University of Strathclyde

Energy Systems Research Unit

**The ESP-r System
for
Building Energy Simulation**

User Guide Version 10 Series

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ESRU Manual U02/1

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Development history and acknowledgements

The ESP-r system has evolved to its present form over more then two decades. From 1974 to 1977 Joe Clarke developed the initial prototype as part of his doctoral research. Then, over the period 1977 to 1980, with funding from the (then) UK Science and Engineering Research Council (SERC), ESP-r was refined in a number of respects: the system was reorganised and documented, validation trials commenced, multi-zone processing was implemented and a graphics orientated user interface was established. From 1981 through 1986 Professor Clarke was joined by Dr Don McLean and, with further funding from SERC and from the CEC, ESP-r's capabilities were extended by the addition of dynamic plant simulation, the inclusion of building air flow modelling, a move to low cost Unix^{TM} workstation technology and the installation of expert system primitives.

In 1987, the Energy Simulation Research Unit (ESRU) was formed to address the problems confronting the further evolution of building energy and environmental simulation. As part of its research portfolio, ESRU has continued to evolve ESP-r - most notably within the framework of the UK Department of Energy's (now Trade and Industry) Passive Solar Programme, the CEC's PASSYS project (a 10 member country concerted action in Passive Solar Architecture), a SERC funded project to establish an intelligent front-end for the package and within a number of ongoing projects concerned with plant and control simulation. These activities ensured that ESP-r continued to evolve, in terms of further validation, technical extensions and user interface improvements.

Over the past two decades many individuals have made valuable contributions to ESP-r developments. The most important of these have come from our research colleagues at the University of Strathclyde who have contributed much in the way of computational methods and technical support. In particular we are indebted to Tom Maver, Harvey Sussock, Alan Bridges, Don Stearn and Iain Forrest (all presently or previously of ABACUS). One other colleague springs readily to mind: Damian Mac Randal, now a project leader within the Informatics Department at the Rutherford Appleton Laboratory. He was the driving force behind our move to Unix workstations.

We also extend our thanks to several other individuals: to Fred Winklemann of the Lawrence Berkeley Laboratory who helped to develop ESP-r's time-step control mechanism; to Cor Pernot of the FAGO group in Eindhoven who installed ESP-r's comfort routines and continues to take an active interest in the system; to Jeremy Cockroft, who worked on the original air flow solver upon which we have built over the years; to Dr Dechao Tang, Dr Essam Aasem, Dr Abdullatif Nakhi, Dr Cezar Negrao and Dr Tin-tai Chow, all formerly PhD students at ESRU, who worked on ESP-r's plant, moisture flow and CFD algorithms.

At the present time the researchers actively involved in ESP-r developments at ESRU include Joe Clarke, Jon Hand, Jan Hensen, Milan Janak, Cameron Johnstone, Nick Kelly, Iain Macdonald, Paul Strachan.

About this User Guide

We assume that the user is familiar with some of the more elementary Unix/Linux commands and is able to use a Unix/Linux workstation. The main purpose of this User Guide is to introduce a new user of ESP-r to the system and to provide training guidance.

Note that ESP-r has extensive in-built tutorial and help facilities which can be consulted throughout the system familiarisation process. Detailed information may also be found in ESRU's World-Wide-Web pages <http://www.esru.strath.ac.uk> and in the Appendices to this User Guide which cover the system's data requirements, operational details, worked examples, adding new features to ESP-r, developers good practice guide, implementation procedure and software structure.

This User Guide only comprises the essential reading material for the first time user of ESP-r, organised in the following sections:

1   Outline of the system structure and examples of the types of design questions ESP-r can be used to answer.

2   General guidance on how to make effective use of the system.

3   A series of consecutive exercises allowing the first time user to become familiar with - and appreciate - the comprehensive features of the system.

4   A number of short case study descriptions illustrating the use of ESP-r in practice.

5   Some information and references on the theoretical basis and validity of the system.

Section One

General description of ESP-r
and its
associated documentation

Contents

1.0 Introduction

This first section of the User Guide gives a general overview of ESP-r (*Environmental Systems Performance; r for "research"*); a computing environment for building and/or plant energy simulation. The application potential of ESP-r is outlined by citing some typical design questions which the model has been used to answer. Then, the program modules which comprise the system are outlined, along with the essential hardware environment. Finally, some further information sources are indicated.

ESP-r is the outcome of model development projects funded over the years by the UK Science and Engineering Research Council (now EPSRC) and the European Commission's DGXII. Significant contributions have also been made by many individuals as outlined in the *Development history and acknowledgements* section.

ESP-r is free software. It is released under the GNU General Public License.

1.1 Purpose of ESP-r

ESP-r is a transient energy simulation system which is capable of modelling the energy and fluid flows within combined building and plant systems when constrained to conform to control action. The package comprises a number of interrelating program modules addressing project management, simulation, results recovery and display, database management and report writing.

One or more zones within a building are defined in terms of geometry, construction and usage profiles. These zones are then inter-locked to form a building, in whole or in part, and, optionally, the leakage distribution is defined to enable air flow simulation. The plant network is then defined by connecting individual components. And, finally, the multi-zone building and multi-component plant are connected and subjected to simulation processing against user-defined control. The entire data preparation exercise is achieved interactively, and with the aid of pre-existing databases which contain standard (or user-defined) constructions, event profiles and plant components. Additional modules exist to permit an increase in simulation rigour if the related data is available.

A central Project Manager allows importing/ exporting of building geometry from/ to CAD packages and other specialised simulation environments such as Radiance for lighting simulation.

ESP-r is equally applicable to existing buildings and new designs, with or without advanced technological features. The system offers sophisticated input/output facilities which enable the user to answer such design questions as

- What, and when, are the peak building or plant loads and what are the rank-ordered causal energy flows?

- What will be the effect of some design change, such as increasing wall insulation, altering the window shape and size, changing the glazing type or distribution, introducing daylight control devices, re-zoning the building, re-configuring the plant or changing the heating/ cooling control regime?

- What is the optimum plant start time or the most effective algorithm for weather anticipation?

- How will comfort levels vary throughout the building?

- What benefits can be expected from the different possible lighting control strategies?

- What are the relative merits of different heating and cooling systems and their associated controls?

- How will temperature stratification, in terms of zone sensor and terminal unit location, affect energy consumption and comfort control?

- What contribution does building infiltration and zone-coupled air flow make to the total boiler or chiller load and how can this be minimised?

- How do suggested design alterations affect air flow and fresh air distribution (i.e. indoor air quality) within the building?

- What is the effect of special glazings (such as thermotropic, holographic, low-e or electrochromic glazing) on summer overheating?

- Which are the benefits from architectural building features such as atria, sunspaces, courtyards, etc?

- What is the contribution (in terms of energy saving and thermal comfort) of a range of passive solar (heating or cooling) features?

- What is the optimum arrangement of constructional elements to encourage good load levelling and hence efficient plant operation?

- What are the energy consequences of non-compliance with prescriptive energy regulations or, conversely, how should a design be modified to come within some deemed-to-satisfy performance target?

- Which heat recovery system performs best under a range of typical operating conditions?

and so on. This allows the user to understand better the interrelation between design and performance parameters, to then identify potential problem areas, and so implement and test appropriate building, plant and/or control modifications. The design to result is more energy conscious with better comfort levels attained throughout.

1.2 Structure of ESP-r

Figure 1.1 shows the relationship between the program and database modules which form the simulation environment. In this User Guide only the Users-side of the environment will be addressed.

The *Project Manager* allows the interactive definition of some building and plant configuration which is to be subjected to some weather influence and simulated over time. The complete description of the building and plant configuration is called the product model. All data items, as input, are subjected to strict range and legality checks before being directed to disk file for later recall. To ease the input burden, the user is given access to standard databases so that constructions, event profiles and plant components can be accessed by name or simple code number reference. Also, many input items have a corresponding default value so that typed responses can vary as a function of the design information to hand at any time during a design's evolution. The Project Manager also controls user access to the other ESP-r programs such as the Simulator for simulation and the
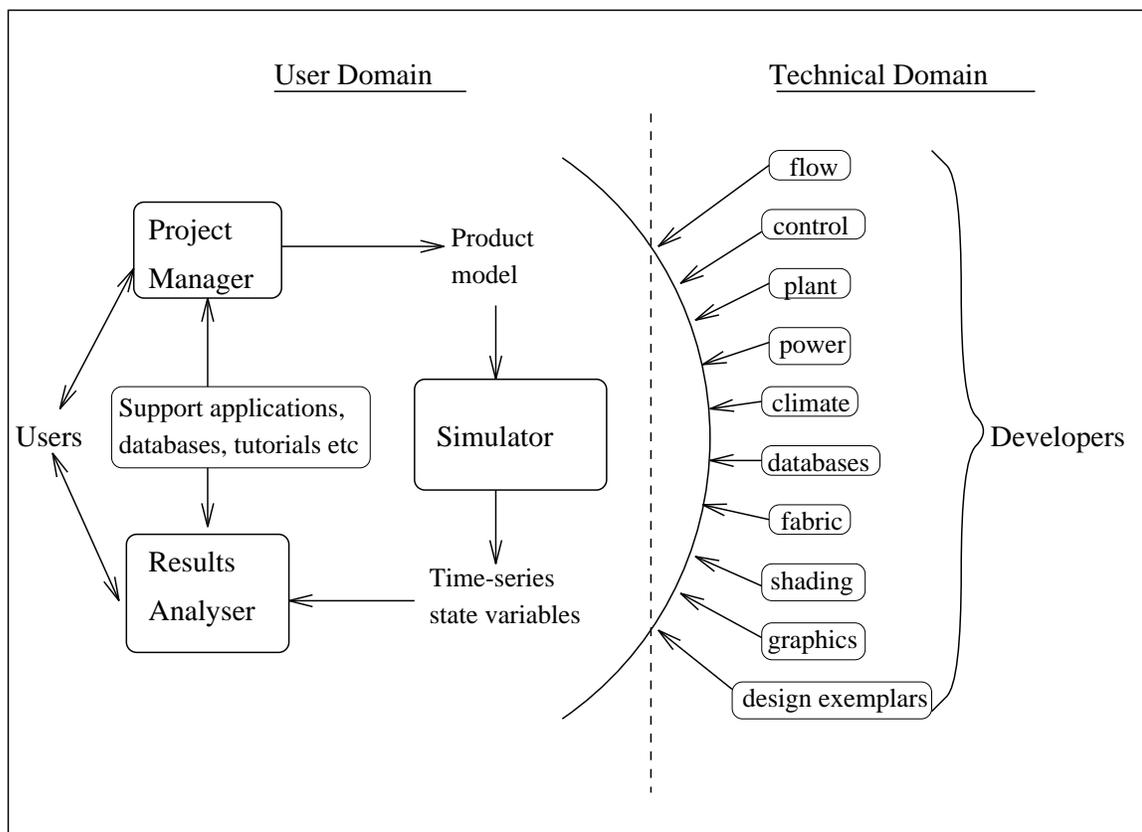
Figure 1.1 Structure of ESP-r

Results Analyser for analysing the time-series of state variables as generated by the Simulator. The *Tutorial Module* is linked to the tutorial material now held as Web pages. The content of the tutorial pages ranges from a general introduction to information on how to use ESP-r in a real world design context. The on-line tutorial mechanism is very powerful since it allows a user to look something up quickly when actually using ESP-r. Since they are in-built, the tutorials are much more easily kept up-to-date than this User Guide.

The *Event Profiles Database Management Module* manages a number of standard or project-specific profiles which define the time dependent variations in zone occupancy, lighting, plant control and miscellaneous appliance usage. These profiles can then be accessed by the Project Manager to define zone and plant behaviour.

The *Plant Components Database Management Module* manages a plant components database. For each plant component, a summary description is held, along with the data required by the Simulator to allow the time dependent generation of the coefficients of the differential equations which represent component heat and mass balance. Component matrix template data is also held to dictate the whole-system matrix building undertaken at each simulation time-step. The database is then accessed from the Project Manager to enable plant network formulation by component interconnection.

The *Climate Database Management Module* manages and analyses climatic data collections. A climate collection spans any period from one day to one year and contains hourly values of dry bulb temperature, direct normal or total horizontal solar intensity, diffuse

horizontal solar intensity, wind speed, wind direction and relative humidity. The climate management module offers solar radiation prediction, curve fitting to daily maximum and minimum data, statistical analysis, graphical and tabular display and general data management. The climate data is required by the Simulator to generate the time dependent boundary conditions for the building and plant configuration.

The *Simulator* is the building and plant simulation engine which predicts building and plant energy/ fluid flows by a rigorous numerical method. The building/ plant network is divided into a large number of finite volumes. Then, at each time-step as a simulation proceeds, an energy and mass balance is applied for all volumes, giving rise to a differential matrix for the entire system. This is then solved by custom matrix processing software in terms of any user-imposed control objectives.

The *Results Analysis Module* operates on the simulation results located in a database by the Simulator. A variety of output options are available: perspective visualisations, results interrogation, statistical analysis, graphical display, tabulations, frequency binning and 3D plotting.

The *Insolation and Shading Module* is a support module which predicts the time-series shading of external zone surfaces (opaque and transparent) as caused by facade and site obstructions and/or the time-series insolation of internal zone surfaces (opaque and transparent) as caused by solar penetration through windows. The predictions for any surface can, optionally, be archived in a shading/insolation database for access and use within a simulation.

The *View Factors Module* computes the black body view factors between each zone surface pairing for use by the Simulator to evaluate internal longwave radiative exchanges. It also evaluates zone comfort level variations.

Building/ plant fluid flow simulation can be performed by the Simulator in tandem with the heat balance calculations. In this case full account will be taken of buoyancy driven air movements between outside and inside and between internal zones. If pressure driven air flow dominates, it is possible to use the *Flows Simulation Module* in stand-alone mode to predict infiltration and zone-coupled air flow. Buoyancy effects are still included but correspond to fixed zone temperatures assigned by the user.

The *Construction Data Management Module* manages (creates, modifies, edits and lists) primitive and composite constructions databases. The materials database contains the thermophysical properties of conductivity, density, specific heat, solar absorptivity and emissivity for a number of standard homogeneous elements. Diffusion resistance factors are also held as required by ESP-r's interstitial condensation computations. A second, project-related database can also be created to hold multilayered constructions formed from elements extracted from the materials' database. Both databases can then be accessed from the Project Manager as required.

A number of ESP-r modules create and/or manipulate random access, binary disk files such as the constructions databases, the event profiles database, and the simulation results database. They also allow for the transformation of ESP-r's binary files to ASCII format and vice versa. This permits the transmission of binary databases to other computer sites (via tape for example) and, if a user is experienced, direct file editing.

In normal use, the three main modules, the Project Manager, the Simulator and the Results Analyser, are used to investigate building and/or plant performance and, by iteration, to assess the consequences of any change to system design or control. The database modules help to reduce the input burden and the support modules exist to allow the sub-system they address to be treated with greater rigour, if this can be justified by the design objectives and data to hand.

The theories underlying ESP-r and the validity of the Simulator are summarised in Section 5 and presented, in detail, in the following references:

- Clarke J A *Energy Simulation in Building Design*, 2nd Edition, Butterworth-Heinemann, Oxford, 2001.

- Tang D *Modelling of Heating and Air-Conditioning Systems*, PhD Thesis, University of Strathclyde, 1985.

- Hensen J L M *On the Thermal Interaction of Building Structure and Heating and Ventilating System*, PhD Thesis, University of Eindhoven, 1991.

- Aasem E O *Practical Simulation of Buildings and AIr-Conditioning Systems in the Transient Domain*, PhD Thesis, University of Strathclyde, 1993.

- Negrao C O R *Conflation of Computational Fluid Dynamics and Building Thermal Simulation*, PhD Thesis, University of Strathclyde, 1995.

- Nakhi A E *Adaptive Construction Modelling Within Whole Building Dynamic Simulation*, PhD Thesis, University of Strathclyde, 1995.

- Chow T T *Air-Conditioning Plant Component Taxonomy by Primitive Parts*, PhD Thesis, University of Strathclyde, 1995.

- MacQueen J *The Modelling and Simulation of Energy Management Control Systems*, PhD Thesis, University of Strathclyde, 1997.

- Kelly N J *Towards a Design Environment for Building-Integrated Energy Systems: The Integration of Electrical Power Flow Modelling with Building Simulation*, PhD Thesis, University of Strathclyde, 1998.

- Hand J W *Removing Barriers to the Use of Simulation in the Building Design Professions*, PhD Thesis University of Strathclyde, 1998.

- Beausoleil-Morrison I *The Adaptive Coupling of Heat and Air Flow Modelling Within Dynamic Whole-Building Simulation* PhD Thesis, University of Strathclyde, 2000.

1.3 Machine environment

ESP-r requires the following hardware and software:

- A UNIX[TM] or LINUX workstation[#] offering X-Windows and with at least 128 MBytes RAM. Implementations exist for SUN, Silicon Graphics and Linux (PC and Mac) platforms.

- A disk capacity to store the executables, manuals, tutorials, training examples (~25 MBytes), perhaps source code (~20 MBytes) and simulation results (~2 MBytes per zone-year at a one hour time step).

- Fortran77 and C compilers.
- A laser writer for graphical hard copy.

