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# The documentation and evaluation of building simulation models

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# THE DOCUMENTATION AND EVALUATION OF BUILDING SIMULATION MODELS

*Contractor*

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prepared by

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ETSU S 1200

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# THE DOCUMENTATION AND EVALUATION OF BUILDING SIMULATION MODELS

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## SUMMARY

S1. The work described in this paper stems from an initiative by the Energy Technology Support Unit (ETSU) to document and evaluate the building simulation models which might be used in the UK Department of Energy Passive Solar Programme.

S2. Criteria for model evaluation were developed in the four key areas of Credibility, Performance Assessment Capability, Ease of Use and Resources.

Credibility is taken as a belief that simulation results are not too far removed from reality. It was considered in terms of:

- Acceptance by the modelling community.
- Extent of participation in validation exercises.
- Technical appraisal of the model and algorithms.

Performance assessment capability relates directly to the use of models in the programme. It was considered in terms of:

- The aspects on which a design is assessed.
- Features which the model was capable of representing.
- Application of the model to example design cases.

Ease of use covers all aspects of using the model, in the areas of:

- The user interface.
- Quality and extent of documentation and user support.
- Modification and development of the model.

Resources are considered in terms of:

- Manpower required to set up and to run simulations.
- Hardware requirements.
- Computer run times.

S3. A questionnaire format was developed to obtain information from the model authors to allow easy comparison of the information given for each model and to ensure that supporting evidence to statements could be traced.

The Questionnaire was structured in a logical order which covered all relevant areas while avoiding unnecessary repetition. Unfortunately, the criteria for evaluation did not provide a suitable framework for meeting these needs, and a separate structure was developed for the Questionnaire. As a result, there was no one-to-one mapping between the replies and the criteria; most criteria require information from several sections of the Questionnaire and many answers are used for a number of criteria.

S4. The Questionnaire was sent to the author groups and a visit was made to each to discuss it and to note any ambiguous or misleading questions. A final visit was then made to discuss the replies with the authors and to make any changes which were needed.

While perhaps seeming an exhaustive and time-consuming process, it did produce a set of answers of clarity and high quality, and helped in building up additional background information.

S5. When the replies were returned in revised form, their most striking feature was the large volume of information. This was reduced and summarised in three stages:

- at the level of individual questions;
- at the level of selection criteria;
- at the level of main merits of each model.

Reduction to the first stage provided a firm basis for comparison by reducing the replies to each question to a similar form and quantity for all the models. The second stage provided the material for mapping back to the criteria, while the final summary of advantages gave a brief overview of the main results from the exercise.

S6. The mapping of the replies from the questionnaire back to the criteria involved abstracting information from different sections of the questionnaire and bringing it together to make a reasoned, but necessarily subjective, evaluation of the strengths and weaknesses of the model. The main problem was achieving a synthesis of those parts of the questionnaire which related most closely to the criterion in question.

S7. The approach adopted in the exercise was successful in evaluating large, complex simulation models on broad criteria. The use of a Questionnaire appears to be a very effective way, perhaps the only way, of obtaining the necessary information in a suitable form for comparison.

In the mapping back from replies to criteria, the lack of a one-to-one correspondence made the task more difficult. However, it is difficult to see how this could have been avoided without compromising one or both of the set of criteria and the Questionnaire content.

The feedback from this process highlighted the major problems. Firstly, completion in sufficient detail to be meaningful is time consuming. It is doubtful whether model authors would undertake the task without some form of reward. Secondly, the process involved a disclosure of information on both model structure and component algorithms which could be regarded as commercially confidential. It is doubtful whether the information would be released for models which are not in the public domain.

S8. It is interesting to note the importance of human judgement in evaluating software for modelling essentially deterministic processes. This seems to be because, while individual algorithms can be 'scientifically' compared relatively simply, their relationship with the real physical and human worlds is entirely external to the software.

# A QUESTIONNAIRE FOR THE DOCUMENTATION OF BUILDING THERMAL SIMULATION MODELS

## 1.0 INTRODUCTION

This report has its origins in an exercise to evaluate three computer models for thermal simulation. The work was initiated by ETSU with the overall objective of selecting, on the best available evidence, the simulation models which should be adopted for the UK Passive Solar Programme [1]. Part of this work was a contract awarded to Newcastle University to prepare and evaluate documented information on the three public domain models ESP [2], HTB2 [3] and SERI-RES [4], which were considered to be the most appropriate candidates for the UK programme.

The initial part of the process was to determine the criteria for model selection; to develop a questionnaire; and to establish a procedure for obtaining the replies. When this was complete, it was found necessary to condense and summarise the replies before mapping them back to the criteria for the purposes of evaluation. Finally, summary tables of the principal advantages and disadvantages of each model were devised showing how they related to the criteria.

The report on the exercise was long and specific to the UK Passive Solar Programme. However, it was felt that much of the material could be of interest to others contemplating exercises of a similar nature. These might include the evaluation of thermal models for use in areas other than passive solar design, where some of the material could be used directly. Another applicationcould be the evaluation of other large simulation packages where some aspects of the work could be adopted.

The outcome was this report, which contains a description of the exercise and the difficulties encountered and an explanation of how the evaluation was made. By way of example, some of the information on the three models is included; this helps to put the process of condensing and summarising replies into context.

## 2.0 CRITERIA FOR MODEL SELECTION

In selecting a model for a particular task, the ideal position is to have a formal and detailed specification against which the candidate model(s) can be evaluated. This would enable any shortfall in performance to be identified and an objective view to be taken of the strengths and weaknesses of the model. Within the time and resource constraint, this was not possible and consequently a formal specification was not drawn up.

This was due firstly to the complex and diverse nature of the problems being addressed and, secondly, it would have resulted in a description of a model which did not exist at that time. It was considered that a more productive way forward was to examine, more in a qualitative than a quantitative way, the four key areas which emerged as a result of discussions with individuals involved in the Passive Solar Programme. These were the following:

1) Credibility
2) Performance Assessment Capability
3) Ease of Use of the Model
4) Resources

The choice of criteria was arrived at subjectively. The same criteria may be suitable for other purposes and are not testable formally, but a different set of criteria may be necessary, dependent both on the nature of the models and the purpose for which they are required. The four areas are discussed in the following sections.

## 2.1 CREDIBILITY

Building simulation is only of use if there is sufficient confidence to make decisions and take actions on the basis of the simulation results. It is now generally recognised that simulation models cannot precisely represent reality. The magnitude of the discrepancy between simulation and reality is specific to each model and to each building/system/use pattern combination. Unfortunately there is currently little information available on this issue for any building thermal simulation model and little consensus on what levels of uncertainty could be tolerated for the different applications.

Model credibility in this context must therefore be taken as a **belief** that simulation results are not too far removed from what happens in reality. The bases of this belief (or lack of it) may come from informed technical appraisals; from the results of applying models to practical problems and (sometimes prejudiced) intuitive judgements on the current state of simulation modelling. Credibility in this context is largely a matter of judgement and implies no definitive statements about accuracy; the science of building simulation is not sufficiently advanced to make such statements possible for any area of application beyond the trivial.

The conclusion is that the users of simulation models must live for the foreseeable future with an unspecified degree of uncertainty in the output from simulation models. While work on understanding the uncertainty of simulation models is being undertaken, two parallel courses of action could be followed to add credence and reduce potential criticism of their use:

- Adopt methods of using simulation which are robust to uncertainties in the models. That is, to openly acknowledge their weaknesses and to use an appropriate strategy for dealing with these weaknesses.

- Ensure that the model(s) being used are state of the art and command some respect and confidence by others.

The former is an issue of methodology and dependent upon particular applications, but some information on the latter can be generated by establishing the **acceptance and use** of the model outside the institution or organization where it was developed; the involvement of the model in **validation** exercises and the perceived **rigour** of the algorithms and model structure.

## Model Acceptance

The term 'model acceptance' is used to encompass a number of issues (distinct from validation) which may give some indication of the credibility of the model to external users:

Evolution: The evolution of a model is indicative of the following issues which contribute towards credibility:

- The direction and aims behind developments.
- The recognition of shortcomings which have triggered modifications.
- The amount of effort which has gone into its development and the expertise which has grown up as a result.
- The 'credibility rating' by those who provide funding for model development.

External Use: External use brings with it a cross-fertilization of ideas and constructive criticism, and sometimes involvement in improving the model. While a list of outside users can be provided, it does not always make clear how extensively a model has been used, although resulting reports can sometimes help. In general, significant external use may indicate that:

- The model is adequately documented for people unfamiliar with its use.
- The input and output data structure and user interface are sufficiently developed for outside users.
- The program will recover from most simple errors made by the user.

The author groups know that they will be judged by the performance of the model, so will only release it when they themselves have some confidence in it.

Future Developments: Future developments often consist of the visions of enthusiastic authors who have yet to secure funding for their ideas. Information on work already in hand, and the general status of the author group and the current model, provide more useful pointers to the future. Of particular interest to potential external users are:

- Availability of funding suggests that the model is perceived as being reliable and that it has a future role to play.
- Fundamental development is unlikely to occur if the software structure is not robust enough to support modifications and additions.

## Validation

A major strand in any argument to support claims of credibility and confidence for any model is its involvement in exercises aimed at establishing its validity.

It is easy to be critical of attempts at model validation. For example, early empirical validation exercises were originally intended to demonstrate the accuracy of the model, but experience has subsequently shown this to be a naive approach. At best, it simply showed by how much (and possibly why) the model diverged from reality for one particular situation. At worst, and quite often, the exercise failed completely because an empirical 'truth' data set of adequate quality could not be produced. While later validation studies have been more comprehensive in their treatment, encompassing inter-model comparison exercises and sensitivity studies, they have yet to fully establish the uncertainties involved with simulation in the building field for any model.

Nevertheless, the process of being used in validation exercises is valuable in itself, for example:

- Independent scrutiny of code often leads to the questioning of assumptions made by the model authors.
- Different boundary conditions and building types will test the scope of the model and may lead to new or improved algorithms.
- Major bugs will normally be shown up.
- Inter-model comparisons often stimulate examination of algorithms, assumptions and input data.

While a review of the performance of the models in validation studies is important in model section, it is a major exercise in its own right. Nevertheless, determining the extent to which the model author groups have been involved in validation studies gives some indication of their concern for the quality of the simulation model.

### Technical Appraisal

A major requirement of any model is that it should be capable of adequately representing the physical systems and situations which are of interest.

Judgements are necessarily of a qualitative nature and based on an understanding of the models' internal structure and depth of treatment of physical processes and components. There are significant difficulties in making such judgements since, at the present time, not enough is known about the depth of treatment needed for adequate modelling of different features in different applications.

In practice, simulation models range between attempts at incorporating an exact and rigorous treatment of all phenomena (impossible to achieve), to very simple treatments in which many phenomena are lumped together and represented by a reduced number of parameters. The simplifications used in a reduced parameter model are intended to be close to realism in a limited set of conditions where they may perform perfectly adequately. A more rigorous, first-principle approach makes fewer simplifications and therefore has the potential of greater applicability and the ability to model more complex situations.

However, it does not follow automatically that the first-principle approach provides 'better' or 'more relevant' answers. Provided the assumptions in the reduced parameter model are not seriously violated, the simpler approach can provide equally valuable answers. There are many reasons to justify such a view, among which are:

- Features in a complex model may be represented by algorithms representing empirically-derived relationships, such as convection coefficients, which are inappropriate to many problems. The resulting simulations may be worse than a simpler approach using, for example, constant values.
- Both approaches require user inputs which may, for different reasons, be difficult to estimate; the reduced parameter model demands broad estimates of things not calculated, such as the radiation distribution, while the first-principle model demands parameters for algorithms which may not be readily available, such as soil properties.
- In all models, there are inconsistencies in the depth of treatment used for different features and the overall accuracy of the simulation may well be determined by the crudest treatment. For example, the error in estimating the annual auxiliary energy requirement may be large, even if the fabric flow is ac-

curately modelled, due to the relatively poor modelling of infiltration and ventilation losses.

