e.g. be able to create and remove files without disturbing other users or corrupting the ESP-r distribution and the example models that are distributed with ESP-r. It helps if this folder has a short path, preferably with no spaces in the names of folders.

Typical model locations:

- Unix/Linux/Cygwin in a folder named Models within your home folder (e.g. /home/ralph/Models)

- OSX in a folder named Models within your home folder (e.g. /Users/ralph/Models)

- Windows 7 or Windows 10 in C:\Esru\Models or C:\Users\ralph\Models. Avoid C:\Documents and Settings\ralph\Models

To interact with ESP-r you need to be working in the standard command terminal of the operating system e.g. xterm or terminal. The following commands set up a working folder for your models named `Models` On OSX the sequence is almost identical except you would be working in the OSX terminal or in a XQuartz terminal. To do this and start up the ESP-r Project Manger type:

```
cd
mkdir Models
cd Models
prj
```

Use Windows Explorer to create a `Models` folder in a location you have control of such as
`C:\ESRU\Models or C:\Users\ralph\Models` Copy the
`esp-r.cmd` file from `C:\Esru\esp-r\Models` into your `Models` folder and then click on the cmd
file to start the ESP-r Project Manager.

If the Project Manager starts then you have completed this exercise. If it does not start then have a look at
Chapter 16. You will be returning to this *Models* in subsequent exercises. In Linux or OSX we will
assume this is `/home/ralph/Models` and in Windows we assume this is `C:\Users\fred\Models`

_____

Exercise 1.2 - Model browsing (referenced by Section 1.2)

Overview: ESP-r is distributed with scores of models, some taken from consulting and research projects.
The five hour office building project is one of these. ESP-r includes facilities to access these models and
have them copied to a location you specify so that you can explore them, modify them and use them to
increase your skills.

Background: The ESP-r project manager scans an 'exemplars' file for the location of known training
models. The structure can also be used to record past models developed by a simulation group. The
selected model is replicated within your *Models* working folder. The original model is preserved.

To interact with ESP-r you need to be working in a terminal and in the terminal go to your working folder.

```
cd
cd Models
prj
```


Use Windows Explorer to go to your `Models` folder and click on the
`esp-r.cmd` file to start the ESP-r Project Manager.

The following interactions within the Project Manager are the same for all operating systems.

```
Model Management -> open existing -> exemplar
real projects -> Office building section with controlled facade vents
proceed
```

You are then asked to confirm where you want to place the model. If you started the Project Manager in
the `Models` folder the `Place model in:` will take the form of: `/home/fred/Models/office_vent`
and the Project Manager will copy the entire model from the ESP-r training folder to this folder. The
wire-frame image of the model should look like Figure 1.1.

_____

Exercise 1.3 - Working with existing models (referenced by Section 1.5)

Overview: ESP-r models are held in a distributed set of folders which follow a standard naming regime. Each will contain a `cfg` folder with one or more model configuration files with a `.cfg` ending. As the model configuration file includes references to the model files in the distributed folders ESP-r works best if you work from the model `cfg` folder. Depending on the operating system, you can start the Project Manager with a command line directive `-file <name of cfg file>` or start the Project Manager with no directive and use in-built file browsing to locate the model configuration file. The first task is to work with the office model browsed in Exercise 1.2.

In a Linux Command window issue the following command (adapt the names to fit your user name):

```
cd
cd /home/fred/Models/office_vent/cfg
ls *.cfg
```

and you will notice that there are a number of model configuration files. What are the differences? In the `doc` folder of the model is a file `office_vent.log` which is a text file that describes each. Lets say you decide to explore `office_vent_netinf.cfg` you could do one of the following:

```
prj -file office_vent_netinf.cfg
```

or you could start the Project Manager and respond to the opening menu list of available files:
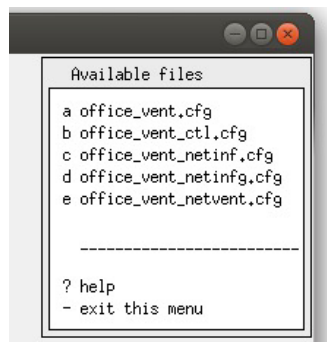
```
prj
```


Figure E1.3.1: List of available model cfg files

If you start the Project Manager in the Models working directory specifying a *remote* model is possible. For the `Model selection options:` question you would select the `other` option. If you are using the GTK interface you are presented with a file browser and with the X11 interface you must type in the full path to a model configuration file. If this is found the Project Manager will offer to restart focused on this model from within the model `cfg` folder.

The steps for OSX are similar except that instead of `/home/fred/Models/office_vent/cfg/` becomes `/Users/fred/Models/office_vent/cfg/` The interactions and choices in the Project Manager are otherwise identical.

Similar options are available in Windows. In order to use command line options in Windows you would have to use a DOS command terminal. Many users find it more convient to use Windows Explorer and either click on the `esp-r.cmd` file to start the Project Manager or to use Windows Explorer to focus on a model `cfg` folder and click on the model cfg file (assuming that files ending with .cfg have been associated with the `esp-r.cmd` file. `Models` folder and click on the `esp-r.cmd` file to start the ESP-r Project Manager.

In response to the `Model selection options:` question you would select the `[other]` option and then user the in-built file browser to locate the model configuration file. The Project Manager will offer to restart focused on this model from within the model `cfg` folder (however a long path might result in the Project Manager claiming that it cannot find the model cfg file).

As an alternative try using Windows Explorer to go directly to the model cfg file and click on it. It should restart focused on the model.

_____

Exercise 2.1 - Model registration (referenced by Section 2.2)

Overview: The initial task in ESP-r is to *register* a model. This involves choosing a *root name* for the model, invoking the ESP-r *Project Manager (prj)*, entering site details and documenting of the intent of the model.

Background: You have just talked to a client about a new project and they have sent you map coordinates, a photo from the site and a synopsis of their initial design goals. It is never to early to attach such information to a model (even if there is, as yet, no compositional information).

Go to your working *Models* folder and start up the Project Manager. In the opening menu choose the `Model Management -> create new` option and immediately you are asked for a *root* name for the model. The initial model discussed in Section 2.2 is a doctor's surgery, use the name *Surgery* as the root name. If you invoked *prj* in the Models folder then the result will be a new ESP-r model folder structure within the folder `Models/Surgery` and at the prompt `Model description?` provide a phrase that clearly identifies the model. The phrase will be see in many places in the interface and in reports. And after you provide this you are asked to confirm the name of a model log file. If you agree with the suggested name just say `[OK]`. You can use the model log file for any purpose. Some people record assumptions and working minutes in such files. It is attached with the model so the commentary it contains can be use to convey useful information. If you ask to edit it the default text editor associated with ESP-r will be invoked (more information about that in the *Setup Appendix*).

Next the dialog asks you `Associate images now?` and if you have site photos or design sketches you can associate them with the model. To do this use the operating system to copy the image files into the model `images` folder. As you register each image you nominate the image type as well as the topic you want to associate it with. If you do not have any images yet so answer `[No]`. The next dialog is `Site latitude?` If you want to know about the concept of latitude in ESP-r use the `[?]` button for contextual help otherwise enter the value.

Section 2.2 mentions Birmingham UK weather file. Let's place our project near this location - latitude 52.45N, longitude difference 1.73 West of time meridian, year 1995. You can enter these now or allow the model site to be updated later when the weather file is selected.

The next dialog is `Longitude difference?` this is the degrees from the site to the **local time meridian**. Find out more via the `[?]` button. The next dialog is `Assessment year?` and this essentially tells the ESP-r what day of the week is associated with 1 January. If the weather file is for a specific year match it, otherwise a common preference is a year where the first of January is a Monday.

At this point you are returned to the main menu and the *registration process* has been completed. You can exit *prj* at this point. Look for the menu item `- exit Project Manager` and select it. This will systematically close all of the open files and then the application. Hitting the `[X]` in the upper corner of the application can leave the model in an unstable state. Use the kill only in an emergency.

Take a note of where your model is located on your computer (it is so easy to forget this). Subsequent Exercises involving the surgery we will want to invoke *prj* from within the `Surgery/cfg` folder, as you practiced in Exercise 1.3.

_____

Exercise 2.2 - Model archiving (referenced by Section 2.2)

Overview: files get lost, computers have faults, clients don't like hearing excuses. This exercise is about backing up models using common operating system facilities.

Background: Each operating system has common tools which can place the contents of a hierarchy of folders and files into a single file. Linux/Unix/OSX typically support *tar and gzip*, Windows uses can use 7zip <?>. Avoid using RAR.

First, use the operating system file manager to look at the folders related to surgery. A standard set of folders (as in the image below) will have been created. All ESP-r models have the same folder structure and the model files use a consistent naming regime based on the model root name.

For example, information about controls is held in a `ctl` folder and the meta information about the project is held in the `cfg` folder and documentation (like the Surgery.log file) is held in the `doc` folder. Now archive the model using tools on the operating system (e.g. create a tar archive file of the whole model structure on Linux/OSX/Cygwin via

```
cd Models
tar cf Surgery_initial.tar Surgery
```

or right click on the model folder in Windows or OSX and make a zip file). Save often and develop a naming strategy to reflect the evolution of the model.

_____

Exercise 2.3 - Creating surgery reception (referenced by Section 2.2)

Overview: Based on the clients brief and the planning sketch this exercise covers the steps needed to define the surgery Reception. It uses the floor-plan extrusion method to create the initial form of the room. Take your time, pause before you press `[ok].` Some ESP-r facilities do not have `[back]` `[abort]` options.

Background: A floor plan extrusion takes a sequence of XY points on a floor plan at a given Z and then extrudes walls and then encloses the thermal zone via a top surface. Default names are given to each surface based on the order it was created and its orientation.

The tasks you will be carrying out for this exercise are:

• The initial floor plan of the reception is extruded into an enclosure with 7 walls and base and top.

• The initial surfaces are attributed for name.

Traverse the menu structure to focus on the geometry of a new zone as. Select `Model Management ->` `browse/edit/simulate -> composition -> geometry & attributions.` Since there are no existing zones you will be asked whether you want to `input dimensions` or `load existing (ESP-r),` `load existing (CAD)` or `[cancel].` Choose to `input dimensions,` name the zone e.g. `reception` is a good choice.

Next you will be asked to describe this zone - paraphrase the clients definition.

The next dialogue asks whether we want to start with an `rectangular plan, polygon plan, general` `3D, bitmap.` Select `polygon plan` and refer to the planning sketch. The height (Z in real space) of the floor is 0.0m and the ceiling is 3.0m.

How many walls? The sketch indicates an additional point at X=4.0 and Y=7.0 where the north wall of the reception changes from facing the outside to facing another space at a similar temperature. Two boundary conditions requires two walls, thus there are 7 walls to extrude.

The coordinates are:

```
0.0  4.0
4.0  4.0
4.0  0.0
8.0  0.0
8.0  7.0
4.0  7.0
0.0  7.0
```

(we need not repeat the initial point). You will have the option to accept the points. If you are *in any way worried*, say no and you will have a chance to check and edit the data.

The `Rotation angle?` dialogue allows you to define co-ordinates in a cardinal orientation and then rotate to reflect site conditions. You can also perform transforms and rotations later. To skip the rotation, leave the rotation angle at zero.

You will be asked to confirm a file name for *model connections*. This files contains the master list of surfaces and their boundary attributes and the name presented is base on the model *cfg* file name so click `[ok]` to accept the suggested name. At this point the reception should look like:
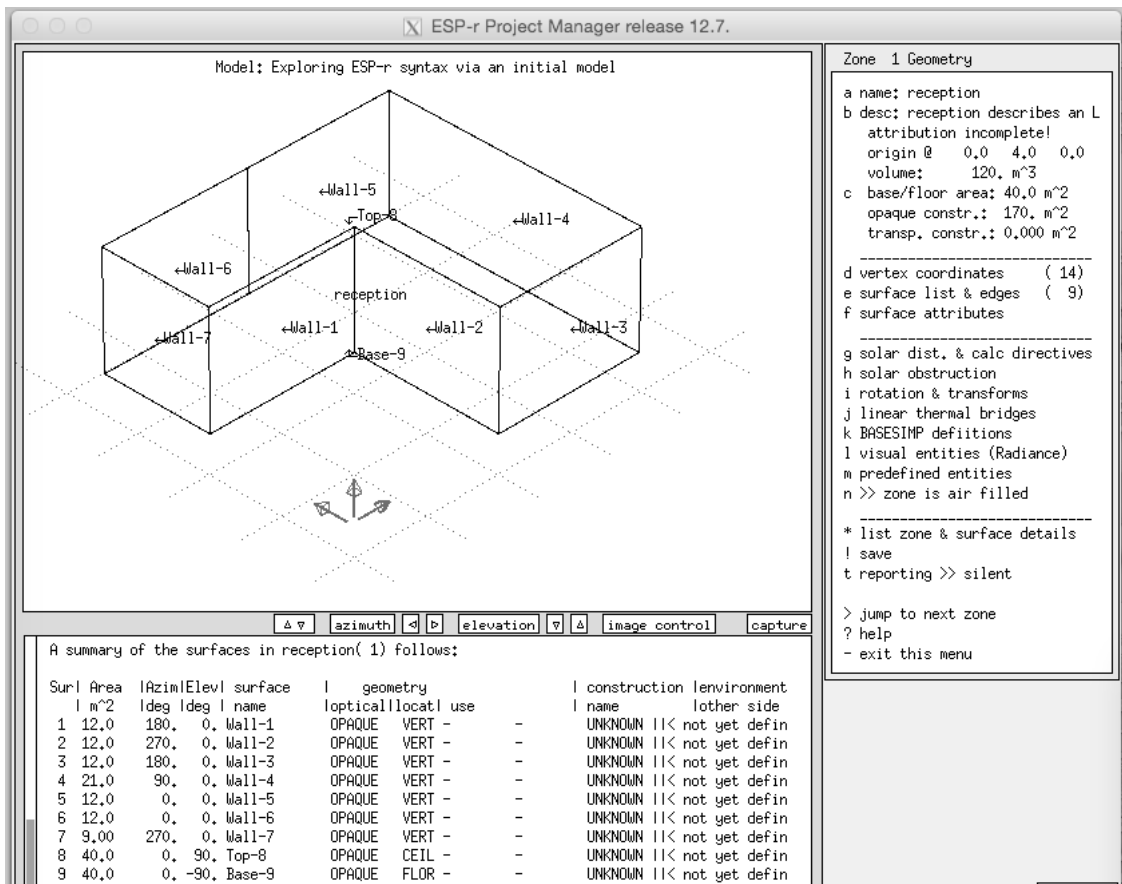
Figure E2.3.1: And here is what it looks like after initial extrusion!

Check to see that the vertices in the list and in the wireframe view match the figure below:
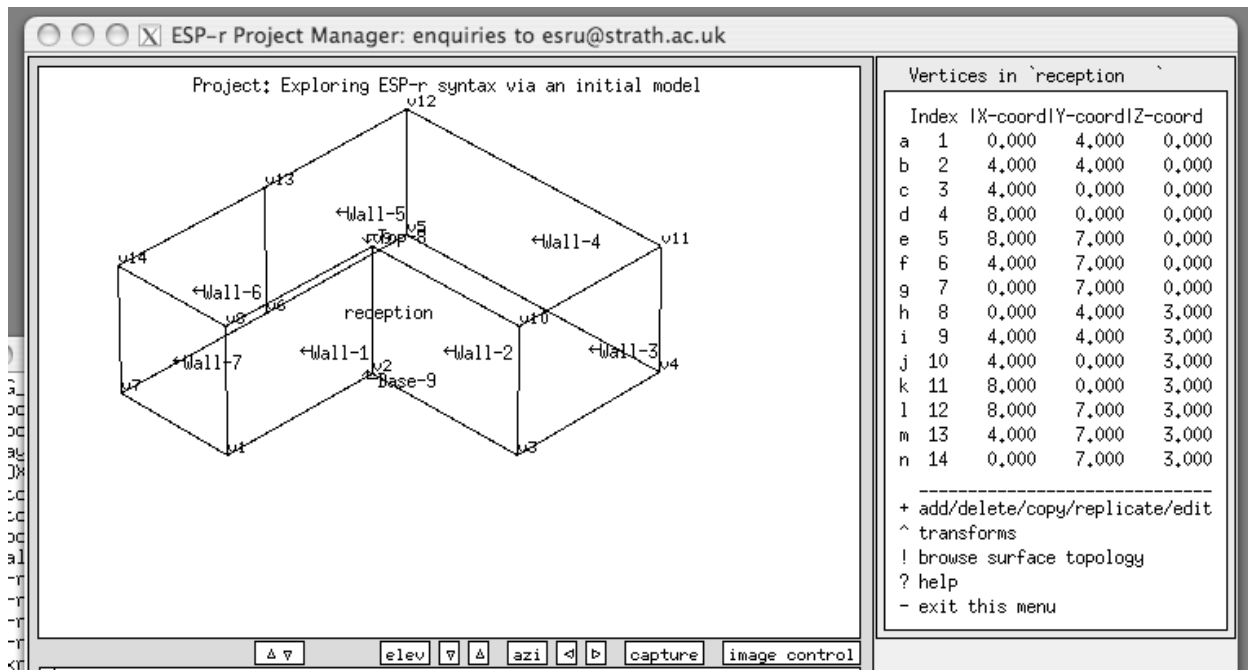
Figure E2.3.2: Initial list of co-ordinates.

The zone geometry menu, like many others in ESP-r is dynamic and it will have updated to reflect the new surface information. For example the volume of the reception is 120.0 m^3 and the base of the reception is 40m^2.

And if we look in the `[surface list and edges]` menu option the polygon definitions (ordered edge list) is available to view and alter as well as facilities to `[add/insert/copy/extrude_from]` an existing surface (more on that later). There is also a `[delete surface]` option (which should be used with caution). The `[transforms]` item opens up a transforms that can be applied to a surface e.g. rotation, shifting along the surface normal, inverting the order of the edges to face in the opposite direction etc. (more on these transforms later).
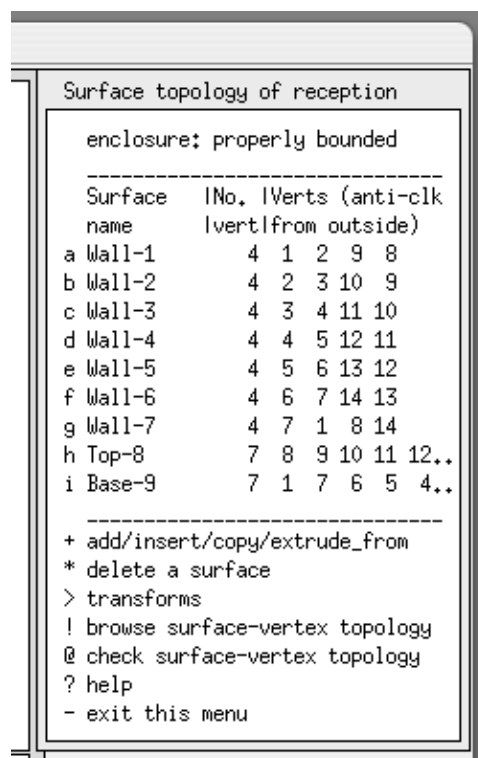
Figure E2.3.3: Initial surface edge lists and management options.

If the names and coordinates and reported values match these figures then select `[save]` in the zone geometry menu for the reception and then select `[- exit this menu]` to return to the model composition menu. Is this a good time to make an archive of your model?

Exercise 2.4 - Controlling wireframe views (referenced by Section 2.3)

Overview: Both the X11 and GTK interface provide wire-frame views of the model geometry. The default view parameters can be altered to shift the viewing direction as well as toggling items in the view e.g. surface names or vertex numbers.

Background: The wire-frame view complements the text based feedback in ESP-r. Although the wire-frame is not usually report quality it can be 'tweaked' to provide clarity if, for example information is obscured. Many users also prefer to be looking at the outside face of a surface when working.

X11 Under the graphic feedback area (of the X11 interface) are a number of buttons for altering the view-point altering the size of the graphic feedback area and controlling the image. Click on the left or right buttons to alter the view azimuth. Click on the up or down buttons to alter the view elevation. You can drag the horizontal bar up and down to change the proportions between the text feedback area and the graphic feedback areas of the application.

GTK Wire-frame control is located under the View tab at the top of the application. There are separate items for left, right, up and down. Changing the view is a bit tedious with the GTK interface.
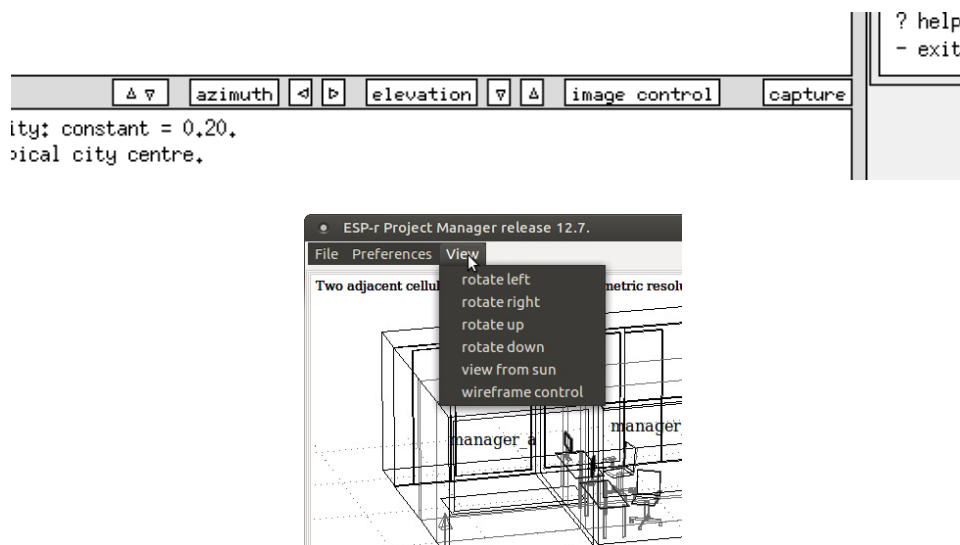

Figure E2.4.1: GTK and X11 arrows for view direction control

X11 image control options include toggles for display of names and vertices, the site grid and origin.

GTK image control options are found in the View item which invokes a proforma which is roughly equivalent to the X11 options.

You can adjust the eye point as well as the point in the model where the view is focused. The angle of view (in conjuction with the view bounds option) approximates a zoomed view so that you can focus on a small part of the room, especially useful if there are vertices close to each other.

The default perspective view can be toggled to plan or elevation. You can include or exclude solar obstructions from the view as well as focus on surfaces that meet specific attributes - like partitions.

The highlight options will use bold lines for surfaces which meet specific criteria or which are not yet fully attributed.

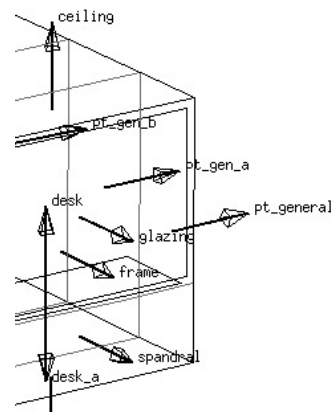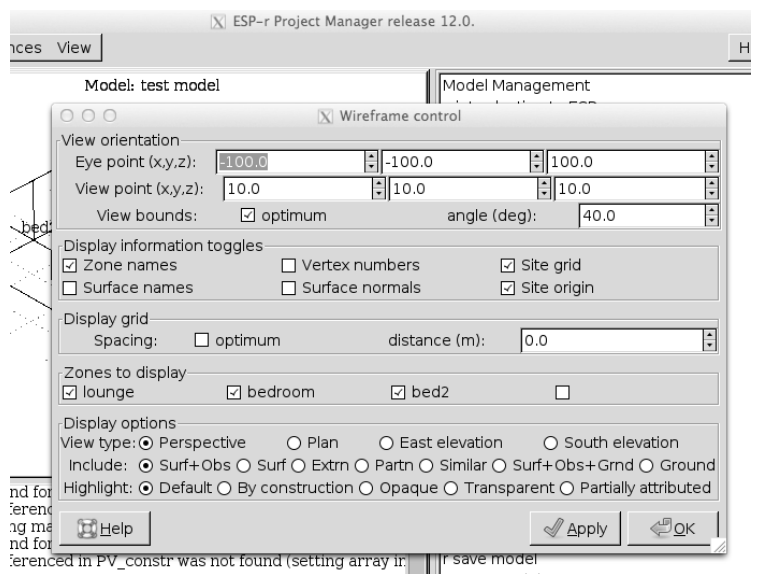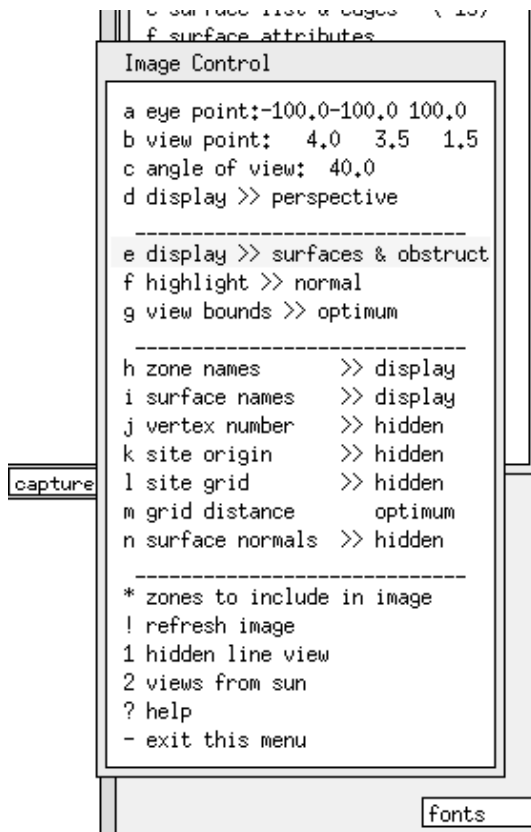And turning on surface-normals is a great way to catch surface polygons which are reversed!

```
Image Control

a eye point:-100.0-100.0 100.0
b view point:   4.0   3.5   1.5
c angle of view:  40.0
d display >> perspective
_____
e display >> surfaces & obstruct
f highlight >> normal
g view bounds >> optimum
_____
h zone names      >> display
i surface names   >> display
j vertex number   >> hidden
k site origin     >> hidden
l site grid       >> hidden
m grid distance      optimum
n surface normals >> hidden
_____
* zones to include in image
! refresh image
1 hidden line view
2 views from sun
? help
- exit this menu
```

Figure E2.4.2: X11 and GTK wireframe control menus

_____

Exercise 2.5 - Adding windows and doors (referenced by Section 2.3)

Overview: We explore inserting doors (surfaces touching the base of an existing wall) and windows (surfaces inserted into a parent surface).