1.4 System documentation

In terms of usage, this User Guide and the web-based tutorial facilities of ESP-r are the main sources of documentation. In addition, a number of papers concerning ESP-r development and application can be found in the literature. A full list of publications can be found on the ESRU web site.

As indicated in the Table of Contents, the User Guide has a number of appendices. These are available from our FTP server: they can be automatically downloaded by accessing ESRU's publication list on the WWW (*http://www.esru.strath.ac.uk/*) or by direct *ftp* (file transfer protocol) transfer. In the latter case, ftp to *ftp.strath.ac.uk* and login as *anonymous* with your email address as the password. The documents will be found in directory *Esru_public/documents*.

Papers and technical reports cover issues such as:

- How to add new entities such as climate data, project-specific construction databases and plant components.
- A list of training assignments enabling an instructor to assess whether the training material is absorbed properly, and enabling the trainee to check whether the training material is understood.
- Good practice guidelines for researchers interested in developing or expanding parts of ESP-r.
- A bibliography describing much of ESP-r's technical detail and philosophy. This list includes books, journal articles, conference papers and internal ESRU reports. In some cases *PostScript* or *pdf* versions of these publications are available.
- A summary of the tasks to be undertaken when implementing ESP-r at a particular site.
- A summary of ESP-r's underlying data model.
- Some step-by-step worked examples of simulation projects.

1.5 Further information

ESP-r is released under the terms of the GNU General Public License. It can be used for commercial or non-commercial work subject to the terms of this open source licence agreement.

Although ESP-r can be used for free, it is often the case that a new ESP-r site will incur a nominal expense. For example it may be appropriate to send someone to one of the ESP-r courses which we organise regularly at ESRU (the cost is approximately £500 per person). We strongly recommend this course of action for all new users to ensure that the learning process is as short and painless as possible. Dates of forthcoming courses are listed on the ESRU web site. In addtion, ESRU offer a range of options for supporting the use of ESP-r in organisations. Contact ESRU for details.

ESP-r can be downloaded from the web site http://www.esru.strath.ac.uk by following the appropriate links to the software. Note that, because ESP-r is under active development at

a growing number of sites, there are frequent updates and revisions.

ESP-r is a building and plant energy simulation environment which is under development at various research centres throughout Europe and elsewhere. These developments involve both enhancements and new developments to the existing system as well as validation activities and application related research.

The people working with ESP-r keep in contact via an electronic communication platform. The purpose of this is to keep each other informed about ongoing and planned developments, system related publications, new results, emerged problems, upcoming releases, etc. To join, simply email the string "subscribe esp-r <your email address" to *majordomo@strath.ac.uk*. After your name has been registered, you can communicate with other subscribers by sending messages to *esp-r@strath.ac.uk*. Please note that any e-mail messages received by the virtual user esp-r@strath.ac.uk will be forwarded unmoderated to all people currently subscribed.

Further technical, operational or commercial details on ESP-r may be obtained from ESRU at the address on the front of this User Guide. Alternatively, you may want to browse through our web pages, which can be accessed from *http://www.esru.strath.ac.uk*.

Section Two

A guide to effective system use

Contents

2.0 Introduction

In use ESP-r can be divided into two distinct parts.

The first is concerned with establishing a valid data model (description of the building and/or plant configuration) for simulation. This will involve the use of the Project Manager. The support modules can then be used to increase the detail of the simulation to follow, if this is deemed necessary.

The second part is concerned with the simulation processing and subsequent results analysis. This will involve the use of the Simulator and the Results Analyser. Note that all ESP-r modules are invoked from the Project Manager.

In using ESP-r it is not important to know all the relationships between the ESP-r program modules and the system's data structures. However for a deeper appreciation these relationships are shown in Figure 2.1.
To work with ESP-r you need to be able to cope with a range of technical concepts relating to material properties, control systems, and the like. Information on the data requirements of ESP-r is held on-line and is accessible through the Project Manager (via its tutorial facility). Additional details are given in a separate document "Summary of ESP-r's Data Model".

For each zone in the building a geometry, construction and operations file must be established. Then, optionally and to increase simulation rigour, one or more of the following zone files can be set up to replace the default schemes implied by the data of the essential files: a shading/insolation file, a blind/shutter control file, a view factor file, an air flow file, a casual gain (control) file and a convection coefficients file. The existence of these optional files is indicated by the entries of a zone utilities file created for the purpose. The system configuration file is now set up to define the zones and, perhaps, the plant components which will participate in a simulation. Following this, the configuration control file is established to define the control to be imposed on building zones and plant components. All of these files are created and/or edited via the Project Manager. This program module can also be used to establish the data sets as required by the *Fluid Flow Simulation Module* and the *Insolation and Shading Prediction Module*; namely, a configuration leakage distribution file, a pressure coefficients file and a site obstructions file. Note that some of the optional zone files can also be created directly from the support modules - for example the *View Factor Prediction Module* can create a zone view factor file. This is a powerful feature of ESP-r.

There are other files active in the system. These include the primitives and composite construction databases, the event profiles database, the plant components database, the windows database and the climate database. In addition: the Simulator will produce two databases, for building- and plant-side, for transmission to the *Results Analyser*; the *Simulator* can also produce a fluid flow results file for analysis and archival purposes; and many of the modules can produce detailed computation trace files for fault finding and highly focused appraisals. Figure 2.1 summarises these possibilities and indicates the file types involved.

The next section of the documentation set outlines a strategy for effective use of these modules. Interactive operation, by means of hierarchical menu drivers or function button protocols, is also explained and advice is given on managing the file structures which result from the data preparation and simulation activities.
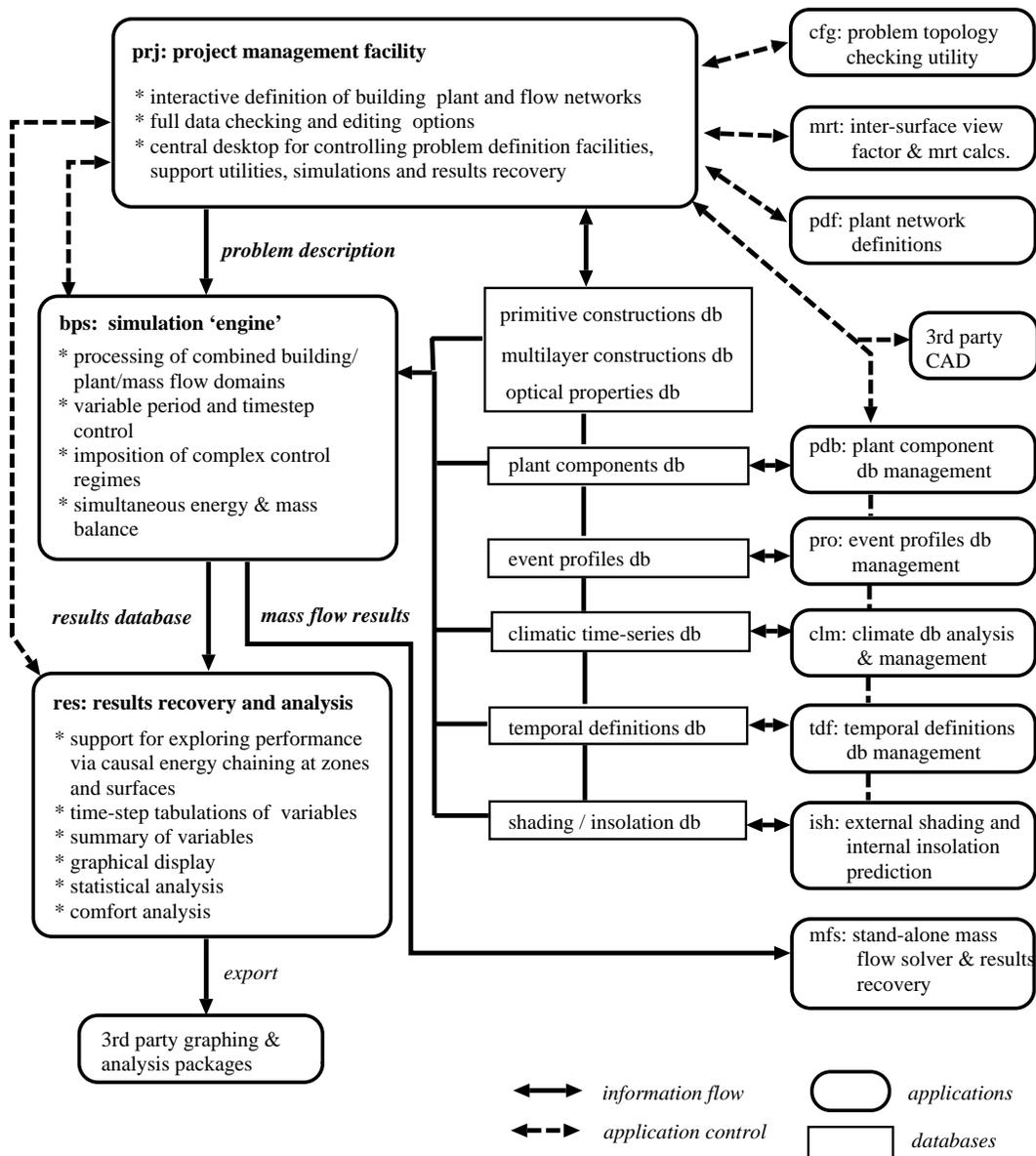
Figure 2.1 Relationship between the ESP-r application modules and databases.

2.1 Simulation strategy

The following step-by-step procedure should be closely followed by a novice. On the other hand, an experienced user may prefer an alternative strategy which bypasses some steps or changes their order.

1.   Analyse the design problem in hand and decide on the performance features to be appraised by ESP-r. Perhaps zone comfort levels are to be determined, the consequences of alternative design options assessed, or an optimum control regime formulated. This is an important task since it will influence the time and expense incurred thereafter.

2. Now decide on the minimum number of building zones and plant components which will yield the performance measures required. For example, a one zone building model will allow an appraisal of summer overheating in the absence of cooling and against any number of design hypotheses. The same model, combined with a six plant component air conditioning plant (a mixing box, humidifier, fan, cooler, heater and supply duct, say), will allow a study of plant energy consumption against several control options. Avoid, in the first instance, any attempt to simulate large, complex building/plant systems. It is, of course, possible to undertake such an exercise, but only at the expense of time (data preparation) and cost (simulation). Very often good design insight can be obtained from simulations directed at portions of the overall system. It is important not to be merely led by the system but to give careful thought to the problem composition. Perhaps small multi-zone building problems, with specified zone conditions maintained, can be used to study several building design options. Then, at some later stage, a plant systems can be progressively added. In ESP-r terminology, the final system for simulation, irrespective of size or composition, is termed the *system configuration.*

3. A computer model of the system configuration must now be created via the Project Manager. The underlying procedure is as follows. Firstly, each building zone in the configuration is described in terms of its *geometry, construction* and *operation.* This results in the creation of three mandatory disk files per zone. A *system configuration* file is then built. This contains a reference to these zone files, information defining zone interaction, and a description of the plant network (if one exists) in terms of individual components, their inter-connections and building associations. At the appropriate point, any of the constructions databases, the event profiles database, the plant components database or the optics database can be accessed and an item contained therein extracted to define a zone property or plant component.

    The designer is simply required to answer a series of questions concerning the system configuration. Control of this interactive dialogue, along with validity checking and automatic disk file building, is the principal function of the Project Manager.

4. At this stage, additional model details can be added.

    An *air flow* file containing time-series infiltration and zone-coupled air flow for use during a simulation. If present, these air flows supersede the design air change profiles specified in the corresponding zone operation file. Note that if a building leakage description is active (see later) then calculated flows will supersede both design air change profiles and time-series air flow data.

    A *casual gains* file containing time-series heat gains for use during a simulation. Again, if specified, the casual gains will supersede any casual gain profiles defined in the corresponding zone operation file.

    A *casual gains control* file containing information on scheduling of casual gains in order to simulate, for example, various switching strategies for artificial lighting based on the availability of daylight.

    A *view factor* file containing inter-surface view factors for use in a simulation to improve longwave radiation calculations.

A *shading/insolation* file containing time-series data on external surface shading and/or internal surface insolation.

A *convection coefficients* file allowing the specification of zone surface convection values to supersede those values which are computed at simulation time on the basis of natural convection considerations.

A *transparent multi-layered constructions* file allowing elected zone multi-layered constructions to be declared transparent.

A *flow domain* file specifying a 1-, 2- or 3-D grid and related parameters in support of a CFD simulation.

Each of these optional zone files can be created by terminal input directed by the Project Manager.

The time taken to reach this stage can vary greatly. An experienced user will require about 20 minutes per zone if the required data is readily available. On the other hand a beginner can take substantially longer. The only rule is to omit complexity in cases where its inclusion cannot significantly influence the performance aspect to be tested. For example, the omission of wall vapour barriers will have little effect on summer cooling loads but will completely alter winter interstitial condensation profiles.

5. A plant network can now be defined, component-by-component, and connected to the established building model. It is normal practice to bypass this step at an early design stage. Instead ideal control statements are associated with each zone to allow a study of the effects of the various design parameters. At some later time the plant is added to allow a study of the control issues. Of course, if the relationship between the building-side design issues and the plant characteristics are strong, and the plant details are known, then a combined building/plant study can be undertaken from the outset.

6. Simulations can now be commissioned from within the Project Manager against the assumption that the configuration is not subjected to control (a free-floating simulation). However, in most cases, some control will be required. From the Project Manager the control regime can be specified in terms of sensors, actuators and control laws. The control specification is stored in the *configuration control* file which is then invoked from the Simulator. This configuration control file, together with the system configuration file (which references the basic zone files and the active plant components), and a climate file are the only files required by the Simulator to completely describe the problem for simulation processing.

7. If air flow within the building configuration is to be simulated by the Simulator in tandem with the energy simulation (and perhaps a zone CFD simulation), it is necessary to define the distributed building leakage and to ensure that the required pressure coefficient sets are located in a related database. Both operations are directed by the Project Manager, resulting in two further disk files: the *fluid flow network* and *pressure coefficients* files. The names of these files are given to the Simulator at the time of configuration file creation. The Simulator will now assess the pressure and temperature driven air flows for the defined zones and disregard any air change profiles (located in the corresponding zone operations file) or active

zone air flow file.

8.   From within the Project Manager it is possible to check configuration geometry by computing area and volume quantities or by generating perspective displays. At this stage, it is possible to create a description of surrounding site obstructions to define the objects which will cause target zone shading.

      Throughout the entire data preparation process, the Project Manager offers editing and listing operations so that mistakes can be easily rectified and hard copy records can be kept.

9.   The climate analysis module can now be used to analyse the climatic collections held on disk in the format required by ESP-r. By this mechanism, one collection is selected, and typical sequences identified, to provide boundary conditions which best stress the performance attribute to be tested.

10.   Simulations are now performed from within the Project Manager against one or more *system configuration* and *configuration control* files. Changing either of these files, or the climate file, allows different design options and control regimes to be tested under different weather influences.

11.   All results recovery and analysis is then undertaken with the help of the Results Analyser (invocable from within the Project Manager), with the principal objective of understanding the cause and effect relationships implied by the energy flowpath magnitudes and directions.

12.   Appropriate design modification can now be implemented via the Project Manager by editing a mandatory or optional zone file, the system configuration file or the configuration control file. In this way constructions can be changed, operational schemes modified, plant layout re-configured, shading devices added or removed, and so on.

2.2 General outline of program operation

A session with ESP-r might adhere to the following sequence.

*   Log on to the computer offering ESP-r.

*   Start ESP-r by issuing the command *esp-r*. This will start ESP-r in its default graphics mode. You can specify an alternative mode from the following list:
          esp-r -mode text   (text only mode with no pauses)
          esp-r -mode graphic (default)

      It is also possible to start up ESP-r directly with a configuration file. For example *esp-r -file xxx.cfg* will start ESP-r with the problem specified in the system configuration file *xxx.cfg* already loaded into the Project Manager.

      The start-up window size can also be controlled: type *esp-r -help* for the required syntax.

*   Select commands as required from the menus displayed and thereby pick a path through the program.

*   Answer the questions posed at each interaction.

*   Eventually terminate the program by returning to the main menu and selecting the *Exit* command.

- Delete any unwanted files; for example, zone files no longer required or results files (usually large) which have been fully analysed.

- Log off after checking that any disk quotas have not been exceeded.

All program menus are hierarchical so that each menu pick will result in a particular processing option (with control returning to the same menu level), or will lead to a lower level command menu. In graphics mode, menu picks are initiated by the left mouse button. In text mode selection is by an identifier.

To questions requiring a yes/no response a user may type 1, Y, y, YES or yes and 0, N, n, NO or no. Also, after some output sequences, the program will pause to allow examination of the displayed page. The pause state is indicated by a **more** button at the bottom screen position. To continue click the left mouse button over the "more" button.

2.3 Data file management

In addition to the database structures essential to ESP-r's operation (containing primitive and composite constructions, event profiles, plant components and climatic collections), the following file types may be produced in a typical session.

- A mandatory *geometry, construction* and *operation* file for each zone.

- An optional *air flow, casual gains, shading/insulation, view factor, surface convection* and *transparent multi-layered construction* file for some or all zones.