While these difficulties must influence the conclusions that can be drawn, an examination of depth and rigour can reveal:

- Whether algorithms incorporated in the model represent the current state of the art.
- A lack of physical realism in the assumptions underlying the algorithms.
- Problems in the provision of input data which are either not easily available or tedious to supply.
- Differences in the uniformity of treatment of different algorithms.
- Energy flow paths not represented in sufficient detail leading to limitations in the problems that can be addressed.

## 2.2 PERFORMANCE ASSESSMENT CAPABILITY

A major and obvious requirement is that the model must be capable of carrying out the necessary performance assessments. A performance assessment can be viewed as the testing and evaluation of a design hypothesis, a process which can be broken down into three distinct parts:

- Determining the aspects on which a design is to be assessed.
- Determining the features which must be available in the model to adequately represent the physical system to be assessed.
- Establishing the method to be used in carrying out a particular performance assessment.

The latter is not addressed in this paper since it is concerned with how the performance assessments should be carried out, which should be model independent. It should, however, with some thought, be possible to determine the capabilities required for a given application. This is not a trivial task since it involves translating a complete understanding of the problem area in terms of both the range and level of treatment of the physical processes that have to be addressed.

This analysis tends to result in the specification of the minimum capabilities required of the model since it may not recognise the continual development in the range and nature of the design questions and the performance assessment that simulation models are being asked to address. For example, in the ETSU Passive Solar Programme, an initial concern with annual space heating energy expanded to encompass comfort and subsequently daylighting, and a more realistic treatment of plant and controls and air movement is now seen as being important in many situations.

This evolution in performance assessments makes it extremely difficult to draw a boundary around the required capabilities of the model. To do so is tantamount to anticipating all the possible questions which designers might wish to address. The conclusion is that there is a need for the model to be capable of responding to future developments.

Depending upon the application, this may require some or all of the following:

- The model possesses, as a minimum, the required performance assessment capability.
- The availability of experience of using the model and source code and user documentation.

- The flexibility to enable algorithms to be changed and new ones added.
- The potential for dealing with future developments in building components and services.

## 2.3 EASE OF USE

For the efficient employment of resources, ease of use of the models is essential. This is considered under three headings: the user interface; documentation and support; and ease of modification.

**The User Interface:** The interface between the model and the user must either be at a sufficiently developed stage or capable of development so that it can be operated successfully by the user.

There may be a need to tailor the model interface to meet the particular needs of a user, especially where standardised performance assessments are being carried out. This streamlining reduces the manpower requirement. The primary requirements are therefore to determine the nature of the existing interface and whether this is already satisfactory, or could be made so within acceptable times and costs, by determining

for inputs:

- The level of user support.
- The time required to become familiar with using the model.
- The guidance available on translating from physical description to input data set.
- The size and form of the input data structures, and the ease with which they may be edited.
- The extent and nature of default values for values not specified by the user.
- What checks are made to ensure that input data are reasonable and consistent.

for outputs:

- The range of possible outputs and the control exercised by the user over the level of output.
- The size and form of the output data structures.
- The facilities available within the model for the processing and communication of the simulation results.
- The ease with which output data sets may be linked to other software for post-processing, such as high quality graphics.

**Documentation and Support:** Documentation and software support are seen as being essential to any programme of simulation studies, even where there is a good blend of computing and architectural science skills. Guidance is essential in helping the user to understand how the model works, to be aware of its limitations, to make intelligent use of its features and to prevent misconceptions arising.

Enquiries must therefore be made with respect to:

- The state of both the user and source code documentation and the level of support available from the model author groups.

**Modification and Development:** The evolutionary nature of performance assessments, already discussed, imposes a need to modify and to extend models. Enquiries must therefore be made of the ease with which the following modifications may be effected:

- Temporary modifications for testing, special configurations, controls or outputs.
- Extensions to capabilities, with little change to existing code.
- Major revisions and extensions affecting the whole model.

## 2.4 RESOURCES

The nature of the problem and the number and duration of simulation runs generate a demand for both manpower and computing resource. Ensuring that costs can be contained is an essential part of any programme of work and may have a significant impact on model selection.

### Manpower Resources

Experience of using models has identified a need for both computing and architectural science skills. An important consideration is the range and balance of skills required and the effort required to carry out the simulations.

The manpower effort is dependent upon both the manpower skills available and the frequency of model use. The model may be used routinely by a group having specialist computing and building science skills; or used occasionally by people without specialised knowledge in architectural or similar practices. The need is therefore to assess:

- The implications for the manpower resources and the skills necessary for using different models.

### Computing Resource

The selection of the model can have resource implications; the machine used must have the hardware features required and sufficient processing power and memory to run the simulations. The run time problem could of course be solved either by investing in more hardware or by changing the methodology so that fewer runs are required.

The enquiries to be made regarding hardware are:

- The hardware facilities required for the model, leaving sufficient spare working capacity.
- The computing time needed to run simulations.

## 3.0 OBTAINING THE INFORMATION

A questionnaire format was adopted to allow easy comparison of the information given for each model and to ensure that supporting evidence to statements could be traced.

The previous work of Littler [5], Lebens [6], James [7] and, especially, the BRE/SERC validation team [8,9,10] were used to establish the basic framework of the questionnaire. This was subsequently revised after a round of discussions with individuals who were actively involved in modelling in the U.K.

The questions were designed, as far as possible, to produce specific and unambiguous answers. It was difficult to avoid asking for similar information in different contexts within the questionnaire, but redundancy was avoided as far as possible. Some important questions could not be asked, such as "how accurate is the model?", because they were impossible to answer. A set of design cases was included to allow the model groups to demonstrate how the model would be used in a range of relevant applications, the application here being passive solar design. These were intended to test the model capabilities and not to test approaches to performance assessment. In general, a set of design cases would be devised which was most appropriate to the evaluation exercise being undertaken.

## 3.1 QUESTIONNAIRE FORMAT

It was clearly essential that the Questionnaire should be structured in a logical order which covered all relevant areas while avoiding unnecessary repetition. Unfortunately, the criteria for selection did not provide a suitable framework for meeting these needs and this is almost certain to be the case for any set of criteria. Consequently, a separate structure was developed for the Questionnaire. As a result, there was no one-to-one mapping between the replies and the criteria; most criteria require information from several sections of the questionnaire, and many answers are used for a number of criteria.

The final version of the questionnaire (Annex 1) is set out in ten sections as follows:

| | | |
|---|---|---|
| SECTION | 1.0 | MODEL DESCRIPTION |
| | 1.1 | Model Identifier |
| | 1.2 | Model Details |
| PURPOSE | To determine which version of the model would be released to ETSU and to obtain an outline of its hardware and software implementation(s). | |
| CRITERIA | None. | |

| | | |
|---|---|---|
| SECTION | 2.0 | STATUS OF RELEASED VERSION |
| | 2.1 | Model Evolution |
| | 2.2 | Previous Use |
| | 2.3 | Model Verification |
| | 2.4 | Documentary Evidence |
| PURPOSE | To provide an overview of the development of the model in order to assess issues relating to credibility and to give the background within which the released version can be evaluated: | |
| CRITERIA | Credibility, Performance Assessment. | |

| | | |
|---|---|---|
| SECTION | 3.0 | CURRENT AND FUTURE DEVELOPMENTS |
| | 3.1 | Current Enhancements |
| | 3.2 | Current Funding |
| | 3.3 | Short Term Enhancements |
| | 3.4 | Future Developments |
| PURPOSE | To anticipate any current and future developments which would be of value to the user. | |
| CRITERIA | Credibility, Performance Assessment. | |

| | | |
|---|---|---|
| SECTION | 4.0 | MODEL STRUCTURE |
| | 4.1 | Primitives |
| | 4.2 | Philosophy |
| | 4.3 | Data Transfer |
| | 4.4 | Geometric Representation |
| | 4.5 | Time |
| | 4.6 | Coupling of Air and Fabric |
| | 4.7 | Coupling of Building and Controls |
| | 4.8 | Multi-zone Treatment |
| | 4.9 | Numerical Solutions |
| | 4.10 | Preconditioning |
| | 4.11 | Limitations |
| PURPOSE | To establish the major structural features of the model in order to determine the overall level of treatment and any major limitations to its performance assessment capability. It is also indicative of possible constraints on future developments. | |
| CRITERIA | Credibility, Performance Assessment, Ease of Use. | |

| | | |
|---|---|---|
| SECTION | 5.0 | COMPONENT ALGORITHMS |
| | 5.1 | Solar Radiation |
| | 5.2 | Building Fabric |
| | 5.3 | Ventilation, Infiltration and Interzone Air Movement |
| | 5.4 | Heat Transfer Mechanisms |
| | 5.5 | Stratification |
| | 5.6 | Casual Gains |
| | 5.7 | Moisture |
| | 5.8 | Occupancy Effects |
| | 5.9 | Comfort |
| | 5.10 | Heating and Cooling Systems |
| | 5.11 | Plant and Controls |
| | 5.12 | Daylighting Systems |
| PURPOSE | To establish the treatment of the thermo-physical processes which are of concern to the user, (e.g. solar radiation and air movement). | |
| CRITERIA | Credibility, Performance Assessment. | |

SECTION 6.0 MODEL FEATURES

6.1 Performance Assessments
6.2 Documentary Evidence
6.3 Building Features
6.4 Plant and Control Features
6.5 Documentary Evidence
6.6 Design Cases

PURPOSE To establish the performance assessment capability, enquiries are made in the context of a particular application. The Design Cases are seen as being of considerable importance in bringing together the model dependent issues involved in making performance assessments.

CRITERIA Credibility, Performance Assessment.

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SECTION 7.0 SOURCE CODE

7.1 Availability
7.2 Coding
7.3 Updating
7.4 Source Code Modifications

PURPOSE To establish the availability of the source code and the ease with which it can be modified. Past experience has shown that source code modification is an essential requirement for adapting the model to meet the evolving needs of the user.

CRITERIA Performance Assessment, Ease of Use.

---

SECTION 8.0 USER SUPPORT

8.1 Availability
8.2 Updating
8.3 User Experience
8.4 Modelling Strategies
8.5 Assistance
8.6 Support

PURPOSE To establish the level of current and future user support in terms of solving software problems, supplying documentation, and updating software as required.

CRITERIA Credibility, Performance Assessment, Ease of Use, Resources.

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SECTION 9.0 USER INTERFACE

9.1 Data Input and Input Constraints
9.2 Output Data Sets
9.3 Training Period
9.4 Free comment on User Interface

PURPOSE To determine the quality of the user interface in terms of documentation, ease of data input, error checking and proceedings for output data processing and interpretation.

CRITERIA Credibility, Performance Assessment, Ease of Use, Resources.

| | |
|---|---|
| SECTION | 10.0 FREE COMMENT |
| PURPOSE | To allow the model groups to raise any points they feel have been inadequately covered elsewhere in the Questionnaire. |
| CRITERIA | Credibility, Performance Assessment, Ease of Use, Resources. |

## 3.2 MANAGEMENT PROCEDURE

A draft of the Questionnaire was sent to the author groups, and a visit was made to each to dicuss it and to note any ambiguous or misleading questions. A revised Questionnaire (Annex 1) was then sent for completion and return. A final visit was then made to discuss the replies with the authors and to make any changes which were needed.

While perhaps seeming an exhaustive and time-consuming process, it appeared to work well. The visits were found to be very helpful. They produced a set of questions and answers of clarity and high quality, and helped in building up additional background information which was found to be invaluable for the later stages. By imposing a series of meetings on the author groups, it was possible to adhere to a programme more easily than it might have been using correspondence, given the other pressures on the author groups.

## 3.3 NATURE OF REPLIES

In order to answer questions fully, it was necessary to disclose detailed information on algorithms and model structure. This caused no problems for the models under study because they are all in the public domain and much is already known about the software. However, for many commercial models, this would probably be unacceptable.

When the replies were returned in revised form, their most striking feature was the large volume of information. When replies were compared, it was clear that despite the careful structuring of questions, the authors had dealt with each question in a slightly different way. The space given for answers varied and had been designed to indicate approximately the amount of information expected, but with no strict limit enforced. Nevertheless, the replies varied greatly in length, with short replies often being quite adequate.

This variation in length sometimes reflected differences in the extent or depth of model treatment, but also the individual approaches to the answering of the questions.

It was clear that much effort had gone into responding to the Questionnaire. Such a good response could not be expected from an author group with no potential rewards in prospect for their efforts.