Background: Entities in a room which have a potential thermophysical impact should be included as surfaces in the thermal zone. A door or window is a surface that has appropriate attributes (name, composition). They may or may not be child surfaces of a parent. They need not be rectangular, however the standard facilities for inserting surfaces assume rectangular shapes. Remember that you can rotate the wireframe viewpoint to get a better view of your work.

```
new surface options:
 a made from existing vertices
 b made from existing vertices (mouse)
 c inserted into a surface
 d copy surface(s) in this zone
 e copy surface(s) from another zone
 f vertical rectangle (origin&azim)
 g horizontal rectangle (origin&rot)
 h extrude sides/top from base surface
 i vertical rect mass (origin&azim)
 j horizontal rect mass (origin&azim)
 _____
 * default is option 'c'
 ? help
 - exit this menu
```

Figure E2.5.1: Options for creating surfaces.

You will be asked to provide an offset and a width and height of the rectangle to be inserted. The offset is from the lower left corner of the existing surface (looking from the outside). If the design includes an arched opening or a round window you can do this (but the surface will have to be made of a number of straight segments linking existing vertices).

According to the sketch in Figure 2.1, the entry door is 1m from the edge and 1m wide. Use the `inserted into a surface->at base` option and provide the offset, width and a height of 2.1m. Wall-2 is 4m wide and if the partition door is to be 1.0m wide (this is a medical facility) then the offset for the door will be 1.5m Use the `inserted into a surface->at base` option. The window in Wall-3 starts 2.0m above the floor and is centered in the wall. So the offset X is 0.5m and the offset Z is 2.0m and the window size is 3.0m x 0.75m. The same offsets and size apply to the window to be inserted into Wall-5. Use the `inserted into a surface->within` option for creating the rough openings.

When you insert new surfaces you are asked to name them and attribute their constructions. Follow the names and composition from the sketch. You will also be asked to select from a set of surface use options which can help in model checking.

The final task is to insert the glass within the rough-opening frames. Let's assume that the frame width is 80mm. Use the `inserted into a surface->frame` option to create the glazed portion 80mm within a frame in the north and south facades. At the end of the process this is how the reception should look.
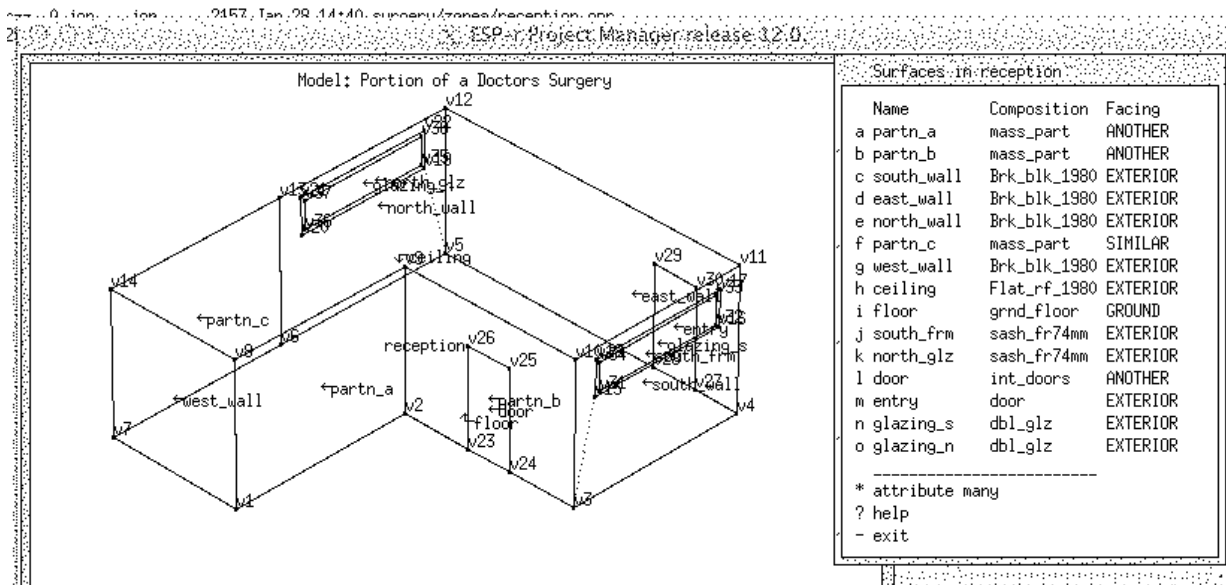

Figure E2.5.2: Reception after the addition of frames windows and doors.

_____

Exercise 2.6 - Attributing surfaces (referenced by Section 2.3)

Overview: This exercise looks at attributing multiple surfaces vis-a-vis names, composition and boundary conditions.

Background: Our model are just CAD representations until we provide the attribution needed to support simulation. Often we would like to apply surface attributes to groups of surfaces.
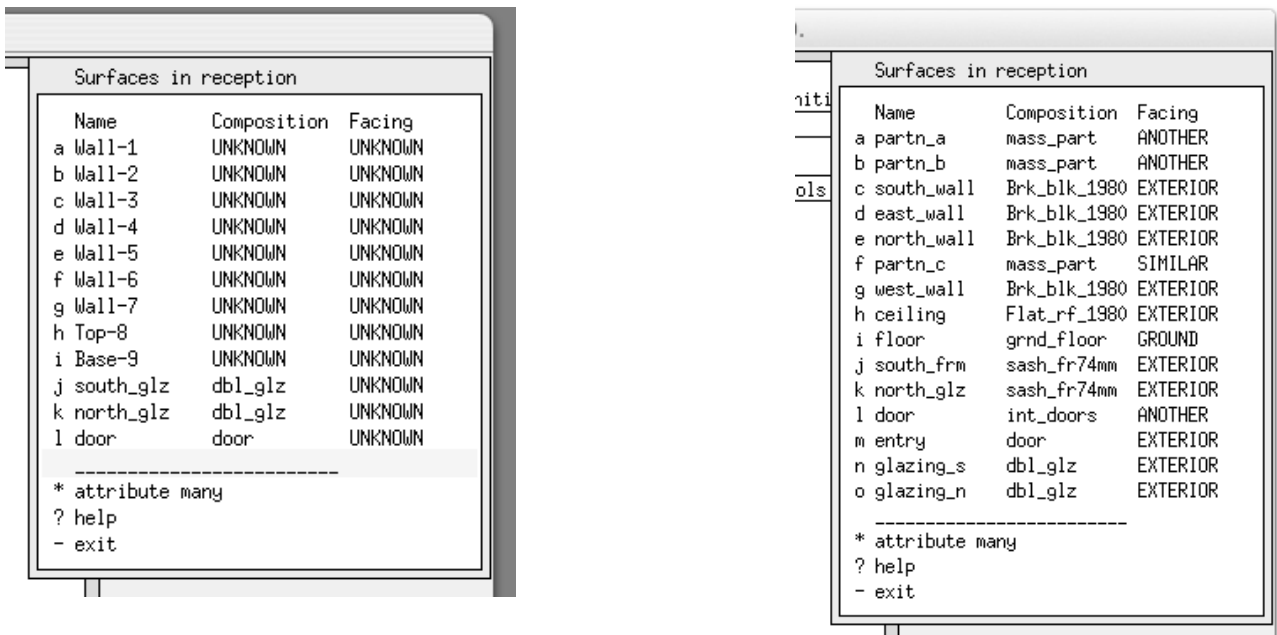
Figure E2.6.1: Surface(s) attribution initial and completed.

The surface attributes menu includes an *attribute many option (this uses a list selection dialogue described in the Interface Appendix). You have a choice of attribution types name, composition, boundary condition, use Select [name] and you will be asked to defined the name of each of the selected surfaces (note the surface is highlighted in the wire-frame drawing).

For the surfaces that have UNKNOWN attributes use the information from the sketch of the model. You can attribute one surface at a time or in groups by selecting the attribute and then identifying which surfaces to apply it to.

Typically adding construction attributions, for those surfaces that you have an opinion about, would be the next task. Use the information from the model sketch. Where several surfaces have the same construction use the *attribute many option. Skip boundary conditions for the moment - there is an automatic process to assign this attribute later in the process.

The point of careful attribution is that the combination of the graphic image and surface attribution ensures that the model is correct. If something called door is composed of concrete and you see it as a horizontal in the image someone is likely to notice!

At the end of the process the interface might look like the right side of Figure E2.6.1.

Exercise 2.7 - Creating the examination (referenced by Section 2.3)

Overview: In this exercise we create the form of the examination room of the surgery. You wil gain experience with a number of geometric definition facilities. The steps are subtly different for the X11 and GTK interfaces.

Background: Although defining geometry is only one of many tasks required to create models the effort required can be moderated by careful planning and the re-use of existing entities. With reference to Figures 2.1 and 2.6 here are the steps: zones composition -> geometry & attribution -> * add/delet/copy and select [add zone] and then select [input dimensions] and then fill in the new zone description as examination and then provide some text about the intent and/or use of the zone examination room for one of the practitioners and then select [rectangular plan] as the base zone geometry. Next supply the origin of the examination 0.0 0.0 0.0 (this happens to coincide with the site origin). You are then asked for the length (4.0m along the X axis) the width (4.0m along the Y axis) and the height (3.0 along the Z axis).

When you complete this there are two questions related to an optional rotation to the orientation and tilt of the initial box shape. If you want to know more about such dialogs use the [?] option in the number input dialog. In this case accept zero for orientation and elevation. Note that as you have supplied these

data the information is echoed in the text feedback.

Depending on prior model definition tasks you might be prompted to update information in a zone ideal control file. If such a file exists then agree to this request.

At this point the initial form of the zone will be shown in the interface. Check that your display looks like Figure E2.7.1
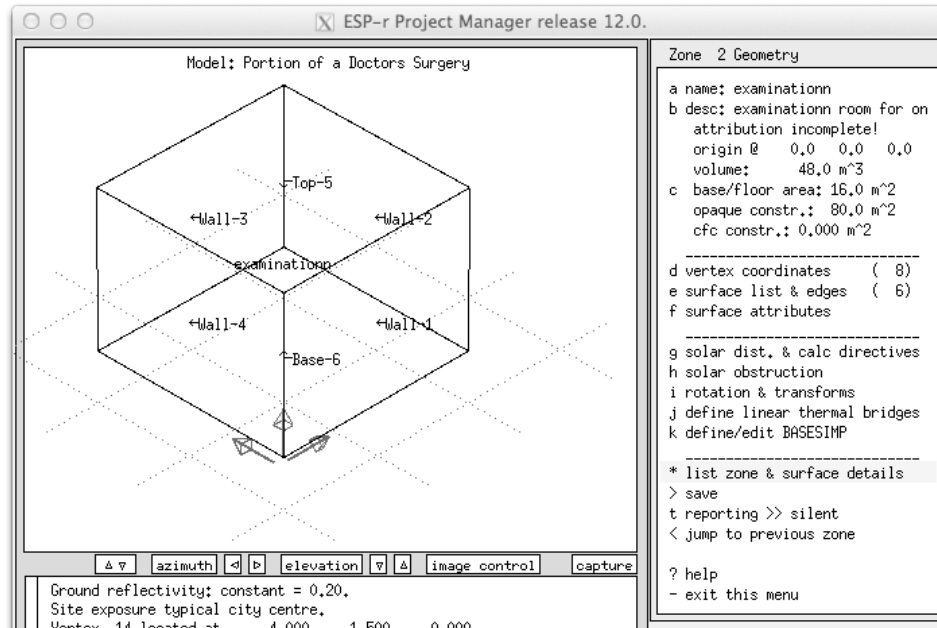

Figure E2.7.1: Initial examination box shape.

Next we want to edit the Z value of the vertices forming the back top edge. Which are these? Use either the `[image control]` or `[view]` options to turn on surface vertex and from this we can see that it is vertex 7 and 8 which need Z to be adjusted from 3.0m to 4.5m. Use the `Zone 2 geometry -> vertex coordinates` menu, select these two vertices and edit the Z value. You will the see that the wire-frame image is updated. You might not yet be able to see the ridge of the roof. When you exit from this menu you will be asked if you want to record these changes. Say yes. And now would probably be a good time to make a backup of the model (look at your notes for how to do this).

If you had made a mistake you could say no when exiting the vertices menu and the glitch would not be preserved.

According to the sequence of transforms at some point you should remove Wall-2 (the right wall in the wire-frame view) and Wall-3 (the back wall) so that we can copy/invert the partitions and door that already exist in the reception.

Why - the lower portion of the back wall faces another room and the upper portion faces the outside - multiple surfaces are needed and we already have three fully attributed surfaces in the reception so let's use them! `Zone 2 Geometry -> surface list & edges -> delete a surface` and select `Wall-2` and then do this again for Wall-3. You will notice that the menu now includes a notice: `enclosure: 6 PROBLEM EDGES.` This is expected - we have broken the rules of enclosure. And to find out more select `check surface-vertex topology` which will highlight the 'unbounded' edges and write a report with the specifics and optionally it will attempt to correct the 'unbounded' edges.
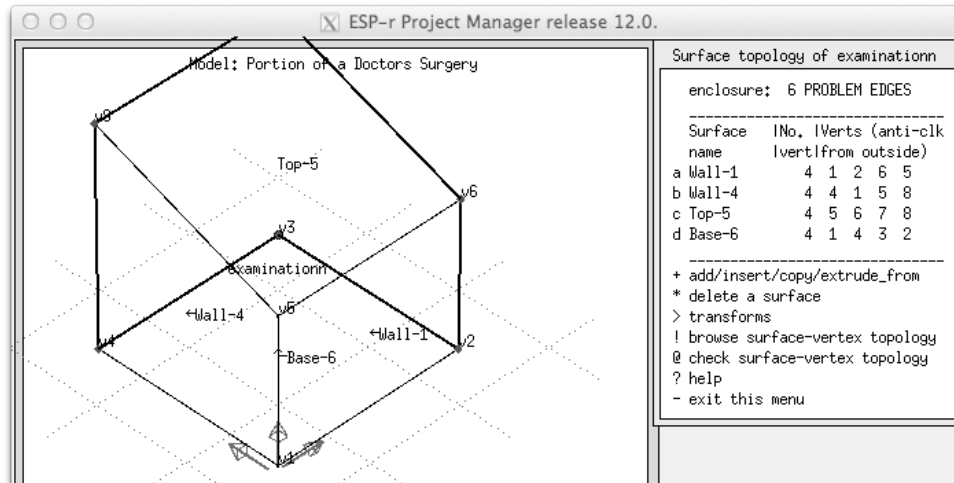
Figure E2.7.1: Examination after raising roof and deleting surfaces.

The next task is to copy three surfaces from reception. `Surface topology of examination ->` `add/insert/copy` and from the list of options select `copy surface(s) from another zone` and select reception and then a list of the surfaces in reception and the wire-frame image of reception are shown. It might be difficult to see all of the labels (which is why we named the surfaces and attributed them earlier). We want to get `partn_a   partn_b   door` and notice what these are made of. It does not matter what order you select. When you have identified the first to copy you will be offered options during the copy process. We need to 'flip' the surfaces around during the copy so choose `invert` and you can also agree to apply this to the other surfaces that you are copying. The wire-frame view will be updated and the menu will include these additional surfaces.

There remains the task of filling in the triangular wall above partn_b, placing a frame and glazing over partn_a and placing a rough opening, frame and glazing in the south facade. Before we do that, exit from the surface list menu and 'save' the zone information.

To see how your recent work fits into the building exit up two levels to the `zones composition` menu and both zones will be shown. To complete the geometry and attribution drill back down: `zones compo-` `sition -> geometry & attribution -> examination` rotat the zone so that you can see the outside of where the triangular wall will be placed and also toggle on the vertex numbers. The triangular surface will be made of vertices 6 9 7. `Zone 2 Geometry -> surface list & edges -> add` and select either `made from existing vertices (mouse)` if you are using the X11 interface and then proceed to click on vertex 6 and then 9 and then 7 followed by the character 'e' to end the selection. Or if you are using GTK interface select `made from existing vertices` and then type in the three indices and click ok. In both cases you will be asked to name the surface (how about triang_wall). Rotate the view until you see the outside of partn_a. Again we are going to add a surface using existing vertices 9 10 8 7 to form the frame for the upper north facing window. That order ensures correct orientation of the new surface. `Surface topology -> add -> made from existing vertices 9 10 8 7` and name it something like `north_frame` And to insert the glass at 80% of the rough opening are use the following sequence: `Surfae topology -> add -> inserted into -> north_frame` and then select `% of sur-` `face area` and give 80 percent. You could also use the `insert within frame` option giving a frame thickness. Check the preview, if correct agree that the position is correct and give it a name like north_glaz. You will be presented with a list of possible constructions. We know from the planning that dbl_glz is to be used so select this from the list. Next you are presented with `surface USAGE options` which you can use to document the intent of the surface e.g. WINDOW (facade complient). This is used in the UK code checks if supplied, otherwise it is only for documentation. There will also be a documentation question about air leakage (a future version of ESP-r will use you answer to automate creation of a flow network).

The wire-frame image and menu will be re-displayed. If correct you will see: `enclosure: properly` `bounded` and this leaves only the task of adding the rough opening, frame and glazing. Follow the same steps as you did when creating these facade elements in the reception. At this point the room should look like Figure E2.7.2.
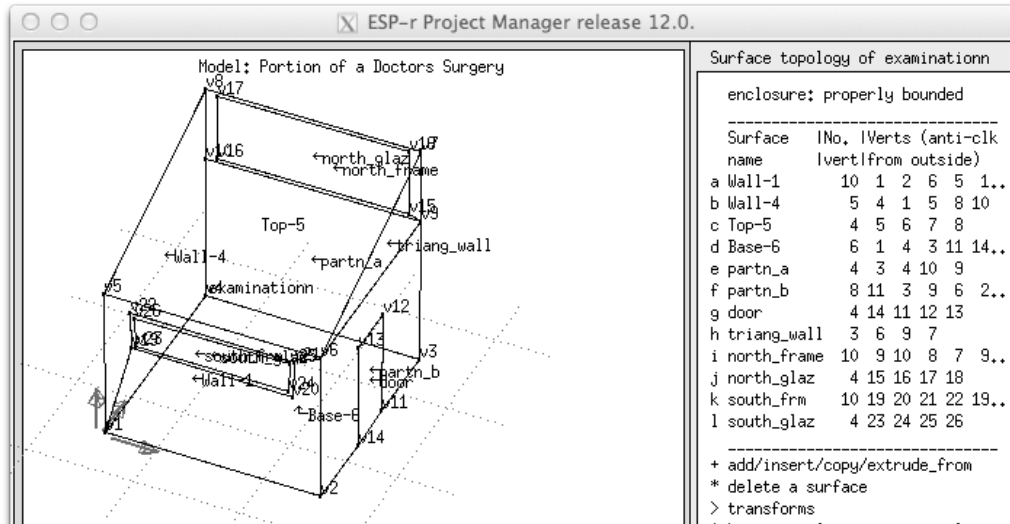
255

Figure E2.7.2: Examination will all surface, some unattributed.

Check to see if what you see is similar to Figure E2.7.2. And what you should notice is that many of the surfaces still have their default names and unknown composition. Use the information in the planning sketch and complete the surface name and composition attribution. Check your work against Figure E2.7.3.
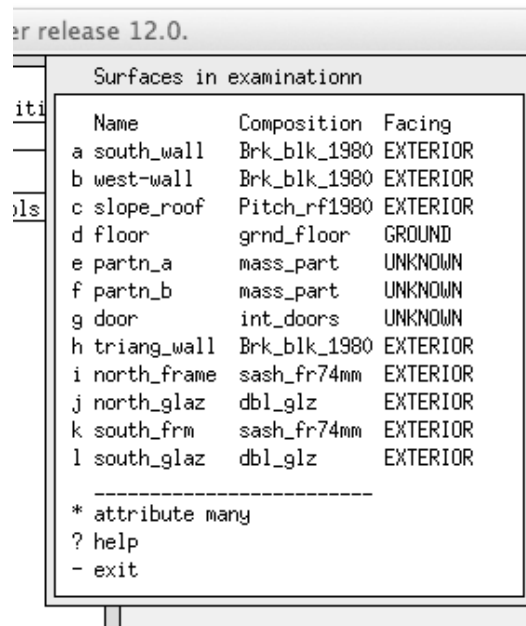

Figure E2.7.3: Examination surfaces user attributed.

We have been through quite a few steps. Time for a nice cup of your favorite brew! But before you do that this is a great time to make a backup copy of the model!.

ESP-r offers facilities to discover which surfaces in a model are partitions and these will be covered in a separate exercise.

_____

Exercise 2.8 - Automated topology checking (referenced by Section 2.3)

Overview: In this exercise we use ESP-r's automated process to establish and/or confirm the surface boundary attributes across all zones in a model.

Background: Setting surface boundary condition attributes surface-by-surface takes time and introduces risk. We can commission an automated facility to systematically explore surfaces in the mode for geometric matches and then agree with the matches discovered or impose our own selection.

256

Go to `Zones composition -> surface connections & boundary` (see Figure 2.40). The option you will want to select (after reading a bit further) is `check via vertex contiguity` but first click on the `?` `help` option and read about the facilities.
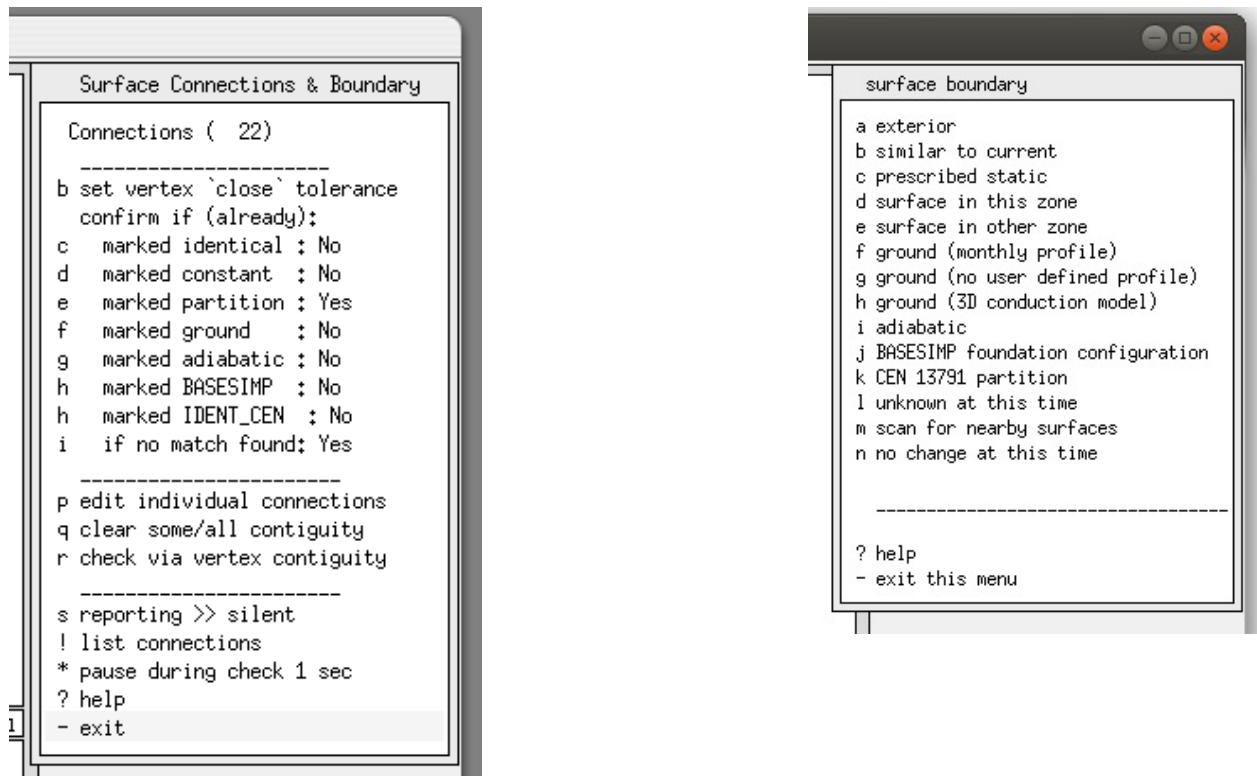

Figure E2.8.1: Topology options and confirmation options.

A word about the options in the interface under `confirm if (already):` the `marked identical: NO` translates to 'if I already said this surface was connected to a dynamic-similar boundary condition' do not ask me to confirm this. Items that are marked yes will ensure that you are asked for confirmation.

Once you are happy with options c-i then you can proceed with `check via vertex contiguity` and watch the process unfold. If a search does not discover a match - e.g. a surface is facing the outside, you can then select the `exterior` option from the list. If you are doing the test in an incomplete building then `UNKNOWN (at this time)` might be a useful response for surfaces facing future zones.

Note that as you evolve your model rather than doing global checks on topology you can use the `surface boundary -> scan for nearby surfaces` Option to deal with new or changed surfaces one at a time.

_____

Exercise 2.9 - Instantiating zone construction files

Overview: Surface construction attributes are used, in conjunction with the thermophysical properties in the common material and common construction files, to populate zone construction files which are used by the simulator. As you are composing your model the first time you must ask for these files to be created (subsequently they can be automatically updated).

Background: The ESP-r simulator scans a number of model files prior to undertaking a simulation. Zone construction files are required for the assessment to proceed and this exercise proceeds through the steps needed for their initial creation.

Task: In the project manager go to: `Model management -> browse -> zone composition -> construction materials` and each of the current zones will be listed as either `(defined)` or `(not found)` and there is an option to `update all zones` which is possible after the initial zone construction files have been created. Choose a (not found) zone from the list and then `create using this name` and if all of the attributes can be resolved and there are no warnings then you can complet the task via `save construction data.` I you select a zone which has existing zone construction files then you can choose to `use it` or `rreate via geometry attributes` and then choose the `save`

`construction data.`   This menu also includes options for setting controls to optical properties.

_____

Exercise 2.10 - Click-on-grid to recreate surgery

Overview: This exercise focuses on the *click-on-grid* facility to recreate the basic enclosures for the reception and examination rooms of the surgery.

Background: The X11 interface supports a click-on-bitmap facility which can either allow you to click on points over an image or a user defined grid for laying out zones. Before you start, review Figure 2.1. In particular consider the dimensions of the rooms and facade elements. The overall plan is 8.0m by 7m, the outside door is 1m wide and offset 1m from the corner while the window rough opening is 3m wide in a 4m parent surface. We could use a 0.5m grid but there are also options for a 0.25m and 0.1m grid available which would allow finer placement. Your choice is partly down to how fine the resulting grid is on your monitor - the fewer pixels per metre the more difficult it is to reliably click accurately.

Begin this new project by exiting any open ESP-r application. Return to where you keep your models and then invoke the ESP-r Project Manager.

Follow the same process as you initially used:

• select `Model Management -> create new` with surgery_click as the root name.