- A mandatory *system configuration* file and, perhaps, a *configuration control* file.

- Optionally, a *fluid flow network description* file (i.e. a leakage distribution file in the case of a building air flow network), a *pressure coefficients* file and a *fluid flow results* file (i.e. air flow results in the case of an air-only flows problem).

- One or more *simulation results* files.

File Type	Extension
System Configuration	.cfg
Connections	.cnn
System Control	.ctl
Geometry	.geo
Construction	.con
Operations	.opr
Shading/Insolation	.shd
View Factors	.vwf
Air Flows	.air
Convection Coefficients	.hcf
Site Obstructions	.obs
Mass Flow Network	.mfn
Transparent Constructions	.tmc
Casual Gains Control	.cgc
CFD file	.dfd

Table 2.1 Filename convention

Effective file management can only follow from a file naming convention (largely automated by the Project Manager) in which the name itself yields information about the project and file type. In ESP-r the file type is reflected in the filename extension as indicated in Table 2.1.

> **Remember to avoid unnecessary complexity by keeping the system configuration as simple as allowed by the design issue being studied.**

Section Three

Exercises

Contents

3.0 Introduction

There a number of simulation tools available for energy efficient building design, ranging from simplified tools to detailed simulation programs. Several of these are described on Web pages that can be found via the Web address given later in this section. To learn the capability of such design tools, it is useful to study:

a)   the types of analysis questions that they can address and the benefits of using energy and environmental simulation;

b)   how to use the tools; and

c)   the underlying theory upon which the numerical processing and analysis functions of the tools are based.

The exercises and assignments described in this section are concerned with how to use one particular detailed simulation program, ESP-r, but those following the course are encouraged to also refer to related Web-based material.

In order to be able to use ESP-r and to appreciate the following sections, it is assumed that you have access to a Unix workstation (you will need a personal user account on the machine) and that you have a number of basic computer skills. A number of exercises have been designed to progress ESP-r users from the category of novice to specialist over a period of time which will depend on the individual's aptitude and stamina. Once a level of proficiency has been attained, the exercises of section 4 can be attempted.

With the exercises are ten assignments which gradually increase in difficulty. It is suggested that the course participant follows the exercises and assignments in the order given. The assignments serve a dual purpose. They enable the instructor to assess whether or not the training material is being absorbed effectively. For the course participant they form a series of "real world" consultancy sub-tasks enabling the participant to check whether the training material is understood, while at the same time placing ESP-r in a realistic context. Each assignment has an associated prerequisite exercise, such as learning email in the case of assignment 1. The outcome of each assignment should be sent by electronic mail to the supervisor.

The exercises and assignments can be accessed by a Web browser, and it is suggested that they are constantly displayed in one window as the course participant progresses through the course.

The relevant Web address is:

http://www.esru.strath.ac.uk

The course participant should follow links from this high level page to ESP-r training courses and from there to the structured exercises.

3.1 List of Exercises

Foundation level exercises

        1 Getting started on the workstation
        2 Configuring the workstation for ESP-r use
        3 Overview of ESP-r
        4 Exploring the in-built training exemplars
        5 Defining a problem to ESP-r - the basics
        6 Simulation - the basics
        7 Results analysis - the basics
        8 Problem definition - databases
        9 Problem definition - geometry
        10 Problem definition - constructions
        11 Problem description - operations
        12 Problem definition - inter-zone connections
        13 Climate data and its analysis
        14 Control capabilities
        15 Simulation - advanced facilities
        16 Results analysis - additional facilities
        17 Review of files and program modules
        18 Review of progress

Intermediate level exercises

        19 Shading and insolation analysis
        20 Fluid flow analysis
        21 Plant and control modelling
        22 Lighting analysis
        23 Other ESP-r facilities
        24 Upcoming features

Expert level exercises

        25 Making Models: CAD and Attribution
        26 Making Models: Fluid Flow, Plant and Control Networks
        27 Making Models: Enhanced Resolution
        28 Integrated Performance Appraisal
        29 Edit/ compile/ link test cycle

Section Four

Example applications
of the
ESP-r system

Contents

4.0 Introduction

Sections 4.1 through 4.11 presents a number of short case studies of typical and atypical designs as analysed by ESP-r. They have been selected to indicate the possibilities for performance assessment by simulation. The remaining sections describe a number of simulation exercises based on exemplars supplied with the system. These have a dual role: to test the ESP-r program modules on first implementation and to provide training for new users thereafter. The exercises progress from the simple to the more complex and have been designed to test several aspects of ESP-r. Each of the training sessions deals with a basic problem type with variations which explore simulation topics.

Throughout the exercises reference is made to standard ESP-r databases and test files. As explained elsewhere, such files are held in a strict directory structure. In the text that follows the Unix syntax is used so that ˜esru/esp-r/climate means sub-directory climate of sub-directory esp-r of the home directory (wherever defined) of esru. Similarly ˜esru/esp-r/training/office means sub-directory office of sub-directory training of sub_directory esp-r of the home directory of esru.

4.1 Parametric studies

Parametric analysis of building energy performance is, perhaps, the prerequisite of a more complete understanding of the issues relating to energy efficient building design. The process of simulation can be used to increase the corpus of knowledge upon which future designs can be built. ESP-r has been used as the simulation tool in a number of parametric studies.

In one, different window designs were analysed in terms of their performance in British and Scandinavian climates. Annual simulations were performed for a number of combinations of facade orientation, window size, window type and fabric capacity sampled from the many combinatorial possibilities. Typical occupancy patterns, internal gains and window curtain operation was assumed throughout. The different windows were then analysed in terms of the cost-benefit associated with the provision of varying comfort standards.

In another study, the model was used to generate design guidelines in public buildings by systematically varying the major design parameters such as insulation, capacity, window size, heating system regulation and degree of air permeability.

4.2 Upgrading strategy

Many Government agencies in the UK own housing stock which dates from the early 1950's. In recent times much of this stock has fallen due for upgrading. Obviously some mechanism must be employed to establish the most productive strategy. ESP-r has been used as such a mechanism.

A sample of houses in any estate are analysed, firstly in their original form, and subsequently with a range of alternative upgrading features formulated on the basis of the initial simulation results. In one case, the prime heat loss path was identified by ESP-r as being through the suspended timber floor. This occurred in a building for which substantial wall insulation was planned. As a result the upgrading proposal was modified and the client's investment put to better use.

4.3 The issue of cost

ESP-r was once used by a large regional council to investigate the possibilities in a proposed building conversion. The study involved an in-depth investigation into heating demand diversity as affected by alternative zoning strategies, plant control schedules and fabric treatments. Their resulting report included the technical details of the project but went on to raise the following general points.

- The total cost incurred by them in the simulation exercise was calculated at half the cost incurred in a parallel exercise which involved only the calculation of zone heat loss by conventional 'manual' methods.

- The results from the ESP-r exercise allowed a more detailed analysis of both the building and plant performance than would have been possible by other means. In particular, the ability to interactively impose design changes was considered to be extremely useful.

- The graphical presentation of results was considered invaluable as a means of conveying information to the design team.

4.4 Inovatory design

ESP-r has also been used to test inovatory design solutions. In one application, the program was used to model a proposed solar wall construction which formed part of a multi-million pound laboratory complex.

The movement of large quantities of air had suggested a design solution in which this air was passed over the entire south-facing building facade and contained within an outer glass skin. ESP-r was used to simulate this solar wall to predict the potential annual pick-up of solar energy and the corresponding reduction of the south facade heat loss due to the insulating effect of the additional glass and air space combination.

Modelling of the system was complicated by the proposed inclusion of ducts within the air space which caused wall shading as well as convective heat pick-up. What was required was a first principle computation method capable of modelling the complexities of the system.

4.5 Low energy housing

In conjunction with a private architectural practice ESP-r was used by the modelling team to develop a specification for a low energy house. Primary objectives were to select a building mass and insulation scheme which, in conjunction with the selected window configuration, would effectively minimise the heating demand. Using real climatic data, initial simulations resulted in decisions on orientation, shape, zoning, window size and window type. Later simulations - assuming real occupancy and plant operational patterns - aided decisions on fabric weight, position of thermal capacity, position of insulation, and effective solar screening to avoid overheating during peak solar times. Issues relating to controlled ventilation and heat distribution between different zones were also examined.

The final scheme was then rigorously analysed over whole year periods and, in this way, efficient energy performance was established.

4.6 Re-design

ESP-r was used to investigate re-design issues in converting a large dockland complex to house departments of a polytechnic. The exercise involved an analysis of the relationship between the existing massive construction and the potential overheating resulting from solar penetration and the introduction of high internal loads. The possible set of conversion solutions were constrained by the existence of a preservation order prohibiting substantive changes to the building facade. The restriction on facade shading devices focused attention on the cost-benefit associated with various glazing types in terms of their ability to minimise solar penetration. ESP-r was used to find a suitable economic solution.

4.7 Critical control

In another new design application ESP-r was used by a central government agency to analyse critical environmental conditions in an astronomical laboratory where control of the thermal environment is crucial to the effective working of the telemetry equipment.

ESP-r was used to select a constructional scheme which would ensure that internal, untreated conditions would remain within ±0.1°C of the required condition. The proposed massive concrete construction had a large thermal time constant which had rendered simple predictive techniques unsuitable.

4.8 Feasibility study

A large practice was asked to carry out a feasibility study and produce a development scheme for the comprehensive redevelopment of a narrow but important urban site; the redevelopment had to include two office blocks, each of 100,000 ft^2, to be let by the client. The narrowness of the site suggested a narrow floor plan in each office block, one rising to six stories, the other to eight stories. The proposal that one of the blocks should be air conditioned, the other not, suggested to the architect an investigation of a broad range of construction types under 'artificial', 'ambient', and 'assisted', environmental control.

In the event, a two-stage ESP-r analysis was carried out in the context of the non-air conditioned building. In the first stage, office modules on the SW and NE orientations were simulated, respectively, under summer and winter conditions; within a fixed external envelope with 35% glazing. ESP-r was used to explore the implications of achieving shading on the SW facade, increasing the thermal mass of internal partitioning, altering the rate of mechanical ventilation and double-glazing the NE facade. In the second stage, more explicit proposals were generated for the pattern of external glazing, the internal sub-division of space, etc; and a similar series of investigations, using ESP-r, carried out.

4.9 Late design-stage use

The design of a building to house a computer and ancillary activities for a nationalised industry was already well advanced when then the opportunity arose to use ESP-r. The air conditioned building, of approximately 6000 m^2, was to be built on four floors, each 30m wide by 50m long; office accommodation would be housed on the perimeter with rooms of more occasional occupancy in the core.

The stimulus for use of a dynamic energy model came from the late decision to alter the building envelope from a lightweight metal cladding system to brickwork, with an associated increase in glazing from 25% to 40%, differentially arranged in the four floors. The effect of these changes on the variable air volume (VAV) distribution ductwork and on the central air-handling plant needed, as a matter of urgency, to be determined.

The ESP-r analysis was applied to spatial modules sited on all four corners of the building and halfway along each facade. For each module, on each floor, the peak load across the VAV terminals was computed and the accumulative effect on the central plant estimated. In relation to the climate data used the peak load on all space modules was seen to occur on a high air temperature July day and not, as had been previously assumed, within the month of September when solar angles are lower. The ability of ESP-r to model the dynamics of thermal behaviour, hour by hour, showed clearly that the peak load occurred in different space modules at different times throughout the critical day; as a consequence, although individual VAV terminal duties had to be increased, no significant increase in load would be experienced by the central plant.

4.10 Comfort

The first phase of an extension to a University Library comprised a reading room with a floor of bookstacks above. The construction proposed by the architect was dense reinforced concrete with double skin patent glazing angled back from sill to ceiling.

Concern for the environmental conditions focused on the maximum occupancy period of the reading room (May with an estimated 350 readers) and on the mid-summer period (June to August, with an estimated 100 readers); the architect also wished an appraisal of the scheme under winter heating conditions.

Climatic data relevant to the study period were created in accordance with the diurnal range known to prevail at the location of the site. The May analysis received a 24 hour heat input requirement under the proposed 10 air changes per hour ventilation regime; as a result of the analysis the proposed air change rate in the Spring was reduced to a level just sufficient to combat odours and meet ventilation requirements. With 10 air changes per hour in August, the maximum temperature was predicted to be 24°C. Given the slightly lower predicted resultant temperature and the possibility of the 100 readers disposing themselves away from the external wall this was considered to be acceptable. A January analysis of heat flow through the double-glazed envelope revealed acceptable comfort conditions.

4.11 Speculative development

In another exercise ESP-r was used, in the context of speculative office developments, to:

- Estimate the relative influence on energy conservation of different external wall constructions and window treatments.

- Compare the generated 'best-buy' solution with other existing schemes.

- Ascertain the impact of such an approach to capital expenditure (the developer's contribution) and running costs (the tenant's contribution).

The analysis indicated that:

- Changes to the fabric alone can result in a +16% or a -24% alteration to the winter heating load relative to the standard.

- Double glazing had a similar effect to that of adding a suspended ceiling, namely a 23% saving of winter energy.

- Substituting internal fabric blinds for external blinds in winter saves about 12% which is comparable to the thermal benefit of retaining full light output.

- There is no apparent advantage in reducing still further the construction U-value.

- Peak cooling demands do not show an exactly negative correlation with peak heating load levels, suggesting that a balance in the fabric/services system between winter and summer conditions may be achievable.

From the study, the architect was able to provide a base of relevant data and conclude generally that, 'if a developer seeks to offer a good level of environment, it may be advantageous to the tenant in terms of running costs to do so by means of design changes to the building rather than by introducing air conditioning'.

4.12 Training Exemplars

The ESP-r system offers a model archiving and browsing facility by which past problems can be maintained and revisited. On delivery, this facility is used to provide a number of exemplar problems which are useful for training support. The following sections relate to some of these on-line exemplar models.

4.12.1 Single office

Figure 4.1.1 gives the geometry, construction and operation details for a single building zone containing office and computing equipment. The user would begin by creating a directory for this problem and moving into it and running ESP-r which contains or allows access to the facilities required to describe the problem, commission simulations and engage in analysis of the results.

The opening display provides a tutorial, database management facility, problem definition, problem simulation and analysis and various support facilities. If the user is a novice it is recommended that some time be spent using the tutorial facility.

When testing ESP-r it is not necessary to create the problem description files since they are supplied. In directory *˜esru/esp-r/training/simple*, the files *cfg/bld_simple.cfg*, *zones/reception.geo*, *zones/reception.con*, *zones/reception.opr* and *ctl/bld_simple.ctl* correspond to the system configuration, zone geometry, zone construction, zone operation and configuration control files respectively. All that is required is to select *problem definition* and supply the problem name *bld_simple.cfg* which will then be loaded. At this point the user may explore the details of the problem or commission a simulation. Notes supplied with the problem should be read by selecting *problem registration:documentation* from within the *problem definition*, accepting the file *bld_simple.log* and then reading the text displayed in the text feedback area.

Of course it is also possible to describe this problem from scratch yourself. Although the user may approach this task of in a number of ways, the following sequence is suggested.

The first task is to select *database management* which allows various databases to be associated with a project. In most cases the defaults provided for climate, pressure distribution, primitive constructions, event profiles, plant components and optical properties will not need to be changed. Indeed some may not be used, but a multi-layered constructions database will need to be defined for the current problem. This database defines the details of wall floor and ceiling constructions - i.e. order, thickness and references to elements in the construction primitives database. To create a new multi-layered constructions database simply supply a new file name and a fresh database with a dummy construction will be created.

For each of the constructions shown in Figure 4.1.1 follow the editing procedures - beginning with the outside face and working in to the layer which faces the zone. You may edit, add or delete an individual layer as necessary. In the case of the double glazing it is necessary to match the properties of the optical database and the best way to do this is to specify the optical properties first and then allow a matching set of layers to be created. It is a good idea to *update* the database frequently. When you have finished the details should be as in Figure 4.1.2. Note that you can also use any text editor to change this file (test.mlc).

TEST 1 PROJECT DETAILS

1. A single zone isolated building with no adjacent objects. No shading analysis required.
2. Air change rate 0.3 ac/h infiltration only.
3. Occupancy - 6 people (90W sensible, 50W latent per person). Radiative/convective split 0.2/0.8. Monday-Friday inclusive 09:00-17:00. Weekends no occupancy.
4. Lighting - 10W/m2 office hours only. Rad/conv split 0.1/0 (special light fittings)
5. Others - 450W from machines during office hours. Rad/conv split 0.2/0.8. 800W from machines, 24 hours/day, 7days/week.
6. Location - Latitude 51.7deg, Longitude -0.5 deg from meridian.