## 3.4 BACKGROUND INFORMATION

During the evaluation of replies, it was felt that no significant areas had been missed out of the Questionnaire. On the other hand, a considerable amount of additional background information on the model had been gathered. Sources included demonstrations of the models, examinations of hard copy of inputs and outputs, and off-the-record comments from authors groups and others. This 'informal' information had contributed an important part to the exercise. In retrospect, it seemed that the Questionnaire could not have been extended to elicit such information, however detailed or searching the questions; the information lay in another dimension.

Firstly, language cannot adequately portray many complex non-verbal processes (such as using an editor). Secondly, many conclusions are only drawn after mentally sifting a large amount of formal and informal information. It would have been ineffective to enquire these of model authors directly; due to the special postion and intimate familiarity of the authors with their models, certain questions could not have been fairly asked, while others would not have produced useful answers.

## 3.5 PROCESSING OF INFORMATION

Given the diverse nature of replies and the importance of background information, it was necessary to reduce and summarise the material. This was done in three stages:

- at the level of individual questions;
- at the level of selection criteria;
- at the level of main advantages and disadvantages.

Reduction to the first stage provided a firm basis for comparison by reducing the replies to each question to a similar form and quantity for all the models. The second stage provided the material for mapping back to the criteria, while the final summary of advantages gave a brief overview of the main results from the exercise. This is described in more detail in Section 4.0 to 6.0.

# 4.0 STAGE 1: SUMMARY OF REPLIES

To produce a first-stage analysis of the replies, the documentation for each model [11,12,13] was evaluated and a summary of all three models together was prepared in the format of the Questionnaire, with a summary section for each question. The first task was to decide what referred specifically to the model in its present form and to distinguish it from additional background material and methods which may be routinely applied but are strictly external to the model. For example, in a performance assessment there is a need to separate the method of approaching the problem from model capabilities.

The next step was to filter out the superfluous information, whatever the differing amounts given, and then to summarise the residual essential information for each model. For most questions this summary was just a short paragraph or a single line. A brief conclusion was also made for each question, designed to assist the reader to identify similarities and differences. For example; "All model treatments similar", or "The lack of ... in X is a serious disadvantage for ... ".

In some cases, judgements were made on possible improvements to models; if it was felt that an important shortcoming in one model compared to the others could (or could not) be overcome by a simple software change, then this was stated. Such judgements reflected the belief that models are likely to continue to evolve and improve according to application.

The outcome of this stage is given as Annex 2. By combining material from all the models under each question, comparisons were greatly facilitated and most of the subsequent work was done using this as the base, with only occasional reference to the original replies being required. However, the availability of the original replies must still be regarded as an essential element in the evaluation.

## 5.0 STAGE 2: EVALUATION AGAINST CRITERIA

The next stage of the analysis was to map the replies from the questionnaire back to the criteria described in Section 2.0. This involved abstracting information from different sections of the questionnaire and bringing it together to make a reasoned, but necessarily subjective, evaluation of the strengths and weaknesses of each model. The main problem was achieving a synthesis of those parts of the questionnaire which related most closely to the criterion in question. At this point the material no longer related directly to the replies and was at a much more general level, with some sections from the Questionnaire relating to more than one criterion. Thus it was a difficult exercise which required a thorough familiarity with the replies and a careful objectivity.

In addition, under each criterion a table of ratings from 1 to 4 for each model and each Questionnaire section included under this criterion was given, with a similar overall table of ratings at the end. While the ratings could be criticised as a very coarse measure, they were useful in making an overall judgement of the models on the criteria. The evaluation of the models against the criteria and the table of ratings are not covered in this report. The reasoning behind this decision is that the models were being evaluated in the context of a particular need and consequently may not be representative of other uses. Consequently, the discussion is limited to setting out some of the issues lying behind the process.

## 5.1 CREDIBILITY

Model Acceptance: The evolution of the model is usually fairly well- known and can be described succinctly. External use is more difficult because use by external groups can vary from progressing little further than acquiring the software, to continuous use. However, the number of active outside users gives some indication of the popularity of the model and acceptability in the modelling community. A description of future developments can be difficult to interpret due to the vagueness of terms. (What, for example, does an 'Intelligent Front End' mean for a particular model?). Future plans may also be coloured by the level of enthusiasm of the authors.

Overall, the answers on this aspect tend to speak for themselves, at least for anyone already familiar with the models being considered.

**Validation:** Limiting the questions to a list of validation exercises without attempting to examine the outcomes is useful for the reasons outlined in section 2.1, and is unambiguous. It can be interpreted, albeit crudely, as 'the more the better'.

**Technical Appraisal:** It is important to have an overall appreciation of model depth, rigour and structure before becoming involved with details of the algorithms; therefore Model Structure was considered separately from Component Algorithms in the questionnaire. While the questions on Model Structure can elucidate certain key points, much of the interpretation comes from general familiarisation and from informal discussion with authors and users outside the model author groups.

Although a precise criterion cannot be formulated relating to model algorithms, questions about these must be precise and detailed. The answers complement the answers on Model Structure by filling in the framework. The overall accuracy of a model depends on the accuracy of all the processes modelled. Therefore key algorithms important for particular aspects of modelling need explaining in detail.

In the interpretation, the first problem was to reduce the large amount of information without losing the important points, and then to separate default algorithms from options. Many options require a large amount of work on the part of the user, and are consequently rarely used. For example, HTB2 requires detailed shading information in the form of masking templates for external surfaces supplied by the user from a preprocessor program. In comparing models, therefore, it was important to bear in mind which capabilities were only achievable through option and the additional effort involved.

## 5.2 PERFORMANCE ASSESSMENT

Determining the Performance Assessment Capability from the questionnaire replies involves a consideration of Model Outputs, the Physical Features which can be modelled and the example design cases. The design cases help to put many aspects of modelling into a particular context, while replies on other aspects give information relevant to all types of assessment.

The answers on model outputs cannot adequately portray the output facilities; this can only come from using the model for real problems. For example, ESP has a database of outputs from which many variables can be derived, including derived variables such as various comfort measures. However, this does not convey the fact that although the database access is quite powerful, some values, such as external temperature, cannot be listed from within this module, only plotted on a graph. Very often, what cannot be obtained is as important as what can.

A description of the solar, plant and control features which can be modelled gives little information on how difficult they are to set up. For ESP, a full plant and control modelling capability is available in principal, but this is very difficult to use and in practice rarely, if ever, employed by many users. By contrast, SERI-RES has plant features which are much more primitive in modelling terms, but which can easily be set up by the user. The section on Component Algorithms helped to explain the approaches adopted in the design cases, which are largely constrained by the algorithms available.

The design cases were found to produce some of the most useful and revealing answers of the questionnaire. The cases were selected to test the models adequately without being biased towards the strengths of any model, while representing a range of typical problems. This section was very helpful for putting together the model capabilities and algorithms, the features which could be modelled, and the outputs into the context of a quasi-real problem. In general, a set of design cases would be devised which was most appropriate to the evaluation being undertaken.

On aspects not currently included within the models, phrases such as "... but could be included by a simple modification to subroutine XYZ" are impossible to interpret without being familiar with the software, but it is fairest to ignore them. The case study for air flow modelling highlighted limitations of SERI-RES, when it was described as being not recommended to be used for this problem. Unlike most sections, which were of necessity generalised, this section served to illustrate matters of particular concern for the Passive Solar Program.

It is important to appreciate that the outcome reflected individual modelling approaches; other respondents would almost certainly have tackled the problems somewhat differently. It was necessary in the interpretation to separate this aspect from the matters relating only to the model.

## 5.3 EASE OF USE

Information for the criterion of Ease of Use came from questions on the user interface (in the section on Model Features) and the section on User Support (from within the model, from manuals, and from author groups). The mapping to the criterion was fairly direct, although an additional overall feeling for the user interface (from first hand or reported experience of it) was found helpful.

## 5.4 RESOURCES

The criterion of Resouces is divided into manpower and machine requirements. There was no separate section on resources in the questionnaire. Most of manpower needs were covered in sections on the user interface and user support, which asked specific questions on manpower, and from information on the software indicating extra work needed to obtain outputs in a suitable form. However, to obtain estimates of the total time required for a typical exercise with different models, of which the time actually using the model is only a part, involves more than can be covered in a questionnaire.

Evaluating machine resources was a difficult area. Minimum machine requirements for running each model were covered by the section on model details. However, it was not felt possible to formulate questions on resources for simulations which could lead to a meaningful comparison between models. Although it might be assumed that resource requirements could be easily expressed numerically as run times and memory requirements, this is not the case for the following reasons:

- Each model runs on one or more machines with difference characteristics, which are changing rapidly as machines evolve.
- The ratio of simulation times for different models varies with the problem.
- The amount of output which is saved can be varied in each model, resulting in different time spent writing to disc and different storage requirements.

However, some general conclusions can be drawn from user comments on run times, file sizes and results from a number of exercises.

A thorough comparison of man and machine resource requirements is itself a significant exercise which was beyond the scope of the Questionnaire. Such an exercise was carried out for the three models considered [14] and a summary of the main results and conclusions is given in Annex 3.

The exercise was carried out for two problems; a simple two- zone model of a test cell (using all three models) and a 13-zone model of a three-bedroomed detached house (using just ESP and SERI-RES).

However, the continuing evolution of the models, machines and associated software means that this is only a snapshot of a changing situation, and is limited to a small number of problems.

## 6.0 STAGE 3: SUMMARY OF KEY FEATURES

Even at Stage 2, the summary material still occupied over twenty pages, and the salient differences between the models were not clearly delineated. Therefore a summary table was produced for each model, listing the advantages and disadvantages in two columns. Each item was covered by a title and a short paragraph; most items appeared in more than one table, although naturally sometimes in different columns. It was felt that this was useful in eliminating many of the less important issues, or areas where all models were similar. The criteria for selection to which each item relates are also given.

### ESP: ADVANTAGES

*Credibility:*
**ACCEPTANCE:** The model has been under development for many years, released to about 60 groups internationally, and adopted by the European solar PASYS programme.

*Credibility:*
**ORIGIN:** Developed by a UK group with full support and future funding.

*Credibility:*
**VALIDATION:** Used in several IEA exercises, and many other validation studies.

*Credibility/Performance Assessment:*
**GEOMETRY:** Full geometry allows explicit internal radiant transfer, reduces user inputs, and allows extensions into other areas.

*Credibility/Performance Assessment:*
**HEAT TRANSFER:** Separate convective and long-wave radiation transfer allowing full definitions of temperatures and heat inputs.

*Credibility/Performance Assessment:*
**AIR FLOW:** Detailed inter-zone model for air flows driven by wind pressure, buoyancy and fans.

*Performance Assessment:*
**PLANT AND CONTROL:** Plant and control module exists for dynamic model of plant items and solar features.

*Performance Assessment:*
**APPLICABILITY:** The scope and depth of the model make possible a wide range of performance assessments.

*Performance Assessment:*
**COMFORT:** Separate air and radiant temperatures allow definition of accepted comfort indices.

*Ease of Use:*
**UNDERSTANDING:** A new user could learn to apply the model to simple problems in about a week on a taught course.

### ESP: DISADVANTAGES

*Credibility/Ease of Use:*
**USER MODIFICATIONS:** No special facilities for temporary software changes by user; software is logically structured and thoroughly documented but amount and complexity of code means changes require good knowledge of programming.

*Performance Assessment:*
**LIGHTING:** No lighting in release 5.4.

*Resources:*
**RESOURCES:** Long run times (despite long time steps) due to model complexity and large datasets; but representation can be simplified to run faster.

## HTB2: ADVANTAGES

*Credibility/Performance Assessment:*
**AIR FLOW:** Inter-zone air flows can be modelled with data from user.

*Credibility/Performance Assessment:*
**APPLICABILITY:** The existing scope, and ease of extension, allow a wide range of performance assessments to be carried out.

*Credibility/Performance Assessment:*
**FLEXIBILITY:** A highly modular and flexible structure which clearly separates different processes makes it easy to change, and to add modules; hence it is well suited to research and unusual problems.

*Credibility/Performance Assessment:*
**HEAT TRANSFER:** Convective and long-wave radiation transfer treated separately, allowing radiant-convective split for definition of temperatures and heat inputs.