• accept the folders for this new model fill in the high level description of the project

• fill in the site data

After the site details have been entered select `browse/edit/simulate -> composition-> geometry & attribution.`

Select dimensional input and provide the name and a description for the first zone (reception). To use the click on grid approach to geometry definition choose the `bitmap` option. This opens up an initial (blank) command window as shown in Figure E2.10.1 which allows you to select one of several pre-defined grids or to supply your own bitmap (scanned from a document or created from a CAD tool). For this exercise we will use the `medium blank bitmap`
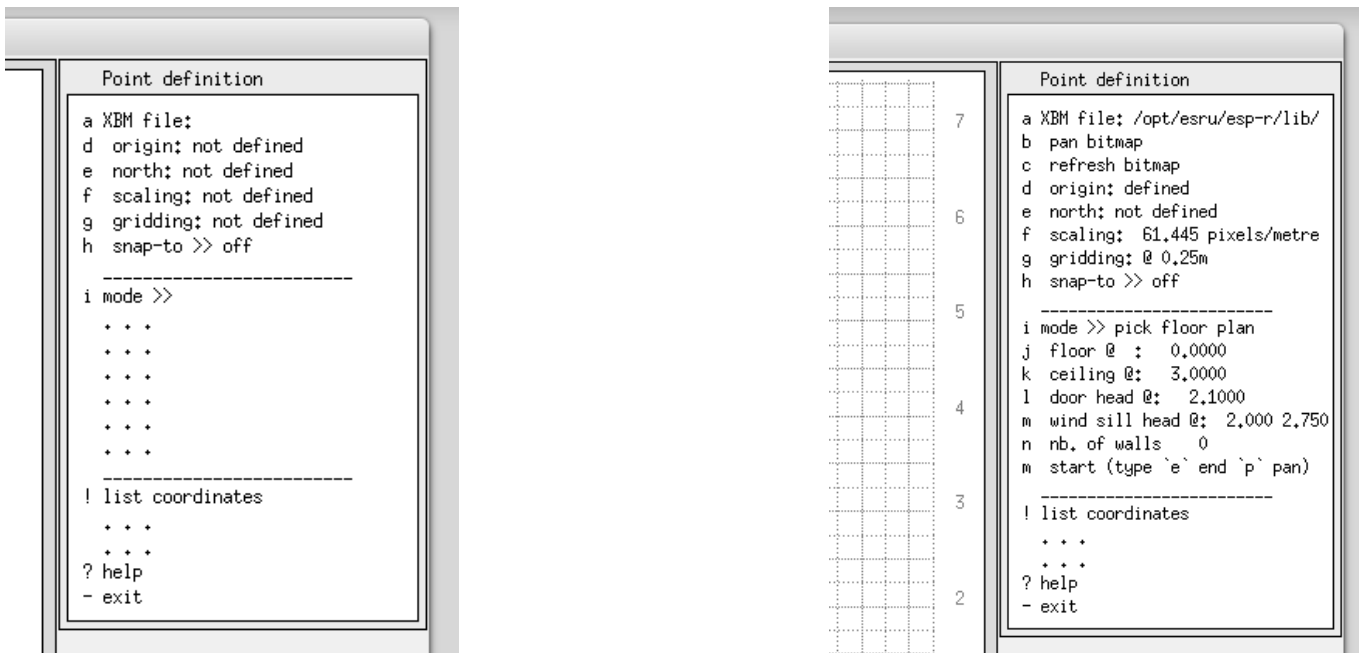

Figure E2.10.1 Opening menus of click-on-bitmap.

Before selecting the grid file, adjust the size of the graphic feedback area to be closer to square. You might also use the window manager to resize the Project Manager so that you have plenty of room to work. This will prevent you having to 'pan-around' the grid as you work.
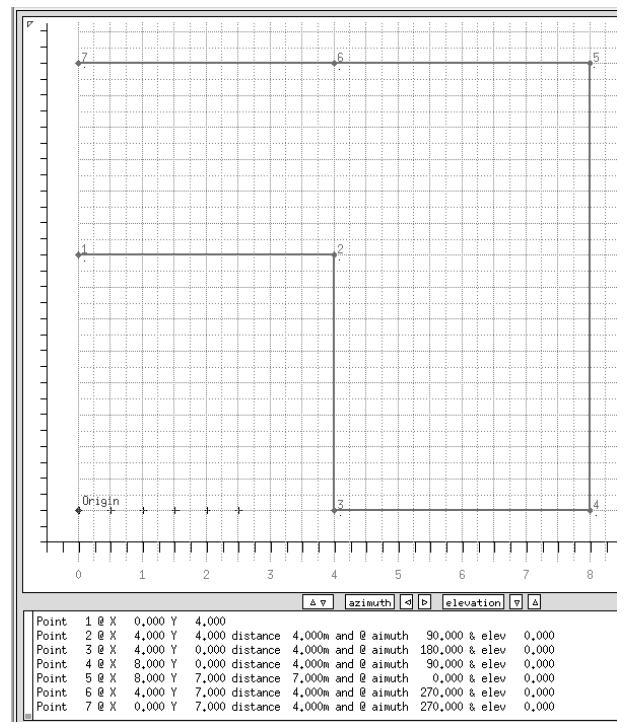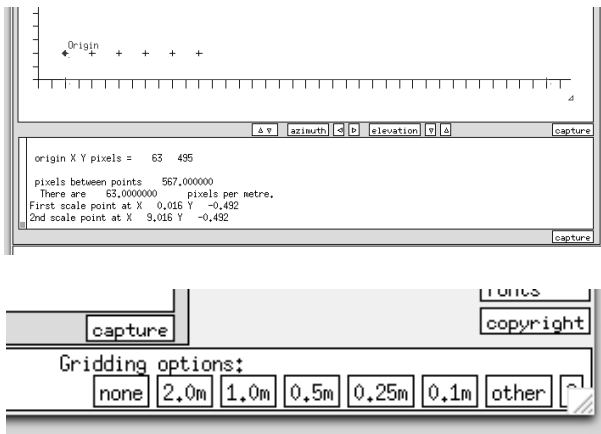
258

Origin

origin X Y pixels = 63 495

pixels between points 567.000000
There are 63.0000000 pixels per metre.
First scale point at X 0.016 Y -0.492
2nd scale point at X 9.016 Y -0.492

capture

capture

copyright

Gridding options:
none | 2.0m | 1.0m | 0.5m | 0.25m | 0.1m | other

Origin

azimuth   elevation

```
Point  1 @ X   0.000 Y   4.000
Point  2 @ X   4.000 Y   4.000 distance  4.000m and @ aimuth   90.000 & elev   0.000
Point  3 @ X   4.000 Y   0.000 distance  4.000m and @ aimuth  180.000 & elev   0.000
Point  4 @ X   8.000 Y   0.000 distance  4.000m and @ aimuth   90.000 & elev   0.000
Point  5 @ X   8.000 Y   7.000 distance  7.000m and @ aimuth    0.000 & elev   0.000
Point  6 @ X   4.000 Y   7.000 distance  4.000m and @ aimuth  270.000 & elev   0.000
Point  7 @ X   0.000 Y   7.000 distance  4.000m and @ aimuth  270.000 & elev   0.000
```

Figure E2.10.2 Defining origin & scale, identifying base points.

For this exercise select the XBM file option and then medium blank option and accept the suggested file name in the dialogue box. This option places a few tick marks in the lower left corner. Define an origin slightly inside the positive axis (as shown below). Next define the scale by clicking below the origin and again close to the end of the X axis and input 9 as the distance. This ensure we are not cramped.

Next select the gridding option and look at both 0.5m and 0.25m. The images below are using the 0.25m grid. Next choose the snap-to toggle to ON

The mode >> menu option (Figure 2.10.2) lists a number of choices for entering data points. The floor plan extrusion option is equivalent to the floor plan extrusion used in the initial exercise but it also includes options to identify door and window jamb positions as well as the origin of pre-defined furniture.

Select the mode option of pick floor plan and set the ceiling to 3.0m and the window sill and head at 2.0 & 2.75m

Just before starting to define points it is worth noting that you are able to interrupt the input process, move around a bitmap and toggle the snap-to via keystrokes.

Use the start option to begin defining points in the same order you used in the previous chapter. Start at the grid nearest x0.0, y4.0 and then x4.0, y4.0 etc. until you reach x0.0, y7.0 (see Figure 2.10.3) after which you will type the character e to end the input.

With the snap-to option you only need to click near the point and it will snap to the nearest grid. If the snap-to option is off the Project Manager will accept the actual point where you click.

If you make a mistake or the point snaps to an incorrect grid point then immediately type the character d to delete the last entry (multiple deletes are possible).

After you have signalled the end of points for the initial zone (by typing the character e) you are given a number of options (see below):
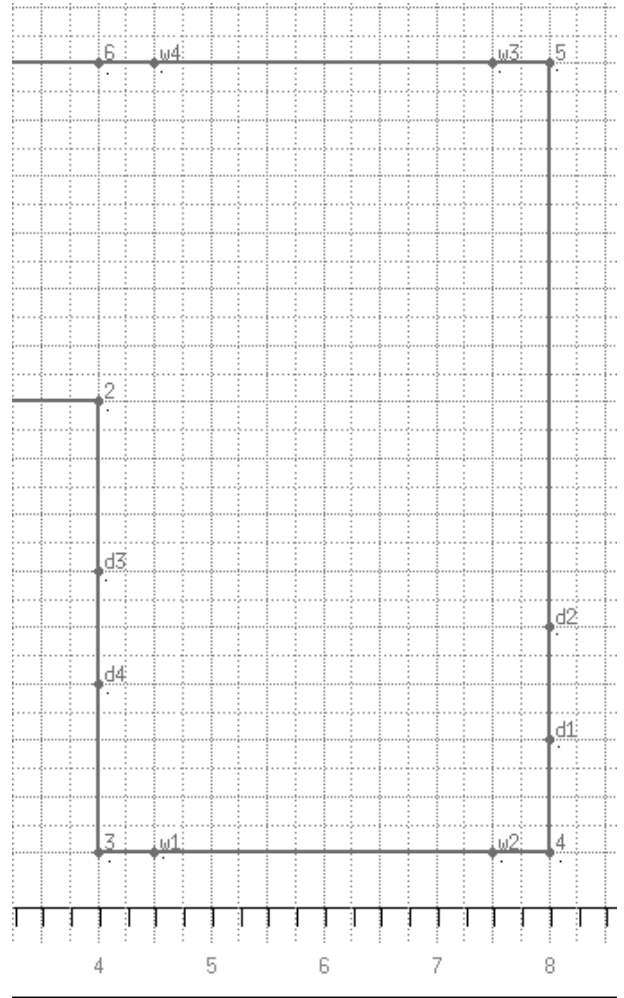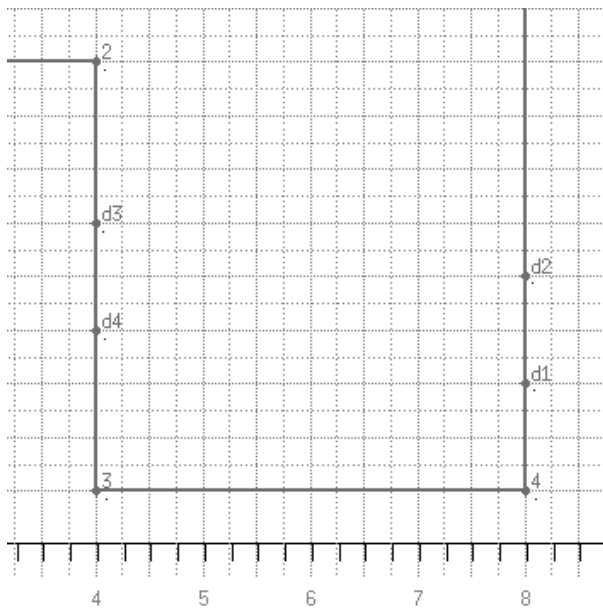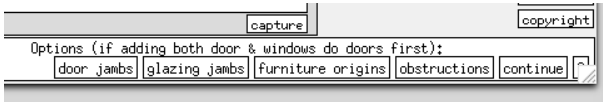
Figure E2.10.3 Defining door jambs and window jambs.

Proceeding anti-clockwise define the jambs of the exterior door and then the interior door. Type e and select the `glazing jambs` option and define the front and back glazing rough openings. After typing e again to close the zone base points and save the zone data.

Select the option `create another zone` will be displayed in the menu once the initial zone is saved. This can be used as many times as required to extrude zones (using the current floor and ceiling height attributes). In the current exercise the examination room needs to be added. It has the same initial floor and ceiling height as the reception zone so those attributes need not be altered. When you are ready, select the `create another zone option` and supply a name and description for the examination room.

Note that three of the corners of the examination room are at the same grid points as used by the reception and unless you specify otherwise, those coordinates will be used (Figure E2.10.4). The base coordinate of prior zones remain visible so that it is easy to create new zones adjacent to existing partitions. Since you are extruding a floor plan you will proceed anti-clockwise from the origin typing the character **e** when you have done all four corners. Again type e to get the choice of adding door jambs. Carefully pick the two door points (the prior points will not be visible). And then type a final e to close off the zone points.
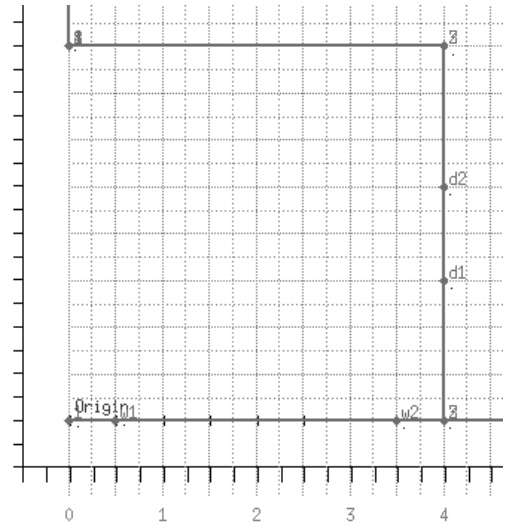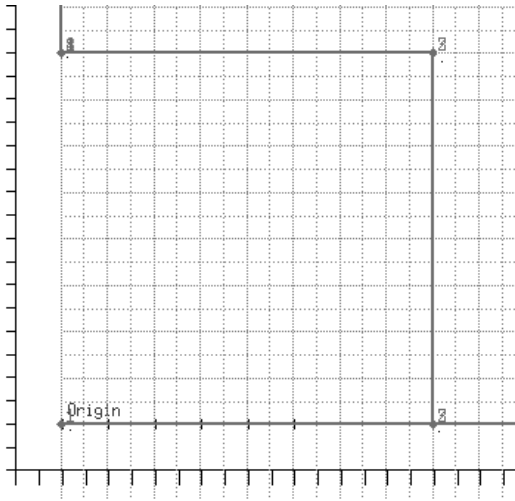
Figure E2.10.4 Reception base and door door jambs.

As the examination room is the last zone, exit from the click-on facility and you will be presented with a wireframe view of the zones you have created (Figure 2.10.5). These zones still require surface attribution as well as the addition of window frames and raising the roof in the examination room. Such tasks can be accomplished by using the geometry & attribution facilities introduced in the previous chapter. And this would also be a good time to revisit Exercise 12, generate a model contents report and compare it with the original model.
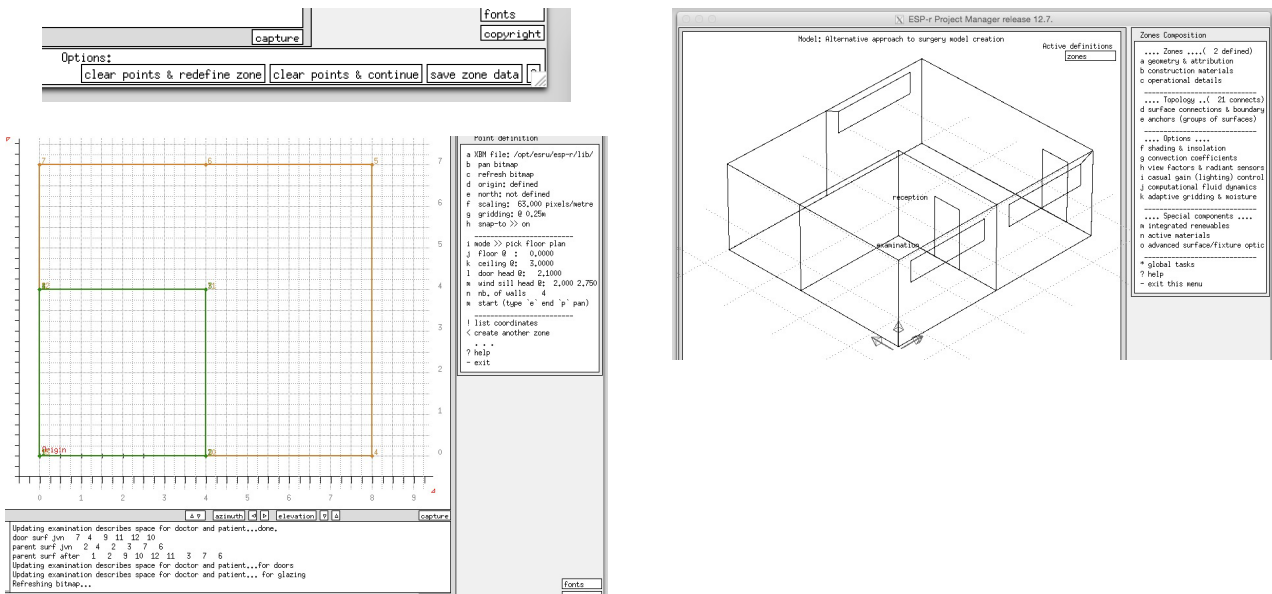

Figure E2.10.5: Completion of the zones via gridding and wireframe view.

_____

Exercise 2.11 - Practice in click-on-bitmap

For this exercise find a floor plan or a portion of a building that comprises several rooms and optionally more than one level (if the floor plates are similar). Ensure the plan includes clues as to its scale and site origin and orientation. Scan the plan at 100, 200 and 300 bits per inch (bpi) and convert to X11 monochrome bitmaps.

Print the plan and on a tracing paper overlay identify the critical points, plan the order the zones will be entered, paying particular attention to T-junctions in partitions between rooms. In the figure below the sketch was on grid paper with a 100mm grid.
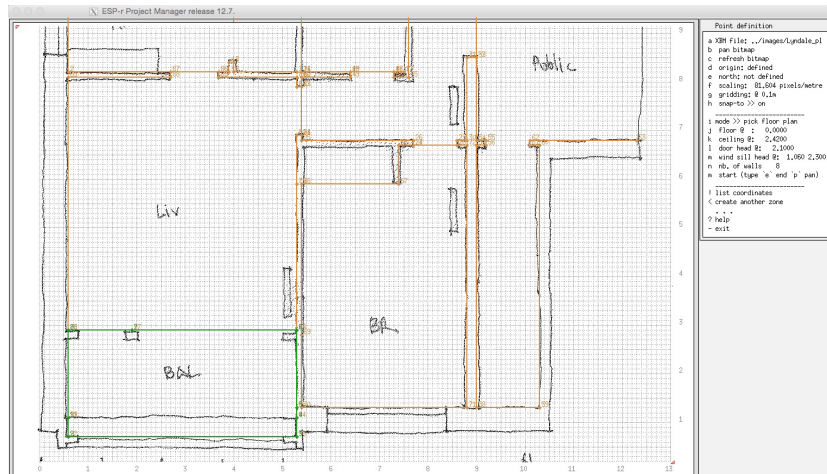
Figure E2.11.1: Working with a site-sketch.

In the *project manager* start a new model, copy the bitmaps to the model images folder (so they can be easily selected) and use the click-on facility to create the zones.

Begin with the medium bitmap resolution, if you find there is a loss of accuracy try a higher resolution. If you spend lots of time panning in the interface then you may need to use a lower resolution.

Keep notes on what worked as well as the resolution of the image and which grid density you used.

————————————————————————————————————

Exercise 3.1 - Identify a cold weekend to test Monday startup

Referenced in Section 3.1. Read Section 3.1 before working on this exercise.

Overview: A classic test of the response characteristics of a building is a Monday morning warm-up after a cold weekend. In this exercise you will explore different data display options to identify a cold period prior to and including a Monday morning.

Background: There are a number of formats for reporting on weather data in the *clm* application - graphs, statistics, column listings. In addition to the data held in the weather file there are derived values such as heating degree days (HDD). Let's find out which work well for your skill sets.

Task: Use the `Graphical analysis` options to look at ambient temperatures. Adjust the period of the display to improve your view. Note the period description in the header of the graphic display.

Can you get this information in other ways? How bout the `Synoptic analysis` options? Pick `dry bulb temperature` and then select either `maximum & minimum` or `days within a range` and then choose the reporting period (daily / weekly / monthly). Make a note of the period - mid-week before the cold weekend until the mid-week after the cold weekend. If the cold period happens on Sunday and Monday then you could change the year of the model to shift that data to a different day of the week.

————————————————————————————————————

Exercise 3.2 - Identify a sequence of warm day to test overheating

Referenced in Section 3.1. Read Section 3.1 before working on this exercise.

Overview: A classic stress-test of buildings or environmental systems (e.g become uncomfortable or make exceptional demands on environmental controls) requires the identification of warm weather patterns.

Background: Some buildings that easily cope with a single hot day can fail if there is a sequence of warm days. We can use the *clm* application to identify sequences which will form a better stress test then the usual worst-day-of-the-year method.

Task: In what ever order you wish use different reporting facilities to identify a sequence of warms days. For example, you could use Cooling Degree Days reporting by week or day as a first pass: `Synoptic analysis` options? Pick `dry bulb temperature` and then select `degree days or hours` and then choose the reporting period (daily / weekly / monthly. Then switch to graphing mode, focus on the month

or a fortnight when CDD were high and confirm the pattern of temperatures. Make a note of the period - several day before the warm sequence until several days after the warm sequence. Adjust the year of the model to get a different day of the week if necessary.

_____

Exercise 3.3 - Identify a cold-clear and windy-cloudy sequences

Referenced in Section 3.1. Read Section 3.1 before working on this exercise.

Overview: This exercises looks at multiple weather data (wind speed, ambient temperature and direct and diffuse solar radiation) to identify two classes of winter weather which can be used to stress-test buildings.

Background: Depending on the form and composition of the building winter building performance may be stressed via periods of cold-clear-calm weather or windly-cloudy-mild weather. We can use the *clm* application to identify sequences which will form a better stress test then the usual worst-day-of-the-year method. Ah, but the weather file does not include clouds. We do have direct and diffuse solar radiation. Days with little direct solar radiation will be cloudy days.

Task: Explore different reporting facilities to identify a sequence of days which match the two types described above. Keep track of what facilities you used. Make of note of the two periods that are a good fit and ensure that any assessment you run start several days before the pattern and extend for several days after the pattern. Place documentation describing this in a convenient location so that you can use them to define assessment periods for use in early assessments.

_____

Exercise 3.4 - Defining season definitions

Referenced in Section 3.2.

Overview: When working with a weather file which is already selectable in the Project Manager weather list it will already have meta data defining the duration of each season as well as a typical week in each season which can be used for short duration assessments.

You might disagree with the periods or you may be working with new weather data which does not yet have this information. This exercise will step through the process using a combination of looking at the patterns of temperatures over the year and the solar radiation. In the weather module choose graphical analysis from the menu options. Then pick dry bulb temperature and draw graph to get a display similar to that in Figure E3.4.1.

The axis at the bottom of the graph is weeks. There are extreme low temperatures in weeks 4, 9, 46 and 52. There is a late cool period in week 12. In week 14 it reaches 22°C. The warmest period is between week 26 and week 32.

Another way to look at weather data is via weekly heating and cooling degree days. To to this select synoptic analysis and then choose dry bulb temperature and then degree days and then weekly. Take the default base heating and cooling temperatures This will produce a table as Figure E3.4.2.
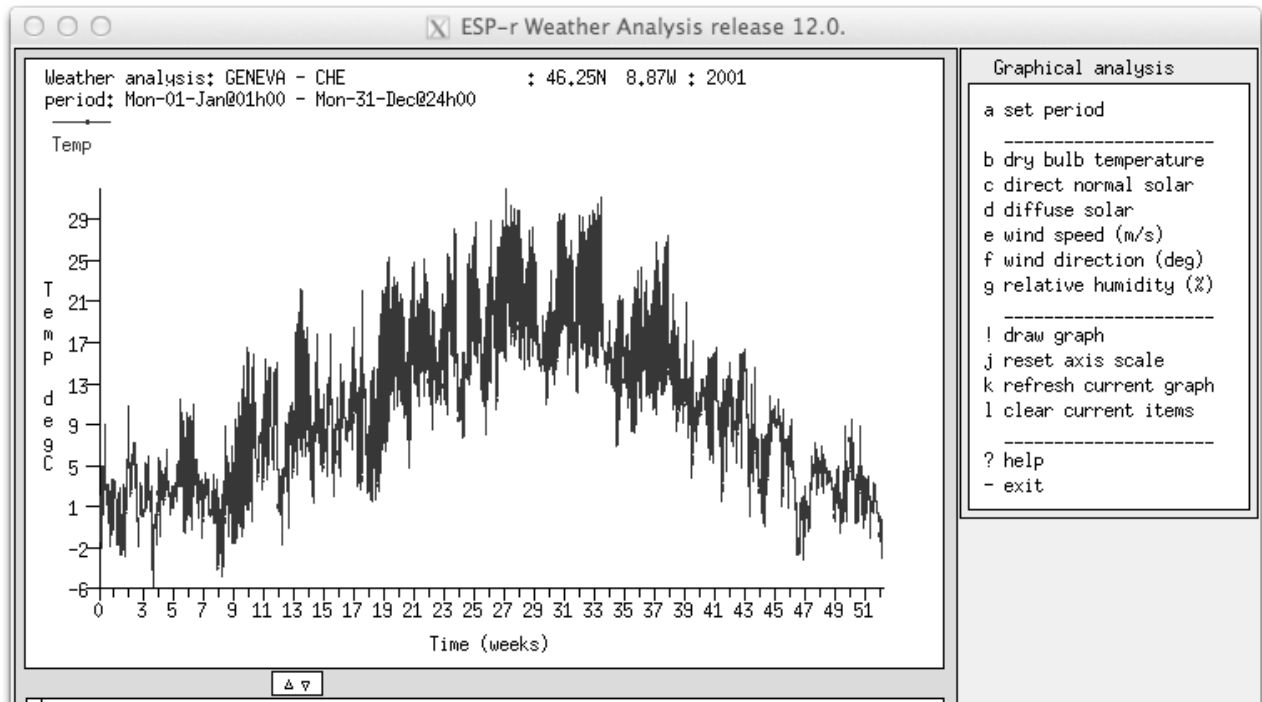
Figure E3.4.1 Annual dry bulb temperatures.

The average heating degree days is ~15.0 for the first nine weeks and then drops to ~8.0 (except for week 13). Weeks 27 to 34 have cooling degree days between 10 and 23. This follows the same pattern as seen in the graph. If we set a winter heating degree day cut-off point of 12 and a summer cooling degree day cut-off of about 10 then the definition of seasons is straightforward.