TEST 1 GEOMETRY

PLAN
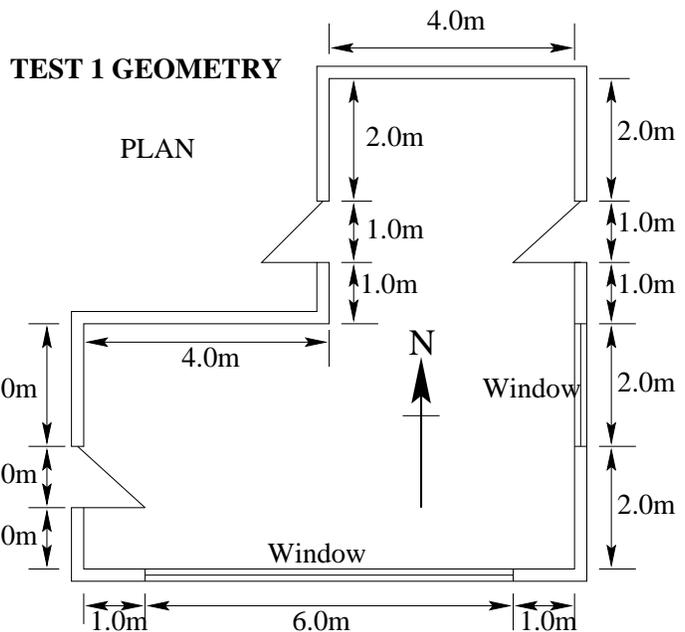
Geometry notes:
1. Floor-ceiling height 3.0m
2. Windows: sill height 1.0m
              head height 2.25m
3. Door height 2.5m
4. Flat roof

TEST 1 CONSTRUCTION

External wall

Outside   Inside

100mm Brick outer leaf
75mm Insulation
50mm Air cavity
100mm Breeze block

Roof

12mm Roofing felt
50mm Light concrete
50mm Air gap
8mm Plaster

Floor

50mm Screed
50mm Concrete
100mm Hardcore
100mm Earth
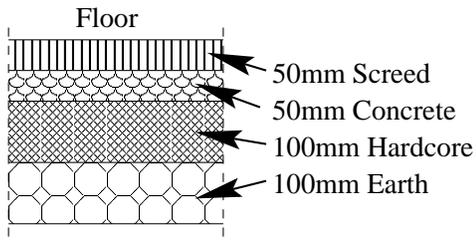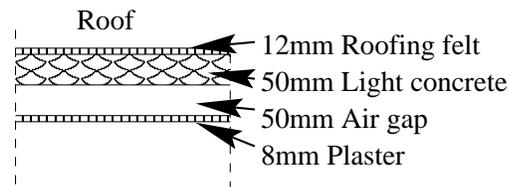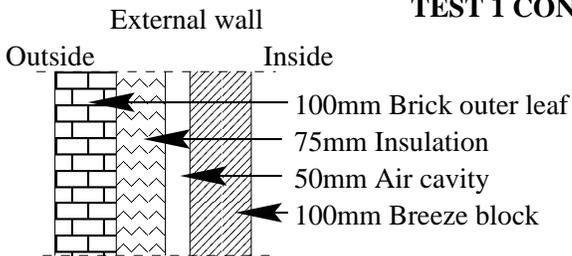
Construction notes:
1. Air gap resistance: 0.17 (m2K)/W.
2. All doors are 25mm thick wood (oak).
3. Double glazed windows (6mm panes, 12mm air gap).
4. Optical properties from standard database.

Figure 4.1.1 Details of the *test1* building

```
# composite construction db defined in multicon.mdb
```

```
# based on primitive construction db constr.db2
   23     # no of composites
# layers  description   optics
    4     extern_wall   OPAQ  OPAQUE
# db ref  thick    db name & air gap R
    6     0.1000  Lt brown brick
  211     0.0750  Glasswool
    0     0.0500  air  0.170 0.170 0.170
    2     0.1000  Breeze block
# layers  description   optics
    3     insul_mtl_p   OPAQ  OPAQUE
# db ref  thick    db name & air gap R
   46     0.0040  Grey cotd aluminium
  281     0.0800  Glass Fibre Quilt
   47     0.0040  Wt cotd aluminium
# layers  description   optics
    2     intern_wall   OPAQ  OPAQUE
# db ref  thick    db name & air gap R
    2     0.1500  Breeze block
  103     0.0120  Perlite plasterboard
# layers  description   optics
    5     partition     OPAQ  OPAQUE
# db ref  thick    db name & air gap R
  104     0.0130  Gypsum plaster
    0     0.0500  air  0.170 0.170 0.170
   28     0.1000  Block inner (3% mc)
    0     0.0500  air  0.170 0.170 0.170
  104     0.0130  Gypsum plaster
 . . .
```

Figure 4.1.2 Multi-layer construction database for *test1*

Exit from the database facility and select *problem definition* and, after reading the message, supply the new problem name *bld_simple.cfg*, indicate that you wish to begin with a new geometry from scratch and supply a name for the zone (this name is for reporting and display purposes and is not the file name).

The zone is most easily described as an extruded shape and after you have supplied the floor and ceiling height as well as the coordinates of the various corners and the connections between this corners,
 you will be presented with a display similar to that in Figure 4.1.3. Use the *geometry-->surface attributes* option from the *problem definition* menu to adapt the (zone)geometry of the problem.
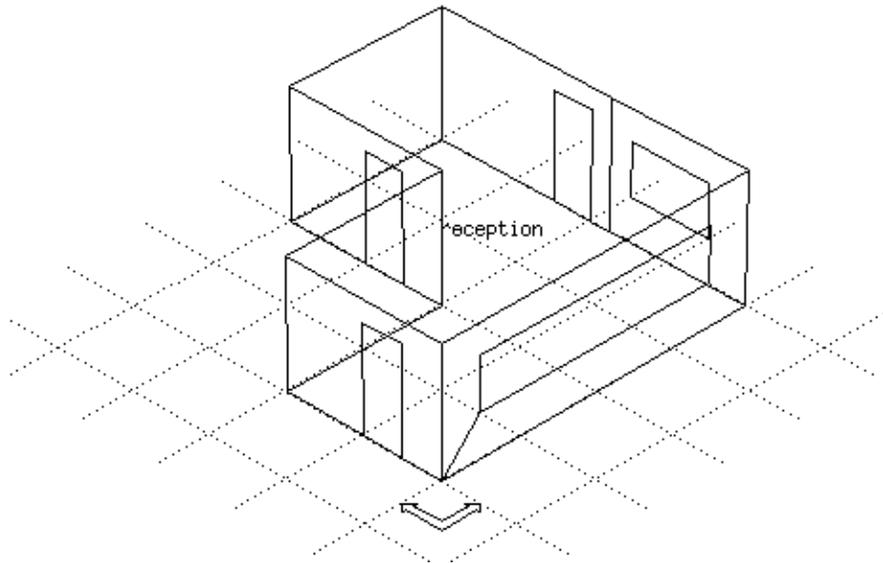
Figure 4.1.3 geometry of bld_simple.cfg.

Note that the surfaces have been given default names. Clarity of presentation is enhanced by replacing the default surface names with names which make sense in the context of a given building. Use the *surface attribute* selection to accomplish this.

Glazing is representation as a multi-layered construction with additional optical properties. The surface of the glazing can be any polygonal shape, although many users will define glazing as an offset from the lower left corner of an existing surface to the lower left corner of the glazing as well as its width and height.

From the *geometry* menu some other subjects like *solar insolation distribution*, *obstruction blocks* and *rotation & transforms* can be selected. These options are not relevant to the test case you are working on at this moment; later on, when you have seen some results of this first test, some shading distributions will be added.

At this point the zone will contain information similar to that in Figure 4.1.4.

```
# geometry of reception defined in: ../zones/reception.geo
GEN   reception               # type    zone name
      34      14    0.000     # vertices, surfaces, rotation angle
#   X co-ord, Y co-ord, Z co-ord
     1.00000      1.00000      0.00000  # vert  1
     9.00000      1.00000      0.00000  # vert  2
     9.00000      4.50000      0.00000  # vert  3
     9.00000      9.00000      0.00000  # vert  4
     5.00000      9.00000      0.00000  # vert  5
     5.00000      5.00000      0.00000  # vert  6
     1.00000      5.00000      0.00000  # vert  7
     1.00000      1.00000      3.00000  # vert  8
     9.00000      1.00000      3.00000  # vert  9
     9.00000      4.50000      3.00000  # vert 10
     9.00000      9.00000      3.00000  # vert 11
     5.00000      9.00000      3.00000  # vert 12
     5.00000      5.00000      3.00000  # vert 13
     1.00000      5.00000      3.00000  # vert 14
     2.00000      1.00000      1.00000  # vert 15
```

```
     8.00000      1.00000      1.00000   # vert 16
     8.00000      1.00000      2.25000   # vert 17
     2.00000      1.00000      2.25000   # vert 18
     9.00000      5.00000      0.00000   # vert 19
     9.00000      6.00000      0.00000   # vert 20
     9.00000      6.00000      2.50000   # vert 21
     9.00000      5.00000      2.50000   # vert 22
     5.00000      7.00000      0.00000   # vert 23
     5.00000      6.00000      0.00000   # vert 24
     5.00000      6.00000      2.50000   # vert 25
     5.00000      7.00000      2.50000   # vert 26
     1.00000      3.00000      0.00000   # vert 27
     1.00000      2.00000      0.00000   # vert 28
     1.00000      2.00000      2.50000   # vert 29
     1.00000      3.00000      2.50000   # vert 30
     9.00000      2.00000      1.00000   # vert 31
     9.00000      4.00000      1.00000   # vert 32
     9.00000      4.00000      2.25000   # vert 33
     9.00000      2.00000      2.25000   # vert 34
# no of vertices followed by list of associated vert
  10,  1,  2,  9,  8,  1, 15, 18, 17, 16, 15,
  10,  2,  3, 10,  9,  2, 31, 34, 33, 32, 31,
   8,  3, 19, 22, 21, 20,  4, 11, 10,
   4,  4,  5, 12, 11,
   8,  5, 23, 26, 25, 24,  6, 13, 12,
   4,  6,  7, 14, 13,
   8,  7, 27, 30, 29, 28,  1,  8, 14,
   7,  8,  9, 10, 11, 12, 13, 14,
  13,  1, 28, 27,  7,  6, 24, 23,  5,  4, 20, 19,  3,  2,
   4, 15, 16, 17, 18,
   4, 19, 20, 21, 22,
   4, 23, 24, 25, 26,
   4, 27, 28, 29, 30,
   4, 31, 32, 33, 34,
# unused indices
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
# surfaces indentation (m)
 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
     3    0    0    0    # default insolation distribution
# surface attributes follow:
# id  surface      geom  loc/  mlc db        environment
# no  name         type  posn  name          other side
  1, south         OPAQ  VERT  extern_wall   EXTERIOR
  2, east          OPAQ  VERT  extern_wall   EXTERIOR
  3, pasg          OPAQ  VERT  gyp_blk_ptn   SIMILAR
  4, north         OPAQ  VERT  extern_wall   EXTERIOR
  5, part_a        OPAQ  VERT  gyp_gyp_ptn   office
  6, part_b        OPAQ  VERT  gyp_gyp_ptn   office
  7, west          OPAQ  VERT  extern_wall   EXTERIOR
  8, ceiling       OPAQ  CEIL  ceiling       roof_space
  9, floor         OPAQ  FLOR  floor_1       CONSTANT
 10, glz_s         TRAN  VERT  dbl_glz       EXTERIOR
 11, door_p        OPAQ  VERT  door          SIMILAR
 12, door_a        OPAQ  VERT  door          office
 13, door_w        OPAQ  VERT  door          EXTERIOR
 14, east_glz      TRAN  VERT  dbl_glz       EXTERIOR
```

Figure 4.1.4 Zone geometry file.

The next descriptive task is to define the thermophysical properties of the zone. The recommended procedure is to use the *surface attribute* facility and for each surface select the appropriate construction. In the case of the glazing in the south wall make sure that it is marked as transparent. Having defined these attributes proceed to use the *construction browse/ edit* facility to create a zone construction file. Since there is a transparent wall in the zone a zone TMC file is required. ESP-r knows about the file structure dependencies and will automatically generate such files. After reading in the geometry (including the

surface attributes) ESP-r will attempt to create the necessary files. During the creation
process it will ask you to confirm that glz_s is transparent, otherwise the process is auto-
matic. You may browse through any of the surfaces thermophysical properties and unless
a change is demanded the data can be merged into the problem. The thermophysical
properties are contained in *reception.con* which is listed below in Figure 4.1.5.

```
# thermophysical properties of reception defined in reception.con
# no of |air |surface(from geo)| multilayer construction
# layers|gaps|  no.   name      | database name
      4,     1  #  1 south          extern_wall
      4,     1  #  2 east           extern_wall
      2,     0  #  3 passage        intern_wall
      4,     1  #  4 north          extern_wall
      4,     1  #  5 part_a         extern_wall
      4,     1  #  6 part_b         extern_wall
      4,     1  #  7 west           extern_wall
      4,     1  #  8 ceiling        roof_1
      4,     0  #  9 floor          floor_1
      3,     1  # 10 glz_s          d_glz
      1,     0  # 11 door_p         door
      1,     0  # 12 door_a         door
      1,     0  # 13 door_w         door
   3,    0.170,    # air gap position & resistance for surface  1
   3,    0.170,    # air gap position & resistance for surface  2
   3,    0.170,    # air gap position & resistance for surface  4
   3,    0.170,    # air gap position & resistance for surface  5
   3,    0.170,
   3,    0.170,    # air gap position & resistance for surface  6
   3,    0.170,    # air gap position & resistance for surface  7
   3,    0.170,    # air gap position & resistance for surface  8
   2,    0.170,    # air gap position & resistance for surface 10
# conduc- |  density | specific | thick- | surf|layer
# tivity  |          | heat     | ness(m)|     |
     0.9600,    2000.0,    650.0,   0.1000  #  1   1
     0.0400,     250.0,    840.0,   0.0750  #      2
     0.0000,       0.0,      0.0,   0.0500  #      3
     0.4400,    1500.0,    650.0,   0.1000  #      4
     0.9600,    2000.0,    650.0,   0.1000  #  2   1
     0.0400,     250.0,    840.0,   0.0750  #      2
     0.0000,       0.0,      0.0,   0.0500  #      3
     0.4400,    1500.0,    650.0,   0.1000  #      4
     0.4400,    1500.0,    650.0,   0.1500  #  3   1
     0.1800,     800.0,    837.0,   0.0120  #      2
     0.9600,    2000.0,    650.0,   0.1000  #  4   1
     0.0400,     250.0,    840.0,   0.0750  #      2
     0.0000,       0.0,      0.0,   0.0500  #      3
     0.4400,    1500.0,    650.0,   0.1000  #      4
     0.9600,    2000.0,    650.0,   0.1000  #  5   1
     0.0400,     250.0,    840.0,   0.0750  #      2
     0.0000,       0.0,      0.0,   0.0500  #      3
     0.4400,    1500.0,    650.0,   0.1000  #      4
     0.9600,    2000.0,    650.0,   0.1000  #  6   1
     0.0400,     250.0,    840.0,   0.0750  #      2
     0.0000,       0.0,      0.0,   0.0500  #      3
     0.4400,    1500.0,    650.0,   0.1000  #      4
     0.9600,    2000.0,    650.0,   0.1000  #  7   1
     0.0400,     250.0,    840.0,   0.0750  #      2
     0.0000,       0.0,      0.0,   0.0500  #      3
     0.4400,    1500.0,    650.0,   0.1000  #      4
     0.1900,     960.0,    837.0,   0.0120  #  8   1
     0.3800,    1200.0,    653.0,   0.0500  #      2
     0.0000,       0.0,      0.0,   0.0500  #      3
     0.3800,    1120.0,    840.0,   0.0080  #      4
     1.2800,    1460.0,    879.0,   0.1000  #  9   1
     2.9000,    2650.0,    900.0,   0.1000  #      2
     1.4000,    2100.0,    653.0,   0.0500  #      3
     1.4000,    2100.0,    650.0,   0.0500  #      4
     0.7600,    2710.0,    837.0,   0.0060  # 10   1
```

```
     0.0000,        0.0,        0.0,   0.0120   #     2
     0.7600,     2710.0,      837.0,   0.0060   #     3
     0.1900,      700.0,     2390.0,   0.0250   # 11  1
     0.1900,      700.0,     2390.0,   0.0250   # 12  1
     0.1900,      700.0,     2390.0,   0.0250   # 13  1
# for each surface: inside face emissivity
   0.90, 0.90, 0.91, 0.90, 0.90, 0.90, 0.90, 0.90, 0.91, 0.25, 0.90, 0.90, 0.90,
# for each surface: outside face emissivity
   0.90, 0.90, 0.90, 0.90, 0.90, 0.90, 0.90, 0.90, 0.90, 0.25, 0.90, 0.90, 0.90,
# for each surface: inside face solar absorptivity
   0.65, 0.65, 0.60, 0.65, 0.65, 0.65, 0.65, 0.60, 0.65, 0.05, 0.65, 0.65, 0.65,
# for each surface: outside face solar absorptivity
   0.93, 0.93, 0.65, 0.93, 0.93, 0.93, 0.93, 0.90, 0.85, 0.05, 0.65, 0.65, 0.65,
```

Figure 4.1.5 Zone construction file.

The optical properties of the transparent glazing surface are contained in *reception.tmc* which is listed below in Figure 4.1.6:

```
# transparent properties of reception defined in ../zones/reception.tmc
   14    # surfaces
# tmc index for each surface
   0  0  0  0  0  0  0  0  0  1  0  0  0  1
    3   DCF7671_06nb # layers in tmc type 1
# Transmission @ 5 angles & visible tr.
    0.611    0.583    0.534    0.384    0.170    0.760
# For each layer absorption @ 5 angles
    0.157    0.172    0.185    0.201    0.202
    0.001    0.002    0.003    0.004    0.005
    0.117    0.124    0.127    0.112    0.077
    0   # blind/shutter control flag
```

Figure 4.1.6 Zone TMC file.