*Credibility/Ease of Use:*
**UNDERSTANDING:** The simple structure combined with very good documentation make the model easy to understand; a new user could run a simple simulation within a week.

*Performance Assessment:*
**TIME:** The treatment of time is clear with few restrictions, and short time steps give good resolution.

*Performance Assessment:*
**PLANT AND CONTROL:** Basic plant and control characteristics included using 'black box' approach, easily extended, but no first principle model of plant items.

*Performance Assessment:*
**COMFORT:** Separate air and radiant temperature allow the definition of comfort indices.

*Performance Assessment/Ease of Use:*
**USER MODIFICATIONS:** Dummy subroutine 'Zipper' facility makes temporary software additions easy to implement.

## HTB2: DISADVANTAGES

*Credibility:*
**ACCEPTANCE:** The current model is a relatively recent recasting of a previous model in modular form; so far it has not been used to a large extent by outside groups.

*Credibility:*
**ORIGIN:** The model was developed in the UK but there is no current funding other than ETSU, and the level of future software support is uncertain.

*Credibility:*
**VALIDATION:** Some algorithms have been tested in an IEA annexe but used in few external validation studies.

*Performance Assessment:*
**LIGHTING:** Current version is limited to basic lighting control strategies.

*Performance Assessment/Ease of Use:*
**GEOMETRY:** No internal geometry, hence lack of physical realism in some areas, and many user inputs required, particularly for radiation transfer.

*Ease of Use:*
**USER INTERFACE:** There is little software for input and output and no graphics facilities for rapid interpretation of output.

*Resources:*
**RESOURCES:** The short time steps (necessary for stability), level of detail and modular structure mean that run times are long.

## SERI-RES: ADVANTAGES

*Credibility:*
**ACCEPTANCE:** Used for many years throughout Europe and the USA; version 1.1 has been released to nine organisations in the UK.

*Credibility:*
**VALIDATION:** Many algorithms have been rigorously tested by SERI, used in IEA exercises, and several field data and intermodel comparison exercisess.

*Performance Assessment:*
**LIGHTING:** The model includes simple lighting control algorithms, but without internal geometry.

*Performance Assessment:*
**USER MODIFICATIONS:** Dummy subroutine 'User Port' facility simplifies temporary changes and additions to code not affecting core of model.

*Ease of Use:*
**CAD INTERFACE:** Draughting tool SCRIBE makes data preparation easier and potentially more reliable.

*Ease of Use:*
**UNDERSTANDING:** The user interface is quick to learn (a few days for a simple simulation), easy to use, and well-proven in practice.

*Resources:*
**RESOURCES:** Typical annual simulations take less than an hour and model runs on small machines.

## SERI-RES: DISADVANTAGES

*Credibility:*
**ORIGIN:** It was developed in the USA with that environment in mind, but the UK version is supported here.

*Credibility/Performance Assessment:*
**GEOMETRY:** No true internal geometry means lack of physical realism in some areas; many user inputs required for radiation transfer.

*Credibility/Performance Assessment:*
**HEAT TRANSFER:** Combined convective and radiant transfer to simplify model means temperatures and heat flows always in a fixed convective : radiant ratio to each other.

*Credibility/Performance Assessment:*
**POOR CODE STRUCTURE:** The complex data structure makes even simple changes to the code in the core of the model difficult to implement.

*Credibility/Performance Assessment:*
**AIR FLOW:** Air mass not represented so air temperatures and air flows between zones not represented.

*Credibility/Ease of Use:*
**USER INPUTS:** There are many parameters whose choice of values depends heavily on user experience.

*Performance Assessment:*
**APPLICABILITY:** Lack of treatment of plant and control, internal radiation, air mass and window capacity limit range of performance assessments which are possible.

*Performance Assessment:*
**COMFORT:** Lack of separate air and radiant temperatures precludes definition of accepted comfort indices.

*Performance Assessment:*
**DAYLIGHT FACTOR:** User-defined daylight factor required, calculated outside model.

## 7.0 CONCLUSIONS

The approach adopted in the exercise has successfully provided a means of evaluating large, complex simulation models on broad criteria. The use of a Questionnaire appears to be a very effective way, perhaps the only way, of obtaining the necessary information in a suitable form for comparison. Making visits to model authors ensured a high standard of questions and replies, and developed a familiarity with the models.

The feedback from this process highlighted the major problems. Firstly, completion in sufficient detail to be meaningful is time consuming with many days of effort required. Indeed, it is doubtful whether model authors would undertake the task without some form of reward for their efforts. Secondly, the process involved a disclosure of information on both model structure and component algorithms which could be regarded as commercially confidential. It is doubtful whether the information would be released for models which are not in the public domain.

For the important issue of manpower and computer resources, evaluation is particularly difficult and is best done by as a separate exercise, ideally by an investigator equally familiar with each model and running them on the same machine.

It is clear that an exercise of this nature will generate a very large volume of information from the Questionnaire which will be indigestible in its raw form. In addition, a great deal of 'informal' background knowledge will accumulate from visits to authors and other sources, much of it not recorded.

To proceed further, both types of information must be combined and distilled into a more concentrated and potent form; this will almost certainly need more than one stage. Unless this is done by one person (with review by others), the problems of managing the process to achieve consistency of treatment will be much greater, although a team approach may be essential in a large exercise.

In the mapping back from replies to criteria, the lack of a one-to-one correspondence made the task more difficult. However, it is difficult to see how this could have been avoided without compromising one or both of the set of criteria and the questionnaire content.

It is interesting to note the importance of human judgement in evaluating entirely procedural, third generation software used for modelling essentially deterministic processes. This seems to be because while individual algorithms can be 'scientifically' compared relatively simply, their relationship with the real physical and human worlds is entirely external to the software. Software knows no context.

Finally, large computer programs have much in common with living organisms; they grow, evolve and eventually die. An exercise of this nature can only give a snapshot which will start to go out of date as soon as it is complete.

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# ANNEX 1

# QUESTIONNAIRE FOR THE EVALUATION OF BUILDING SIMULATION MODELS

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# Table of Contents

# 1.0 MODEL DESCRIPTION

Purpose: To identify and describe the fully operational version of the model which could be released to ETSU in March 1987.

Notes: In the following questionnaire all comments should refer to this released version of the model.

The simulation models and the user interfaces should be identical for the alternative hardware implementations options cited in table 1.2 below.

## 1.1 Model Identifier

If relevant describe the structure underlying the identifier used to designate released versions of the model.

## 1.2 Model Details

| | Released | Hardware Options | |
|---|---|---|---|
| | | 1 | 2 |
| Model Name<br>Identifier<br>Release Date | | | |
| Programme Languages | | | |
| Operating System | | | |
| Hardware<br>Implementations | | | |
| Memory Requirements<br>Core<br>Disk | | | |

Comment if Required

## 2.0 STATUS OF RELEASED VERSION

| | |
|---|---|
| Purpose: | To provide a context in which the released version of the model can be evaluated. |
| Notes: | Reference number refers to existing documentary evidence which should be listed on page 2.4. |

### 2.1 Model Evolution

Brief description of evolution of model indicating dates of key developments resulting in significant changes to the model.

| Date | Model Id. | Key Development | Ref. No. |
|---|---|---|---|
| | | | |

**Comment if required**

## 2.2 Previous and Current Use

Previous use of model including both ‘in house’ consultancy and external users. This should cover when and for what purposes the model was used, distinguishing between academics and industry.

| Date | Model Id. | Previous Use | Ref. No. |
|---|---|---|---|
| | | | |

**Comment if required:**

## 2.3 Model Verification

The nature and extent of verification exercises should be declared, but excluding the current SERC/BRE study.

| Date | Model Id. | Verification Studies | Ref.No. |
|---|---|---|---|
| | | | |

**Comment if required:**

## 2.4 Documentary Evidence

References to the documentary evidence cited in Sections 2.1 to 2.3

| Ref. No. | Reference |
|---|---|
| | |

## 3.0 CURRENT AND FUTURE DEVELOPMENTS

Purpose: To anticipate current and future developments.

### 3.1 Current Enhancements

Enhancements already incorporated into the version of the model which is currently under 'in-house' development.

### 3.2 Current Funding

Current funding of model; sources and amount of support including ETSU funding.

## 3.3 Short Term Enhancements

Enhancements planned within the next six months.

## 3.4 Future Developments

Anticipated future funding and plans for the development of the model.

## 4.0 MODEL STRUCTURE

| | |
|---|---|
| Purpose: | To establish the major structural features of the model. This is intended to provide an insight into the general approach adopted and to determine whether this results in fundamental limitations in the way in which buildings and systems may be modelled. |
| Notes: | Terms such as modularity, whose meaning may be in doubt, should be clearly defined<br>Where possible reference has been made to the BRE/SERC Questionnaire. |

### 4.1 Primitives

Definition of any primitive entities fundamental to structure, such as 'zone', 'wall' etc.

### 4.2 Philosophy

Brief description of the philosophy underlying the software architecture and data structures.

## 4.3 Data Transfer

Forms of data access and output at run time, distinguishing between main types of data and form of storage (eg ASCII, binary files).

## 4.4 Geometric Representation

Principle underlying geometric representation including any limitations on spatial form.

(See also question 9.1, section 3 for detailed treatment)

## 4.5 Time

1. Is allowance made for the difference between mean solar time at the site and local solar time at site (ie the equation of time)?

2. Is it possible to represent a difference between mean solar time and local clock (time zone) time?

3. Is it possible to include British Summer Time, Daylight Saving Time and the like?

4. How does the program treat the time difference between the site and the location(s) at which weather data was recorded?

5. How does the program handle the effects of differences in latitude, and uncorrected differences in time and or longitude between site and weather data, e.g. what does it do when the local sun has set but there is still direct solar in the weather file?

6. Can schedules for casual gain depend on local solar time (e.g. for lighting) separately from clock time (e.g. activities)?

7. Can schedules distinguish between different days of the week, in particular can Saturday and Sunday be different from Monday to Friday?

8. How long can a simulation be; are there limits on the numbers of time steps, the length of each time step, the total period simulated? Can the program handle leap years?

9. Does the program expect the weather data file to contain values that are averages over some time interval t, or spot measurements at some time T? If values are associated with T is the average taken between T-t and T; T-t/2 and T+t/2, or T and T+t? E.g. what does hour one mean in the weather file, the output and the schedules?

10. How does the temporal resolution of the model output depend on the algorithms chosen to solve the heat conduction equations and on the time step lengths used in the solutions and for schedules and weather data?

11. Which parameters can be scheduled?

## 4.6 Coupling of Air and Fabric

Way in which zones are coupled to the fabric; separate or combined radiation and convection treatment; meaning of zone or node point; and options for treatment of the transfer mechanisms in different ways.

## 4.7 Coupling of Building and Controls

The interaction of the model with control and plant modelling software. Is this software contained within the model or does it use external routines? Describe the nature of the treatment of HVAC components (eg explicitly by node representation, or using 'black-box' algorithms) and the effects of control modelling on the numerical solution (stability, convergence, iterations).

(See also questions 5.10 and 5.11)

## 4.8 Multi-zone Treatment

1. Number of independently controlled zones which can be modelled.

2. How does the program solve the inter-wall and interzone interaction problem, eg. does it solve the equations explicitly by matrix inversion or implicitly by iteration?

3. Treatment of adjacent but unmodelled zones.

4. If one space is divided into zones, for example, to handle stratification, is interzone radiation transfer possible?

## 4.9 Numerical Solutions

1. Brief description of solution technique (implicit, explicit or mixed) used at each time step, and how iteration is used if at all.

2. Criteria used to establish time step(s) for solution.

3. Is it possible for the user to specify the computational (iteration) accuracy required for a particular variable (eg, wall surface temperature or heat flux). Does the program tell the user the accuracy achieved for particular variables? Can the user always rely on achieving some known level of accuracy for some variables.

4. Treatment of non-linearity in equations, including effects of both non-linear terms in equations, and the effect of these when an implicit solution technique is used (e.g. iteration required).

## 4.10 Preconditioning

Default and user-controlled preconditioning of state variables for typical simulation, and advice to user.