Before we actually set the dates, note that 1 January is on a Sunday and the start of each subsequent week is also a Sunday. Later, when we search for typical weeks they will begin on a Sunday. Some practitioners prefer to run assessments that begin on Mondays and end on Sundays. If we wanted to enforce that preference what we need to do is to change the year of the weather set so that January happens on a Monday (e.g. 2001). This change can be found in the `edit site data` menu option of the main clm menu. Once this is changed, return to synoptic analysis and ask for the weekly degree day table again.

```
Weather analysis: GENEVA-CHE: 46.25N 8.87W:2001    Week     (starting)   Heat dd          Cool dd
period: Mon-01-Jan@01h00 - Mon-31-Dec@24h00                          avg/day total avg/day tot
Degree day: heat base at 17.0 & cool 21.0 Deg C    Week:19 (Mon-07-May)  7.14 49.99   0.03   0.21
Week      (starting)    Heat dd          Cool dd    Week:20 (Mon-14-May)  2.24 15.67   0.30   2.07
                   avg/day   total avg/day tot      Week:21 (Mon-21-May)  3.05 21.36   0.21   1.45
Week: 1 (Mon-01-Jan)  15.43  108.02  0.00  0.00     Week:22 (Mon-28-May)  1.33  9.28   0.22   1.56
Week: 2 (Mon-08-Jan)  15.85  110.93  0.00  0.00     Week:23 (Mon-04-Jun)  2.65 18.53   0.01   0.08
Week: 3 (Mon-15-Jan)  14.01   98.08  0.00  0.00     Week:24 (Mon-11-Jun)  1.65 11.53   0.69   4.81
Week: 4 (Mon-22-Jan)  15.80  110.60  0.00  0.00     Week:25 (Mon-18-Jun)  2.41 16.90   0.93   6.48
Week: 5 (Mon-29-Jan)  14.29  100.02  0.00  0.00     Week:26 (Mon-25-Jun)  1.77 12.36   0.63   4.43
Week: 6 (Mon-05-Feb)  13.02   91.16  0.00  0.00     Week:27 (Mon-02-Jul)  0.42  2.96   1.68  11.73
Week: 7 (Mon-12-Feb)  13.93   97.52  0.00  0.00     Week:28 (Mon-09-Jul)  0.03  0.18   3.43  24.03
Week: 8 (Mon-19-Feb)  15.83  110.82  0.00  0.00     Week:29 (Mon-16-Jul)  0.20  1.37   1.43  10.02
Week: 9 (Mon-26-Feb)  15.92  111.43  0.00  0.00     Week:30 (Mon-23-Jul)  1.29  9.04   0.16   1.13
Week:10 (Mon-05-Mar)  11.78   82.44  0.00  0.00     Week:31 (Mon-30-Jul)  0.57  3.99   2.07  14.47
Week:11 (Mon-12-Mar)   9.91   69.40  0.00  0.00     Week:32 (Mon-06-Aug)  0.57  3.99   1.52  10.66
Week:12 (Mon-19-Mar)   8.52   59.64  0.00  0.00     Week:33 (Mon-13-Aug)  0.14  0.98   2.56  17.93
Week:13 (Mon-26-Mar)  11.83   82.83  0.00  0.00     Week:34 (Mon-20-Aug)  0.70  4.91   1.44  10.09
Week:14 (Mon-02-Apr)   4.64   32.46  0.03  0.18     Week:35 (Mon-27-Aug)  2.38 16.64   0.02   0.12
Week:15 (Mon-09-Apr)   8.38   58.69  0.00  0.00     Week:36 (Mon-03-Sep)  2.77 19.39   0.09   0.60
Week:16 (Mon-16-Apr)   8.21   57.46  0.00  0.00
Week:17 (Mon-23-Apr)   6.59   46.10  0.00  0.00
Week:18 (Mon-30-Apr)   7.58   53.06  0.01  0.08
```

Figure E3.4.2 Heating and cooling degree days.

Using these cut-offs the seasons are as:

• early-year winter 1 January - 11 March

- spring 12 March - 24 June
- summer 25 June - 26 August
- autumn 27 August - 18 November
- late-year winter 19 November - 31 December.

_____

Exercise 3.5 - Defining climatelist entries

Referenced in Section 3.3.

Overview: This exercise is a continuation of Exercise 3.4. It explores recording seasonal definitions into a block of text which can be included in the so-called *climatelist* file.

Starting from the `Manage climatelist -> list/generate/edit documentation` option initialize option and then use the `[save]` option to write out the data to a file. It will give it a name based on the original weather file with a .block extension. The block of text that was generated is listed below. It needs to be pasted into the so-called *climatelist* file. There is an edit option. Also open the block file, check the entries and add any text you want to have displayed to users (in the *help_start to *help_end).

Insert the text (carefully) between an existing *help_end and *item line and save it. Don't forget to copy your newly created weather file to the standard folder. The next time ESP-r is used the new weather file should be available and the seasons and typical weeks should be registered.

Before closing the clm module, it is useful to save the ESP-r weather data into an ASCII format file. Do this via the `export to text file` option of the main menu. Accept the default file name CHE_Geneva_IWEC.a and the period. The weather file CHE_Geneva_IWEC should be placed in the standard folder (e.g. /usr/esru/esp-r/climate) and the ASCII version CHE_Geneva_IWEC.a should be kept as a backup in case the binary weather file becomes corrupted. Again, on some systems, you may have to ask administrative staff to copy to file to /usr/esru/esp-r/climate (or wherever the file climatelist is located on your machine).

```
*item                                        Jun  7.7 @ 1h00 Tue 19 29.0 @16h00 Mon 25
*name GENEVA-CHE                             Jul 10.5 @ 4h00 Thu  5 32.1 @16h00 Mon  9
*aide GENEVA-CHE was sourced from US DoE     Aug  7.1 @ 4h00 Thu 30 31.4 @13h00 Wed 22
*dbfl                                        Sep  8.3 @ 7h00 Fri  7 27.6 @16h00 Sat 22
*avail     OFFLINE                           Oct  0.1 @ 7h00 Wed 31 21.1 @13h00 Mon  1
*winter_s  1  1 11  3 19 11 31 12            Nov -4.1 @ 7h00 Sun 25 14.7 @16h00 Fri  2
*spring_s 12  3 24  6 27  8 18 11            Dec -4.0 @22h00 Mon 31  9.8 @13h00 Mon 17
*summer_s 25  6 26  8                        Ann -6.8 @ 4h 26 Jan 32.1 @16h 9 Jul 10.4
*winter_t 19  2 25  2 17 12 23 12              ---Seasons & typical periods---
*spring_t 21  5 27  5  1 10  7 10            Winter season is Mon  1 Jan - Sun 11 Mar
*summer_t  6  8 12  8                        Typical winter week begins Mon 19 Feb
*help_start                                  Spring season is Mon 12 Mar - Sun 24 Jun
Climate is GENEVA - CHE                      Typical spring week begins Mon 21 May
Location: 46.25N  8.87W : 2001              Summer season is Mon 25 Jun - Sun 26 Aug
Month Minimum  Time    Maximum   Time        Typical summer week begins Mon  6 Aug
Jan -6.8 @ 4h00 Fri 26 11.1 @16h00 Sun 14    Autumn season is Mon 27 Aug - Sun 18 Nov
Feb -5.8 @ 7h00 Tue 27 11.7 @16h00 Wed  7    Typical autumn week begins Mon  1 Oct
Mar -2.7 @ 7h00 Tue 27 16.8 @16h00 Sat 10    Winter season is Mon 19 Nov - Mon 31 Dec
Apr  1.4 @ 7h00 Wed 11 22.4 @16h00 Wed  4    Typical winter week begins Mon 17 Dec
May  1.6 @ 4h00 Tue  8 25.5 @16h00 Tue 15    *help_end
```

It might also be necessary to import weather data from a file that does not conform to the EPW standard. The other file format that ESP-r understands is its own ASCII version as well as Korean MET office data as well as comma separated data files such as used by the UK MET office.

If possible convert your weather data into a format similar to that defined below:

```
*CLIMATE                                              77,16,0,10,240,92
# ascii climate file                                  72,18,0,12,240,92
# defined in: CHE_Geneva_IWEC.a                       55,20,0,13,240,92
# col 1: Diffuse solar horiz (W/m**2)                 30,22,0,15,240,92
# col 2: Ext dry bulb T (Tenths DEG.C)                6,19,0,12,240,93
# col 3: Direct normal solar (W/m**2)                 0,15,0,8,240,93
# col 4: Wind speed (Tenths m/s)                      0,12,0,5,320,93
# col 5: Wind direc (clockwise deg north)             0,7,0,7,320,92
# col 6: Relative humidity (Percent)                  0,3,0,8,320,91
GENEVA - CHE        # site name                       0,-2,0,10,310,92
2001,46.25,-8.87,0  # year lat ...                    0,-5,0,10,310,92
1,365    # period (julian days)                       0,-7,0,10,310,92
* day  1 month  1                                   * day  2 month  1
 0,-24,0,10,250,81                                    0,-10,0,10,260,92
 0,-18,0,8,250,85                                     0,-12,0,8,260,92
 0,-14,0,7,250,88                                     0,-13,0,7,260,92
 0,-14,0,5,240,90                                     0,-15,0,5,10,91
 0,-15,0,12,240,91                                    0,-20,0,5,10,91
 0,-17,0,19,240,93                                    0,-25,0,5,10,91
 0,-18,0,26,240,90                                    0,-30,0,5,360,91
 0,-14,0,17,240,90                                      . . .
 11,-10,0,9,240,90
 81,-6,53,0,0,89
 94,1,361,3,0,89
 155,9,130,7,0,91
```

The comment lines (start with #) are optional. Notice also that there are lines that start with * *day*. These are called day demarcation lines and they are also optional (the clm module will ask you if there are day demarcation lines included in your file).

The first line of the file should be *CLIMATE* and the next non-comment line is interpreted as the site name (up to 40 characters are used).

The site name line is followed by a site-data line. Included on the line

```
2001,46.25,-8.87,0  # year lat, ...
```

where the first token is the year, the second token is the latitude (positive degrees is Northern hemisphere and negative degrees is Southern hemisphere), the third token is the degrees from the weather data site to the nearest time meridian and the last item is a zero if the solar data was measured as direct normal solar and the value 123 if the solar data was measured as global horizontal.

The line after site-data is assumed to contain two numbers which define the period of the weather file. Normally data begins on the 1st of January and ends on the 31st of December. If your import file is for a shorter period then the other hours of the year will have zero data.

Notice that data are all integers and they are comma separated. You can use a space to separate data if that is more convenient. The column order must follow the pattern shown above. The integer values for diffuse solar, direct solar, wind direction and relative humidity are converted directly into the nearest Watt, degree or percentage. Take care with the dry bulb temperature and wind speed. -18 becomes -1.8 degrees and 8 becomes 0.8 m/s.

To record this information go to the `manage climatelist` option on the main menu. You will be presented with the options shown in Figure E3.5.1.

What is shown are initial default dates for seasons and typical periods which you will need to update. If the `menu string` item and the `menu aid` are not clear then start by editing the menu selection and documentation text.

For example the menu aide memoir could be Geneva CHE was source from US DoE. Menu option c is the full path and name of the weather file that ESP-r will access *after it has been installed in the standard location*. For the file we have been working with this is /usr/esru/esp-r/climate/ CHE_Geneva_IWEC. Menu option d is a toggle which tells ESP-r whether the file is ONLINE or OFFLINE. Set this to ONLINE. If it is OFFLINE then others will not see this file.

The section of the menu under seasons allows us to edit the beginning and ending date of each season. After defining each season we can then use the `scan weather` for best-fit weeks that are closest to the seasonal average conditions. Notice that in this case, each season begins on the same day of the week. You could also define seasons that do not start at the same day of the week.

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```
directory
12.0.

Weather list item

a menu str: Geneva - CHE
b menu aid: Geneva - CHE was sourced f
c clm file: /Users/jon/esru_jwh/esp-r/
d available: ONLINE
  ----seasons--------------------days
e  1st win Sat-01-Jan  Sat-11-Mar  70
f  spring  Sun-12-Mar  Sat-24-Jun 105
g  summer  Sun-25-Jun  Sat-26-Aug  63
h  autumn  Sun-27-Aug  Sat-18-Nov  84
i  2nd win Sun-19-Nov  Sun-31-Dec  43
  ----typical periods-------------days
j  1st win Sat-19-Feb  Fri-25-Feb   7
k  spring  Sun-21-May  Sat-27-May   7
l  summer  Sun-06-Aug  Sat-12-Aug   7
m  autumn  Sun-01-Oct  Sat-07-Oct   7
n  2nd win Sun-17-Dec Sat-23-Dec    7
<  scan weather for best-fit weeks
  ----documentation (27)----------
o  list/generate/edit documentation

  ------------------------------
>  save item documentation
>  edit climatelist file
*  graph ambient T & seasons
?  help
-  end
```

Figure E3.5.1 Menu for creating a *climatelist* entry.

The criteria for heating and cooling are based on a combination of heating and cooling degree days and solar radiation. For example, the seasonal average weekly heating degree days and cooling degree days (102 and 0 for early year winter) as well as the solar radiation (11.05). It will then look for the week with the least deviation after confirming the weighting we want to give to heating DD, cooling DD and radiation. These are initial set to 1.0 to give an equal weighting (but you can change this if you want). It finds the smallest deviation (0.14) for the week eight which starts on Monday 19 February. This method can result in a good estimate of the energy use over a season although it will be less accurate for worst case peak assessments.

Use the `scan weather for best-bit weeks` option to search for the typical weeks. If you later ask to `graph ambient T and seasons` you will see something like Figure E3.5.2.
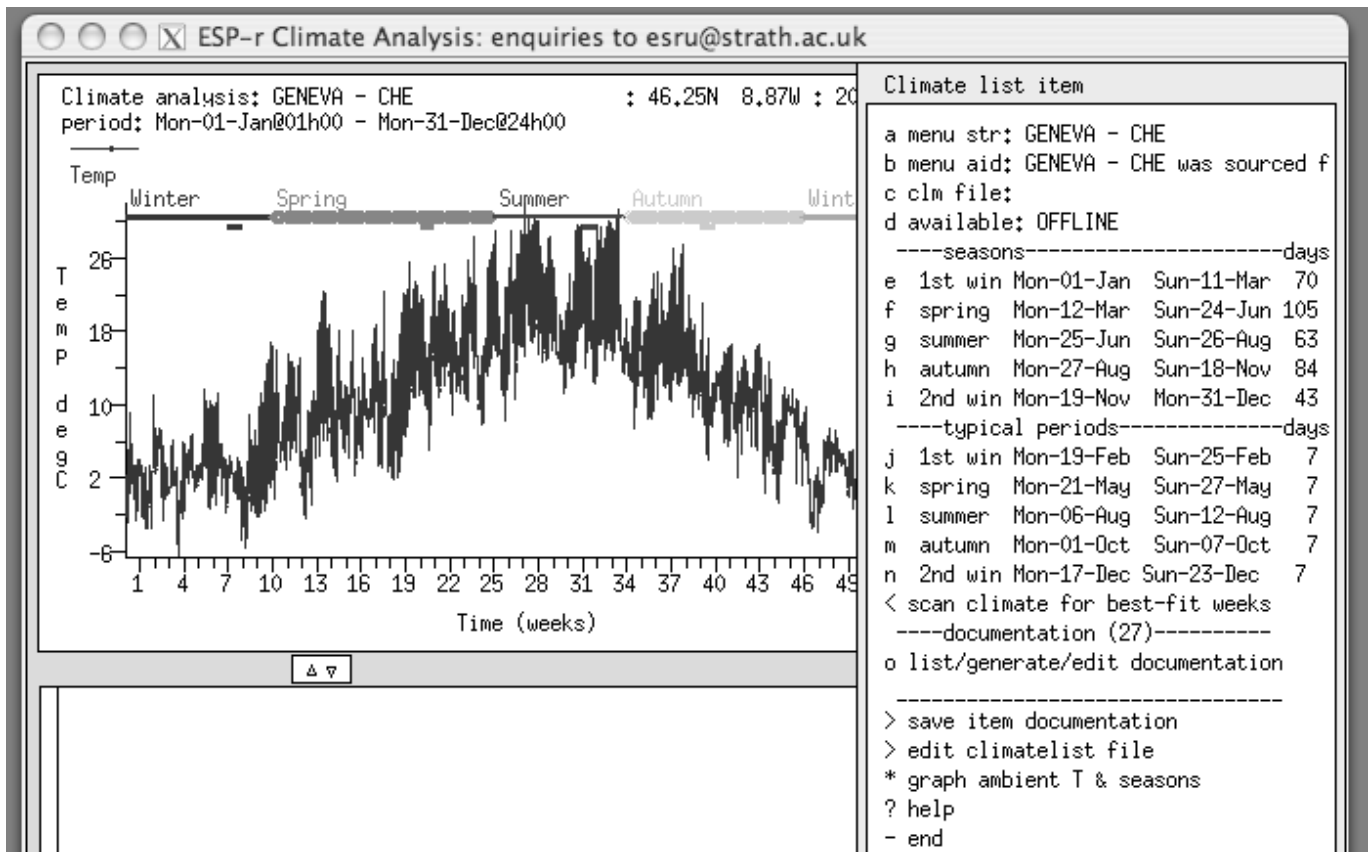
Figure E3.5.2 Seasons of the year and temperatures.

Exercise 3.6 - Importing weather data

Referenced in Section 3.1. Read Chapter 4 up to Section 3.4 before working on this exercise.

Overview: The steps needed to convert and add a new weather file to ESP-r is covered in this exercise. A second task is to identify the duration of seasons using either your own criteria or via reports generated as the weather data is scanned.

Background: Selecting boundary conditions allows us to explore the response of a design to different weather patterns. A tactical approach is to identify specific weather sequences which will support initial understanding of the model as well as project goals.

Typical weather sources:

The United States DoE web site (on one line) <http://apps1.eere.energy.gov/ buildings/energy-plus/ cfm/weatherdata.cfm>. offers EPW weather files (which can be converted into ESP-r weather files for US, Canadian, and International Locations. Let's choose an international location - Geneva Switzerland. The file for this site is CHE_Geneva_IWEC.zip. Download it and save to a convenient location and unpack the zip file. One of the files will be CHE_Geneva_IWEC.epw. Most current EPW files can be imported directly into the ESP-r clm module.

For Linux/Mac/Unix (or the Windows text version) use a command window. Go to the folder with the EPW file and issue the command (as one line):

```
clm -mode text -file CHE_Geneva_IWEC -act epw2bin silent CHE_Geneva_IWEC.epw
```

This creates a new ESP-r weather file CHE_Geneva_IWEC. The message `error reading line 1` is sometimes seen when doing the conversion, but does not usually affect the conversion. The command given to the clm module includes the name of the new binary weather file to be created after the key word -file. The words `-act epw2bin silent` tells it to undertake the conversion without further interactions.

For the Native Windows interface you will have to start up the clm.exe module interactively and provide a new ESP-r weather file name and provide the name of the EPW file in the `[import]` option.

To check that the conversion worked, invoke the clm module with the new file or use the file browser to locate the new file:

```
clm -file CHE_Geneva_IWEC
```

If the conversion was correct you should see the lines

```
Climate data: GENEVA CHE
46.2N  8.9W: 1984  DN
```

in the text feedback area of the interface. And for good measure try to graph temperatures and solar radiation.

If there is an issue with the EPW file then open it in a text editor (nedit is used in Figure E3.6.1). There are several changes you might need to make in the file.

Line 6 might include a # character before the WMD number and this should be replaced by a blank character so it is not treated as a comment. Some EPW files have a blank line at the end of the file (line 8769). Remove this line, save the file and try importing again. Further instructions for working with EPW files will be found in the ESP-r source distribution in the climate folder.
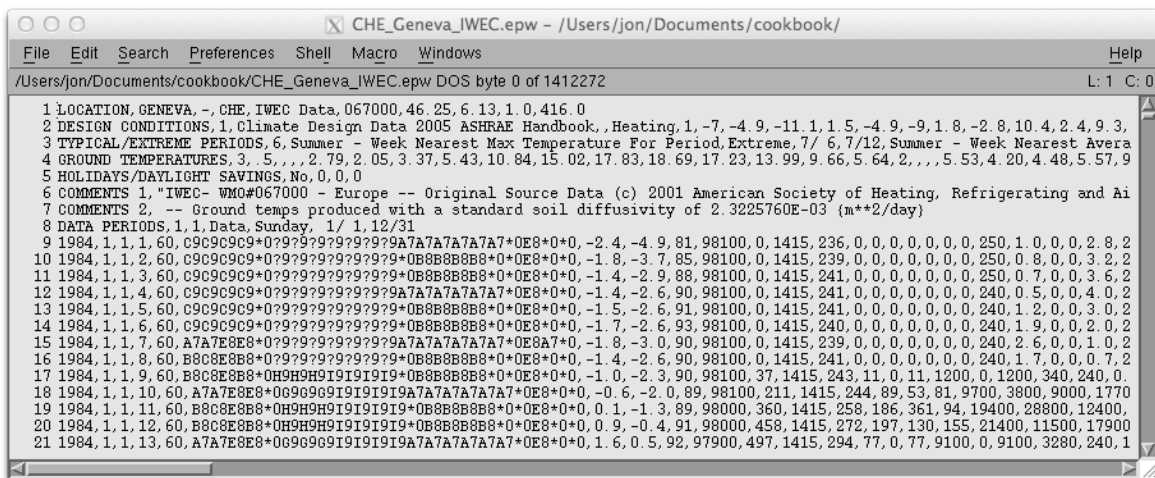
Figure E3.6.1 Editing of EPW file.

_____

Exercise 3.7 - Browsing common materials (referenced by Section 3.5)

Overview: This exercise explores common materials within one of the files distributed with ESP-r as well as techniques for locating relevant materials. A common materials file can hold hundreds of items in a score of categories. Navigation skills and selection techniques are used during planning models to locate items which are a good match to construction documents.

Background: ESP-r solves the performance of buildings dynamically and this requires explicit thermo-physical properties for the layers of materials in walls and roofs. The air gaps within constructions are also required and the common materials file also contains a category for GAPS.

Task: Search within the concrete category for heavy weight and light weight concrete. In the Project Manager go to `Model Management -> database maintenance -> materials -> select file from list` select `material.db4.a` and note the categories of materials (see Figure E3.7.1). Some categories, such as concrete, are straightforward. Each entry has six values and a short phrase for identify and a longer phrase for documentation. The units of the six values are shown at the top.
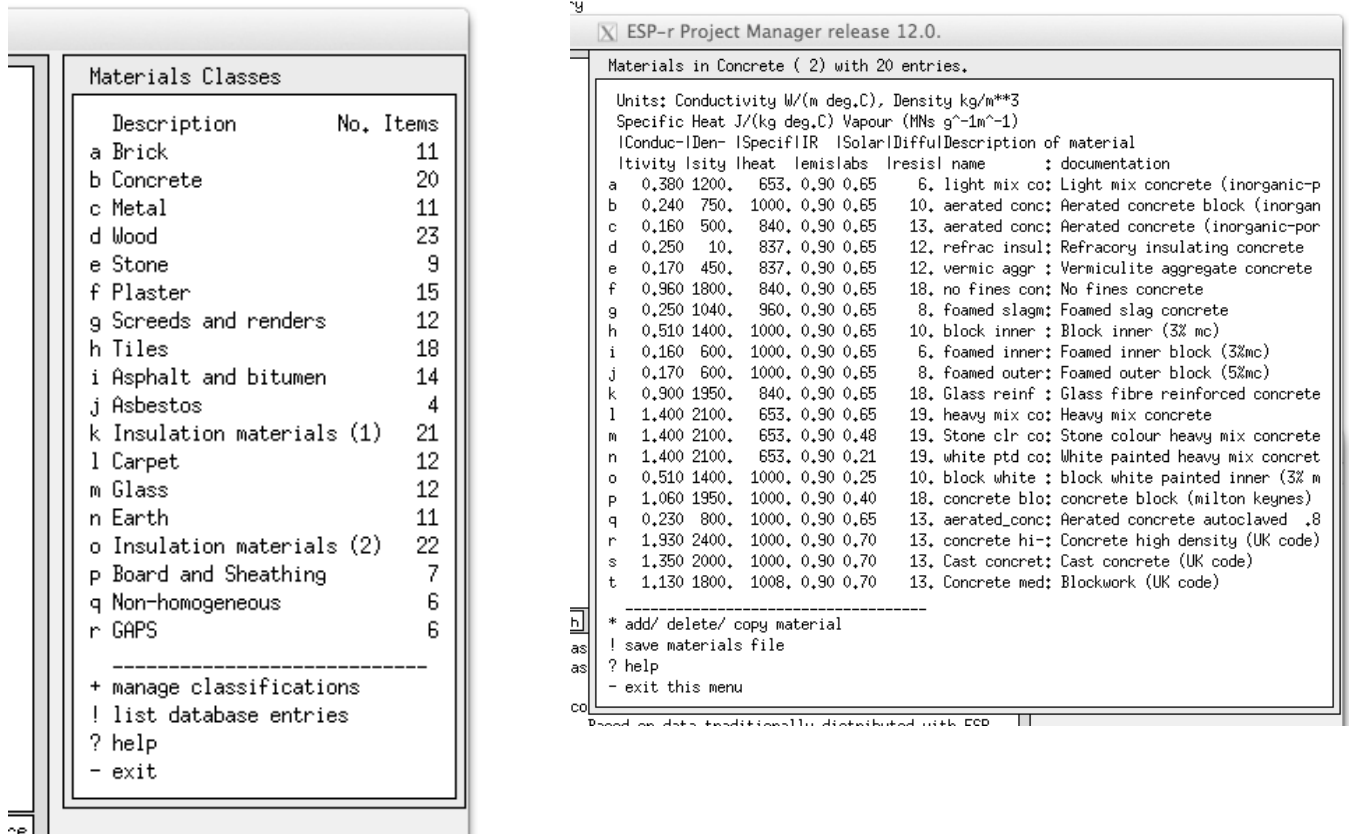
Figure E3.7.1 List of materials classes and concretes.

To conserve space only a portion of the material name and the material documentation is displayed. And the thermophysical values are also shown at lower resolution than is held in the file. When you select an item you can see more.

Locate a concrete with the highest density as well as concretes with a density between 400 and 550 kg/m^3.

What is the difference between the thermophysical properties of [Foamed inner block] and the [Foamed outer block]? Do a google search for *foamed concrete block* and see how these compare.

The category named GAPS is included to signal a non-solid layer which is treated as a resistance to heat flow (values for vertical and sloped and horizontal positions). For example, a low-e coating in glazing increases the resistance to heat flow across the cavity and the resistance values would reflect this. Unless you are working with non-homogeneous constructions where an air gap is represented as a conductivity, stick with the first air gap material (see Figure E3.7.2) and supply the resistance values for the standard orientations.
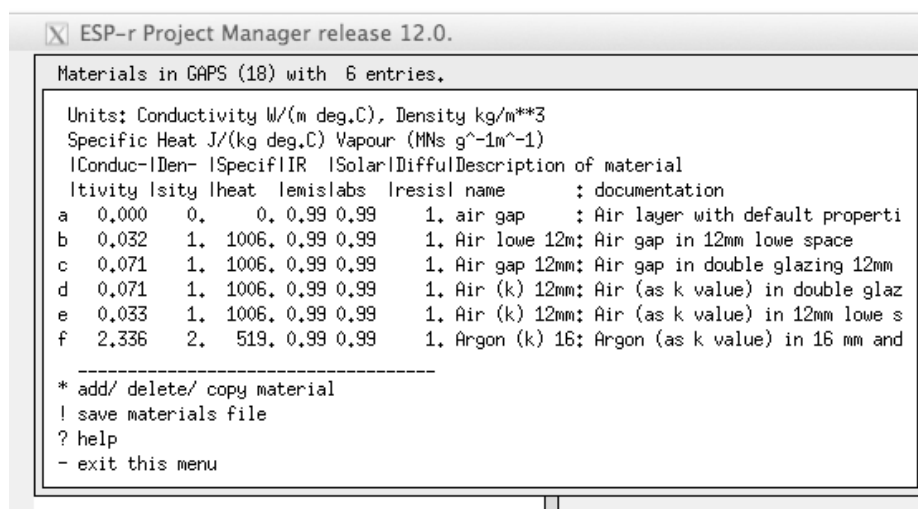

Figure E3.7.2 List of GAP materials.

270

Task: Explore the standard air gap. Select the first GAP material named [air gap]. Notice that it is marked as a gap type and the thermophysical properties are zero. Strange? An air gap when used in a construction has attributes of thickness and three resistance values.

Task: Explore a gap defined as a conductivity. Select the item [Air (k) 12mm lowe]. This is marked as an opaque material and it has thermophysical properties. If this is used in a construction it is treated as an ordinary layer. Note the conductivity is specific to the thickness of 12mm. Gaps as solids are required for non-homogeneous constructions.

_____

Exercise 3.8 - Browsing common constructions (referenced by Section 3.6)

Overview: This exercise gives you practice in searching a common construction file for items matching specific criteria for the initial Surgery model.

Background: Some ESP-r projects can be populated with existing constructions if it is possible to determine a good fit. Criteria such as the overall thickness of the construction or its equivalent U-value may be used.

Task: Using the Project Manager identify relevant constructions for each of the typical building elements. The first step is `Model management -> database maintenance -> constructions -> select file from list` and look for the file `multicon.db5` and the list of constructions is presented. These are shown in Figures E3.8.1, E3.8.2 and E3.8.3.
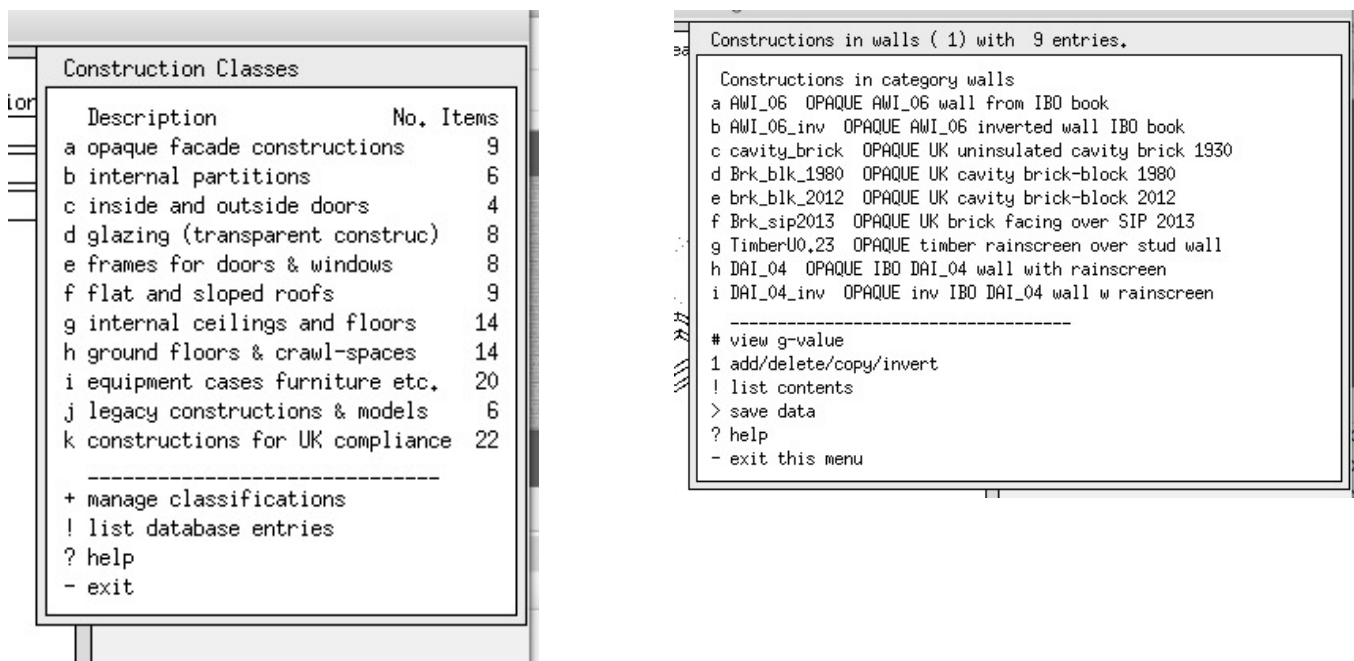

Figure E3.8.1 Constructions categories and wall cat.

Figure E3.8.2 Floor and fittings constructions available.

Figure E3.8.3 Details of Brk_blk_1980 (brick facade with block circia 1980).

Notice the ISO line in Figure E3.8.2 which reports standard U values for the construction. Also notice the overall thickness which is reported in the `Number of layers` line.

_____

Exercise 3.9 - Making a model specific common materials file (referenced by Section 3.4)

Overview: This exercise takes you though the steps of copying a standard common materials file into your model ../dbs folder.

Background: ESP-r can hold common materials in the standard distribution database folder (e.g. C:/Esru/esp-r/databases or /opt/esru/esp-r/databases) or within a model's *dbs* folder. Such local databases can support ad-hoc additions that are project specific.

Task: Go to the cfg folder of a model that you control and open it in the ESP-r Project Manager and focuse on the `database maintenance` menu. Lets grab a local version of the corporate `material.db4.a` file. When copied it will take on the root name of the model (with an option to change its name).