To define the infiltration, occupancy, equipment and lighting within the zone select *operations* and you will be placed into an editing environment which allows each of these to be defined. Normally you will focus on weekdays first and then toggle to Saturdays and Sundays. The operations file *reception.opr* is listed below in Figure 4.1.8

```
# operations of reception defined in:
# reception.opr
base case          # operation name
# control(no flow control        ), low & high setpoints
     0      0.000      0.000
        1    # no weekday flow periods
# wkd: start, stop, infil, ventil, source, data
    0, 24,     0.300     0.000     0     0.000
        1    # no Saturday flow periods
# Sat: start, stop, infil, ventil, source, data
    0, 24,     0.300     0.000     0     0.000
        1    # no Sunday flow periods
# Sun: start, stop, infil, ventil, source, data
    0, 24,     0.300     0.000     0     0.000
        4    # no weekday casual gains
# wkd: type, start, stop, sens, latent, rad_frac, conv_frac
     3,    0,   24,     800.0,       0.0, 0.200, 0.800
     3,    9,   17,     450.0,       0.0, 0.200, 0.800
     2,    9,   17,     600.0,       0.0, 0.140, 0.000
     1,    9,   17,     540.0,    300.0, 0.200, 0.800
        1    # no Saturday casual gains
# Sat: type, start, stop, sens, latent, rad_frac, conv_frac
```

```
    3,    0,   24,     800.0,      0.0, 0.200, 0.800
      1   # no Sunday casual gains
# Sun: type, start, stop, sens, latent, rad_frac, conv_frac
    3,    0,   24,     800.0,      0.0, 0.200, 0.800
```

Figure 4.1.8 Zone operation file.

There are several points within *ESP-r* where information related to the problem topology can be supplied. Within the *problem definition* menu there is the *connection and boundary* selection which allows one or more of the connections to be manually edited, topology to be checked and generated via a vertex matching algorithm or topology to be imported from surface attribute boundary specifications. Within the *geometry browse & edit* facility you may specify boundary conditions as surface attributes or import the connection topology to the surface attributes.

By definition, the initial assumption for the topology of a problem is that all surfaces face the outside. This can be confirmed by exiting to the *problem definition* menu and consulting the *connection and boundary* selection. As most of the walls face the outside a quick way to update the surface boundary attributes is to return to the *geometry browse & edit* and select *update topology from problem*.

Two surfaces in the zone do not face the outside and this can be defined in two ways:

1)   supply the boundary for the other side of the 'passage' and the 'floor' as surface attributes and then exit to the *connection and boundary* and import this information or;

2)   edit the connection in the *connection and boundary* display and then move to the *geometry browse & edit* and import the information.

After updating the problem (system configuration) file *simple_office* should look like the listing in Figure 4.1.9

```
* CONFIGURATION3.0
# ESRU system configuration defined by file
# bld_basic.cfg
*date Mon Jun 26 16:50:29 2000  # latest file modification
*root bld_basic
*zonpth ../zones                 # path to zones
*netpth ../networks              # path to networks
*ctlpth ../ctl                   # path to controls
*radpth ../rad                   # path to radiance files
*imgpth ../images                # path to project images
*indx    1 # Building only
 51.700   -0.500    # Latitude & Longitude (diff from meridian)
      2   0.200    # Site exposure & ground reflectivity
* DATABASES
*prm  /usr/esru/esp-r/databases/constr.db2
*mlc  /usr/esru/esp-r/databases/multicon.db2
*opt  /usr/esru/esp-r/databases/optics.db2
*prs  /usr/esru/esp-r/databases/pressc.db1
*evn  /usr/esru/esp-r/databases/profiles.db1
*clm  /usr/esru/esp-r/climate/clm67
*pdb  /usr/esru/esp-r/databases/plantc.db1
*ctl  ../ctl/bld_basic.ctl
*year  1967 # assessment year
*img GIF    FZON  ../images/basic_montg.gif
*img GIF    FZON  ../images/foyer.gif
*img GIF    ****  ../images/daylight.gif
```

```
# prim energy conv (heat,cool,lights,fan,sml pwr,hot water)
*pecnv  1.250 3.600 3.600 3.600 3.600 1.250
*htemis   190.000     0.200     0.100 # heating emissions CO2,NOX,SOX
*clemis   612.000     2.060     7.500 # cooling emissions CO2,NOX,SOX
*ltemis   612.000     2.060     7.500 # lighting emissions CO2,NOX,SOX
*fnemis   612.000     2.060     7.500 # fan/pump emissions CO2,NOX,SOX
*spemis   612.000     2.060     7.500 # small power emissions CO2,NOX,SOX
*hwemis   190.000     0.200     0.100 # dhw emissions CO2,NOX,SOX
*ipv  bld_basic.ipv
# sim setup: no. sets startup zone_ts plant_ts save_lv
*sps     4    3    1   10     2
   9   1  15    1  def      # period & name
*sblr bld_basic_def.res
*sipv
*end_set
   9   1  15    1  win      # period & name
*sblr bld_basic_win.res
*sipv bld_basicwin_ipv.rep
*end_set
   6   3  12    3  trn      # period & name
*sblr bld_basic_trn.res
*sipv bld_basictrn_ipv.rep
*end_set
  11   7  17    7  sum      # period & name
*sblr bld_basic_sum.res
*sipv bld_basicsum_ipv.rep
*end_set
*end_sps
* PROJ LOG
bld_basic.log
* Ground
*mgp    1
   4.60  2.80  3.30  5.10  6.10  9.60 11.40 13.60 14.30 12.70  7.50  5.50
*end
* Building
Basic 3 zone model.
     3  # no of zones
*zon   1   # reference for reception
*opr ../zones/reception.opr  # schedules
*geo ../zones/reception.geo  # geometry
*con ../zones/reception.con  # construction
*tmc ../zones/reception.tmc  # transparent constr
*zend
*zon   2   # reference for office
*opr ../zones/office.opr  # schedules
*geo ../zones/office.geo  # geometry
*con ../zones/office.con  # construction
*tmc ../zones/office.tmc  # transparent constr
*zend
*zon   3   # reference for roof_space
*opr ../zones/roof_space.opr  # schedules
*geo ../zones/roof_space.geo  # geometry
*con ../zones/roof_space.con  # construction
*zend
*cnn  bld_basic.cnn  # connections
     0   # no fluid flow network
```

Figure 4.1.9 Problem definition (system configuration) file.

Now a configuration control file must be created using the *building controls & actuation* facility. This file contains the control statements to be obeyed by the *Simulator* at simulation time. This file can be confusing for some users of *ESP-r*. Previous releases provided only minimal editing facilities, however *ESP-r* includes a extensive editing and reporting facilities which should ease the process considerably.

To set up a an ideal control with a heating capacity of 1000W max. and 0W min., a cooling capacity of 1000W max. and 0W min. and the following temperature profile:
weekday....
0h00 - 7h00 free floating
7h00 - 9h00 15°C heating setpoint and 100°C cooling setpoint
9h00 - 17h00 20°C heating setpoint and 100°C cooling setpoint
17h00 - 24h00 free floating

Saturday....
0h00 - 24h00 free floating

Sunday....
0h00 - 24h00 free floating

A summary of the meaning of the file as well as the raw file are listed below:

```
Within the current project  1 control functions have been specified.
The overall project control has been named <test 1> and the building
control has been named <summer/winter>.

The sensor for function  1 measures the temperature of the current zone.

The actuator for function  1 is air point of the current zone
The day types are Weekdays, Saturdays & Sundays

Day type  1 is valid Period: Tue  1 Jan To: Tue 31 Dec  YEAR:1991
and contains  4 control periods.
Period| Start |sensed    |actuated   | control law      |
no    | time  |property |property   |                  |
    1    0.00   db temp   > flux      free floating
    2    7.00   db temp   > flux      ideal control
        data...  1000.0     0.0  1000.0     0.0   15.0   100.0
    3    9.00   db temp   > flux      ideal control
        data...  1000.0     0.0  1000.0     0.0   20.0   100.0
    4   18.00   db temp   > flux      free floating

Day type  2 is valid Period: Tue  1 Jan To: Tue 31 Dec  YEAR:1991
and contains  1 control periods.
Period| Start |sensed    |actuated   | control law      |
no    | time  |property |property   |                  |
    1    0.00   db temp    > flux      free floating

Day type  3 is valid Period: Tue  1 Jan To: Tue 31 Dec  YEAR:1991
and contains  1 control periods.
Period| Start |sensed    |actuated   | control law      |
no    | time  |property |property   |                  |
    1    0.00   db temp    > flux      free floating
zone  1 << control  1
```

```
simple building  # overall descr
* Building
convective heating, ideal control  # bld descr
   1  # No. of functions
* Control function
# measures the temperature of the current zone.
    0    0    0    0  # sensor data
# actuates air point of the current zone
    0    0    0  # actuator data
    0 # No. day types
    1  365  # valid Sun  1 Jan - Sun 31 Dec
     4  # No. of periods in day
```

```
   0    2   0.000  # ctl type, law (free floating), start @
     0.  # No. of data items
   0    1   7.000  # ctl type, law (ideal control), start @
     6.  # No. of data items
 1000.000 0.000 0.000 0.000 20.000 100.000
   0    1   9.000  # ctl type, law (ideal control), start @
     6.  # No. of data items
 1000.000 0.000 0.000 0.000 20.000 100.000
   0    2  18.000  # ctl type, law (free floating), start @
     0.  # No. of data items
   1  365  # valid Sun  1 Jan - Sun 31 Dec
    1  # No. of periods in day
   0    2   0.000  # ctl type, law (free floating), start @
     0.  # No. of data items
   1  365  # valid Sun  1 Jan - Sun 31 Dec
    1  # No. of periods in day
   0    2   0.000  # ctl type, law (free floating), start @
     0.  # No. of data items
# Function:Zone links
  1  1  0
```

Figure 4.1.10 System control information and file.

A simulation is now performed via the *Simulator* using the climate file *˜esru/esp-r/climate/clm67*. Two simulations should be performed, saving both in the same results library called, for example, *ex1.res*. The first should span the period 9th January to 15 January inclusive. The second should span the period 11 July to 17 July inclusive. Both simulations should have a one hour time-step.

Now *Results Analysis Module* is used to see the results obtained from the simulation. After entering the library name (*ex1.res* in this case) you can select *graph*, *time-variable* and *inside air temperature* to obtain a common temperature-profile of the inside air. According to these profiles (see figures), the following items can be discussed (you should generate these profiles yourself):

1)   In winter the maximum heating capacity of the actuated control is not satisfactory to achieve the heating setpoint (20°C from 9h00 to 18h00) of the inside air. To perform the next simulation, you can change this maximum heating capacity for instance up to 3000 [W], you will notice that now -during weekdays- the setpoint temperature is reached during the afternoon (figure 4.1.11 and 4.1.13). The new control file is listed below in figure 4.1.12.

2)   In summer the cooling setpoint (100°C from 7h00 to 18h00) never actuates the cooling capacity because this setpoint-temperature never occurs. In the new control file (figure 4.1.11) this setpoint-temperature is adapted to 25°C actuating a cooling capacity of 3000 W. If you generate a temperature-profile now you can see that the inside air temperature is decreased during weekday.

Tsteps: sim@ 60m, output@ 60m (not averaged) Lib:res_9_15.jan
Period: Mon 9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967
 Zones: 1,
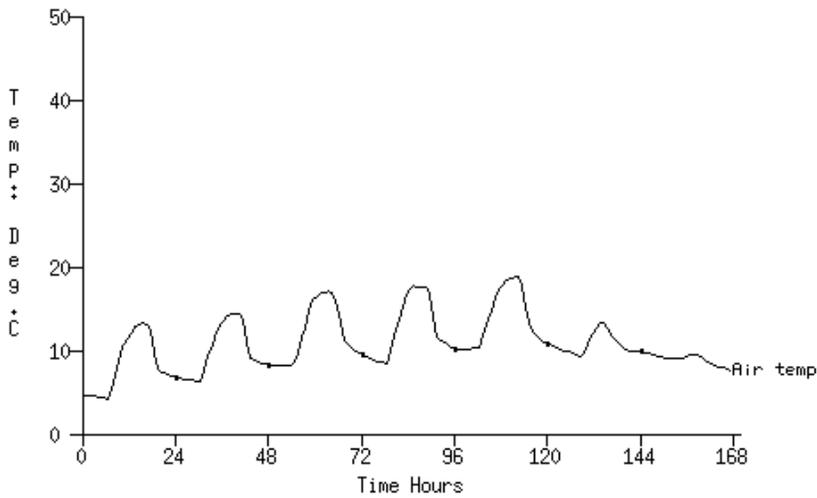
Tsteps: sim@ 60m, output@ 60m (not averaged) Lib:res11_17.jul
Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
 Zones: 1,
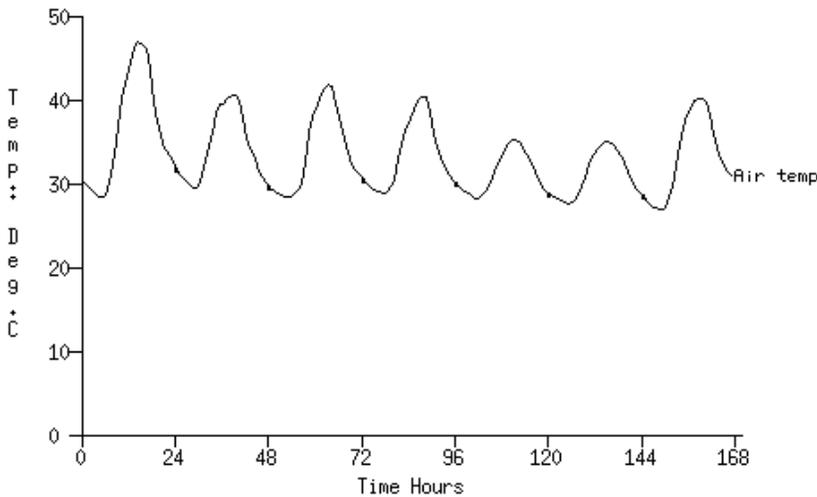
Figure 4.1.11 Temperature profiles for control as listed in fig. 4.1.10.

```
simple building  # overall descr
* Building
increased convective heating, ideal control  # bld descr
   1  # No. of functions
* Control function
# measures the temperature of the current zone.
    0    0    0    0  # sensor data
# actuates air point of the current zone
    0    0    0  # actuator data
    0 # No. day types
    1  365  # valid Sun  1 Jan - Sun 31 Dec
     4  # No. of periods in day
     0    2   0.000  # ctl type, law (free floating), start @
      0.  # No. of data items
```

```
     0    1   7.000  # ctl type, law (ideal control), start @
        6.  # No. of data items
  3000.000 3000.000 0.000 0.000 20.000 25.000
     0    1   9.000  # ctl type, law (ideal control), start @
        6.  # No. of data items
  3000.000 3000.000 0.000 0.000 20.000 100.000
     0    2  18.000  # ctl type, law (free floating), start @
        0.  # No. of data items
     1  365  # valid Sun  1 Jan - Sun 31 Dec
      1  # No. of periods in day
     0    2   0.000  # ctl type, law (free floating), start @
        0.  # No. of data items
     1  365  # valid Sun  1 Jan - Sun 31 Dec
      1  # No. of periods in day
     0    2   0.000  # ctl type, law (free floating), start @
        0.  # No. of data items
# Function:Zone links
    1  1  0
```

Figure 4.1.12 Listing of the new control file

4.12.1b Additional shading analysis

In the previous test, only a default insolation distribution has been used (i.e.. all internal surfaces receiving diffuse solar incidence). Before defining the geometry of the first test, we didn't take any notice of subjects like *solar insolation distribution*, *obstruction blocks* and *rotation & transforms*. These subjects affect the time-series dependent solar incidence.

In order to increase the resolution of the problem (to make the problem more corresponding to reality) a second variant is included called *bld_simple_shd.cfg*. You may access this by specifying it as the problem name and the relevant information will be loaded. As you can see a large obstruction (for instance a flat-block) is created at the south-side of the office.

If you select *obstruction blocks* from the *geometry*-menu you can see in detail that this obstruction is build out of four blocks. In this menu you now can change the geometry of this blocks in order to make it cope with the outdoor situation you wish to simulate. Again don't forget to update this new situation into the new obstruction file. Obstruction data are listed below in Figure 4.1.14.

```
# site obstruction file defined in ../zones/reception.obs
# associated with zone geometry file ../zones/reception.geo
 0. 0.    # dummy values for site position
    4     # no obstruction blocks
# origin  X    Y    Z     width  depth  height  angle  descr
   -5.000  -7.000   0.000   5.800   1.000  25.000    0.0  blk_1  # block  1
    1.200  -7.000   0.000   3.600   1.000  25.000    0.0  blk_2  # block  2
    5.200  -7.000   0.000   3.600   1.000  25.000    0.0  blk_3  # block  3
    9.200  -7.000   0.000  10.800   1.000  25.000    0.0  blk_4  # block  4
# grid opq X  opq Z  win X  win Z
   20     20     5     5
```

Figure 4.1.14 Obstruction data

The next action to perform is to go back to the main menu and to start the *Shading/ Insolation Module* via the *shading & insolation* option. This program calculates the insolation distribution and it writes the results to a database for use in subsequent simulations.