## 4.11 Limitations

A statement which indicates possible limitations inherent in the formulation of the model.

## 5.0 COMPONENT ALGORITHMS

| | |
|---|---|
| Purpose: | To establish the major simulation algorithms of the model. |
| Note: | This draws heavily on the BRE/SERC Questionnaire with some additional enquiries concerning issues of particular importance to ETSU's Passive Solar Programme. |

### 5.1 Solar Radiation

1. Determination of external diffuse and direct radiation and specification of reflectivity of ground and surrounding buildings.

To be continued on additional sheets.

2. Shading of direct and diffuse radiation by surroundings and building itself, window geometry, blinds, shutters etc.

3. Treatment of single and multiple glazing systems including the use of special coatings and materials and dynamic or 'smart' glazing systems.

4. Distribution of diffuse and direct solar radiation on room surfaces and component retransmitted through the window.

5. Treatment of furnishings,internal walls and movable thermal insulation.

6. Treatment of transmission through two windows into (i) another zone, (ii) directly to outside (eg, across the corner of a conservatory).

## 5.2 Building Fabric

1. Method used for wall conduction.

2. Method used for windows.

3. Method used for ground floor conduction.

4. Method used for roof and roof spaces.

5. Method used for doors, window frames (etc) conduction.

6. Time step used for solution of conduction equation.

7. Method for determining node placement and number of nodes.

8. Treatment of walls partitions and furniture within zones.

9. Is there any facility to take into account moisture effects on fabric thermal behaviour, including latent load from evaporation from external surfaces, and changes in conduction due to moisture content of fabric?

## 5.3 Ventilation, Infiltration and Interzone Air Movement

**Treatment of infiltration and ventilation losses related to wind, temperature, occupant behaviour and mechanical systems? Inter zone exchanges within building.**

## 5.4 Heat Transfer Mechanisms

Note: For each of the following make explicit any difference in the treatment of opaque and window elements.

1. Internal convection coefficients.

2. Internal long wave radiation exchange

### 3. External convection coefficients

### 4. External longwave radiation

## 5.5 Stratification

Treatment of stratification within a zone.

## 5.6 Casual Gains

Types of casual gain included and scheduling by time, zone and radiative/ convective split

## 5.7 Moisture

Treatment of moisture production and transfer and condensation risk.

## 5.8 Occupancy Effects

To what extent can occupancy effects such as the following be taken into account:

- operating window screens, such as curtains, blinds and shutters
- window and door opening and closing
- latent inputs from washing, cooking and metabolism
- manual lighting control

If these are scheduled what is the time increment?

Can occupancy effects be initiated from within the simulation?

## 5.9 Comfort

Calculation of indices of comfort as a function of: air movement; humidity; air temperature; radiant temperature; direct solar radiation; activity; clothing levels.

Are these calculated during simulation or from output data.

## 5.10 Heating and Cooling Systems

How are heating and cooling systems modelled?

(See also question 4.7)

## 5.11 Plant Controls

How is control of heating and cooling systems implemented? How can the control points for the systems be defined.

## 5.12 Daylighting Systems

Treatment of daylight levels within zones and control of daylighting and artificial lighting installations. Can the interaction between the lighting and thermal systems be modelled.

## 6.0 MODEL FEATURES

| | |
|---|---|
| Purpose: | To identify how closely the model maps on to ETSU's simulation requirements. |
| Notes: | Within the passive solar programme simulation models are used for the following purposes: |

Understanding the behaviour of new designs

Relative performance of alternative designs

Absolute performance of alternative designs

Optimisation of performance

Design and interpretation of field trials

Design and interpretation of test cell experiments

### 6.1 Performance Assessments

In evaluating the models their ability to assess performance in the following areas will be considered. An opportunity is therefore provided to comment freely on capabilities of the model in this respect.

Note: Reference number refers to existing documentary evidence which should be listed in section 6.2.

1. Energy accounting: What accounting methods are available?

| Procedures for assessing utility of casual and solar gains.<br>Breakdown of losses by time and type. | Ref. No. |
|---|---|
| | |

Continue on next page if required

## 2. Plant Performance: Plant sizing; Demand profiles, etc

| | |
|---|---|
| | Ref. No. |

## 3. Overheating

| | |
|---|---|
| | Ref. No. |

## 4. Comfort Assessment

| | |
|---|---|
| | Ref. No. |

## 5. Utilization of Daylight and artificial lighting

| | |
|---|---|
| | Ref. No. |

## 6. Site Layout

|  | Ref. No. |
|---|---|
|  |  |

## 6.2 Documentary Evidence

References to the documentary evidence cited in Section 6.1

| Ref. No. | Reference |
|---|---|
|  |  |

## 6.3 Building Features

The determination of the scope of the model by establishing the physical features that can be handled. Additional items to be added if required.

| Note: | Type (n) Not Modelled | Type (s) Steady State |
|---|---|---|
| | Type (e) Empirical Relationship | Type (qs) Quasi Steady |
| | Type (f) First Principle | Type (d) Dynamic |

Reference number refers to existing documentary evidence which should be listed in section 6.5.

1. Features: Direct gain, conservatory, atria, isothermal storage etc.

| Feature | Type | Comment if Required | Ref. No. |
|---|---|---|---|
| | | | |

## 6.4 Plant and Control Features

The determination of the scope of the model by establishing the plant and control features that can be handled. Additional items to be added if required.

| Note: | | |
|---|---|---|
| | Type (n) Not Modelled | Type (s) Steady State |
| | Type (e) Empirical Relationship | Type (qs) Quasi Steady |
| | Type (f) First Principle | Type (d) Dynamic |

Reference number refers to existing documentary evidence which should be listed in section 6.5.

1. Heat Sources and Emitters: Fires, Boilers, Electric Storage Radiators, Wet Radiators etc.

| Feature | Type | Comment if Required | Ref. No. |
|---|---|---|---|
| | | | |

2. Distribution Systems: Air, water, fans and pumps etc.

| Feature | Type | Comment if Required | Ref. No. |
|---|---|---|---|
| | | | |

3. Heat Recovery Systems: Run around coils, cross flow heat exchangers, thermal wheels etc.

| Feature | Type | Comment if Required | Ref. No. |
|---|---|---|---|
| | | | |

4. Plant Controls: Thermostats, radiator valves, proportional, integral, digital control etc.

| Feature | Type | Comment if Required | Ref. No. |
|---|---|---|---|
| | | | |

5. Domestic Hot Water Supply.

| Feature | Type | Comment if Required | Ref. No. |
|---|---|---|---|
| | | | |

6. Lighting Controls: Manual, Photo electric, Dimming.

| Feature | Type | Comment if Required | Ref. No. |
|---|---|---|---|
| | | | |

## 6.5 Documentary Evidence

References to the documentary evidence cited in Section 6.4.

| Ref. No. | Reference | | |
|---|---|---|---|
| | | | |

## 6.6 Design Cases

Many aspects of modelling have already been addressed. However, it is difficult to appreciate how these would all come together when the model is used. This section presents some design cases which are judged as being of importance to the passive solar programme. The authors are requested to outline the modelling techniques which they might adopt for simulations incorporating a high level of detail. It should be emphasized that the primary concern is with the capabilities of the model and not with issues related to performance assessment methods. Particular attention should be paid to the following:

(a) How the building and plant would be represented and the assumptions and approximations.

(b) The specification of the required user inputs.

(c) The modelling techniques that would be adopted to undertake the performance assessments necessary to evaluate the given design options.

(d) The output that can be generated to indicate the thermal and lighting conditions of the building to provide understanding of the mechanisms involved as an aid to design evaluation and decision making.

(e) An assessment of the time it would take a user with a good basic experience of the model to input the data for a simulation

Three examples have been selected from Energy World 1986 at Milton Keynes with the fourth example coming from the ETSU Non-domestic design studies:

1. CASE STUDY 1: WINDOW SYSTEMS
2. CASE STUDY 2: CONSERVATORY
3. CASE STUDY 3: AIR FLOW NETWORK
4. CASE STUDY 4: DAYLIGHTING

# 1. CASE STUDY I: WINDOW SYSTEMS

## Description

This case study is based on features of the Haslam Homes houses designed by the Feilden Clegg Design and the Research in Building Group of PCL, and built for the 1986 Milton Keynes Exhibition. The following description is from Ted Stevens "Case Studies", Building Design, Energy and Insulation Supplement, July 1986, and Dean Hawkes "Energetic Twosome", Architects Journal, 28th January 1987.

The houses are grouped to form protected courtyards which provide privacy in spite of the very high levels of south facing glass. This solution also affords a layout capable of using roads on a north-south grid as well as the normal "solar" east-west grid.

In the Courtyard Houses, RIB explored the limits of south facing windows using computer simulations. The computer was asked whether the use of advanced forms of glazing covering 100 per cent of the south facade could reduce heating costs still further. Simulations were carried out for a detached three-bedroom house, using the SERI-RES computer program. This showed, in round terms, that for glass with a U-value of 0.85 and a solar transmission of 50 per cent, systematically increasing the south facing area systematically decreased fuel bills until the whole facade was covered.

This idea was interpreted by Fielden Clegg Design, who felt that an enclosed court would give owners the privacy which is lost when large windows face the street.

Clerestory glazing is used to throw light to the back of the rooms. It also delivers beam solar radiation to the heavyweight north wall.

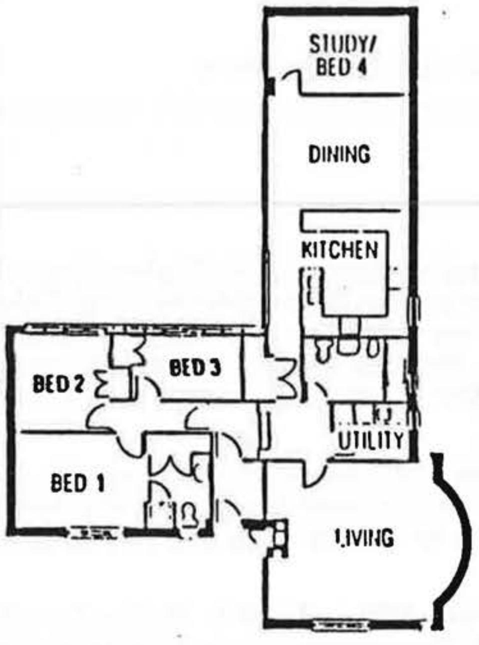
At night wide thermal curtains with few overlaps will reduce the U- value to 0.6. To prevent glare and overheating in summer, and reduce heat loss in winter, the clerestory glazing incorporates rotational louvres, white on one side and metallic on the other.

The heating system has been designed as a two temperature hot water system with a condensing boiler supplying hot water to three zones: living rooms, bedrooms and hot water supply.