```
Standard data maintenance:
 Folder paths:
 Standard <std> = /home/jon/esru_sps/esp-r/databases
 Model <mod> = ./../dbs
 _____
 a annual weather        : <std>clm67
 b multi-year weather    : None
 c material properties   : <std>material.db4.a
 d optical properties    : <std>optics.db2
 e constructions         : <mod>multicon.db5
 f active components     : <std>mscomp.db1
 g event profiles        : <std>profiles.db2.a
 h pressure coefficients : <std>pressc.db1
 i plant components      : <std>plantc.db1
 j mould isopleths       : <std>mould.db1
 k CFC layers            : <std>CFClayers.db1.a
 l predefined objects    : <std>predefined.db1
 _____
 ? help
 - exit this menu

Material properties <mod>:
 a browse/edit
 b select file from list
 c select from model ../dbs
 d copy default file to model
 e copy file from common to model
 f legacy binary >> ascii export
 g not applicable
 h create new materials
 _____
 * default is option 'a'
 ? help
 - exit this menu

 Material properties <mod>:?> d
The source file is:/usr/esru/esp-r/databases/material.db4.a
The suggested destination file is:../dbs/cellular_furn.materialdb
Suggested name of the model copy of standard file.
Confirm:
 The existing string (../dbs/cellular_furn.materialdb) will be used.
copying file via
cp /usr/esru/esp-r/databases/material.db4.a ../dbs/cellular_furn.materialdb

Materials Classes:
    Description          No. Items   k Insulation materials (1)   21
  a Brick                      11    l Carpet                     12
  b Concrete                   20    m Glass                      12
  c Metal                      13    n Earth                      11
  d Wood                       24    o Insulation materials (2)   22
  e Stone                       9    p Board and Sheathing        13
  f Plaster                    17    q Non-homogeneous             6
  g Screeds and renders        12    0 page:  1 of  2 ------
  h Tiles                      18    + manage classifications
  i Bitumen and plastics       16    ! list database entries
  j Asbestos                    4    ? help
  - exit
```

Exercise 3.10 - Managing common materials (referenced by Section 2.3)

Overview: This exercise explores the creation of a variant brick material.

Background: Standard materials are a good starting point for projects. If you using a new vendor for a project register these differences in a project-specific database (like we created in Exercise 3.9) as a new material and provide documentation.

Task: We can begin with a similar material. In this case lets assume that we have updated density and solar absorption. The steps below copy an existing brick, provide the provenance for the new vendor and adjust its attributes. Material names can contain spaces and be up to 32 characters.

```
Materials Classes:
    Description          No. Items   k Insulation materials (1)   21
  a Brick                    11    l Carpet                      12
  b Concrete                 20    m Glass                       12
  c Metal                    13    n Earth                       11
  d Wood                     24    o Insulation materials (2)    22
  e Stone                     9    p Board and Sheathing         13
  f Plaster                  17    q Non-homogeneous              6
  g Screeds and renders      12    0 page:  1 of  2 ------
  h Tiles                    18    + manage classifications
  i Bitumen and plastics     16    ! list database entries
  j Asbestos                  4    ? help
  - exit
 Materials in Brick ( 1) with 11 entries.:
  Units: Conductivity W/(m deg.C), Density kg/m**3
  Specific Heat J/(kg deg.C) Vapour (MNs g^-1m^-1)
   |Conduc-|Den- |Specif|IR  |Solar|Diffu|Description of material
   |tivity |sity |heat  |emis|abs  |resis| name        : documentation
 a   0.960 2000.    840. 0.93 0.70    12. Paviour bric: Paviour brick (inorganic-porous
 b   0.440 1500.    650. 0.90 0.65    15. breeze block: Breeze block (inorganic-porous)
 c   0.620 1800.    840. 0.93 0.70    29. inner leaf b: Inner leaf brick (inorganic-por
 d   0.960 2000.    650. 0.90 0.93    25. outer leaf b: Outer leaf brick (inorganic-por
 e   0.270  700.    840. 0.90 0.65    12. vermic insul: Vermiculite insulating brick (i
 f   0.960 2000.    650. 0.90 0.70    25. Lt brown bri: Light brown brick (inorganic-po
 g   0.840 1700.    800. 0.90 0.70    25. brick (MK)  : Brick (milton keyns)   <<<<<< TO COPY
 h   0.120  375.    940. 0.90 0.65    12. refractory_b: Vermiculite refractory brick (w
 i   0.770 1700.    940. 0.90 0.65    12. Brick slips : Brick slips thin cladding typic
 j   0.770 1700.   1000. 0.90 0.70    12. Brick outer : Brick (UK code) (inorganic-poro
 k   0.270  800.   1000. 0.90 0.70    35. brick honeyc: Brick extruded honeycomb from I
     _____
  * add/ delete/ copy material
  ! save materials file
  ? help
  - exit this menu

  Materials in Brick ( 1) with 11 entries.:?> * Options:
     a) Delete existing material, b) Add material,
     c) Derive non-homogeneous material, e) copy existing material, f) cancel ? e

Copy which material?
  a Paviour brick
  b breeze block
  c inner leaf brick
  d outer leaf brick
  e vermic insul brk
  f Lt brown brick
  g brick (MK)
  h refractory_brick
  i Brick slips
  j Brick outer leaf
  k brick honeycomb
     _____
  < index select
  ? help
  - exit this menu
 ::?> g
Name of copied material confirm: brick (York Acme)

Materials in Brick ( 1) with 12 entries.:
 a   0.960 2000.    840. 0.93 0.70    12. Paviour bric: Paviour brick (inorganic-porous
 b   0.440 1500.    650. 0.90 0.65    15. breeze block: Breeze block (inorganic-porous)
 . . .
 k   0.270  800.   1000. 0.90 0.70    35. brick honeyc: Brick extruded honeycomb from I
 l   0.840 1700.    800. 0.90 0.70    25. brick (York : brick (York Acme) (copy of bric
     _____
  * add/ delete/ copy material
  ! save materials file
  ? help
  - exit this menu
```

```
Materials in Brick ( 1) with 12 entries.:?> l

Material details:
a Name: brick (York Acme)
b Note: brick (York Acme) (copy of brick
c Conductivity (W/(m-K)  :     0.8400
d Density (kg/m**3)      :  1700.00
e Specific Heat (J/(kg-K):   800.00
f Emissivity out (-)     :     0.900
g Emissivity in (-)      :     0.900
h Absorptivity out (-)   :     0.700
i Absorptivity in (-)    :     0.700
j Vapour res (MNs g^-1m^-1):    25.00
k Default thickness (mm) :   100.00
l type >>legacy opaque
_____
? Help
- Exit
```

And after editing we get....

```
Material details:
a Name: brick (York Acme)
b Note: Brick sourced from Yourk Acme pr
c Conductivity (W/(m-K)  :     0.8700
d Density (kg/m**3)      :  1740.00
e Specific Heat (J/(kg-K):   800.00
f Emissivity out (-)     :     0.900
g Emissivity in (-)      :     0.900
h Absorptivity out (-)   :     0.700
i Absorptivity in (-)    :     0.700
j Vapour res (MNs g^-1m^-1):    25.00
k Default thickness (mm) :   100.00
l type >>legacy opaque
_____
? Help
- Exit
```

_____

Exercise 5.1 - Add calendar day types

Referenced in Section 5.1. Read Section 5.1 before working on this exercise.

Overview: The client definition of the surgery identifies a different building usage on thursday afternoons and this exercise adds another day type to the model calendar. Day types should be set prior to defining either zone controls or zone operations.

Background: Both zone operations (schedules) and ideal zone controls reference the model calendar and support different schedules and control logic for each day type. A critical planning activity is to identify early in the project likely day types.

Task: The following sequence adds a day type named Thursday to the model calendar. Note: if you already have zone operations or a model control defined back up these files before you proceed. `Model management -> browse -> model context -> calendar` and choose the `manage day types` option. And then the `add a day type or set of daytypes` giving the name as Thursday and a short description. The next step, which is a bit tedious, is to assign Thursday to the matching days of the Julian calendar. This is done via the `apply day type to many days` option in the menu. And while you are at it nominate some days of the year as Holiday! When you finish this be sure to save the model.

_____

Exercise 5.2 - Define zone casual gains for the surgery reception

Referenced in Section 5.1. Read Section 5.1 before working on this exercise.

Overview: The client definition of the surgery was translated into a number of periods with casual gain data outlined in Table 5.1. That data will be used to define casual gains for the reception.

The definition of the reception casual gains will begin with documentation and then the periods for each day type will be defined: `Model management -> browse -> zone composition -> operational details -> reception` and confirm the suggested file name. Choose the option `define from scratch` and you will be asked to provide labels for casual gains in reception as well as their type. Use *recep:visit* of type *people* with units Watts. You are then asked to supply the number of periods in each day type: `weekdays - 10, Saturday 7, Sunday 1, Holiday 1, Thursday 8` And from Table 5.1 give the start hour of each period in the dialog. This process is repeated for each day type. Take your time, double check before you commit.

The next casual gain type is Lighting and the number of periods for each day type is: `weekdays - 4, Saturday 4, Sunday 1, Holiday 1, Thursday 4` And again refer to Table 5.1 for the start hour of each period. Lastly define the ITkit of type equipment and the number of periods for each day type is: `weekdays - 4, Saturday 4, Sunday 1, Holiday 1, Thursday 4`

Wow, so many numbers, and we still have to define the magnitude of the gains in each period. But first let's document the casual gains. Choose: `casual gain notes:` and you can write up to 240 characters (avoid commas) so a statment such as:

`Mon-Wed and Friday normal office hours with diversity. Thursday staff only in afternoon. Saturday only morning but more visitors. Standy SH.`

Now return to the `edit casual gains` and you will be presented with the periods which need to be filled in as in Figure E5.1
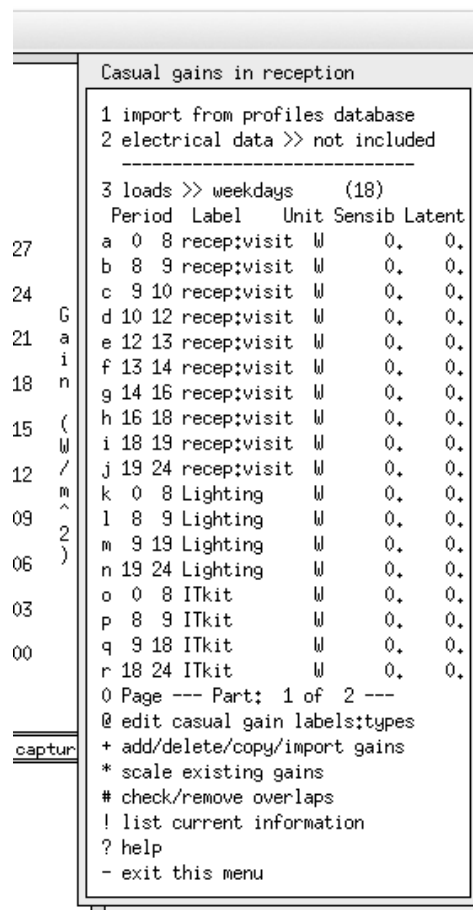
Figure E5.1 Reception periods awaiting magnitude.

Click on each period, in turn and confirm the start and end of the period (just say ok) followed by the sensible and latent Watts. For this exercise set the latent at half the value of the sensible for occupants and zero for lighting and ITkit.

You will also be presented with suggested values for the radiant and convective split. The default values should be ok as they have been set based on the type of the casual gain. Again, take your time and check the values before you say ok.

When you have completed provide the magnitude save the zone operations. If it asks to sort the periods say no. The interface should look like:
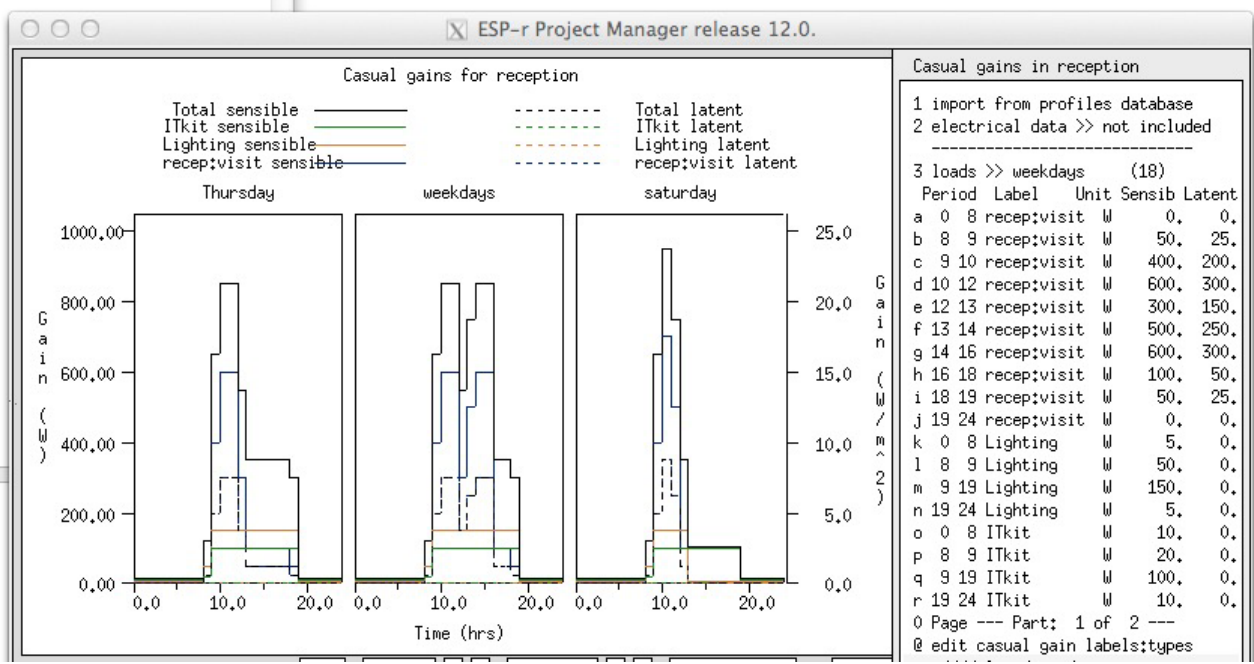
Figure 5.2 Reception periods completed.

_____

Exercise 6.1 - Basic control model (referenced by Section 6.3.1)

Overview: ESP-r is distributed with scores of models and many are variants of a two cellular offices with a passage. The variant used in this exercise implements a simple control regime. Use the steps described to follow along with the dialog in Section 6.3.1.

Background: As with Exercise 1.1, the ESP-r project manager scans an 'exemplars' file for the location of known training models. Having selected a model it is replicated in a location of your choosing:

- Unix/Linux/Cygwin in a folder named Models within your home folder (e.g. /home/ralph/Models)
- OSX in a folder named Models within your home folder (e.g. /Users/ralph/Models)
- Windows 7/8 in C:\Esru\Models or C:\Models or C:\Users\ralph\Models.

From a terminal e.g. xterm or terminal issue the following commands:

```
cd
mkdir Models
cd Models
prj
```

Use Windows Explorer and go to your Models folder and click on the
`esp-r.cmd` file to start the ESP-r Project Manager.

```
Model Management -> open existing -> exemplar
technical features -> base case model: two offices and a passageway
proceed
```

As in Exercise 1.1 specify where you want to place the model e.g. `/home/fred/Models/cellu-lar_bc` and the Project Manager will copy the entire model from the ESP-r training folder to your new Model folder. To focus on environmental controls, continue with the following command sequence:

```
browse/edit/simulate -> Controls zone
```

This brings you to the interface shown in Figure 6.5. Notice the control loop includes a separate entry for each of the day types in the model but the initial entry for the control loop includes seven numbers which encode the sensor and actuator attributes. If you select the menu item with these numbers then you have options to edit the sensor (left portion of Figure 6.6), actuator (right portion of Figure 6.6) or period data.

Selecting a menu item for one of the day types takes you to the attributes of the control logic for each of the periods in that day type. The numbers to the right of the menu entry are the attributes of the control law for that period. Although such lists of numbers take getting used to, the reporting in the text feedback clarifies their meaning.

Selecting a period changes the focus to the control law attributes. In the case of the basic controller, Figure 6.7 shows the values for minimum and maximum capacities for heating and minimum and maximum capacities for cooling as well as heating and cooling setpoints. The minimum values are typically set at zero, however if the room has exposed piping or the device has standby losses then these can be represented via non-zero minimum values. A dead-band exists if there is a gap between the heating and cooling setpoints.

The `RH control` item is a toggle between `OFF` or RH via moisture injection or RH via conservation heating (as used by museums and archives to allow the temperature to drift so as to reduce fluctuations in humidity).

The `list details` option will parse the control loop details and regenerate the report. If you alter control law details the changes will be reported as you exit the menu and they will be recorded to file only if you agree to update the model when exiting.

_____

Exercise 6.2 - Basic control model assessment (referenced by Section 6.3.1)

Overview: We explore commissioning an assessment of the performance of the model used in exercise 6.1. Use the steps described to follow along with the dialog in Section 6.3.1.

Background: ESP-r models can include attributes defining assessments to be carried out e.g. the period of the assessment, the level of performance detail to be recorded as well as the names of the files where performance data is to be written.

Return to the model used in exercise 6.1 (use the operating system to change your focus to the model `cfg` folder and invoke the ESP-r project manager. On Windows you should be able to double click on the model cfg file. On Linux/OSX/Cygwin issue the command:

```
prj -file cellular_bc.cfg
```

The following interactions within the Project Manager are the same for all operating systems.

```
browse/edit/simulate -> Actions simulation -> simulation presets
-> (select win1)
```

The preset parameters for `win1` have now been selected. Take a minute to review the attributes for the period, startup days, file names. These attributes should allow a specific assessment to be reliably regenerated in the future.

To commission an assessment select the `integrated assessment` option. You are given the option to run the assessment `interactively` or `silently` so choose `[inteeractive]` so we can observe the process. This will start up the ESP-r simulator **bps** with the current model and with the current assessment focus.

You will be asked to confirm the model cfg file name. Just click on `[OK].` and choose: `[Initiate simulation]` and confirm the file name to hold the performance data (this was one of the attributes of the simulation parameter set). To watch the assessment progress:

```
Monitor state variables -> all items -> temperature
-> accept temperature range to plot
Invoke simulation
```

You are asked to confirm control file name and to provide a brief description of the intent of the assessment. This phrase will be displayed at the top of graphs and reports.

The simulation will progress, displaying the zone temperature in the graphic feedback area and with estimates of the time remaining in the text feedback. At the end of the assessment you will be asked to `[save results]` to which you should always say yes unless there was a fault in the assessment. You are then returned to the project manager interface.

Exercise 6.3 - Floor heating model (referenced by Section 6.3.2)

Overview: This model builds on the usual two cellular offices and passageway with an additional geometrically thin zone for the floor structure and another one for the ceiling structure. This so-called thin zone approach captures many of the attributes of heating embedded in a structure but without having to use detailed plant components.

Background: As with Exercises 6.1 and 6.2, in your Models folder start the ESP-r project manager and follow these steps:

```
Model Management -> open existing -> exemplar
technical features
-> base case model: with floor heating & chilled ceiling
proceed
```

When asked where you want to place the model e.g. `/home/fred/Models/cellular_flh` and the Project Manager will copy the model from the ESP-r training folder to your new Model folder. The planning of this model (zones and composition) needed to reflect the specific demands of the thin-zone approach to the environmental control.

In addition to the two cellular offices and the passage there are separate *thin* zones for the floor slab and ceiling structure. The upper face of the floor slab zone is composed of the screed and flooring above where pipes would be located and the lower face of the floor slab zone is composed of the balance of the floor structure. Rather than using fluid to deliver heat, we are going to inject heat into the thin zone air node and use high heat transfer coefficients to ensure that this is transferred to the structure above and below the fluid layer. Heat will then be absorbed by and pass through the floor composition and the warmer surface of the floor will exchange heat with the room via convection and radiation. In this way the characteristic heat flow paths within the room are robustly represented although the delivery of heat within the floor slab is abstract.

If you want to explore the geometry and composition of the floors and ceilings do so but this exercise concerns control so change the focus of the interface to control via:

```
browse/edit/simulate -> Controls zone
```

For the floor heating there are three control loops. The first loop is not referenced (it is available if the user wants to revert back to a convective approach). The second loop is linked to the floor zone and its actuator is the air of the thin floor zone. We use an ideal multi-sensor control law to bypass the standard sensor description so that we can sense conditions in the occupied spaces above. The multi-sensor control law includes capacities for heating and cooling (to be applied to within the floor zone) which may rise to 35C in order to maintain a setpoint of 21C in the room above.

Unfortunately the interface for the multi-sensor controller is rather primitive and you can only see a few of the attributes of the control in each dialog and you have to supply the numbers defining the auxiliary sensor loop links to the ceiling_slb zone.

As for a listing of the control loops in order to see the details for the second and third control loops.

_____

Exercise 6.4 - Model with bounding zones (referenced by Section 6.3.3)

Overview: This model begins with the two cellular office model and includes an explicit ceiling void above the offices, an abstract occupied space above the ceiling void as well as an abstract ceiling void below the occupied space. These additional zones are used to define a robust section of a building.

Background: As with Exercise 6.3, in your Models folder start the ESP-r project manager and follow these steps:

```
Model Management -> open existing -> exemplar
technical features -> with bounding zones above and below
proceed
```

When asked where you want to place the model e.g. `/home/fred/Models/cellular_bound` and the Project Manager will copy the model from the ESP-r training folder to your new Model folder.

Menues of interest:

• zone geometry - to review the details of each room

• surface attributes for the ceiling and floor composition

• zone controls (beginning with the offices)

Although the zone controls have already been specified in the training model the steps below were followed when creating the model. Follow along in the menus.

• Create a basic (ideal) controller for the occupied space `manager_a` which is the same as that used in the previous example.

• Create a variant of the `manager_a` controller for `manager_b` which uses a smaller dead-band.

• Create a control law for `floor_below` which uses an `ideal temperature match` controller which pays attention to the current temperature in `ceiling_above` and forces `floor_below` to the same temperature.

• Create a control law for `boundary_up` which uses an `ideal temperature match` controller which pays attention to the current temperatures in `manager_a` and `manager_b` and forces `boundary_up` to the mean temperature.

The summary report of the controls are listed below:

```
Control description:
Ideal control for dual office model. Weekdays normal office hours,
Saturday reduced occupied hours, Sunday stand-by only. One person per
office, 100W lighting and 150W small power. Tighter set-points for
manager_b (so the mean control in boundary_up works).