Tsteps: sim@ 60m, output@ 60m (not averaged) Lib:janres
Period: Mon 9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967
 Zones: 1,
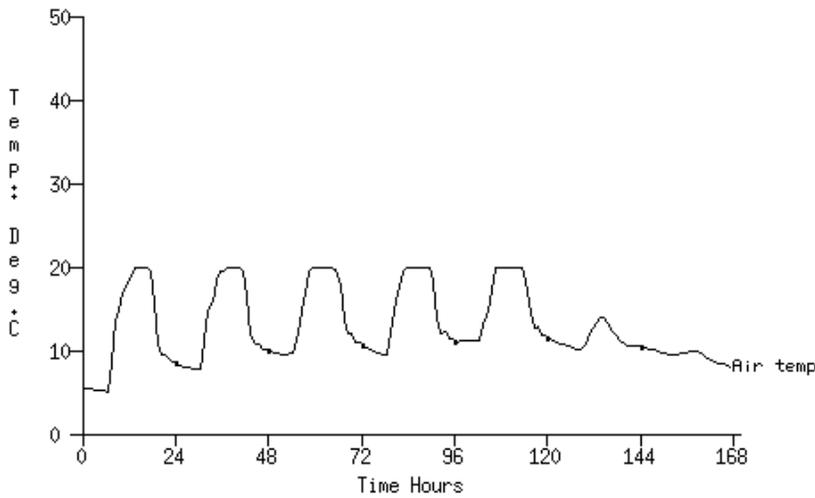
Tsteps: sim@ 60m, output@ 60m (not averaged) Lib:julyres
Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
 Zones: 1,
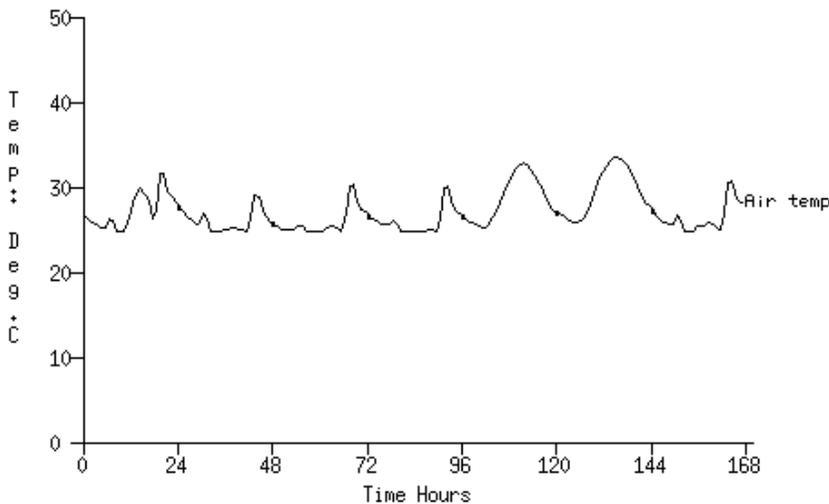
Figure 4.1.13 Temperature profiles for control as listed in fig. 4.1.12.

The results that you will obtain now show no difference in winter. In this period the solar radiation is not remarkable. However in summer (cooling capacity 1000 W, actuated at 25°C) a slight difference occurs as you can see from Figure 4.1.15. Note that in these figures the internal and external surface temperatures of the south wall are drawn instead of the inside air temperature.

If no shading/insolation database exists, the default insolation distribution of the zone operations file will be used. In this case ESP-r assumes no obstructions so that only the building geometry is needed for calculation of the insolation distribution.

Tsteps: sim@ 60m, output@ 60m (not averaged) Lib:julyres
Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
Zones: 1,

Tsteps: sim@ 60m, output@ 60m (not averaged) Lib:schad-res-11-17-jul
Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
Zones: 1,
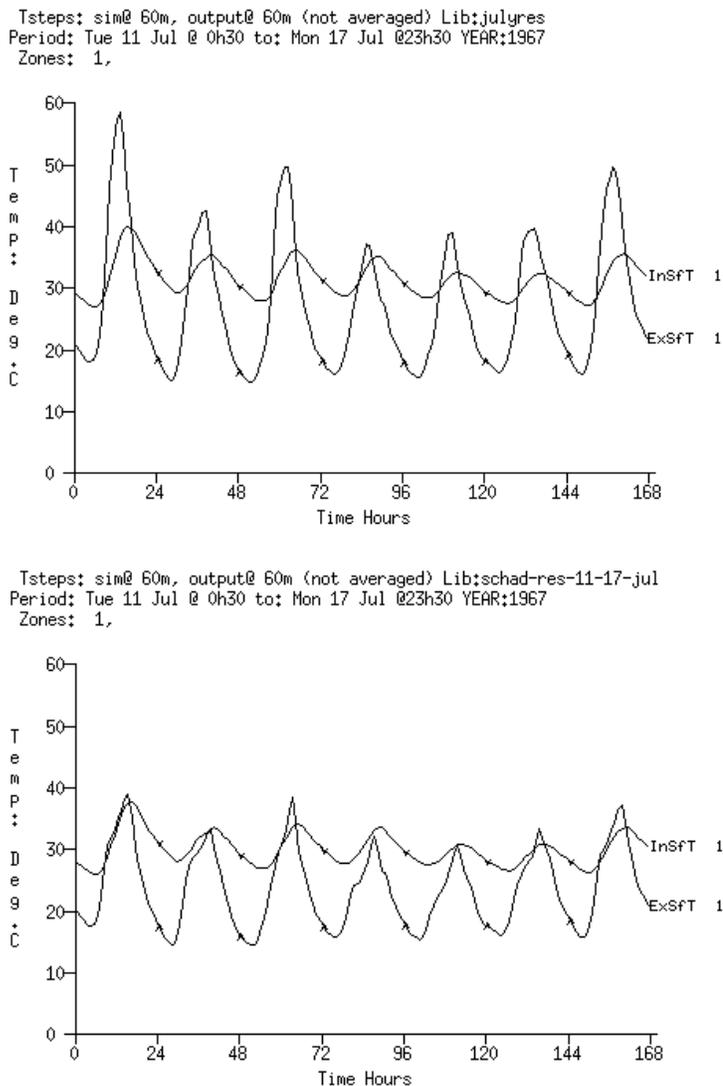
Figure 4.1.15 Temperature-profiles for summer.

4.12.2 Simple building

We now move to a multi-zone problem and ask what will be the effect on winter heating energy and summer overheating. Again there is no need to generate the zone and configuration files since the data has already been prepared and can be copied from directory *˜esru/esp-r/training/basic*.

This directory contains several subdirectories including one that contains different problem configurations. A discussion of each of the problems is contained in the files *cfg/bld_basic*.log* which may be looked at via a text editor or by the facilities provided in the project manager. A summary of these configurations is included below.

file   description
bld_basic.cfg   basic three zone model
bld_basic_shd.cfg   model with shading

file description	
bld_basic_af1.cfg	model with infiltration
bld_basic_af2.cfg	model with controlled infiltration
bld_basic_prht.cfg	model with ideal pre-heat control
bld_basic_sns.cfg	model with zone temperature matching

Each problem assumes the same building geometry and construction, only different utilities are added. The building geometry is shown below in Figure 4.2.1.

Rather than list each of the different problem files the user is invited to make use of the display facilities within the project manager or the various UNIX file listing facilities. At least you should list the different configuration files to see how the *bld_basic.cfg* geometry is used for describing different problems.

Now perform the same winter and summer simulations as were performed initially in training session 1 for the base case problem *bld_basic.cfg*. Using the results analysis program you should now compare your results with the corresponding results for the winter period 9 to 15 January in the following listings (assuming the default climate collection).
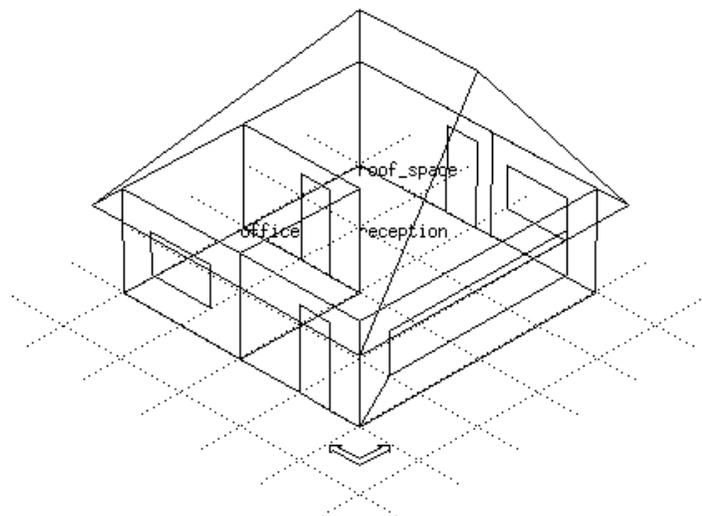
Figure 4.2.1 Simple_building geometry.

```
Selected monthly energy statistics (kWhr) by zone.
Period: Mon  9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967
Tsteps: sim@ 60m, output@ 60m (not averaged)

   Zone      Period|ML constr.** |Casual Gains |Infil.| Plant
             in|int.surf.conv| conv. radnt.|& Vent|Heat  |Cool
             |  int.  ext. |             |      |      |
1 reception Jan  -31.3  -49.3  139.2   38.2  -64.4   19.5    0.0
2 office    Jan  -17.5  -14.0    5.8    2.6    0.4   46.4    0.0
3 roof_spac Jan   10.1  -21.2   11.2   16.3    0.0    0.0    0.0
```

```
   All zones Jan   -39.   -85.   156.   57.   -64.   66.    0.

** Opaque & transparent multilayer construction: via
      conduction from surfaces facing zone (internal/external).
    Note that connections to ground are considered internal.
 Interrogation output for result-set  1
 Period: Mon  9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)

 Zone radiant & convective plant used (kWhrs)
     Zone            Heating          Cooling
  id name            Energy  No. of   Energy  No. of
                     (kWhrs) Hr rqd   (kWhrs) Hr rqd
    1 reception       19.541   39.0    0.000    0.0
    2 office          46.428   60.0    0.000    0.0
    3 roof_space       0.000    0.0    0.000    0.0

     All              65.969            0.000
 Casual gains summary (kWhrs) for zone 1: reception
 Period: Mon  9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)

 Casual gain    | Convect |  Total  | Radiant by connection type
                | portion | Radiant | external    internal    ground
 UC type 1 @opq    17.280     4.271     1.133       3.139      0.000
 UC type 1 @trn                0.049     0.049       0.000      0.000
 UC type 2 @opq     0.000     3.322     0.881       2.441      0.000
 UC type 2 @trn                0.038     0.038       0.000      0.000
 UC type 3 @opq   121.920    30.137     7.992      22.145      0.000
 UC type 3 @trn                0.343     0.343       0.000      0.000
 Totals           139.200    38.160    10.435      27.725      0.000

 @opq = associated with opaque MLC,
 @trn = associated with transparent MLC,
 UC = uncontrolled, C = controlled, all in kWhr.
 Causal energy breakdown (kWhrs) at air point for zone 1: reception
 Period: Mon  9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)


                             Gain        Loss
 Infiltration air load       0.000     -35.797
 Ventilation air load        0.179     -28.828
 Uncontr'd casual type 1    17.280       0.000
 Uncontr'd casual type 2     0.000       0.000
 Uncontr'd casual type 3   121.920       0.000
 Opaque MLC convec: ext      0.000     -28.412
 Opaque MLC convec: int      2.765     -34.043
 Transp MLC convec: ext      0.021     -20.900
 Transp MLC convec: int      0.000       0.000
 Convec portion of plant    19.541       0.000
 Totals                    162.215    -162.104
 Causal energy breakdown (Whrs) for south ( 1) in reception ( 1)
 Surface is opaque MLC, area= 16.50m2 & connects to the outside
 Period: Mon  9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)


                   Facing Zone  1          Facing Zone  0
                   Gain        Loss        Gain        Loss
 Conductive flux      0.00  -16106.23   29184.56  -15845.35
 Convective flux   7822.55      -6.54   10173.91  -13390.11
 Longwave rad int  4049.18    -325.08       --         --
 LW rad ext >bldg      --         --       20.32   -1908.40
 LW rad ext >sky       --         --        0.00  -64480.62
 LW rad ext >grnd      --         --    11175.86   -1975.07
 Shortwave rad.    1408.22       0.00   47656.58       0.00
 Unctrl cas typ 1   385.34       0.00       --         --
       cas typ 2    299.71       0.00       --         --
       cas typ 3   2718.81       0.00       --         --
 Heat stored       1837.48   -2083.43    8037.96   -8649.63
```

```
┌─────────────────────────────────────────────────────────────────────┐
│ Plant                        0.00          0.00          0.00          0.00 │
│ Totals                    18521.29     -18521.28     106249.20    -106249.19 │
├─────────────────────────────────────────────────────────────────────┤
│ Casual gains summary (kWhrs) for zone 2: office                     │
│ Period: Mon  9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967           │
│ Tsteps: sim@ 60m, output@ 60m (not averaged)                        │
│                                                                     │
│ Casual gain   | Convect | Total   | Radiant by connection type     │
│               | portion | Radiant | external    internal    ground │
│ UC type 1 @opq    5.760     1.440     0.397       0.744      0.299  │
│ UC type 1 @trn              0.000     0.000       0.000      0.000  │
│ UC type 2 @opq    0.000     1.120     0.309       0.578      0.233  │
│ UC type 2 @trn              0.000     0.000       0.000      0.000  │
│ UC type 3 @opq    0.000     0.000     0.000       0.000      0.000  │
│ UC type 3 @trn              0.000     0.000       0.000      0.000  │
│ Totals            5.760     2.560     0.706       1.322      0.532  │
│                                                                     │
│ @opq = associated with opaque MLC,                                  │
│ @trn = associated with transparent MLC,                             │
│ UC = uncontrolled, C = controlled, all in kWhr.                     │
├─────────────────────────────────────────────────────────────────────┤
│ Causal energy breakdown (kWhrs) at air point for zone 2: office     │
│ Period: Mon  9 Jan @ 0h30 to: Sun 15 Jan @23h30 YEAR:1967           │
│ Tsteps: sim@ 60m, output@ 60m (not averaged)                        │
│                                                                     │
│                          Gain          Loss                         │
│ Infiltration air load        0.000        -9.078                    │
│ Ventilation air load         9.531        -0.017                    │
│ Uncontr'd casual type 1      5.760         0.000                    │
│ Uncontr'd casual type 2      0.000         0.000                    │
│ Uncontr'd casual type 3      0.000         0.000                    │
│ Opaque MLC convec: ext       1.244       -15.231                    │
│ Opaque MLC convec: int       4.804       -22.338                    │
│ Transp MLC convec: ext       0.000         0.000                    │
│ Transp MLC convec: int       0.000         0.000                    │
│ Convec portion of plant     46.428         0.000                    │
│ Totals                      67.987       -67.952                    │
└─────────────────────────────────────────────────────────────────────┘
```

Figure 4.2.2 Tabular statistics during winter simulation period.

From this tabular report you can see that during the simulation period, the office requires most heating energy (46 kWh) while the reception looses most energy (160 kWh). The energy statistics table and the causal energy breakdown table show that the reception zone loses most energy due to conduction (total 80 kWh). However the reception zone also suffers a high casual gain from equipment (type 3) so the reception net heat loss is less than the office net heat loss.

If you look to the operation files you will see that a coupled air flow from the reception into the office is defined. In the listed energy statistics you can see that (due to this inter-zonal airflow) the heat loss from the reception to the office is more or less 10 kWh.