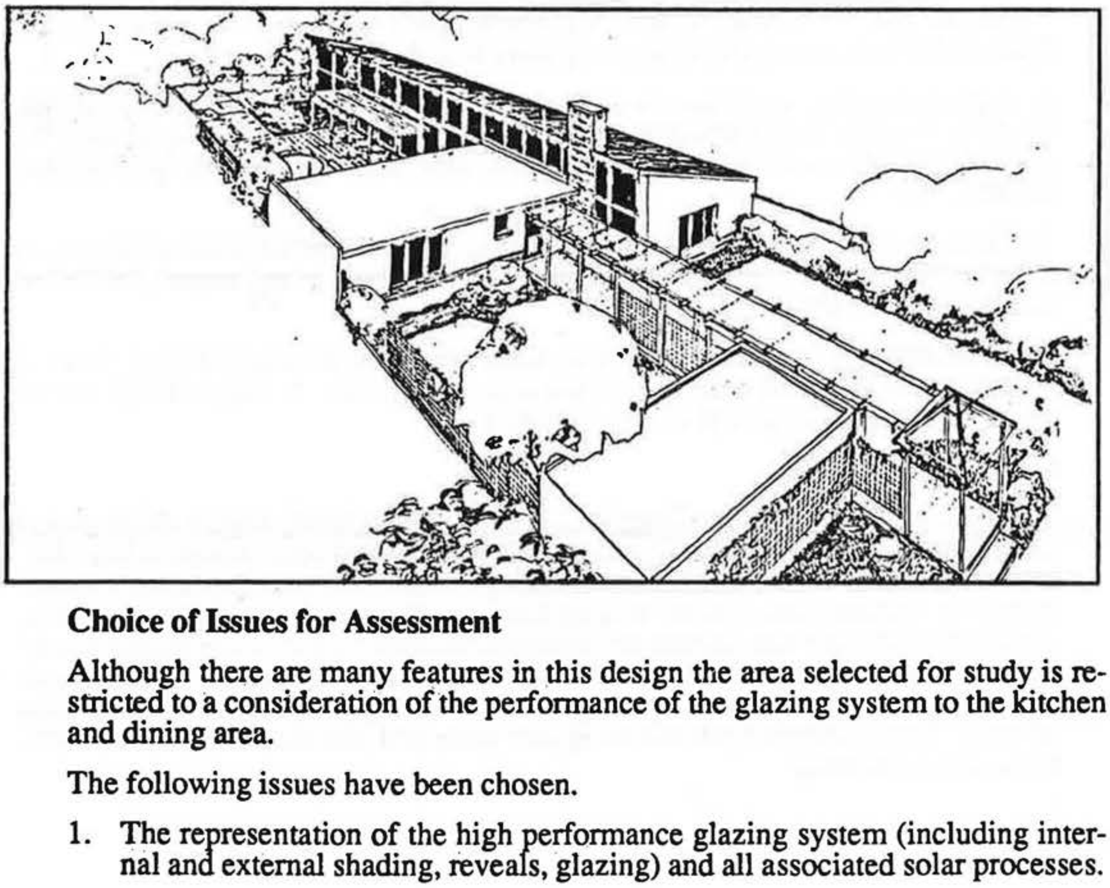
It is intended that each zone should be controlled independently with individual time controls, two port zone valves and zone thermostats. A sophisticated whole house controls package will also be installed.

### Glazing System

The windows in the Feilden Clegg houses have triple-glazed, Argon- filled sealed units. These have a very low U-value (0.85 $W/m^2K$)and solar transmission characteristics which ensure that the south- facing windows (depending on the curtaining/blinds/shutters) could achieve a net heat gain through the heating season. External and internal fixed louvres are provided to control glare in the highly glazed kitchen and dining room, and automatically operated low emissivity coated blinds are located in front of the main glazing of the clerestory protected by a fourth sheet of glass. This is a further precaution against glare and will also help to avoid summertime overheating.



| | |
|---|---|
| Living Room | 6.00m x 4.78m |
| Dining Room | 4.40m x 3.55m |
| Kitchen | 3.25m x 3.95m |
| Study/Bedroom 4 | 4.40m x 2.36m |
| Bedroom 1 | 3.80m x 2.85m |
| Bedroom 2 | 2.80m x 3.05m |
| Bedroom 3 | 3.35m x 2.05m |



## Choice of Issues for Assessment

Although there are many features in this design the area selected for study is restricted to a consideration of the performance of the glazing system to the kitchen and dining area.

The following issues have been chosen.

1. The representation of the high performance glazing system (including internal and external shading, reveals, glazing) and all associated solar processes.

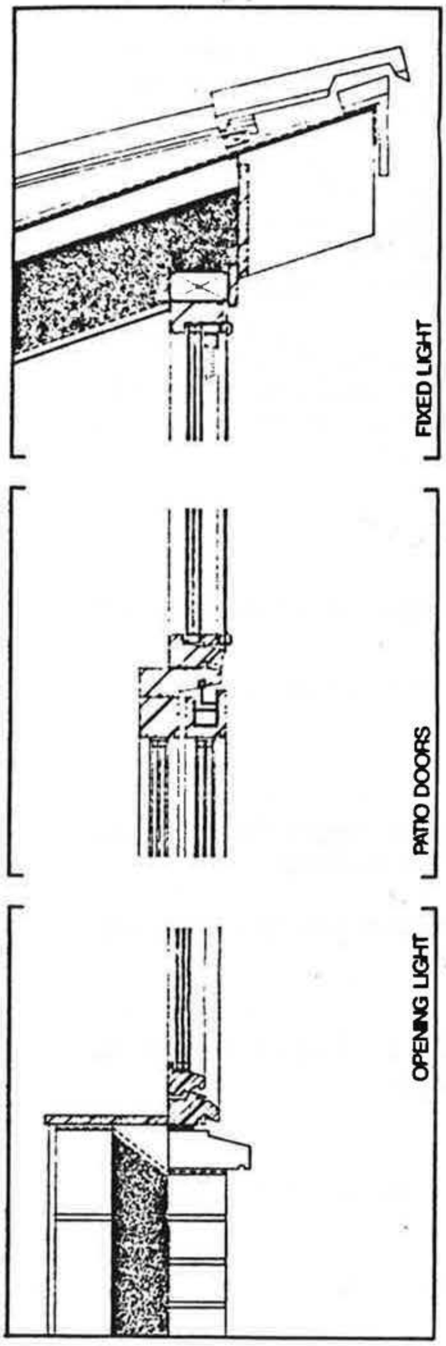
2. Particular features of interest are:

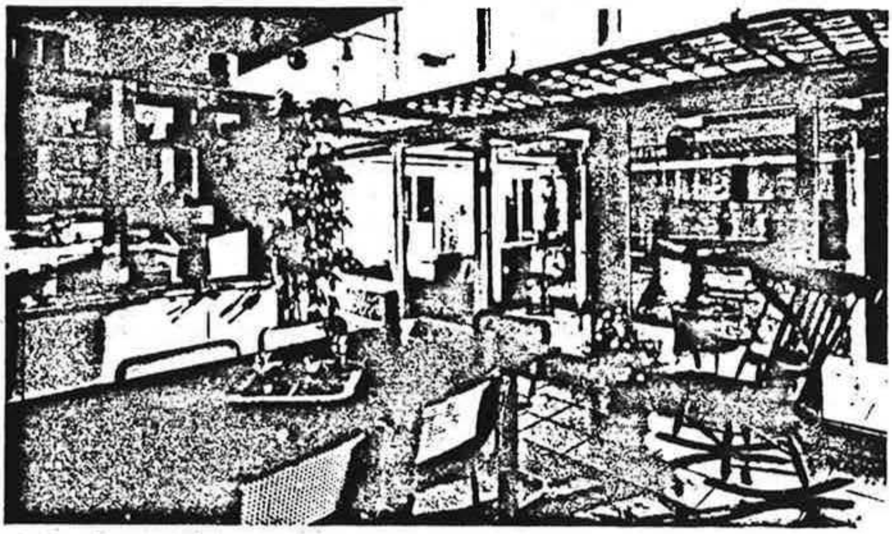
   (a) The ability of the model to cope with the operation of the blinds within the glazing over short time periods (less than 1 hour) and the consequent effect on light, solar radiation and heat transmission.

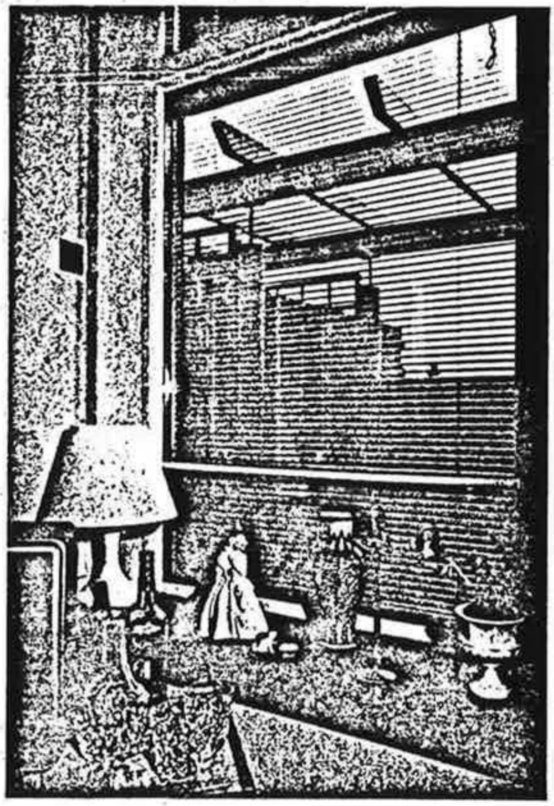
   (b) Facilities within the model to control the operation of the blinds as a function of parameters such as internal temperature or comfort conditions.

   (c) Control of window openings for ventilation and how possible interactions with the operation of the blinds may be modelled.

3. What data could be generated by the model to investigate the energy balance of the window system.







## 2. CASE STUDY 2: CONSERVATORY

### Description

This case study is based on on the features of the C.P. ROBERTS home designed by the John Bonnington Partnership and built for the 1986 Milton Keynes Exhibition. The following description is based on Ted Stevens " Case Studies" Building Design, Energy and Insulation Supplement, July 1986.

The 4 bedroomed house is square on plan with a double-height, double-glazed quadrant shaped conservatory placed in the south-east corner of the plan. With this orientation, the conservatory will receive morning solar gains and will be shielded from afternoon solar gains when external air temperatures are likely to have risen to a point during the summer that would cause overheating.

The house has a low external surface to habitable floor area ratio.

The interior of the house is placed to maximise the extent of glazed areas of habitable rooms that open into the conservatory as the rate of heat loss through double-glazing is seven times greater than that of any other part of the building envelope.

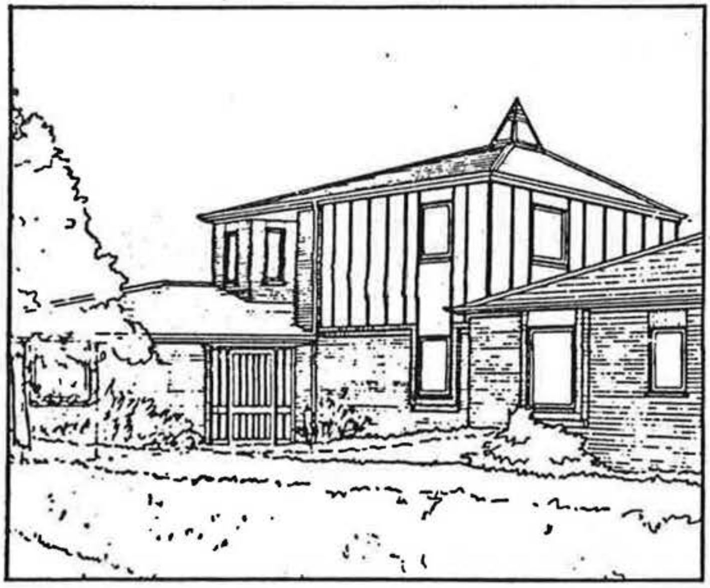
Some 150mm of mineral wool has been used in the roof and studwork walls and 50mm of mineral wool partly fills the cavity. The inner leaf is of lightweight aerated "Turbo" blockwork. The suspended boarded ground floor is laid on polystyrene blocks on concrete joists to reduce heat loss. All windows, external doors and conservatories are double-glazed, rebated and fitted with Sealmaster seals.

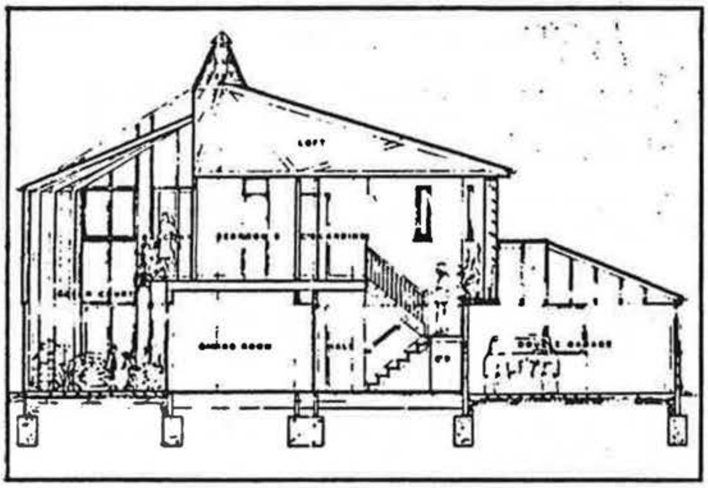
The house is primarily heated by a wet space heating system using a gas-fired low water content triple-pass condensing boiler with a balanced flue. Low temperature hot water is distributed to high-efficiency radiators fitted with thermostatic valves by a low-power consumption pump. Hot water is generated from the same boiler and stored in an insulated thermostatically regulated cylinder.