Zones control includes  4 functions.
The floor_below zone is controlled to the temperature of the suspended ceiling
zone (to act as a boundary). The boundary_up zone is controlled to the mean
```

temperature of manager_a and manager_b.

 The sensor for function 1 senses the temperature of the current zone.
 The actuator for function 1 is air point of the current zone
 The function day types are Weekdays, Saturdays & Sundays
 Weekday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with 3 periods.
 Per|Start|Sensing |Actuating | Control law | Data
   1 0.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 15.00C cool 26.00C.
   2 6.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 19.00C cool 24.00C.
   3 18.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 15.00C cool 26.00C.
 Saturday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with 3 periods.
 Per|Start|Sensing |Actuating | Control law | Data
   1 0.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 15.00C cool 26.00C.
   2 9.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 19.00C cool 24.00C.
   3 17.00 db temp   > flux   free floating
 Sunday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with 1 periods.
 Per|Start|Sensing |Actuating | Control law | Data
   1 0.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 10.00C cool 30.00C.

 The sensor for function 2 senses dry bulb temperature in floor_below.
 The actuator for function 2 is the air point in floor_below.
 There have been 1 day types defined.
 Day type 1 is valid Sun-01-Jan to Sun-31-Dec, 1967 with 1 periods.
 Per|Start|Sensing |Actuating | Control law | Data
   1 0.00 db temp   > flux   senses dry bulb tem
match temperature (ideal): max heat cp 2000.W min heat cp 0.W max cool cp 2000.W min
heat cp 0.W Aux sensors 1. mean value @senses dry bulb T in ceiling_abv. scale 1.00
offset 0.00

 The sensor for function 3 senses dry bulb temperature in boundary_up.
 The actuator for function 3 is the air point in boundary_up.
 There have been 1 day types defined.
 Day type 1 is valid Sun-01-Jan to Sun-31-Dec, 1967 with 1 periods.
 Per|Start|Sensing |Actuating | Control law | Data
   1 0.00 db temp   > flux   senses dry bulb tem
match temperature (ideal): max heat cp 2000.W min heat cp 0.W max cool cp 2000.W min
heat cp 0.W Aux sensors 2. mean value @senses dry bulb T in manager_a. & senses dry bulb
T in manager_b.

 The sensor for function 4 senses the temperature of the current zone.
 The actuator for function 4 is air point of the current zone
 The function day types are Weekdays, Saturdays & Sundays
 Weekday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with 3 periods.
 Per|Start|Sensing |Actuating | Control law | Data
   1 0.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 16.00C cool 26.00C.
   2 6.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 20.00C cool 23.00C.
   3 18.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 16.00C cool 26.00C.
 Saturday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with 3 periods.
 Per|Start|Sensing |Actuating | Control law | Data
   1 0.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 15.00C cool 26.00C.
   2 9.00 db temp   > flux   basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 19.00C cool 24.00C.
   3 17.00 db temp   > flux   free floating
 Sunday control is valid Sun-01-Jan to Sun-31-Dec, 1967 with 1 periods.
 Per|Start|Sensing |Actuating | Control law | Data

```
   1  0.00 db temp   > flux        basic control
basic control: max heating capacity 2500.0W min heating capacity 0.0W max cooling
capacity 2500.0W min cooling capacity 0.0W. Heat set-point 10.00C cool 30.00C.

 Zone to control loop linkages:
 zone ( 1) manager_a    << control  1
 zone ( 2) manager_b    << control  4
 zone ( 3) coridor      << control  1
 zone ( 4) floor_below  << control  2
 zone ( 5) ceiling_abv  << control  0
 zone ( 6) boundary_up  << control  3
```

_____

Exercise 7.1 - Model with graphic flow network (referenced by Section 9.4)

Overview: This model begins with a small rectangular room with three places where air may flow through the facade. A simple flow network is created to show the process. If you prefer to use the text based flow description many of the steps are similar.

Background: As with other exercises we will begin with a base case model without a flow network in the ESP-r project manager and add the network via the following steps:

```
Model Management -> open existing -> exemplar ->
training workshops -> A simple room to add a graphic flow network
proceed
(adjust path as required)
```

The single room model (as per Figure 7.8) should display. In the *Project manager* look for `Model man-agement -> browse/edit -> air flow` and choose `flow network -> graphic tool` At this point the **enet** application will start. The opening menu will look like Figure E7.1.1.
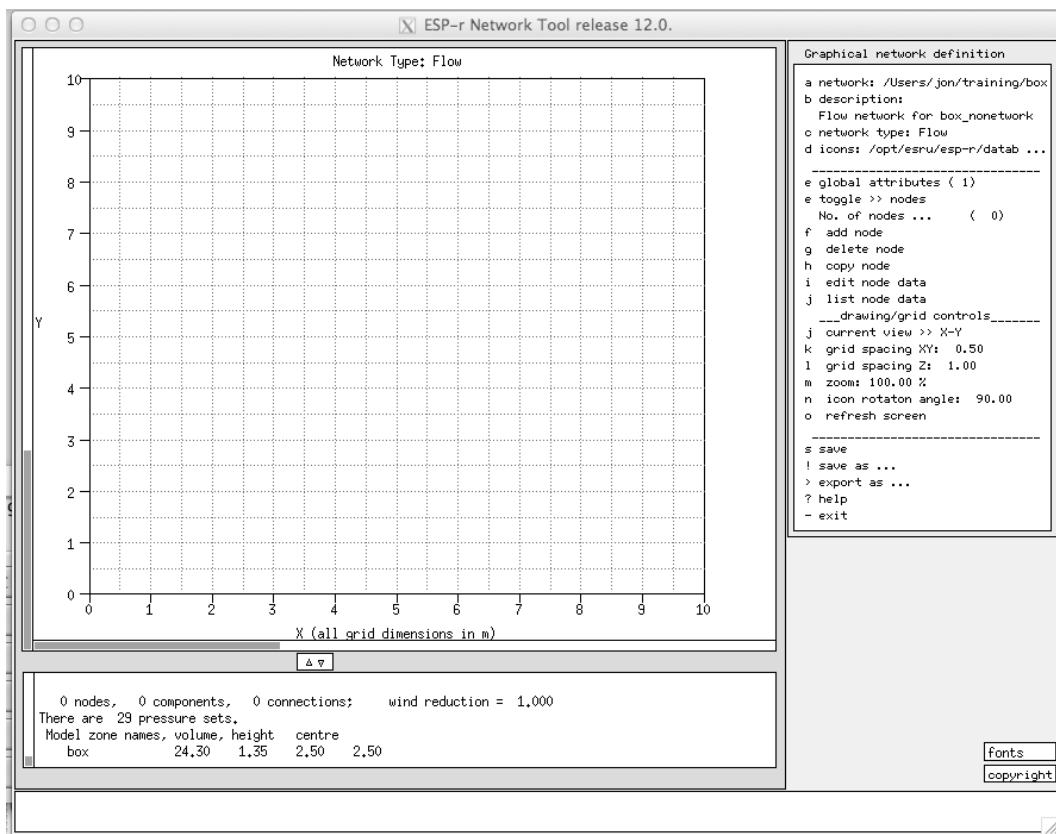

Figure E7.1.1: opening menu of enet.

The initial view is looking down and the initial site is 10m x 10m and you can alter the zoom if required. The **project manager** will have passed some information to **enet**, for example the name and volume of

the box zone. The initial focus is: `e toggle >> nodes` So lets create the node for the room and then the boundary nodes at the south east and north based on the information shown in Figure E7.12. Use the option

`f add node -> internal nodes -> unknown variable pressure` and the interface waits for you to click on the grid to place the node for the room. Alter the suggested name. The icon for the node will change to reflect the type. The menu shows the attribution options for the node. Initially it will look like Figure E7.1.2.
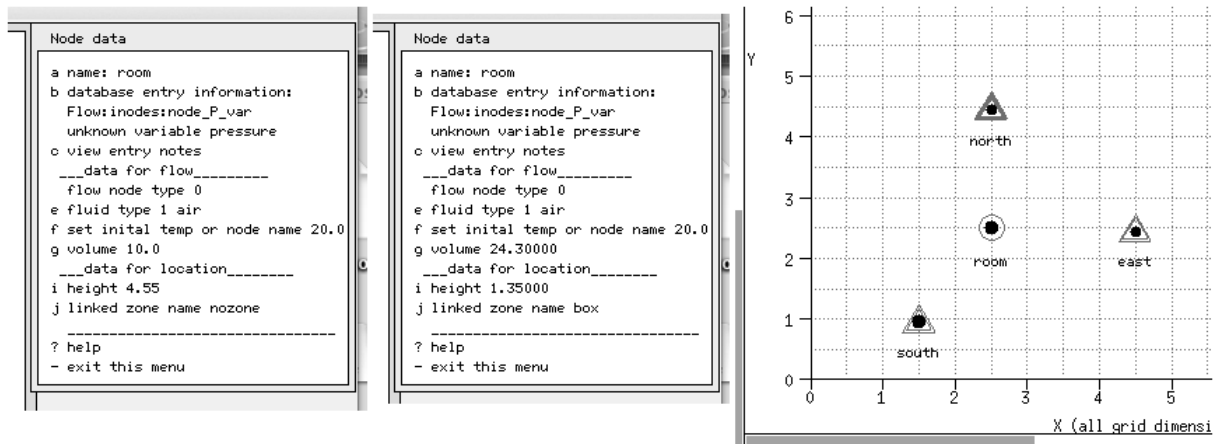

Figure E7.1.2: Initial (left) and updated (right) node data menu and layout.

If you select the `g volume` item and then accept the suggested volume and height the other attributes will have been set (right of Figure E7.2. To create a boundary node at the south facade the pattern is similar:

`f add node -> boundary nodes -> wind induced pressure` and click on the grid to place the south node. It is usually best to click at least 0.5m within the grid bounds. Edit the suggested node name to south. To assign attribute select the `g azimuth` option. A list of the surfaces in the model is presented. Select the `door in box` item from the list and then select the `low ( 0.00m)` position and take the suggested azimuth. Continue to add the boundary node on the east (associated with `glazing in box` item from the list and the `cog ( 1.35m)` position and take the suggested azimuth. Also add a north boundary node at the `grill in box` item as well as the `cog (2.1m)` positon and take the suggested azimuth. This is a good time to save the network. Alter the focus to components e.g. `e toggle >> components` and add in the crack-door, crack-2mmx10 and extract.

`f add component -> cracks @ doors and glazing -> door crack 10mmx0.8` and after placing the component confirm the suggested name. You will want to set the height of the component to zero. Next add the east frame perimeter crack via:

`f add component -> cracks @ doors and glazing -> window crack` place on the grid, rename to crack-2mm10m and reset the crack length to 10m and the height to 1.35m to match the boundary node height. Lastly add the extract fan via:

`f add component -> basic flow components -> constant volume flow` place it on grid, alter the name to extract and set the flow rate to 0.006666 m^3/s and the height to 2.1m to match the boundary node.

The Figure below shows the details of the boundary node menus.

```
Node data

a name: south
b database entry information:
   Flow:bnodes:node_windbP
   wind induced pressure
c view entry notes
 ___data for flow_____
   flow node type 3
   fluid type 1 air
f pressure coef index 1.0
g azimuth 180.00000
 ___data for location_____
i height 0.00
j linked zone name box
k linked surface name door

 ----------------------------
? help
- exit this menu
```

```
Node data

a name: north
b database entry information:
   Flow:bnodes:node_windbP
   wind induced pressure
c view entry notes
 ___data for flow_____
   flow node type 3
   fluid type 1 air
f pressure coef index 1.0
g azimuth 0.00
 ___data for location_____
i height 2.10000
j linked zone name box
k linked surface name grill

 ----------------------------
? help
- exit this menu
```

```
Node data

a name: east
b database entry information:
   Flow:bnodes:node_windbP
   wind induced pressure
c view entry notes
 ___data for flow_____
   flow node type 3
   fluid type 1 air
f pressure coef index 1.0
g azimuth 90.00000
 ___data for location_____
i height 1.35000
j linked zone name box
k linked surface name glazing

 ----------------------------
? help
- exit this menu
```
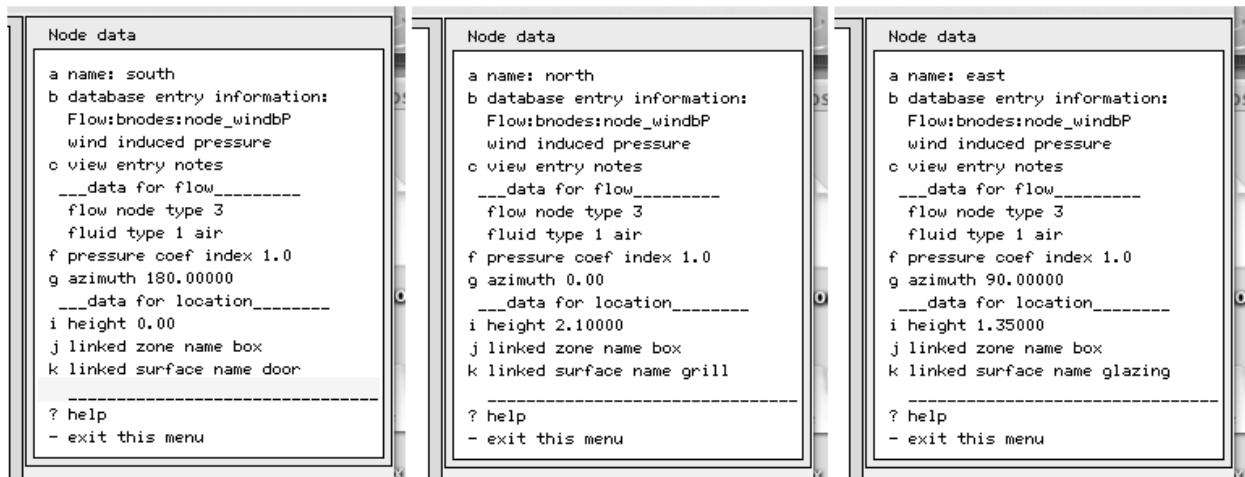
Figure E7.1.3: Details of boundary nodes.

And now we can change the focus to connections. Lets use the `select via menu` option to select the start-node to end-node via component dialogs. A suggested order is: `node south to node room via crack-door` followed by `node east to node room via crack2mmx10m` followed by `node room to node north via extract.` This ensure the air blows outwards! The resulting connections are shown below. Save the network. When you exit you are asked to link the zone in the model to one of the nodes in the network. Select room.

This is a good time to save the network! If you decided to use the menu-based flow network definition interface within the project manager many of the steps would have been similar.

_____

Exercise 7.2 - Control of an extract fan (referenced by Section 7.5)

Overview: The small rectangular room with and volume flow extract fan requires a control to ensure it reacts to overheating conditions. A simple ON/OFF control will be used.

Background: We continue with the same model as Exercise 7.1 and the proposed logic via the following steps:

```
Model Management -> browse edit -> Controls network flow
<< more details to be added >>
```

The high level interface for flow controls is terse (see the initial and post editing states in Figure E7.2.1).

```
Control periods

  function  1 day type  1
  number of periods:  1

  ---------------------------------------
  per| start|sensed  |actuated | control law    | data
  no.| time |property|property |               |
a 1   0.00 dry bulb > flow     on / off         23.00 1.00 1.00
  ---------------------------------
* add/ delete a period
? help
- exit
```
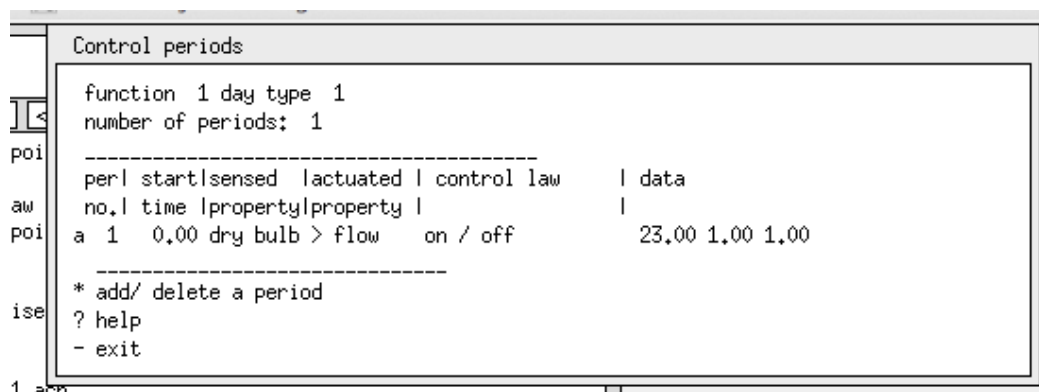
Figure E7.2.1: Flow control menu for typical period.

Although this is a simple controller, the pattern for more complex controls follows a similar path.

_____

Exercise 7.3 - Exploring flow performance in res (referenced by Section 7.7)

Overview: The Surgery model with the flow network and control needs to work better. To understand performance we need to be able to drive the **res** module to show relationships between performance metrics - for example temperatures and solar radiation levels.

Background: Skills to use **res** interactively aids understanding and speeds up investigations. Having run an assessment what does it take to generate graphs such as Figure 7.3.1

After starting up **res** with the initial summer predictions select `graph facilities` and the `Time:var graph` where we can look at the energy embodied in the movement of air. Selecting `climate -> ambient temperature` and `temperatures -> zone temperature` and `zone flux -> infiltration` will generate graphs similar to 7.13. Use the axis scaling option to reduce overlaps. Explore the use of labels and user defined headings to overlay on graphs for added clarity.

In addition to the zone reporting and graphs there are a number of reporting options for flow networks. Use the `Network flow ->` option and request `air change rates -> total entering node` to generate a graph similar to Figure 7.11. Explore other flow reporting options, for example flows along specific connections, for example does the majority of the make-up air for the extract arrive via the door under-cut or the crack at the window frame?

Consider that time spent in the results analysis module working out for yourself which reports and graphs help you to understand the patterns of flow as an investment. Many a practitioner has be caught out by a cursory inspection of flow data!

———

Exercise 7.4 - Control of windows (referenced by Section 7.9)

Overview: The Surgery model with a flow network needs to have a control applied to the windows but we are not yet sure what operation of the windows would be more successful. Lets start with a simple ON/OFF control.

Background: We will adapt an existing model to explore control editing issues. Either find the folder with the Surgery model (typically named office_for_doctor) and start the **project manager** on that model or start **project manager** and select the model from the list of exemplars via the following steps:

```
Model Management -> open existing -> training workshops -> Office for doctor with
Model Management -> browse edit -> Controls network flow
```

and accept the suggested control file name. Begin by editing the description line for the flow control and give a synopsis of the flow controls included. Add the first loop which will be used to define the window opening regime (closed at night and weekends and open 25% if over 22°C) during 8h00-18h00 weekdays (Figure E7.4.1).

Figure E7.4.1: control loop interface before and after adding periods

Select the 'wkd' day type and define the sensor and actuator for the flow connection for the window on the south of the reception (Figure E7.19). The sensor should be located at the reception flow node. And when asked about the flow actuator pick `single flow connection` and then the relevant connection that uses long_win.

Next edit the period data for the 'wkd'. The first period is unoccupied so use a high temperature for the set point. The interface should now look like Figure E7.4.2.

When filling in the data for Saturdays and Sundays there is no need to re-define the sensor and actuator (flow control loops use the same sensor and actuator location for all day types and periods). Once all the day types have been defined save the control file. To use similar logic for the north window in reception copy the first loop and re-assign the sensor and actuator. To use this logic again for the Examination room copy the second control loop and re-assign its sensor and actuator. It is a good idea to keep a note of which control loop is for each of the windows.

The extract fan is probably a simple design with a thermostat that does not know what day it is. The control should reflect this by having one day type and one period. This control will sense the temperature at Examination and act on the connection related to the extract fan.

Update the control file, generate a new QA report and look at the details and your notes confirm the data.

Re-run the simulation with monitoring turned on and you might see something like the Figure E7.4.3. Temperatures in both rooms are closer and they are both warmer than ambient. In the results analysis tool the flow entering the Reception is based on the crack component because the temperature did not go above the control set point.

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Figure E7.4.2: control loop period details
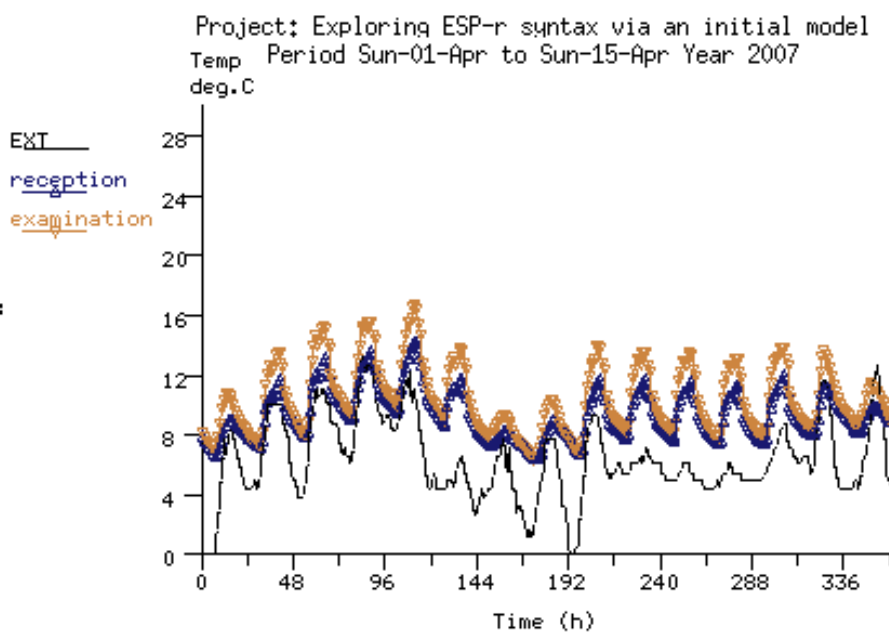
Figure E7.4.3: spring simulation progress with controlled windows

Select a warmer period of the year e.g. the first week in July and confirm the control works. When monitoring the simulation (Figure 7.4.4) the Examination seems to peak at 24°C (which happens to be the set point for the extract fan) and there are some rapid changes in the reception near the 22°C temperature point. Because Examination is constrained by flow under the door it has almost no air movement until the extract fan turns on.

The energy implications of the window opening is clearly seen if we plot `zone flux -> infiltration` in the results analysis module. The windows open briefly except for the last day where they are open for several hours. The extract fan is also on for brief periods except for the warmest days where it also runs for several hours.
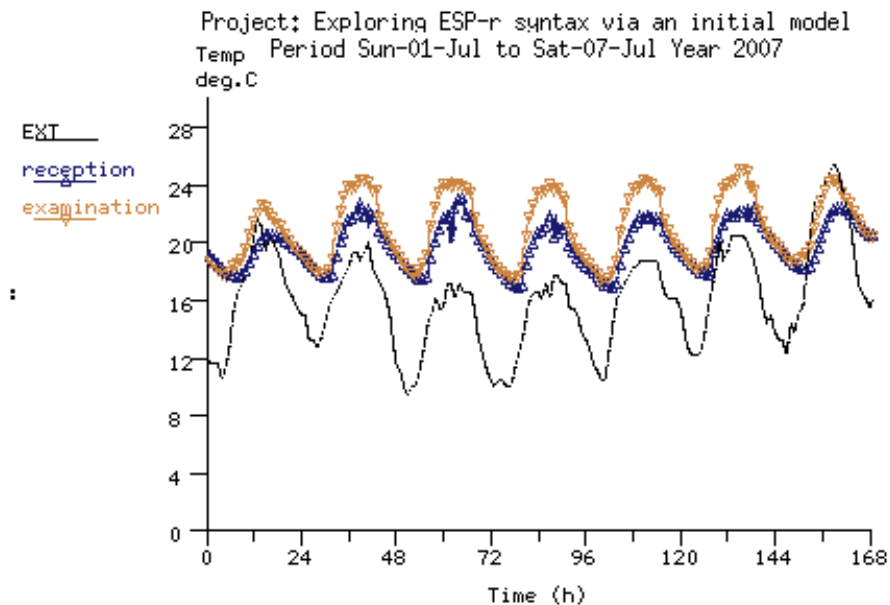
Figure E7.4.4: warm period with controlled windows
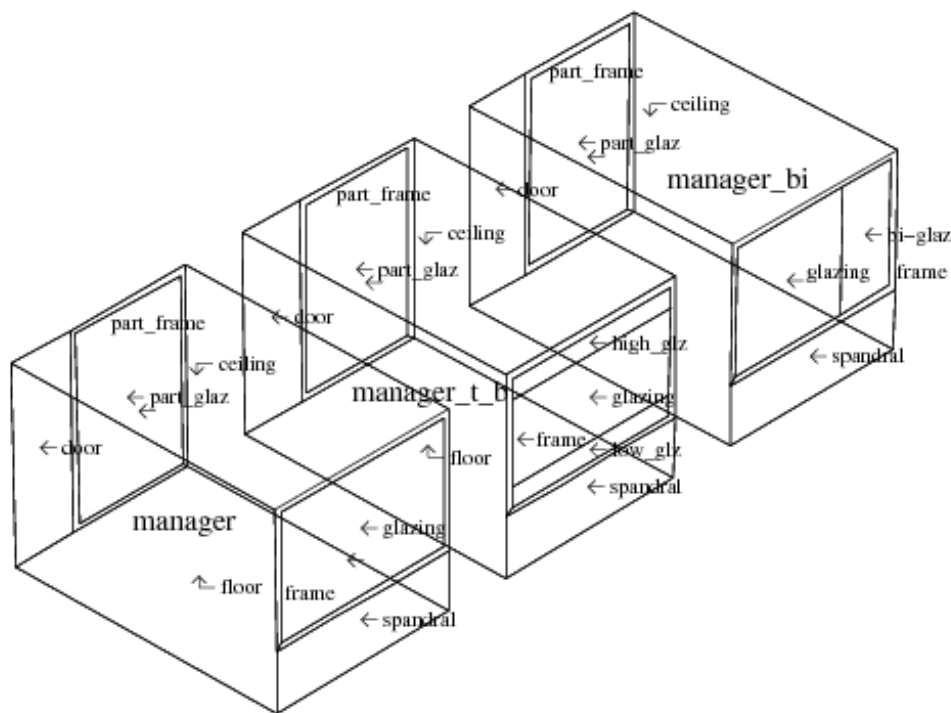
Project: Three offices with different window representations.

Figure E7.23: wire-frame of three test rooms

Exercise 8.1 - CFD grids (referenced by Section 8.2)

Overview: This exercise explores how an initial zone geometry can be scanned and converted into the regions and cells associated with a domain.

Background: It often makes sense to plan zone geometry so that grids can be easily extracted. The rules mentioned in section 8.2 can assist in designing zones.

An existing training model representing a small space (3m along x 1m along y 2m along z) with an 0.2m x 0.4m inlet on the left wall and an 0.2m x 0.6m extract on the ceiling as shown in Figure E8.1 is the

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starting point. The exercise will setup an initial grid of ˜12 cells along the X, 8 cells along the Y and 10 cells along the Z axis.

Figure E8.1.1: small space to be gridded

In the Models folder on your computer start the ESP-r Project Manager and load the exemplar model: `Model management -> open existing -> workshops -> Small space to test CFD gridding and volumes` and notice that surfaces have been created for the inlet and outlet. Next, change the focus to CFD:
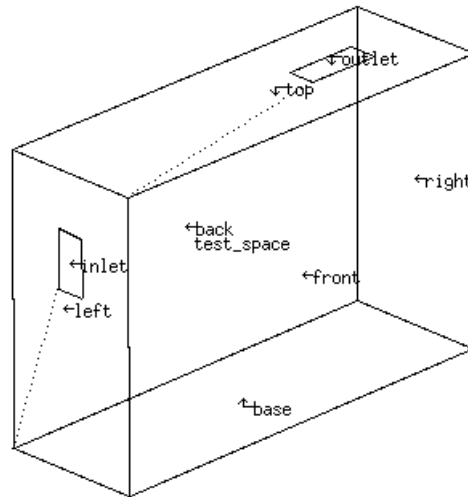`Model management -> browse/edit/simulate -> zone composition -> computational fluid dynamics` and select the `test_space.` Enter the file name `../zones/test_space.dfd` in the dialog box and you are presented with the menus in Figure E8.1.2
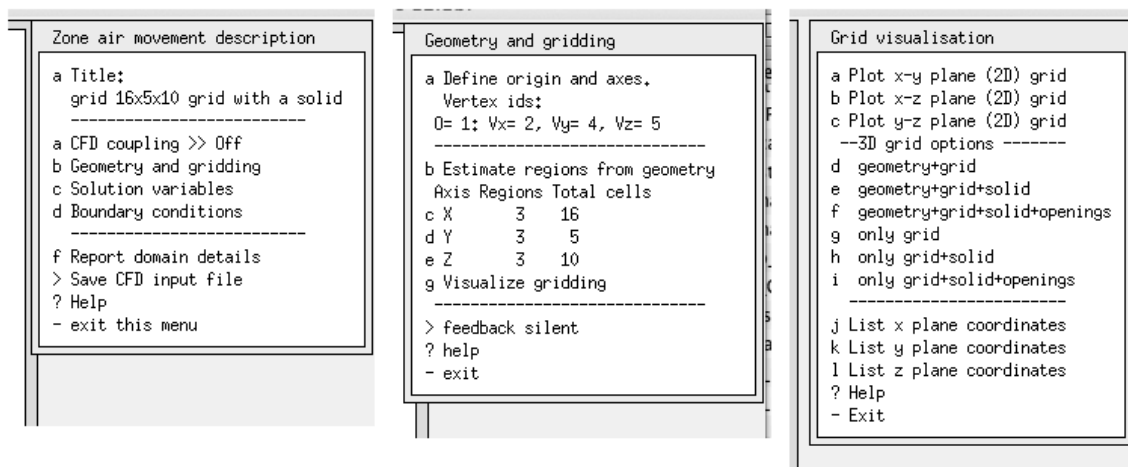
Figure E8.1.2: CFD top level menus.

On the left is the top menu where you set the title of the domain, option b is expanded in the centre of the Figure and on the right are the options for viewing and listing the current grid.

Set a title for the domain such as *small space with inlet and outlet* and then select `Geometry and gridding` and next you will be asked to identify the zone vertices at the end of each axis - for a rectangular zone this is typically 1, 2, 4 & 5. The interface now presents a `Geometry and gridding` menu with no regions or cells (left portion of Figure E8.3). The geometric scan will identify unique coordinates in each axis and use these to define regions in each axis. It will then attempt to allocate cells within each region. Select the `Estimate regions from geometry` entering 12 for the X axis, 8 for Y axis and 10 for the Z axis. This results in the three regions in each axis but with only 11 cells in the X, 7 in the Y and 8 in the Z as in the upper right of Figure E8.1.3:

Figure E8.1.3: Interface during auto grid session.

In general we want cells to have roughly the same dimension in each axis. We could either manually adjust the regions as in Figure E8.1.4 to get 12 x 7 x 10 cells for 840 total cells for a low resolution domain.
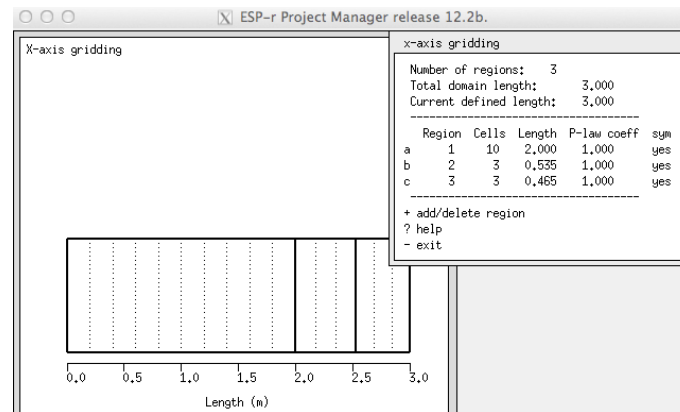
Figure E8.1.4: Focus on the X axis grid scheme.

If we ask for a second estimate with a higher number of requested cells, e.g. 18 x 9 x 16 yields 17 x 7 x 15 (1785 total cells) as in the lower left of Figure 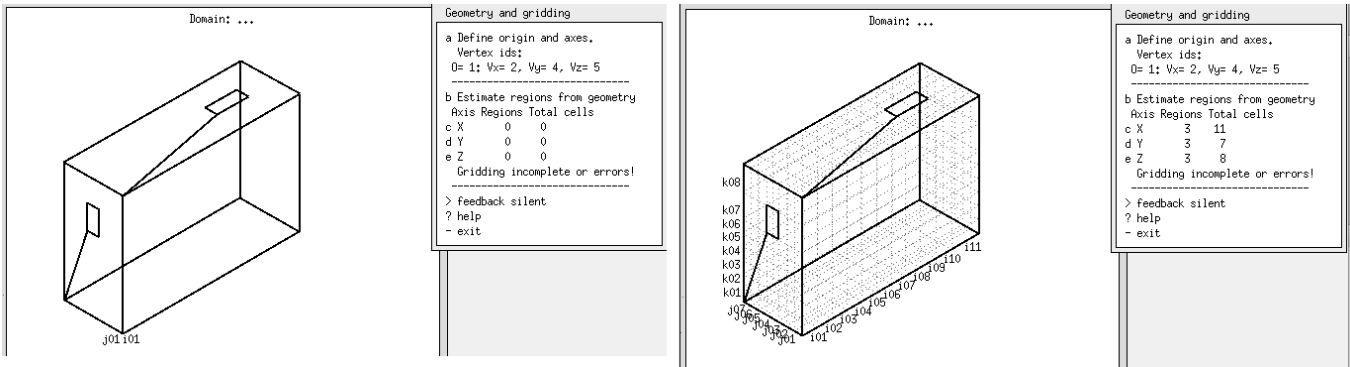8.4 (in Section 8.3). And lastly, if we wanted cells of roughly 100mm then 30 x 10 x 20 yields 29 x 9 x 18 cells (4698 total cells) and with minor tweaks this can become 29 x 10 x 20 (5800 total cells) as in the lower right of Figure 8.4. Higher resolutions provides additional information at the cost of assessment resources.

——

Exercise 8.2 - CFD volumes (referenced by Section 8.2)

Overview: This exercise explores the creation of volumes within the domain and their attribution. This is a continuation of Exercise 8.1.

Background: Associating cells or groups of cells into named volumes is a key step and should be carefully planned to avoid overlaps and gaps.

You first task is to review the wire-frame layout of the regions and existing cells to define boundary volumes. For this exercise create the following named volumes where the X axis is & if, Y axis is js jf and Z axis is ks kf:

```
name          is if  js jf  ks kf
south          1 16   1  1   1 10
right         16 16   1  5   1 10
back           1 16   5  5   1 10
left_low       1  1   1  5   1  6
left_mleft     1  1   4  5   7  8
inlet          1  1   3  3   7  8
left_mright    1  1   1  2   7  8
left_upper     1  1   1  5   9 10
base           1 16   1  5   1  1
top_left       1 10   1  5  10 10
top_mbk       11 13   4  5  10 10
```

```
outlet      11 13    3   3 10 10
top_mfr     11 13    1   2 10 10
top_right   14 16    1   5 10 10
```

Most of the initial boundary volumes will be of type `Solid surface` and the specification of the start and end grid indicators for the boundary is assisted by identifying which face of the domain each of the volumes is associated with. The volumes `inlet & outlet` will be of type `Air flow opening` (more on these types later).

As volumes are created you attribute them as to their purpose and each has a set of associated attributes. On the left is the boundary region named `left_mright` which is a solid with an initially fixed temperature of 20C. On the right of the Figure is the definition of the `inlet` volume which imposes an air flow rate of 0.01 kg/s at a temperature of 14C. Somewhat confusingly it is termed a velocity type although the units are in kg.
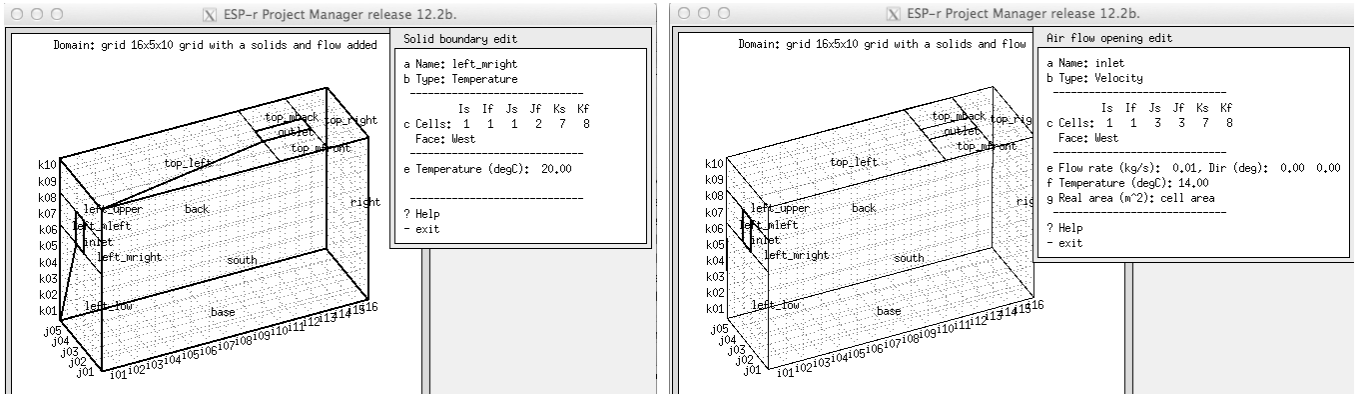
Figure E8.2.1: Boundary volumes (left) and flow inlet (right).

Upon completion the interface should look like Figure E8.2.2.
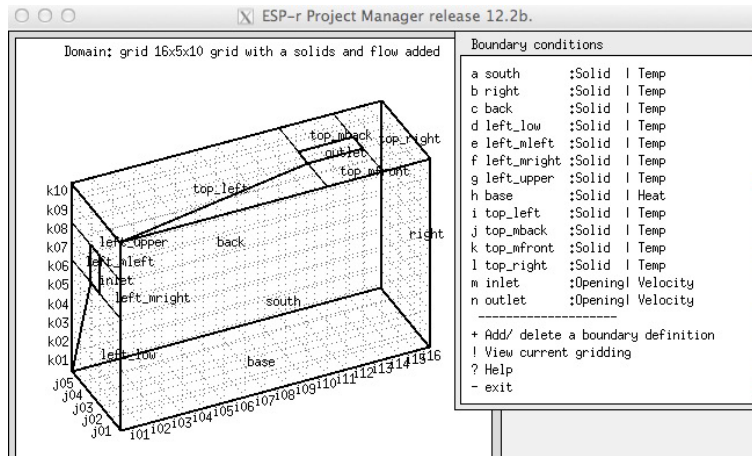
Figure E8.2.2: Boundary volume list.

Exercise 8.3 - Stand-alone CFD module (referenced by Section 8.4)

Overview: This exercise explores the use of the stand-alone **dfs** module to check whether the performance of a domain can be solved. This is a continuation of Exercise 8.2.

Background: Testing that a domain is capable of solution is the primary task of the stand-alone CFD module **dfs**. It supports assessments based on static boundary conditions and as well as a number of performance views and reports.

The **dfs** module takes its directives from the zone domain (dfd) file. Go to the folder with the dfd file and manually invoke it:

```
dfs -file the_dfd_file_name
```

or start it via

```
Browse/Edit -> simulation -> fluid flow only -> CFD
```

and you will be presented with the interface shown in Figure E8.3.1
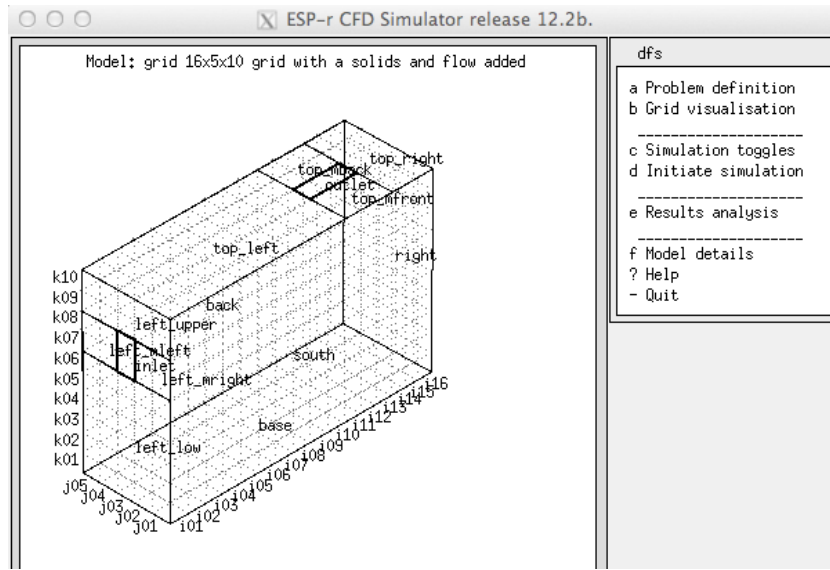
Figure E8.3.1: **dfs** module opening menu.

You can re-load the zone dfd file via the `a Problem definition` menu. The `b Grid visualisation` menu provides the same views of the domain as in **prj**. The `c Simulation toggles` provides some expert options. The `d Initiate simulation` starts the solver with the current domain and directives. The menu `e Results analysis` provides a number of ways to view and/or export predictions. Lastly, the `f Model details` scans the domain and generates a report of its contents.

Assuming the domain has been correctly scanned, use `Model details` to review the domain you are about to solve. Next `Initiate simulation` And you should see the oh-so-familiar monitoring graphs with residuals on the left and current values on the right. In this case the solution became stable well above the convergence criteria. Sometimes this happens.
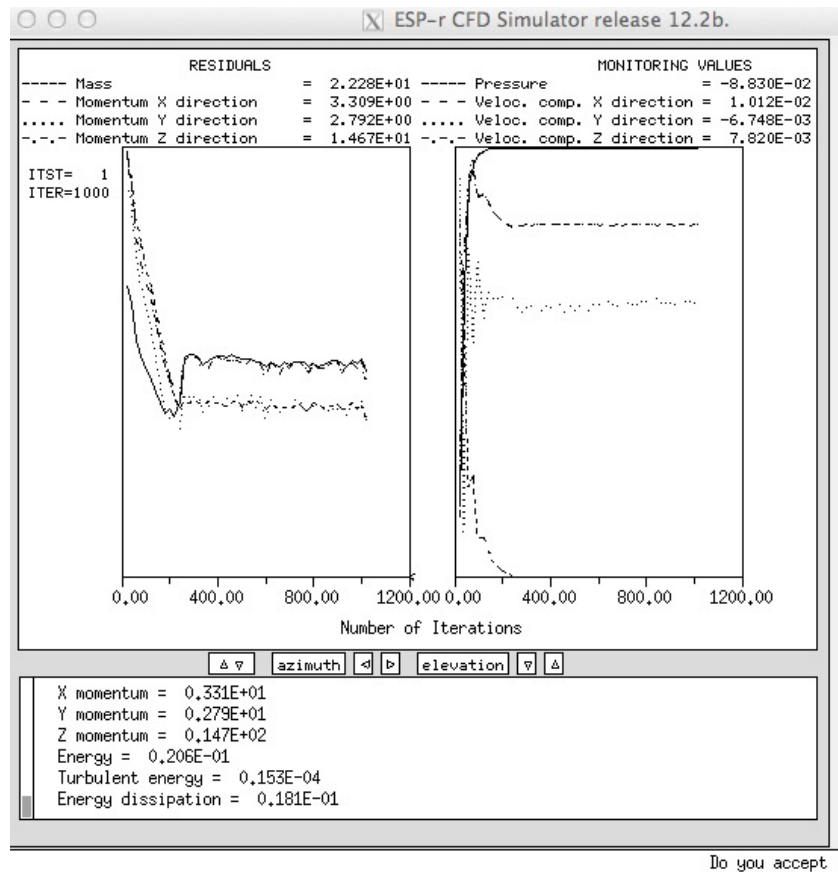
Figure E8.3.2: **dfs** monitoring in progress.

Next, select the `Results analysis` menu where the following choices are available:
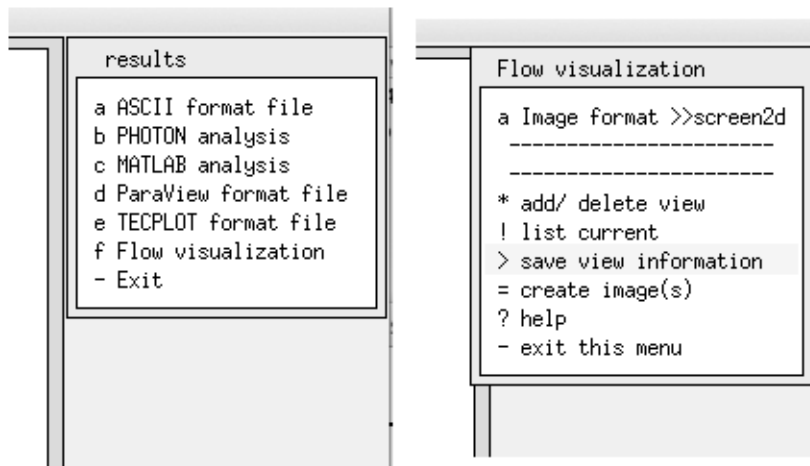
Figure E8.3.3: Options for export or visualisation.

There are several graphics file formats supported which can then be used with 3rd party software. The `f Flow visualization` uses internal facilities to draw 2D slices or 3D wire drawings of flow patterns or create colour renderings. Examples of these are shown in Figure E8.3.4.
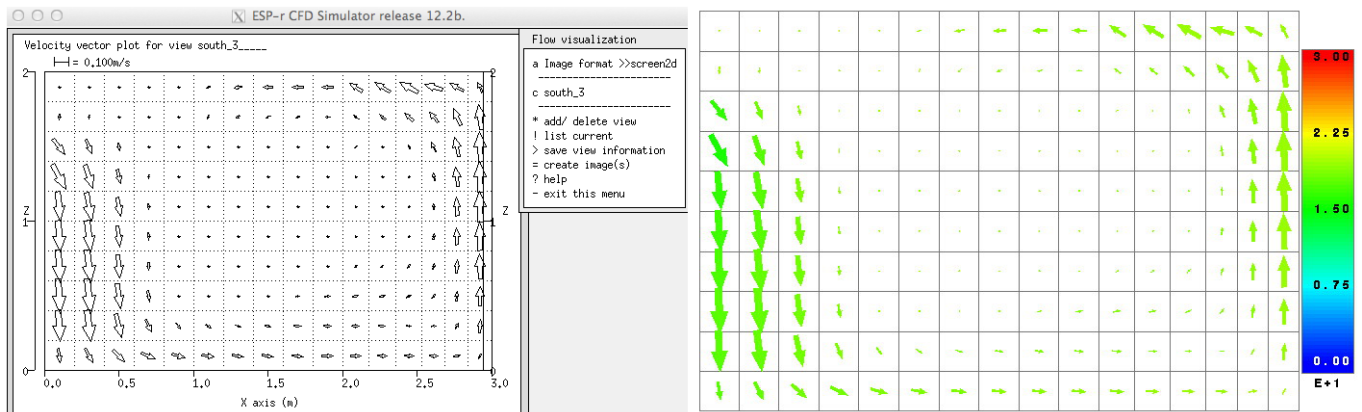
Figure E8.3.4: Examples of visualisation.

There are a number of possible combinations of 2D and 3D image files - test out options for applying colour to represent temperature or velocity.

_____

Exercise 8.4 - Exporting CFD performance (referenced by Section 8.4)

Overview: This exercise explores exporting performance data from the stand-alone **dfs** module for use by PARAVIEW. This is a continuation of Exercise 8.3.

Background: The understanding predictions of air movement often benefits from multiple viewpoints. The open-source Paraview tool has an extensive tutorial (www.paraview.org/Wiki/The_ParaView_Tutorial). Read this prior to undertaking this exercise.

Return to the folder where you were working for Exercise 8.3 and, if the predictions file still exists go into the `results -> ParaView format file` and use it to generate a `ParaView_1.vtk` file. If the predictions file does not exist re-run the stand-alone assessment and then export the performance data.

Startup paraview and then open the ParaView_1.vtk file in the model folder. There are three view types that are useful to explore:

- slice view - allows you to cut a 2D slice in your domain and, by default see a contour view of the performance data coloured by temperature or velocity. Figure E8.4.1 (left) shows the interface with such a slice with temperatures.

- glyph view - allows you to plot vectors of velocity in all cells or a 2D slice with glyphs. In Figure E8.4.1 (right) the Slice1 layer was used at the base to which Glyph1 was added. There are also many possible tweaks to scale factors. In this case the scaling was adjusted to minimise the cells with little movement.

- stream lines view - allows you to identify a region of cells (in this case near the inlet) and track forwards (or backwards) to create stream lines. This is often mis-understood as representing flow over time but is actually at one instance in time if a stand-alone assessment was run.

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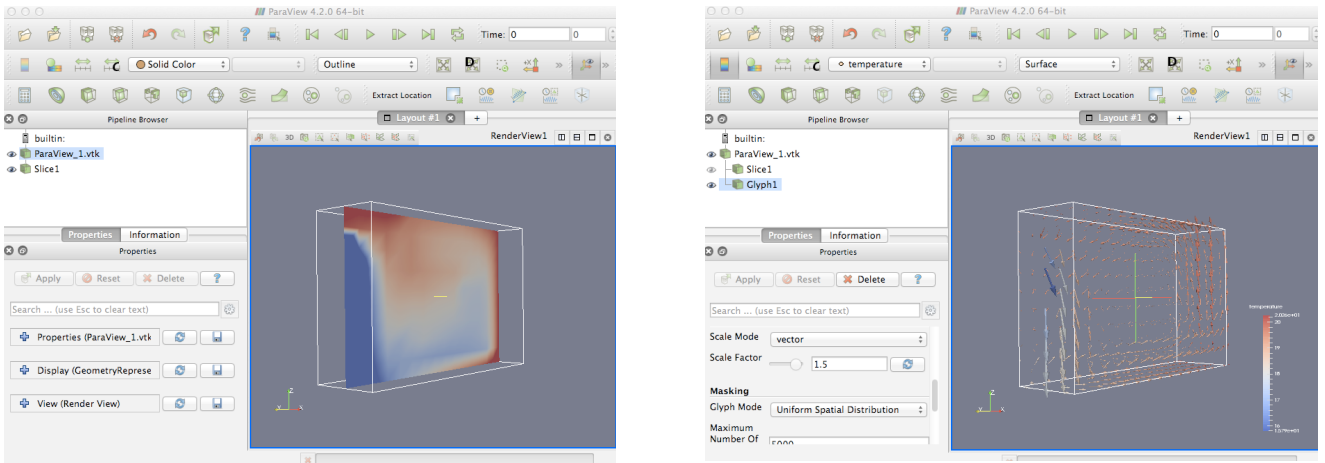
Figure E8.4.1: 2D contour slice and with velocity glyphs.
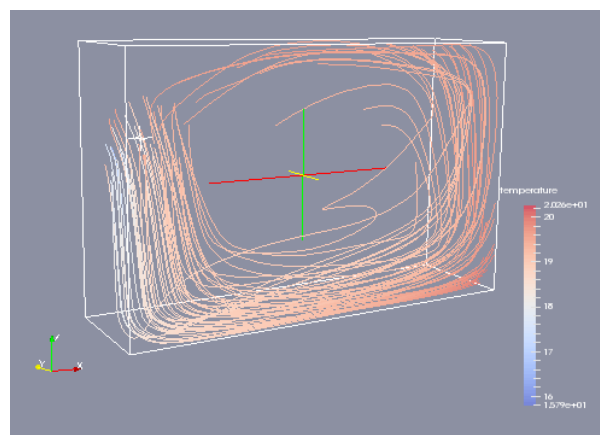
Figure E8.4.2: Example of stream lines.

Explore a range of display options and keep notes about what combinations work. For example, you might want to keep a note of the scaling used for subsequent assessments and images.

With what you learn in this exercise you can apply to coupled assessments where you might have scores of time steps of data to work with (ParaView also can generate animations!).

_____

Exercise 8.5 - Coupled CFD assessments (referenced by Section 8.5)

Overview: This exercise explores coupled (multi-domain) assessments. The decoupled domain definition will be the starting point and the tasks will include updating the solid boundary volumes to associate them with zone surfaces.

Background: When we switch from a stand-alone domain assessment to a coupled assessment we need to adapt boundary conditions as well as some solution parameters.

If you want to work with the the model variant which already has been setup for coupling restart **prj** and browse to the workshop exemplars and select the coupled variant. The menus of interest are shown in Figure E8.5.1 and the detailed parameters are shown in Chapter 10 Figure 8.5.
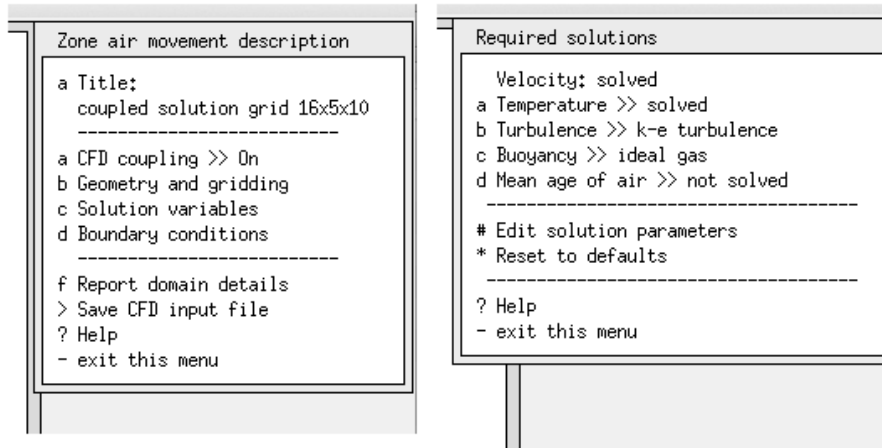
Figure E8.5.1: Domain directives for coupled assessments.

If you want to start from scratch, use the operating system to copy the decoupled model cfg file to a new name and also copy the zone domain file to a new name. When you focus on CFD within the interface edit the domain file name to match.

In the upper level CFD menu toggle `a CFD coupling >> On` and then go into the menu `Solution variables` and turn on `Temperature`, `Buoyancy` and then enter the menu `Edit solution parameters` and set them to match Chapter 10 Figure 8.5.

Next we need to tell the domain about associations with the surfaces in the zone as well as the type of *handshaking* to be done for each of the boundary volumes. Select the `d Boundary conditions` and for each of the `solid volumes` (not the inlet or outlet), the boundary conditions need to be updated. An example for the volume named `left_mright` is shown in Figure E8.5.2. Select the `Type: Conflated` and then select the surface name in the zone which it exchanges information with.

HINT: instructive zone surface names and instructive volume names makes this process a lot easier.

If you have no other opinion select the `One-way log-law BSIM` handshaking option as seen in Figure E10.16.
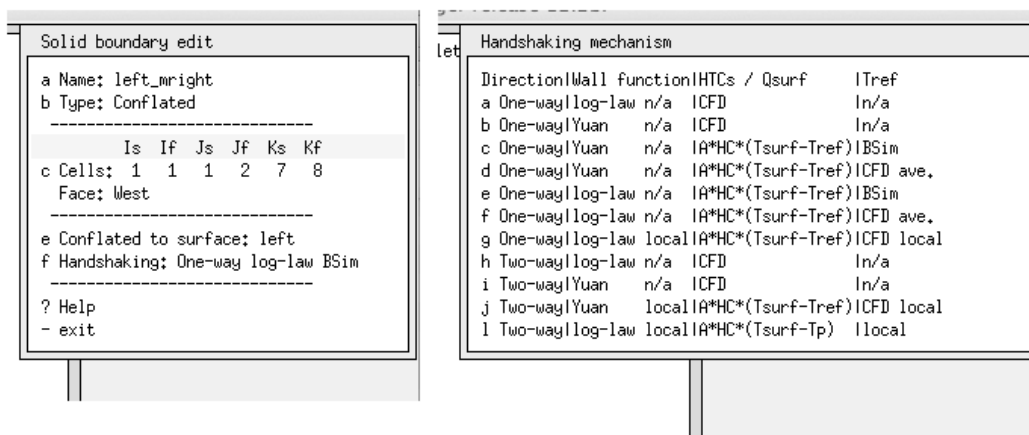
Figure E8.5.2: Setting solid boundary associations.

After you have dealt with all of the solid boundary volumes save the zone domain file. You can then test a coupled assessment. Return to the simulation menu of the project manager, create a simulation parameter set with 6 time steps per hour, one day startup and a simulation period of the 1st and 2nd of March.

Request a simulation. The simulator will start and when it is about to start the assessment you will be asked whether to run the CFD for the whole period `say NO` and then you will be asked if the CFD should be run in the startup period `say NO` and lastly you will specify the time it should start using the domain solver on the first day of the assessment (default is 0.00) and when it should end on the last day of the assessment (default is 23.00). When you commission the assessment you should see something like the CFD monitoring as shown in Chapter 8 Figure 8.1. It might take a half hour to run the two day assessment.

If the multi-domain assessment worked then there will be a domain predictions file created and this can be interrogated with the CFD results menu in the **res** module. The options for visualising the domain performance are similar to that you already experienced in the stand-alone **dfs** module.

Exercise 9.1 - Exploring base case model to which mechanical ventilation will be added. (referenced by Section 9.1)

Overview: This exercise explores a two zone model to which you will later add system components.

Background: Systems are best understood when they run in the context of a model with diverse demands. Once you understand the nature of the rooms the context of the components will be clearer.

In the Models folder on your computer start the ESP-r Project Manager and load the exemplar model: `Model management -> open existing -> workshops -> A pair of room to add component based mech vent` and spend 10 minutes looking at the following:

- Volume of each room
- Patterns of occupancy in each room
- open up the model contents report in the doc folder via a text editor
- run the default assessment and see the magnitude of heating (and cooling) needed based on an ideal control.

Return to Chapter 9.

Exercise 9.2 - Exploring available system components. (referenced by Section 9.1)

Overview: This exercise explores the types of components included in an ESP-r plant template database.

Background: System components are held in a database and are managed by a plant component database manager **pdb**.

To access the database do the following: `Model management -> database maintenance -> plant components -> browse-edit` Which will start a utility application **pdb** as shown in Figure E9.2.1