Next you should perform the same simulation for the summer (11-17 July) and generate a tabular report. You will obtain results as listed below.

```
 Selected monthly energy statistics (kWhr) by zone.
 Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)

   Zone     Period|ML constr.** |Casual Gains |Infil.| Plant
            in|int.surf.conv| conv. radnt.|& Vent Heat  |Cool
               | int.  ext. |             |      |
1 reception Jul  -30.7  -19.9  139.2   38.2  -80.3    0.0    0.0
2 office    Jul   -5.1   -4.7    5.8    2.6   11.9    0.0    0.0
3 roof_spac Jul    2.8  -14.0   11.2   16.3    0.0    0.0    0.0

   All zones Jul  -33.   -39.   156.    57.   -68.    0.     0.

** Opaque & transparent multilayer construction: via
     conduction from surfaces facing zone (internal/external).
   Note that connections to ground are considered internal.
```
```
 Interrogation output for result-set  1
 Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)

 Zone radiant & convective plant used (kWhrs)
    Zone            Heating           Cooling
  id name          Energy   No. of   Energy   No. of
                   (kWhrs)  Hr rqd   (kWhrs)  Hr rqd
   1 reception       0.000     0.0     0.000     0.0
   2 office          0.000     0.0     0.000     0.0
   3 roof_space      0.000     0.0     0.000     0.0

     All             0.000             0.000
```
```
 Casual gains summary (kWhrs) for zone 1: reception
 Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)

 Casual gain    | Convect |  Total  | Radiant by connection type
                | portion | Radiant |  external    internal    ground
 UC type 1 @opq    17.280    4.271     1.133       3.139      0.000
 UC type 1 @trn              0.049     0.049       0.000      0.000
 UC type 2 @opq     0.000    3.322     0.881       2.441      0.000
 UC type 2 @trn              0.038     0.038       0.000      0.000
 UC type 3 @opq   121.920   30.137     7.992      22.145      0.000
 UC type 3 @trn              0.343     0.343       0.000      0.000
 Totals           139.200   38.160    10.435      27.725      0.000

 @opq = associated with opaque MLC,
 @trn = associated with transparent MLC,
 UC = uncontrolled, C = controlled, all in kWhr.
```
```
 Causal energy breakdown (kWhrs) at air point for zone 1: reception
 Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)

                         Gain         Loss
 Infiltration air load   0.000      -29.759
 Ventilation air load    0.000      -50.511
 Uncontr'd casual type 1 17.280       0.000
 Uncontr'd casual type 2  0.000       0.000
 Uncontr'd casual type 3 121.920      0.000
 Opaque MLC convec: ext   1.258     -14.654
 Opaque MLC convec: int   0.213     -30.938
 Transp MLC convec: ext   3.420      -9.899
 Transp MLC convec: int   0.000       0.000
 Convec portion of plant  0.000       0.000
 Totals                 148.601    -148.412
```
```
 Causal energy breakdown (Whrs) for south ( 1) in reception ( 1)
 Surface is opaque MLC, area= 16.50m2 & connects to the outside
 Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
 Tsteps: sim@ 60m, output@ 60m (not averaged)

                     Facing Zone  1           Facing Zone  0
                     Gain       Loss          Gain        Loss
 Conductive flux    4721.47   -11392.12     86257.12   -81218.40
```

```
Convective flux           4928.98     -1191.62          95.71   -152806.64
Longwave rad int           629.11     -9413.97           --           --
LW rad ext >bldg              --          --           130.47    -10867.78
LW rad ext >sky               --          --             0.00   -116121.70
LW rad ext >grnd              --          --           177.24    -50955.58
Shortwave rad.            8829.52         0.00       325326.09         0.00
Unctrl cas typ 1           385.34         0.00           --           --
      cas typ 2            299.71         0.00           --           --
      cas typ 3           2718.81         0.00           --           --
Cntrld cas typ 1             0.00         0.00           --           --
      cas typ 2              0.00         0.00           --           --
      cas typ 3              0.00         0.00           --           --
Heat stored               2774.05     -3289.23        30477.60    -30494.03
Plant                        0.00         0.00            0.00         0.00
Totals                   25286.99    -25286.95       442464.22   -442464.09
```
```
Casual gains summary (kWhrs) for zone 2: office
Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
Tsteps: sim@ 60m, output@ 60m (not averaged)
```

Casual gain	Convect portion	Total Radiant	Radiant by connection type		
			external	internal	ground
UC type 1 @opq	5.760	1.440	0.397	0.744	0.299
UC type 1 @trn		0.000	0.000	0.000	0.000
UC type 2 @opq	0.000	1.120	0.309	0.578	0.233
UC type 2 @trn		0.000	0.000	0.000	0.000
UC type 3 @opq	0.000	0.000	0.000	0.000	0.000
UC type 3 @trn		0.000	0.000	0.000	0.000
Totals	5.760	2.560	0.706	1.322	0.532

```
@opq = associated with opaque MLC,
@trn = associated with transparent MLC,
UC = uncontrolled, C = controlled, all in kWhr.
```
```
Causal energy breakdown (kWhrs) at air point for zone 2: office
Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
Tsteps: sim@ 60m, output@ 60m (not averaged)


                            Gain          Loss
Infiltration air load      0.000        -4.881
Ventilation air load      16.797         0.000
Uncontr'd casual type 1    5.760         0.000
Uncontr'd casual type 2    0.000         0.000
Uncontr'd casual type 3    0.000
```
```
Causal energy breakdown (Whrs) for West_w ( 4) in office ( 2)
Surface is opaque MLC, area=  9.50m2 & connects to the outside
Period: Tue 11 Jul @ 0h30 to: Mon 17 Jul @23h30 YEAR:1967
Tsteps: sim@ 60m, output@ 60m (not averaged)


                     Facing Zone  2           Facing Zone   0
                     Gain        Loss          Gain        Loss
Conductive flux     4622.67    -3264.31      47702.53    -49506.59
Convective flux     2592.00     -689.66        109.20    -71829.94
Longwave rad int     700.83    -5732.03          --           --
LW rad ext >bldg       --          --         3400.98     -5749.41
LW rad ext >sky        --          --            0.00    -69593.95
LW rad ext >grnd       --          --          177.87    -32013.02
Shortwave rad.      1593.01         0.00     177342.20         0.00
Unctrl cas typ 1     175.57         0.00          --           --
      cas typ 2      136.56         0.00          --           --
      cas typ 3        0.00         0.00          --           --
Cntrld cas typ 1       0.00         0.00          --           --
      cas typ 2        0.00         0.00          --           --
      cas typ 3        0.00         0.00          --           --
Heat stored         1319.85     -1454.46      18571.47    -18611.29
Plant                  0.00         0.00          0.00         0.00
Totals             11140.49    -11140.46     247304.25   -247304.19
```

Figure 4.2.3 Tabular statistics during summer simulation period.

The heat loss due to the conduction through building partitions is less and infiltration & ventilation becomes the greatest heat loss factor. Because of the internal casual gains and the high cooling setpoint-temperature (100°C as you can see from the control file) no heating or cooling energy is required.

For example now it is interesting to run a simulation (winter and summer) to establish the heating and cooling energy required to maintain the zone 1 and 2 air temperatures constant at a setpoint of 24°C during the control period.

Therefore, first you should adapt the control file (or make a new one) to change the capacity and setpoint temperatures of both the heating and cooling plant. You can enter an extremely high capacity in order to be sure that the set-point temperature is reached when the control period starts. You should run the simulations and check the calculated temperature profiles using the *Results Analysis Module*. Finally, you can find the required energy data from the energy statistics.

When you perform the simulations correctly, you will find 60 and 70 kWh respectively for the reception and the office in winter and 130 and 6 kWh in summer. Due to the high casual gain in the reception less heating energy is required in winter and more cooling energy is required in summer. You can perform the same simulations as has been done for the basic problem configuration, for the other configurations.

4.12.2b Additional fluid flow analysis

At the start of training session 2, a summary of the files *bld_basic*.log* was given. As you can see, two problem definition files exist in which fluid flows are governed by a flow network. Below, a summary of these problem definition files is included.

file	description
bld_basic_af1.cfg	basic building model with infiltration
bld_basic_af2.cfg	basic building model with controlled infiltration

The basic building with air movement is restricted to flows via crack openings (under doors and around windows) in the occupied spaces. Separately, the roof is vented by soffit and ridge vents. Use the configuration control file bld_basic.ctl which provides 1kW to the reception and office.

A variation is the base case with the addition of a component 'door' between the rooms in the mass flow network and a window which is controlled. Browse and use the configuration control file *bld_basic_af2.ctl*.

The base case mass flow network is described in *bld_basic_af1.afn* and contains four boundary nodes (north, east, south, west) and three nodes (roof, recep, offic) which match the thermal zones. Mass flow components (drcrk, wincrk, soffit, roofv) define the flow restrictions. The flow paths are between each zone and the outside via window cracks and between the two occupied rooms via a crack under the door. The roof space has two flow paths to the outside - one through the soffit and one by way of the roof vent.

The mass flow network with window control is *bld_basic_af2.afn*. The control is made via a configuration control file *bld_basic_af2.ctl*. A window in the reception is assumed to open if the room temperature rises above 20°C. A similar set of paths is defined for

the office.

During a summer simulation the flow is restricted to the cracks in the windows until the room warms. Then the window opens, flow is allowed and then when the temperature drops below 20°C the window closes. In the results analysis you will probably detect a sawtooth pattern as the window opens and closes. The decision to open or close the window is only taken once per timestep and you should experiment with different simulation timesteps to see how this ventilation control changes.

As it is important to check the *leakage characteristic* of a space, we will first discuss a simple simulation of the fan pressurisation method.

A simple fan pressurisation apparatus consists essentially of a large variable-speed fan with an attached air flow measuring station. The rig is sealed into the doorway of the space under test with internal and external connections taken to a differential micro-manometer. The flow rate is measured over a range of pressure differences between 10 and 100 Pascals and the results presented as a curve of volume flow rate against pressure difference. This curve (with leakage parameters k and n) can be fitted by an expression of the form;

$$Q = k(\Delta P)^n$$

In order to simulate fan pressurisation, a mass flow network description as printed in Figure 4.2.4 can be used. Only air leakages (door and window cracks) in the reception zone (space under test) are considered. These air leakages (or flow restrictions) are determined by a thorough investigation of the room partitions. The fan pressurisation apparatus is simulated by a constant mass flow component in the east door. By altering the constant mass flow rate and reading the corresponding pressure differences from the results file, the leakage curve can be calculated (Figure 4.2.5).

```
   7     5     3     1.000      (nodes, components, connections, wind reduction)
 Node    Fld. Type   Height     Temperature    Data_1       Data_2
 north    1     3   0.0000            0.        32.000          0.
 east     1     3   0.0000            0.        32.000        90.000
 south    1     3   0.0000            0.        32.000        180.00
 west     1     3   0.0000            0.        32.000        270.00
 roof     1     0   0.0000         20.000          0.         49.000
 recep    1     0   0.0000         20.000          0.         144.00
 offic    1     0   0.0000         20.000          0.         48.000
 Comp   Type C+ L+ Description
 drcrk   120   3   0 Specific air flow crack            m = rho.f(W,L,dP)
    1.00000    1.00000E-02    1.00000
 wincrk  120   3   0 Specific air flow crack            m = rho.f(W,L,dP)
    1.00000    5.00000E-03    3.00000
 soffit  110   2   0 Specific air flow opening          m = rho.f(A,dP)
    1.00000    1.00000E-02
 roofv   110   2   0 Specific air flow opening          m = rho.f(A,dP)
    1.00000    2.00000E-02
 fan   35   3   0 Constant mass flow rate component   m = rho.f(A,dP)
    1.00000    0.05000  0.
 +Node   dHght    -Node   dHght    Comp     Snod1   Snod2
 south   0.000    recep   0.000    wincrk
 west    0.000    recep   0.000    drcrk
 east    0.000    recep   0.000    fan
# pressurisation reception
```

Figure 4.2.4 Fluid flow network describing pressurisation
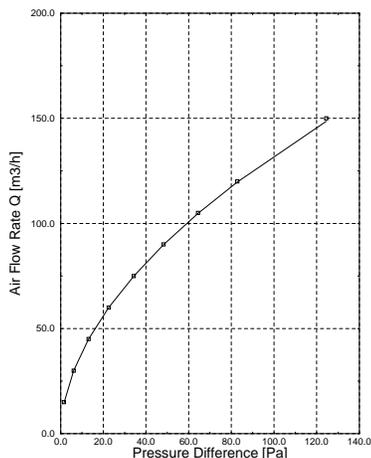
$$n \qquad = 0.53$$
$$k \qquad = 3.20 \ [dm3/s * Pa\hat{\ }1/n]$$
$$Qv,10 \qquad = 14.0 \ [dm3/s] (NEN\ 2686, Netherlands)$$

Figure 4.2.5 Leakage characteristic (simulated) for the reception zone. The graph is drawn by use of copying the predicted flow data to the XVGR tool.

The leakage characteristic as printed above should be compared with data acquired by performing a fan pressurisation (as already explained). In case differences occur between measured data and simulation results, flow restrictions should be altered. For now we assume simulation results to be correct (i.e. more or less in agreement with the measured data). Reading National Standards on pressurisation testing you will find these leakage parameters to be very low and satisfying.

Now, when copying leakage data of various zones to an overall building mass flow network, you are able to perform accurate simulations concerning energy gains and losses due to infiltration and ventilation. Results for a winter's simulation are printed below in Figure 4.2.6. Comparing these data to the ones printed in Figure 4.2.2 you will find the reception infiltration and ventilation energy loss to be less.

```
 Selected monthly energy statistics (kWhr) by zone.
 Period: Sat  9 Jan @ 0h30 to: Fri 15 Jan @23h30 YEAR:1960
 Tsteps: sim@ 60m, output@ 60m (not averaged)

   Zone      Period|ML constr.** |Casual Gains |Infil.| Plant
             in|int.surf.conv| conv. radnt.|& Vent|Heat  |Cool
                int.  ext. |            |      |
 1 reception Jan  -52.9  -64.2 139.2   38.2  -10.1   9.0    0.0
 2 office    Jan   -8.1  -11.6   5.8    2.6   -2.1  43.6    0.0
 3 roof_spac Jan   14.9  -24.9  11.2   16.3   -1.1   0.0    0.0

   All zones Jan  -46.  -101.  156.    57.   -13.   53.    0.

** Opaque & transparent multilayer construction: via
    conduction from surfaces facing zone (internal/external).
  Note that connections to ground are considered internal.
```

```
Interrogation output for result-set   1
Period: Sat   9 Jan @ 0h30 to: Fri 15 Jan @23h30 YEAR:1960
Tsteps: sim@ 60m, output@ 60m (not averaged)

Zone radiant & convective plant used (kWhrs)
    Zone              Heating          Cooling
 id name             Energy   No. of   Energy   No. of
                     (kWhrs)  Hr rqd   (kWhrs)  Hr rqd
  1 reception          9.022    22.0    0.000     0.0
  2 office            43.578    60.0    0.000     0.0
  3 roof_space         0.000     0.0    0.000     0.0


    All               52.600            0.000
```
```
Causal energy breakdown (kWhrs) at air point for zone 1: reception
Period: Sat   9 Jan @ 0h30 to: Fri 15 Jan @23h30 YEAR:1960
Tsteps: sim@ 60m, output@ 60m (not averaged)


                             Gain        Loss
Infiltration air load        0.000      -8.859
Ventilation air load         0.000      -1.224
Uncontr'd casual type 1     17.280       0.000
Uncontr'd casual type 2      0.000       0.000
Uncontr'd casual type 3    121.920       0.000
Opaque MLC convec: ext       0.000     -36.295
Opaque MLC convec: int       0.073     -53.000
Transp MLC convec: ext       0.035     -27.979
Transp MLC convec: int       0.000       0.000
Convec portion of plant      9.022       0.000
Totals                     149.146    -149.094
```
```
Causal energy breakdown (kWhrs) at air point for zone 2: office
Period: Sat   9 Jan @ 0h30 to: Fri 15 Jan @23h30 YEAR:1960
Tsteps: sim@ 60m, output@ 60m (not averaged)


                             Gain        Loss
Infiltration air load        0.000      -2.630
Ventilation air load         0.483       0.000
Uncontr'd casual type 1      5.760       0.000
Uncontr'd casual type 2      0.000       0.000
Uncontr'd casual type 3      0.000       0.000
Opaque MLC convec: ext       3.199     -14.844
Opaque MLC convec: int      11.728     -19.824
Transp MLC convec: ext       0.000       0.000
Transp MLC convec: int       0.000       0.000
Convec portion of plant     43.578       0.000
Totals                      65.232     -65.209
```
```
Causal energy breakdown (kWhrs) at air point for zone 3: roof_space
Period: Sat   9 Jan @ 0h30 to: Fri 15 Jan @23h30 YEAR:1960
Tsteps: sim@ 60m, output@ 60m (not averaged)


                             Gain        Loss
Infiltration air load        6.825      -7.971
Ventilation air load         0.000       0.000
Uncontr'd casual type 1      0.000       0.000
Uncontr'd casual type 2     11.200       0.000
Uncontr'd casual type 3      0.000       0.000
Opaque MLC convec: ext       0.031     -24.894
Opaque MLC convec: int      15.650      -0.734
Transp MLC convec: ext       0.000       0.000
Transp MLC convec: int       0.000       0.000
Totals                      33.706     -33.598
```

Figure 4.2.6 Tabular energy statistics of winter simulation

In the basic problem configuration, air change rates of infiltration and ventilation were estimated by 0.3 ($\tilde{}$ 43 m^3/h) and 1.0 ($\tilde{}$ 144 m^3/h) for the reception zone. If you analyse your mass flow results you will find these rates to be overestimated. With known wind pressure coefficients and wind velocities as boundary conditions, air flows of the

reception are in order of magnitude of 10 m^3/h for both infiltration and ventilation. Note that we already mentioned the leakage parameters to be very low.