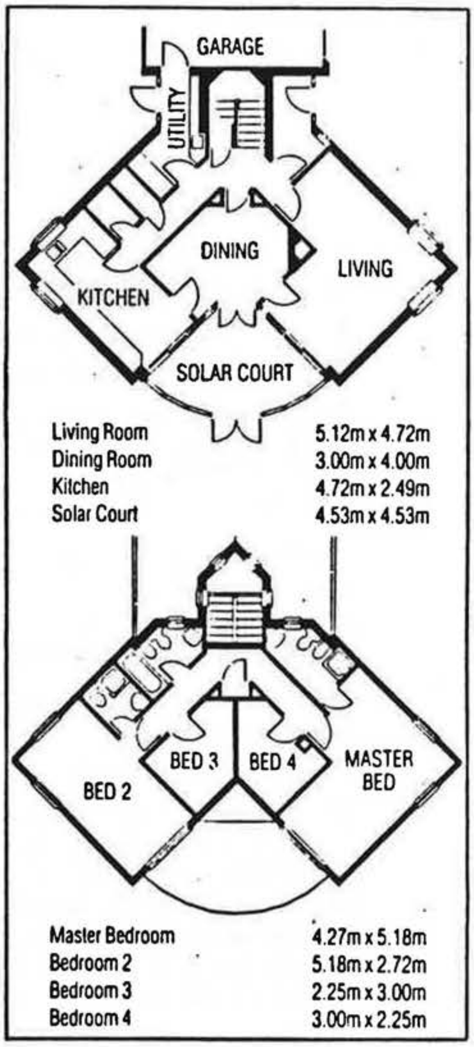
### Choice of Issues for Assessment

The area for study is the performance of the double height conservatory and the following issues have been selected:

1. The representation of the energy flow paths between the house and conservatory including conduction and air movement.
2. The particular features of interest are:
    (a) The facilities within the model to handle the solar input to the house and conservatory taking into account the form of the building.
    (b) Longwave radiation exchange between house, conservatory and outside.
    (c) Stratification within the conservatory.
    (d) Control and representation of ventilation and/or shading mechanisms to prevent summer overheating in the conservatory.
3. What information could be generated to assess:
    (a) The environmental conditions within the conservatory, especially the effect of direct insolation on comfort.
    (b) The net energy flow between house and conservatory.

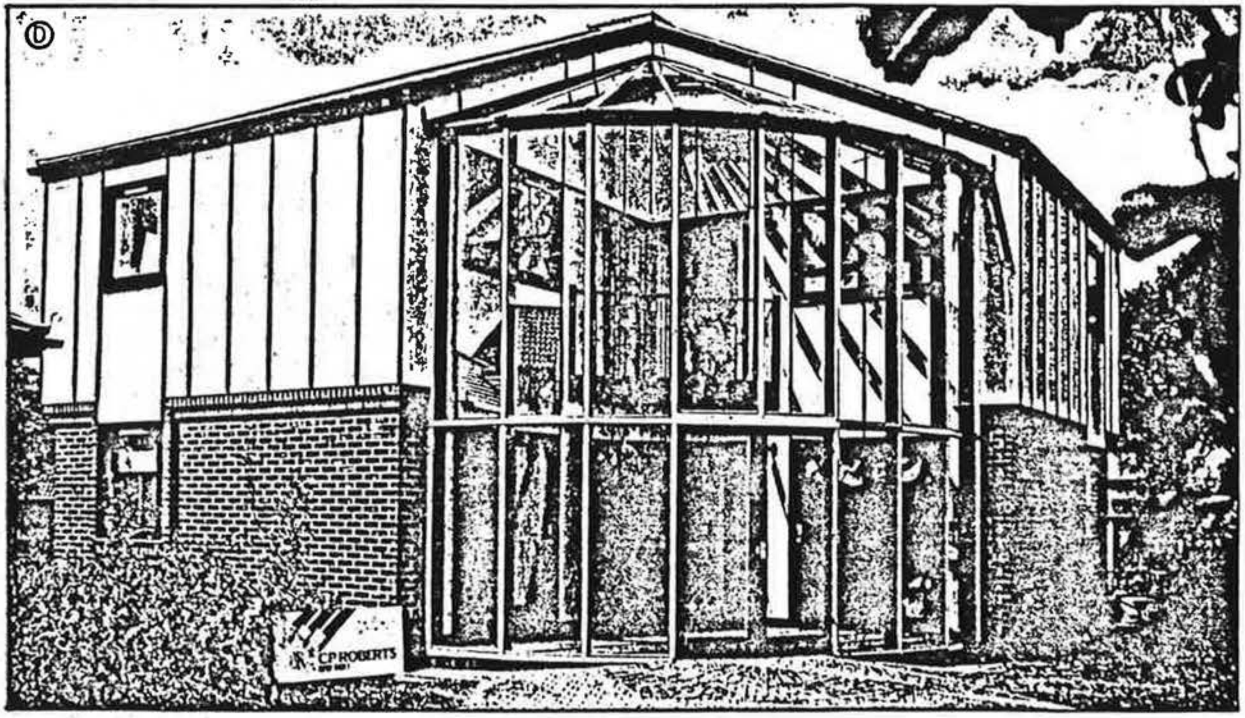






| | |
|---|---|
| Living Room | 5.12m x 4.72m |
| Dining Room | 3.00m x 4.00m |
| Kitchen | 4.72m x 2.49m |
| Solar Court | 4.53m x 4.53m |

| | |
|---|---|
| Master Bedroom | 4.27m x 5.18m |
| Bedroom 2 | 5.18m x 2.72m |
| Bedroom 3 | 2.25m x 3.00m |
| Bedroom 4 | 3.00m x 2.25m |



## 3. CASE STUDY 3: AIR FLOW NETWORK

### Description

The following description is based on Ted Stevens "Case Studies" Building Design, Energy and Insulation Supplement, July 1986.

A simple, "low-tech" approach to energy saving has been adopted by Mowlem for its four-bedroom house, designed by Phippen Randall & Parkes.

Based on the company's experience of building low-energy housing for the Pennylands project, an experimental estate constructed in Milton Keynes by Mowlem during 1979, this solution demonstrates the cost-effective savings which can be achieved using simple, proven and reliable systems.

The house makes good use of passive solar design principles and incorporates features including a poured concrete inner wall, a large sun-space, a low water content/high efficiency boiler, lobbies on outer doors, controlled ventilation with heat recovery, and high levels of insulation in the roof, walls and floor.

In energy terms, the house is efficient because of its shape, the thermal capacity of the structure itself which acts as a heat store, the high levels of insulation and the efficiency of the controlled heating ventilation system.

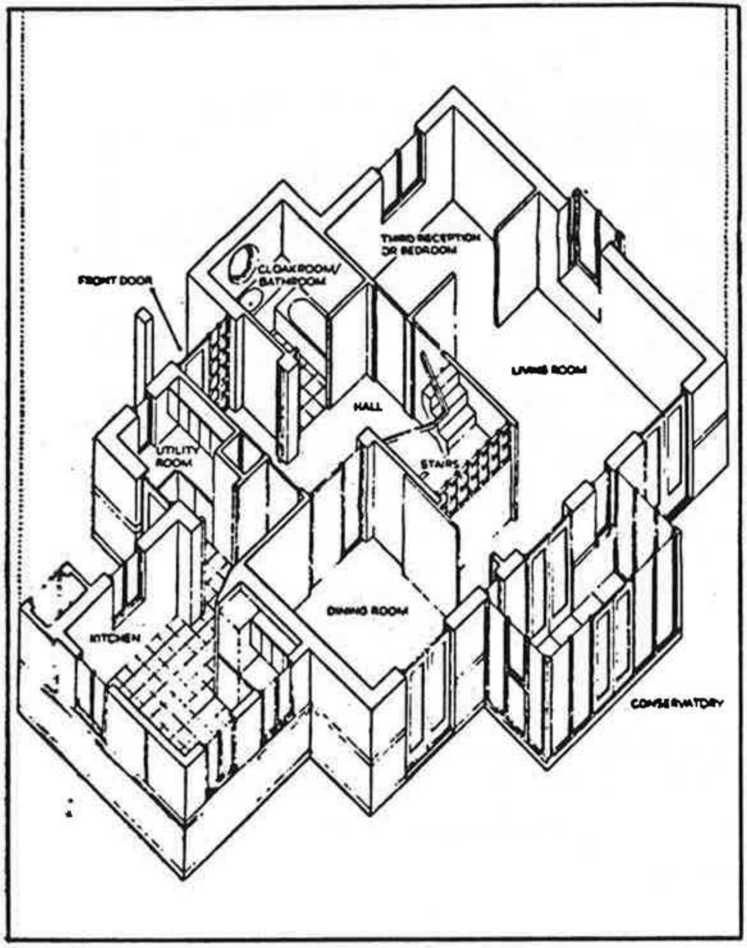
The sunspace is designed to pre-warm air for the heat recovery system and also increases solar heat gain to the adjoining living spaces and bedrooms. Two of the bedrooms have a door and a balcony into the conservatory. The main entrance on the north side of the house is protected from cold north-east winds by the bathroom projection and porch roof. The garage and covered link to the utility/service entrance provide additional screening. The utility room acts as a draught lobby for the service entrance into the kitchen.

All bedrooms have corner windows which allow sunlight to reach the two bedrooms on the north side of the house and improve direct solar gain to the two main bedrooms on the south side.

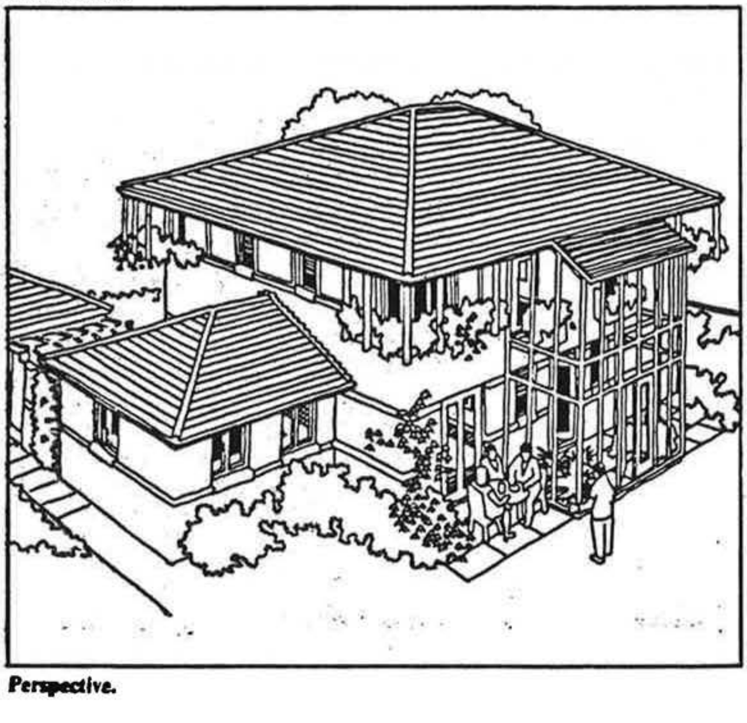
The house is built using a poured concrete system for the inner skin with 100mm expanded polystyrene insulation included in the construction. The ground floor is insulated with 50mm expanded polystyrene under the floor slab and the roof with 150mm glass- fibre insulation above ceiling level. The concrete to the inner skin and the ground floor is dense (1,800kg per cubic metre) which gives the house thermal mass for the passive solar design. Solar radiation, absorbed by the concrete during sunny days, is stored and released as temperatures fall at night, reducing the diurnal change.

A very low rate of air infiltration will be achieved as a result of using a poured concrete construction, draughtproofed and weather stripped double-glazed windows and doors, draught lobbies at the north entrances and a room-sealed, balanced-flue boiler. On houses of similar construction at Pennylands, infiltration air change rates of 0.3 per house have been achieved. A mechanical ventilation system will therefore be installed to extract moist air from the kitchen and bathroom and fresh air will be drawn from the conservatory to supply pre-warmed air in a controlled way to living rooms and master bedroom. The extracted air will pass through a heat recovery unit, so that heat is transferred to the fresh air with an efficiency of about 70 per cent.