```
Plant comp : duct_ret_a

a Component total mass (kg)                  :    3.7000
b Mass weighted average specific heat (J/kgK) :   500.00
c UA modulus (W/K)                           :    5.6000
d Hydraulic diameter of duct (m)             :    0.12500
e Length of duct section (m)                 :    2.0000
f Cross sectional face area (m^2)            :    0.12270E-01
* All items in list

    -------------------------------------------

? Help
- Exit
```
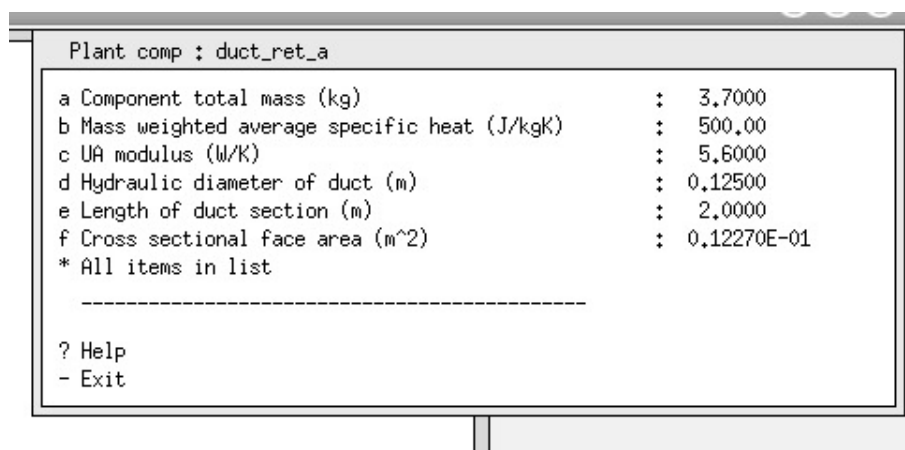
Figure E9.2.1 Project manager invoking plant database manager.

The option `g Summary of entries` does what it says on the tin. You will notice entry 1 is an air mixing box which will be quite useful, entry 6 is an air duct, entry 3 is a centrifugal fan with optional control, entry 5 is a heating coil.

To see the details of a component select `e Edit a component` and a list of components is shown. Select, for example the `air mixing box or converging junction -> list data` and it will show both the basic component default attributes as well as equivalent mass flow default attributes. You could also select the `b List & export components -> Unordered` option in the main menu which will take you

sequentially through the database. You can ignore the other options within the `Edit component` menu (you do not want to alter the common attributes held in the database).

Notice each of the entries has a component index. For example air ducts point to db reference 6. Include this number on your sketch as in Figure E9.2.2. Why? Because there are a few places in the interface where you have to type in this index rather than selecting from a list of component names.
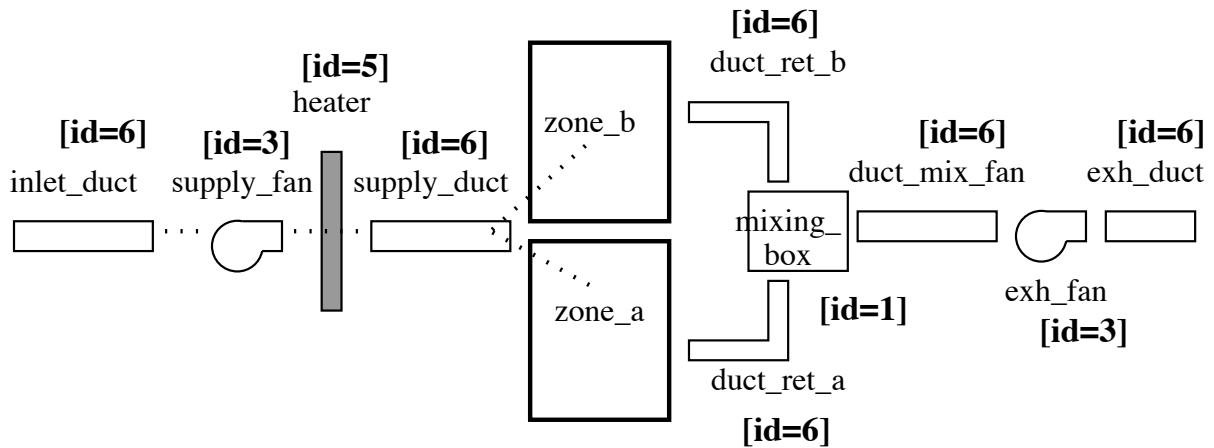
Figure 9.2.2 Id of components for ease of attribution.

To complete the exercise, list the attributes of the other useful database entries.

Exercise 9.3 - Creating a component network for mechanical ventilation. (referenced by Section 9.1)

Overview: This exercise explores the Project Manager facility for creating a component network from scratch as well as browsing a completed network.

Background: Creating a network against our planning sketches and doing so with minimal confusion takes practice. The first part of this exercise builds the network from scratch.

Return to the model you were exploring in Exercise 9.1. We want to create a variant to add the components to so that base case model is preserved. The first step is to return to the `Model management >` `save model as` option and change the names slightly e.g. `mech_vent_sys.cfg` for the model cfg file, `mech_vent_sys` for the model root name and `mech_vent_sys.cnn` for the model connections file. Next go to `browse/edit/simulate` and the the `Networks -> plant & systems -> explicit` and you will be asked which general system type you want to create. For this model choose `a Mechanical ven-tilation system` And we are presented with an essentially blank network that we can add components to (Figure E9.3.1).

```
Network definition:edit

a Network name :../nets/mech_vent_sy
b Simulation type : Energy + two phase.
c Project title   :
  --------------------
  Problem status...
  --------------------
  No. of components ...        (   0 )
d  Components
  --------------------
  No. of connections ...       (   0 )
e  Connections
  --------------------
  No. of containments ...      (   0 )
f  Containments
  --------------------
  No. of comp. + electrical data (   0 )
g  Electrical data
  --------------------
h Link to fluid flow network
  --------------------
  No. of linked zones ...      (   2 )
i Link plant to zone(s)
  --------------------
j plant config file format > descriptive
  --------------------
! Update plant config file
? Help
- Exit
```

Figure E9.3.1 Network definition at start.

The next step is to begin adding components in the order defined in our sketch. Essentially all of the components will be from the `air conditioning` category. You are asked if you want to modify the default values. For example, if the duct_ret_b was 2m long and weighed 3.7kg then we would alter these values. The list below includes the specific attributes for the components to be imported. For the supply and exhaust fans you are asked for the volume flow rate. Lets start with 0.06m^3/s.

```
Component: duct_ret_a ( 1)  db reference  6
Modified parameters for duct_ret_a
Component total mass (kg)                 :   3.7000
Mass weighted average specific heat (J/kgK): 500.00
UA modulus (W/K) :   5.6000
Hydraulic diameter of duct (m)            :   0.12500
Length of duct section (m)                :   2.0000
Cross sectional face area (m^2)        : 0.12270E-01

Component: duct_ret_b ( 2) db reference   6
Modified parameters for duct_ret_b
Component total mass (kg)                 :   1.8500
Mass weighted average specific heat (J/kgK): 500.00
UA modulus (W/K)                          :   2.8000
Hydraulic diameter of duct (m)            :   0.12500
Length of duct section (m)                :   1.0000
Cross sectional face area (m^2)        : 0.12270E-01

Component: mixing_box ( 3) db reference   1
Modified parameters for mixing_box
Component total mass (kg)                 :   1.0000
Mass weighted average specific heat (J/kgK):  500.00
UA modulus (W/K)                          :   3.5000

Component: duct_mix_fan ( 4) db reference  6
Modified parameters for duct_mix_fan
Component total mass (kg)                 :   9.2500
Mass weighted average specific heat (J/kgK):  500.00
UA modulus (W/K)                          :   14.000
Hydraulic diameter of duct (m)            :   0.12500
Length of duct section (m)                :   5.0000
Cross sectional face area (m^2)        : 0.12270E-01
```

```
Component: exh_fan ( 5) db reference   3
Control data:    0.060
Modified parameters for exh_fan
Component total mass (kg)                    :   10.000
Mass weighted average specific heat (J/kgK):   500.00
UA modulus (W/K)                             :    7.0000
Rated total absorbed power (W)               :   50.000
Rated volume flow rate (m^3/s)               : 0.10000
Overall efficiency (-)                       : 0.70000

Component: exh_duct ( 6) db reference   6
Modified parameters for exh_duct
Component total mass (kg)                    :   5.5000
Mass weighted average specific heat (J/kgK):    500
UA modulus (W/K)                             :   8.4000
Hydraulic diameter of duct (m)               :   0.12500
Length of duct section (m)                   :   3.0000
Cross sectional face area (m^2)          : 0.12270E-01

Component: inlet_duct ( 7) db reference   6
Modified parameters for inlet_duct
Component total mass (kg)                    :   9.2500
Mass weighted average specific heat (J/kgK):   500.00
UA modulus (W/K)                             :    14.000
Hydraulic diameter of duct (m)               :   0.12500
Length of duct section (m)                   :    5.0000
Cross sectional face area (m^2)          :  0.12270E-01

Component: supply_fan (8) db reference   3
Control data:    0.060
Modified parameters for supply_fan
Component total mass (kg)                    :   10.000
Mass weighted average specific heat (J/kgK):    500.00
UA modulus (W/K)                             :    7.0000
Rated total absorbed power (W)               :    50.000
Rated volume flow rate (m^3/s)               :  0.10000
Overall efficiency (-)                       :  0.70000

Component: heater (9) db reference   5
Control data: 3000.000
Modified parameters for heater
Component total mass (kg)                    :   15.00
Mass weighted average specific heat (J/kgK):   1000.0
UA modulus (W/K)                             :    3.5000

Component: supply_duct (10) db reference   6
Modified parameters for supply_duct
Component total mass (kg)                    :   1.8500
Mass weighted average specific heat (J/kgK):    500.00
UA modulus (W/K)                             :    2.8000
Hydraulic diameter of duct (m)               :   0.12500
Length of duct section (m)                   :    1.0000
Cross sectional face area (m^2)          : 0.12270E-01
```

When you have finished creating the components your list should look like Figure E9.3.2.
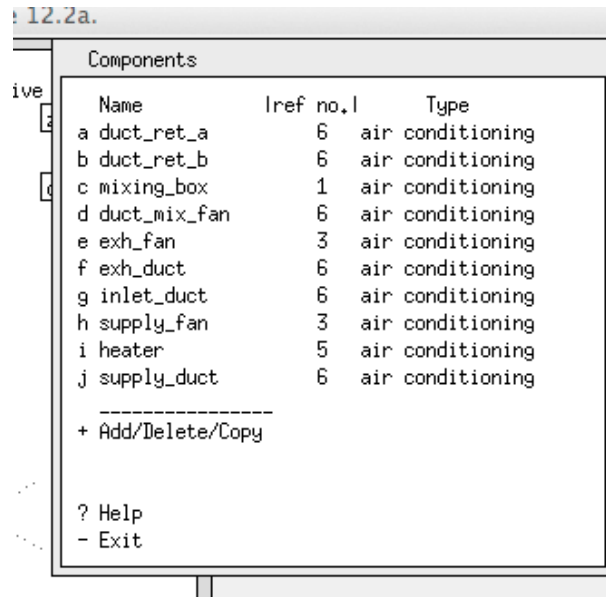
```
 ┌─ Components ──────────────────────────────┐
 │                                           │
 │    Name            |ref no.|      Type     │
 │ a duct_ret_a          6    air conditioning│
 │ b duct_ret_b          6    air conditioning│
 │ c mixing_box          1    air conditioning│
 │ d duct_mix_fan        6    air conditioning│
 │ e exh_fan             3    air conditioning│
 │ f exh_duct            6    air conditioning│
 │ g inlet_duct          6    air conditioning│
 │ h supply_fan          3    air conditioning│
 │ i heater              5    air conditioning│
 │ j supply_duct         6    air conditioning│
 │                                           │
 │   ----------------                        │
 │ + Add/Delete/Copy                         │
 │                                           │
 │                                           │
 │ ? Help                                    │
 │ - Exit                                    │
 └───────────────────────────────────────────┘
```

Figure E9.3.2 Initial components.

_____

Exercise 9.4 - Linking components to form a network for mechanical ventilation (referenced by Section 9.2)

Overview: This exercise explores the Project Manager facility for linking components to form a network.

Background: Creating a network against our planning sketches and doing so with minimal confusion takes practice. Some users find the sequence of tasks difficult to image if they are browsing an existing model so this exercise goes through the relevant steps.

Begin with the model used in Exercise 9.3. To be save, consider making a backup copy of the plant network file before continuing. Figure E9.4.1 shows the goal. As with the creation of mass flow networks, focus on the task, have your network sketch available and mark the sketch as you proceed. This exercise will proceed to create links in the same order so Figure E9.4.2 is a mark-up of the sketch with (a) to (m) to match the interface.

```
 |X| ESP-r Project Manager release 12.2a.
 ┌─ Connections ──────────────────────────────────────────────────────────────┐
 │                                                                             │
 │    Sending comp  @   Node      to   Receiving comp @   Node   | Conn Type | Mass Div│
 │ a outside air      ambient     --> inlet_duct      air node 1   zone/amb    1.000   │
 │ b inlet_duct       air node 1  --> supply_fan      air node 1   to compt    1.000   │
 │ c supply_fan       air node 1  --> heater          air node 1   to compt    1.000   │
 │ d heater           air node 1  --> supply_duct     air node 1   to compt    1.000   │
 │ e zone_a           zone air    --> duct_ret_a      air node 1   zone/amb    0.500   │
 │ f zone_b           zone air    --> duct_ret_b      air node 1   zone/amb    0.500   │
 │ g duct_ret_a       air node 1  --> mixing_box      air node 1   to compt    1.000   │
 │ h duct_ret_b       air node 1  --> mixing_box      air node 1   to compt    1.000   │
 │ i mixing_box       air node 1  --> duct_mix_fan    air node 1   to compt    1.000   │
 │ j duct_mix_fan     air node 1  --> exh_fan         air node 1   to compt    1.000   │
 │ k exh_fan          air node 1  --> exh_duct        air node 1   to compt    1.000   │
 │                                                                             │
 │   ----------------                                                          │
 │ + add/delete/copy                                                           │
 │                                                                             │
 │                                                                             │
 │ ? Help                                                                      │
 │ - Exit                                                                      │
 └─────────────────────────────────────────────────────────────────────────────┘
```
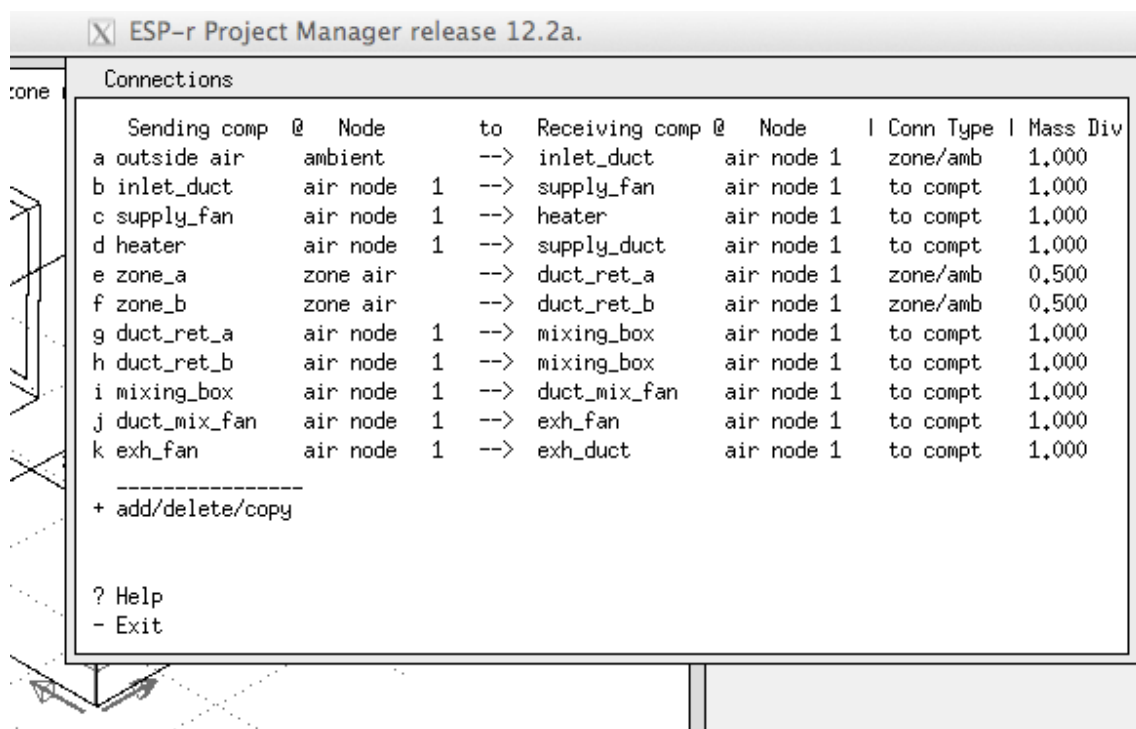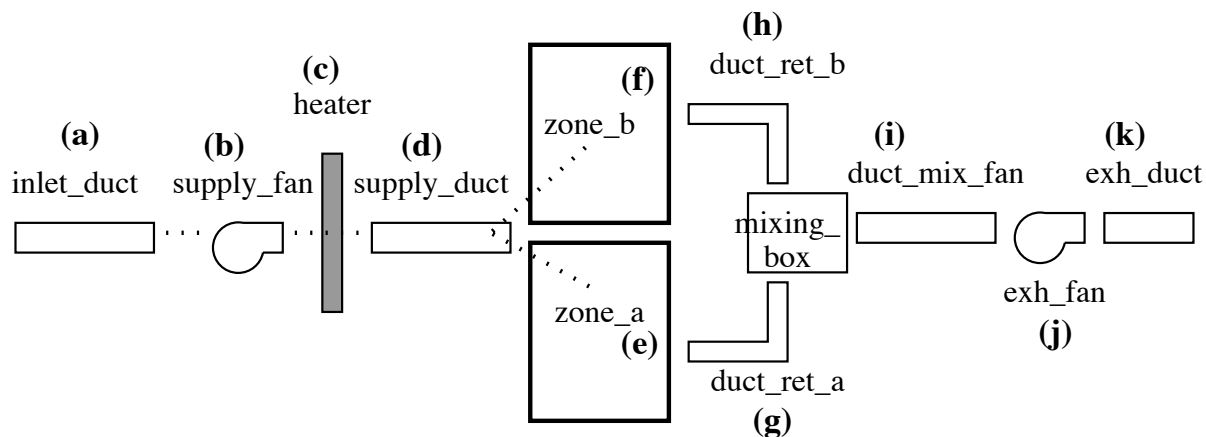
Figure E9.4.1 Connections after editing.

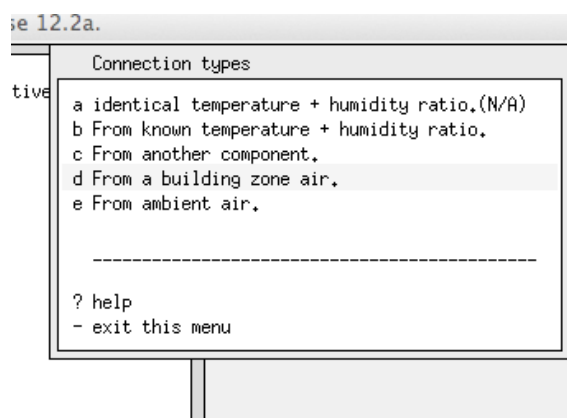Figure E9.4.2 Markup of network sketch.

Figure E9.4.3 Connection types for components being linked.

Go into the `connections` menu item and ask to `add` a connection. You will be presented with a list of the available *receiving* components. Select the `inlet_duct` and then you are presented with a choice of `connection types` (as in Figure E9.4.3). The inlet gets its air from ambient so select `From ambient air` but you are warned that the inlet cannot figure out an incoming flow rate so you have to nominate the `supply_fan` for it to use. Feel free to grumble. Next add in the supply_fan which takes its input from the inlet_duct component, then the heater which takes its input from the supply_fan component as well as the supply_duct which takes its input from the heater componet.

We now come to connections into and out of the two thermal zones which are entries e & f of Figure E9.4.1. Duct_ret_a needs to be associated with the thermal zone_a (select zone_a) and then you are asked to nominate the component which is supplying air to zone_a (supply_duct with diversion ratio of 0.5). Do the same for duct_ret_b.

The `mixing_box` takes air from both the `duct_ret_a` and `duct_ret_b` so there are two entries. Each has a mass diversion ratio of 1.0. The remaining connections are completed using the same pattern which should result in Figure E9.4.4.

Figure E9.4.4 Connections after input tasks.

Exercise 15.1 - Creating a model contents report

Overview: This exercise explores the steps required and the options available for creating a model contents report via the Project Manager.

Background: Relying only on the tool interface for tasks related to model quality checking can be time-consuming and there are some relationships which you may not be able to identify. And looking at the raw model files may provide useful clues, but model files are often formatted for ease of machine reading. ESP-r offers a reporting facility that generates a model contents report based on your specifications and which is designed to produce hard-copy which can be used in conjunction with the ESP-r interface to explore model details.

Begin with `Model management -> browse -> results & QA reporting` and notice in the section below the entry `QA report` that some entries are in the form of `databasses >> verbose` these can be toggled between terse / verbose and in some cases very verbose. You can select a subset of zones to include (the default is all zones). The entry `QA report >> text feedback` can be toggled to write to a file. By default it is placed in the model *doc* folder and takes its name from the model *root name*. After using the toggle then select `generate QA report` to populate the file with the report. If you are working on Linux or OSX or Cygwin and have the text editor *nedit* then the menu option `edit QA:` `../doc/the_file_name_you_asked_for` will be invoked so you can review it. On Windows use NotePad++ to view the report or WordPad. The report is designed to be used in conjunction with the Project Manager interface -the words and the images reinforcing and adding clarity. Spend some minutes reviewing both. Mark on the report items that you need to check further or where additional work is needed. Return to section 15.9 for a discussion about how to interpret the model contents report.