Finally two temperature profiles (Figure 4.2.7) are added for the reception and office zone. These profiles show the difference calculated between the basic problem (solid line) and the combination with fluid flow simulation (dashed line).
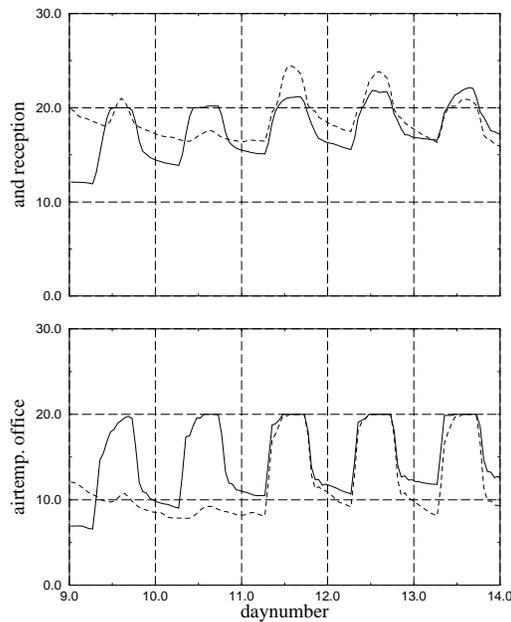
Figure 4.2.7 Temperature profiles for winter simulations.

4.12.3 Small house

This training session focuses on the training directory *house/sun_space* which holds the description of a small dwelling proposed for a remote Scottish island. It is designed for high exposure locations. The provision of a unheated but protected space for inclement weather is part of the design brief. Because of site constraints the model is rotated so that the lounge faces south-west. The dwelling is defined with ten thermal zones:

1) combined kitchen and lounge (kitliv)
2) hollow south-west wall (west_space)
3) passage (hall)
4) bathroom (bath)
5) bedroom (bed1)
6) bedroom (bed2)
7) buffer south-west portion (buf_1)
8) buffer north-east portion (buf_2)
9) upper buffer (buf_roof)
10) roof over occupied space (roof)

The dwelling has deep window reveals and its orientation suggests that a detailed treatment of shading and solar penetration is called for. To this end obstruction blocks define the deep window reveals in the bedrooms and kitchen/lounge and correctly limit sunlight entering the dwelling.

The model uses seasonally adjusted mass flow networks to predict air movements. There are timed extract fans in the kitchen and bathroom as well as logic to open the windows during particular hours and if internal temperatures rise above a particular point. This is defined in the configuration control file.

The subdivision of the buffer space into three thermal zones allows warm air to rise into the upper space but for the front and back of the space to evolve different temperatures as a result of solar radiation patterns. This requires that 'fictitious' boundaries be used between the zones and project based optical properties and multilayer construction databases have been created.

Of interest is the treatment of the south-west wall of the lounge as a separate thermal zone rather than as a conventional multilayer construction. The reason for this is the large void (300mm) within this wall which, thus described, will have a more detailed treatment of radiant exchanges.

There are two configuration files, *house_win.cfg* which is used for winter simulations and *house_sum.cfg* for summer simulations. Similarly there are two mass flow network descriptions (*ss_sum.afn* and *ss_win.afn* for summer and winter respectively). The control file *ss_win.ctl* should be used with winter simulations and *ss_sum.ctl* with summer simulations.

To browse the fluid flow network associated with a given problem use the appropriate command of the project manager. The winter fluid flow network with the corresponding control functions is listed below.

```
   13    7    18     1.000     (nodes, components, connections, wind reduction)
   Node   Fld. Type    Height     Temperature     Data_1         Data_2
   liv      1    0   1.2000       20.000          0.             62.500
   hall     1    0   1.2000       20.000          0.             40.960
   bath     1    0   1.2000       20.000          0.             26.200
   bed1     1    0   1.2000       20.000          0.             48.980
   bed2     1    0   1.2000       20.000          0.             48.980
   buf_1    1    0   1.2000       20.000          0.            113.56
   buf_ro   1    0   4.3000       15.000          0.            211.45
   ext_we   1    3   1.2000        0.             5.0000        270.00
   ext_ea   1    3   1.2000        0.             5.0000         90.000
   roof_w   1    3   4.3000        0.             8.0000        270.00
   roof_e   1    3   4.3000        0.             8.0000         90.000
   north    1    3   2.0000        0.             1.0000          0.
   buf_2    1    0   1.2000       20.000          0.             60.000
   Comp   Type C+ L+ Description
   door     130  5   0 Specific air flow door            m = rho.f(W,H,dP)
      1.00000   0.300000    2.10000    1.50000    0.920000
   door25  130  5   0 Specific air flow door            m = rho.f(W,H,dP)
      1.00000   0.300000    2.10000    0.50000    0.920000
   horop   110  2   0 Specific air flow opening          m = rho.f(A,dP)
      1.00000   3.00000
   bathex  460  3   0 Fixed flow rates controller
      1.00000   0.       2.20000E-02
   kitex   460  3   0 Fixed flow rates controller
      1.00000   0.       1.40000E-02
   crck    120  3   0 Specific air flow crack            m = rho.f(W,L,dP)
      1.00000   1.00000E-02    1.00000
```

```
 crckl   120  3  0 Specific air flow crack          m = rho.f(W,L,dP)
   1.00000    2.00000E-02   1.00000
+Node   dHght   -Node   dHght   Comp     Snod1  Snod2
ext_we  0.000   liv     0.000   crck
ext_we  0.000   buf_1   0.000   crck
ext_ea  0.000   bed2    0.000   crck
ext_ea  0.000   bed1    0.000   crck
ext_ea  0.000   buf_2   0.000   crck
liv     0.000   buf_1   0.000   crckl
liv     0.000   hall    0.000   door25
hall    0.000   buf_1   0.000   crckl
hall    0.000   bath    0.000   door25
hall    0.000   bed1    0.000   door25
hall    0.000   bed2    0.000   door25
buf_1   0.000   buf_ro  0.000   horop
buf_2   1.000   buf_ro -1.000   horop
buf_1   0.000   buf_2   0.000   door
buf_ro  0.000   roof_w  0.000   crckl
buf_ro  0.000   roof_e  0.000   crckl
liv     0.000   north   0.000   kitex
bath    0.000   north   0.000   bathex
```

```
* Mass Flow
opening control  # flow descr
   2  # No. of controls
* Control mass
# measures mass flow node or connection.
   -4    0    0    0  # sensor data
# actuates mass flow component:   4 bathex
   -4    4    1  # actuator data
    1 # No. day types
    1  365  # valid Sun  1 Jan - Sun 31 Dec
     5  # No. of periods in day
    1    0   0.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  30.000 1.000
    1    0   7.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  0.000 1.000
    1    0   9.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  30.000 1.000
    1    0  17.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  10.000 1.000
    1    0  19.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  30.000 1.000
bath          north         bathex        bath
* Control mass
# measures mass flow node or connection.
   -4    0    0    0  # sensor data
# actuates mass flow component:   5 bathpm
   -4    5    1  # actuator data
    1 # No. day types
    1  365  # valid Sun  1 Jan - Sun 31 Dec
     5  # No. of periods in day
    1    0   0.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  30.000 1.000
    1    0   7.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  0.000 1.000
    1    0   8.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  30.000 1.000
    1    0  17.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
  0.000 1.000
    1    0  18.000  # ctl type (dry bulb > flow), law (on / off), start @
     2.  # No. of data items
```

```
  30.000 1.000
liv            north          kitex          liv
```

Figure 4.3.1 Mass flow description for a small house.

By now, you should be able to extract more detailed information about the problem definition from the different problem files.

As an exercise, three different types of occupants use are considered. Those types resulting in respectively lower (E-), normal (N) and higher (E+) energy consumption are printed below in Table 4.3.2.

Table 4.3.2: Control parameters for different types of occupants use
for a single family house.

| Variables | Types of occupants use | | |
	E-	N	E+
Minimum air temperature °C			
- living floor	19	20	21
- first floor	14	16	18
- roof	14	16	18
- night set-back	16	16	16
Infiltration 1/h			
- living floor	0.20	0.40	0.60
- first floor	0.20	0.40	0.60
- roof	0.10	0.20	0.30
Infiltration + ventilation 1/h			
- apartment building	0.3	0.5	1.3
- block-house	0.6	0.8	1.0
- stand alone-house	0.7	1.0	1.3

Six simulations were performed; three simulations in which both temperatures and ventilation were controlled according to Table 4.3.2 and three simulations in which only temperatures were controlled and ventilation was governed by the original mass flow description as printed in Figure 4.3.1. January 1967 from the climate file clm67 was taken for the simulation period. The control file for one of these simulations (normal energy consumption) is printed in Figure 4.3.3.

```
winter_ht  # overall descr
* Building
winter_htg  # bld descr
   2  # No. of functions
* Control function
# measures the temperature of the current zone.
   0    0    0    0  # sensor data
# actuates air point of the current zone
   0    0    0  # actuator data
```

```
     1 # No. day types
     1  365  # valid Sun  1 Jan - Sun 31 Dec
      1  # No. of periods in day
     0     2   0.000  # ctl type, law (free floating), start @
      0.   # No. of data items
* Control function
# measures the temperature of the current zone.
     0    0    0    0  # sensor data
# actuates air point of the current zone
     0    0    0  # actuator data
     0 # No. day types
     1  365  # valid Sun  1 Jan - Sun 31 Dec
      3  # No. of periods in day
     0    1   0.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 16.000 50.000
     0    1   6.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 19.000 50.000
     0    1  22.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 16.000 50.000
     1  365  # valid Sun  1 Jan - Sun 31 Dec
      3  # No. of periods in day
     0    1   0.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 16.000 50.000
     0    1   8.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 19.000 50.000
     0    1  23.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 16.000 50.000
     1  365  # valid Sun  1 Jan - Sun 31 Dec
      3  # No. of periods in day
     0    1   0.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 16.000 50.000
     0    1   8.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 19.000 50.000
     0    1  22.000  # ctl type, law (ideal control), start @
      6.   # No. of data items
  2000.000 0.000 0.000 0.000 16.000 50.000
# Function:Zone links
  2  0  2  2  2  2  0  0  0  0
```

Figure 4.3.3 Control file for simulation of normal occupants use.

The simulation results (i.e. total energy consumption in january) are gathered in Table 4.3.4. Occupants use E- and E+ are of the same frequent occurrence as type N: the simulation shows that energy consumption for this house will vary ~230 kWh (15%) within this range of common occupants use. You can also see that the roof needs extra insulation in order to decrease energy consumption. Besides, the simulations with mass flow description show that the original mass flow description correlates (in terms of energy consumption) with the E+ occupants use.

Table 4.3.4: Calculated total energy consumption in January
for types E-, N and E+.

	ENERGY CONSUMPTION [kWhr]					
Zone	**E-**	**E-(mfs)**	**N**	**N(mfs)**	**E+**	**E+(mfs)**
- kitchen	54	127	97	138	151	153
- hall	126	141	152	146	178	147
- bath	8	2	13	1	24	7
- bed1	25	47	52	64	84	83
- bed2	28	51	52	65	83	82
- roof	1136	1117	1252	1225	1320	1293
Total consumption	1377	1484	1618	1638	1839	1764

Succeeding simulations can be performed to determine the variation in summer's cooling energy.

4.12.4 Large house

Increasing the complexity of the models we now turn to the training directory *house/svph* which is an example of a moderate size dwelling based on a direct gain house in Milton Keynes. It has become a *de facto* modelling standard within the UK.

The directory structure, as for other exemplars described above, is an example of using several subdirectories to hold different portions of the problem definition. The benefit of this is that each directory has only a limited number of files.

```
training/house/svph
'-----configuration (cfg)
'-----control (ctl)
'-----networks
'-----zones
```

4.12.5 Test cells

To be completed.

4.12.6 Special focus

There are a number of specialised facilities within ESP-r which are provided for expert users and those who require additional detail in their simulation work. Several examples are given in the exemplars. One example relates to the thermophysical property replacement facility.

It is based on the simple_building problem. The situation modelled in *constr/tp_sub* is that the conductivity of the glass wool in some of the external walls is increased when the internal air temperature rises above a certain temperature (20°C). This is obviously not a real situation, but a similar situation could occur if the conductivity of a particular constructional material was sensitive to temperature.

An additional entry (glasswool_mod, #282) has been made in the primitives database (tp_subs.pdb). This is similar to glasswool (#211) but with increased conductivity. A new

entry has also been made in the multi-constructional database (tp_subc.mlc) which is for ext_wall_mod. This is the same as for the entry for extern_wall except that it uses the modified properties of glasswool.

The control file demonstrates the activation of the replacement constructions. For the space named reception, constructions 'south', 'east' and 'north', and for the office space, constructions 'North_w' and 'West_w', use the replacement construction whenever the room temperature exceeds 20°C. In the control file, control function 1 (assigned to the reception) has a 'nested' control function 3 which gives details of the thermophysical property control. Similarly, control function 2 (for the office) has a 'nested' control function 4.

4.12.7 Office block

This session switches the focus to full scale commercial buildings with a two level office block located in the north-east of Scotland. The 17-zone model makes use of mass flow simulation and opening of windows to control summer overheating. Images of the problem (in gif format) are included in the images directory.

To access the problem definitions go into the configuration directory. Within the configuration directory is a file *office.log* which should be viewed via UNIX or project manager facilities.

As this is a large problem it is recommended that simulations be kept to a few days. In summer simulations you will note that the zone temperatures are to some extent a function of wind velocity and direction.

4.12.8 Plant

To be completed.

Section Five

Theoretical basis and validity
of the
ESP-r system

Contents

5.0 Introduction

A comprehensive description of ESP-r's mathematical model, and the verification tests applied to it, would occupy much space, and so is not undertaken here. Instead, ESP-r's theory is stated conceptually and the various publications covering theory and validity are referenced.

5.1 Theoretical basis

ESP-r uses an advanced numerical method to integrate the various equation types (algebraic, ordinary differential and partial differential) which can be used to represent heat and mass balances within buildings. The system is non-building type specific and can handle any plant system as long as the necessary component models are installed in the plant components' database. Components, if missing, can be added by a user so that they become available for selection to participate in any multi-component plant configuration. *But since component models must conform to state-space formulations, new component derivation and insertion is often a non-trivial task - the price of plant modelling in the transient domain.*

In addition to the usual energy analysis features (comfort assessment, condensation checks, and the like), ESP-r can handle the spectral analysis of glazing systems which include thin films, time varying shading caused by site obstructions, solar ray tracing, pressure and buoyancy induced air movement and complex, distributed control systems.

A conceptual explanation of ESP-r's calculation technique would go something like:

> The system offers a way to rigorously analyse the energy performance of a building and its environmental control systems. For each observable energy flow-path in the real world, ESP-r has a corresponding mathematical structure. Within a simulation, a special numerical technique ensures that all flow-paths evolve simultaneously to fully preserve the important spatial and temporal relationships. Stated briefly, ESP-r will accept some building/plant description in terms of 3-D geometry, construction, usage and control. This continuous system is then made discrete by division into many small, but finite, volumes of space - perhaps as many as 10,000 for a medium sized building. These finite volumes will represent the various regions of the building and plant within and between which energy and mass can flow. Throughout any subsequent simulation, ESP-r will track the energy and mass balance for all finite volumes as they evolve under the influence of the system boundary conditions (climate & control) and the constraints imposed by the inter-volume links. This technique ensures that all regions of the building are correctly connected across space and time and so any excitation at some point in space or time will have the correct causal effect.

The following publication details the theory and structure of ESP-r:

> Clarke J A, *Energy Simulation in Building Design*, 2nd Edition, Butterworth-Heinemann, Oxford, 2001.

ESP-r's mathematical approach is derived and the numerical method used to achieve the repetitive and simultaneous integration of each flow-path over time is explained.

As described in Section One, ESRU maintains a list of bibliographic references, describing much of ESP-r's technical detail and philosophy. This list is available from ESRU on

request.

5.2 Validity

Many model users do not yet appreciate the complexities of large scale energy model validation. Indeed it is probably true that absolute declarations of validity will never be possible. This is because the data used to describe the problem is itself subject to great uncertainty, and because the combinatorial links between input assumptions, logic representations, mathematical techniques and output interpretations is very large. It is now widely recognised that confidence levels can only be improved by developing verification *methodologies* and by repeatedly undertaking studies which aim to verify discrete aspects of a model under different operating conditions. In this respect ESP-r has a good track record. It was/is a participant model in the International Energy Agency's Annex 1, 4 and 10 projects concerned with inter-model and empirical model verification in both building and systems simulation modes. ESP-r has also been tested by several organisations external to ESRU and found to agree well with known analytical solutions and monitored data sets. On the basis of these findings the program has been declared the European Reference Model for Passive Solar Architectural Design and has been examined extensively in a SERC (now EPSRC) funded research project to develop a model verification methodology. ESP-r has also been well tested within the EC's PASSYS project. Several validation reports have been generated at ESRU and elsewhere. iA summary can be obtained by file transfer from: <ftp://ftp.strath.ac.uk/Esru_public/documents/validation.pdf>.

5.3 Model value

ESP-r is a state-of-the-art model which allows the rapid performance assessment of proposed building designs incorporating traditional and/or advanced energy features. For the first time, a user is able to conduct a high integrity, first principle appraisal whilst modelling all aspects of the energy subsystem simultaneously and in the transient domain. Indeed many design problems (for example fabric design, comfort or condensation assessment, control system appraisal, etc.) can only be meaningfully assessed when considered in this manner, as one portion of some complex set of interactions. That is, a piecemeal approach, in which a particular region is considered in isolation, is totally inappropriate and often misleading. At an early design stage a model such as ESP-r is particularly powerful since it can be used to quantify the performance impact of the site, the building geometry and construction; all factors which have considerable impact on operational performance and costs. Then, at the more detailed design stage, the model allows the designer to focus on issues of control and comfort.