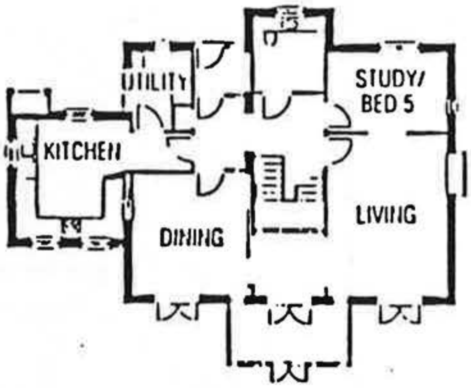
Heating is by a wet radiator system using a low water content, gas- fired boiler sized for a building heat loss of 5.5kW. The heating system assumed to have zonal controls and individual room thermostatic radiator valves.



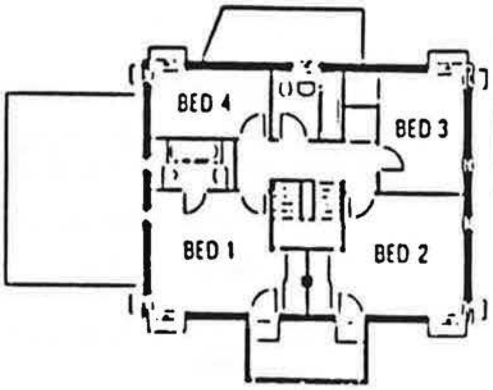
Ground floor.



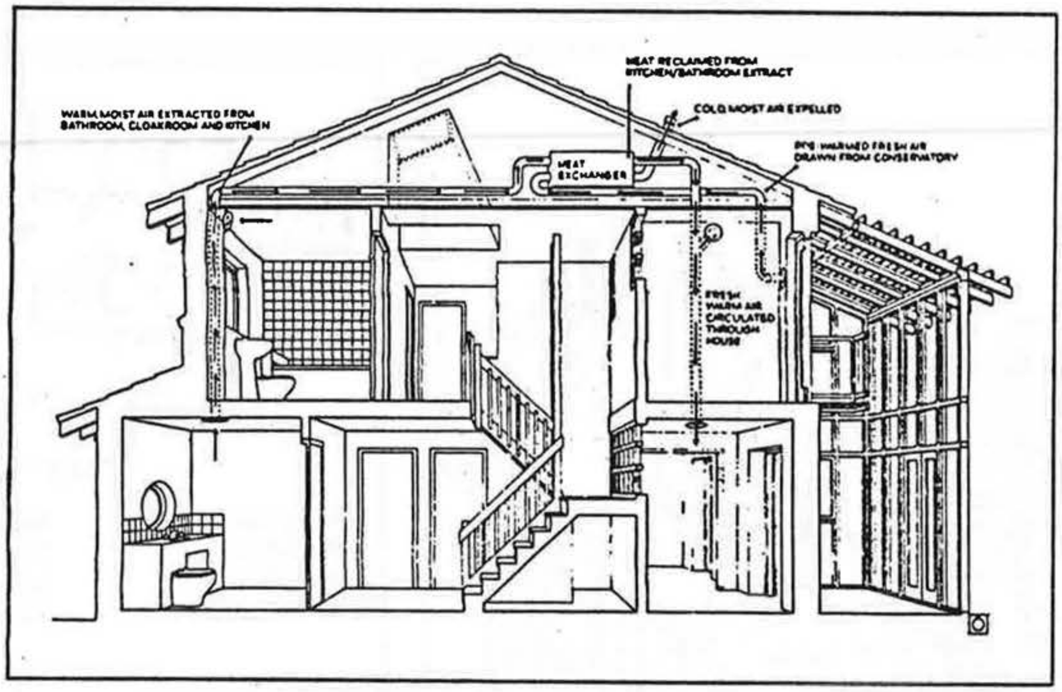
Perspective.



| | |
|---|---|
| Living Room | 3.61m x 5.00m |
| Dining Room | 3.61m x 3.70m |
| Study/Bedroom 5 | 3.61m x 2.40m |
| Kitchen | 3.25m x 3.56m |



| | |
|---|---|
| Bedroom 1 | 4.81m x 3.70m |
| Bedroom 2 | 4.81m x 3.70m |
| Bedroom 3 | 2.51m x 3.70m |
| Bedroom 4 | 3.61m x 2.10m |



### Choice of Issues for Assessment

The area for study is the performance of the air flow network within the house and the heat recovery system and the following issues have been selected:

1. The representation of the air flow network, heat recovery and heating systems.
2. The particular features of interest are:
   (a) The ability of the model to handle latent energy in the heat recovery system.
   (b) The facilities to handle energy exchanges within the house given zonal control of the heating system.
3. What information could be generated to assess:
   (a) The effect of the operation of the heating system and the redistribution of solar gains via the air flow network on solar utilization.
   (b) The benefit of the heat recovery system and its dependence on the airtightness of the house.

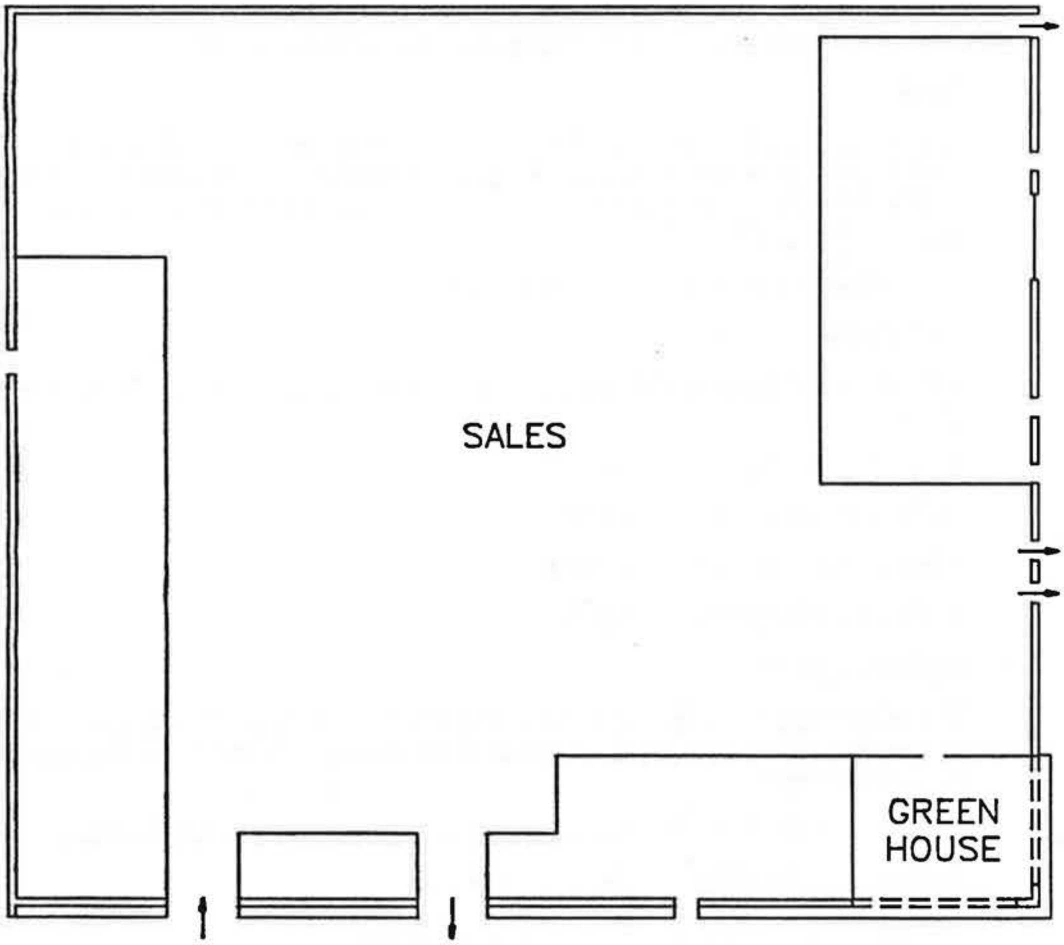
## 4. CASE STUDY 4: DIY SUPERSTORE

### Description

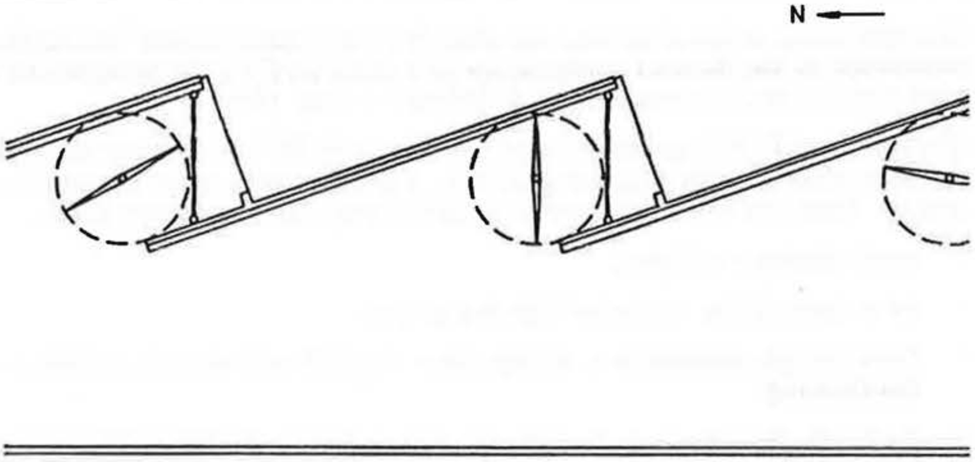
The case study is based on material taken from an interim report "An Analysis by simulation of the thermal performance of a retail DIY Centre designed by Glazzard Architects Co-operative", CAP Scientific, Aug. 1986.

The proposed DIY Superstore is single storey, with 80% of the floor area taken by the sales floor and the remaining 20% by a greenhouse, coffee bar and ancillary spaces. There are several features intended to exploit solar energy gains:

- south-facing rooflights;
- an automatically controlled lighting system;
- heavyweight construction to maximise thermal storage and control summer overheating;
- rooflight shutters as both night insulation during the heating season and as blinds in the summer.



Ground floor plan



Rooflight elevation

The only glazing on the facades is to the greenhouse, which is fully glazed on both the south and east facades. However, there are rooflights over the whole floor, which are shown above. Note the shutter blades which are designed to act both as shading in summer and as night insulation in the heating season.

- People

  For simplicity, it is assumed that there are 400 people (including staff) in the building during weekends, and 100 during weekdays. Each person contributes 140W sensible casual gain and the total gain is distributed into zones on the basis of their floor area.

  Store open 8 a.m. to 8 p.m. six days per week.

- Equipment

  The assumed electrical equipment is in four zones, emitting the following gains:

| | |
|---|---|
| Sales floor (tills) | 1000W |
| Offices (computer) | 600W |
| Kitchen (snacks prep.) | 2000W |
| Toilets (hand dryers) | 800W |

- Lighting systems

  The illuminance levels provided in the brief were simplified to give the list below. Also shown (in brackets) is the thermal output for the luminaires at their full rated output.

| | | |
|---|---|---|
| 300lux | (13.7W/m$^2$) | Entrance lobbies, toilets, loading and storage |
| 500lux | (22.4W/m$^2$) | Offices, staff areas |
| 800lux | (36.5W/m$^2$) | Sales floor, coffee bar |

1500lux (68.4W/m$^2$) Greenhouse

For the sales area, it is assumed that 15% of the total lighting capacity is used on product display gondolas and the wallpaper department, and is constantly on during occupied hours.

## Choice Of Issues For Assessment

The design proposal contains a set of passive solar design measures which have been evaluated as part of ETSU's Design Studies project to demonstrate which measures are successful and should be retained and which measures are not and should be either modified or removed.

Starting out from the design team's stated intent and their proposed solution, the following issues have been selected:

1. The representation of both the daylighting and artificial lighting installations and the control of the systems by (i) Photo electric on/off control and (ii) A continuous dimming system.
2. The particular features of interest are:
    (a) The computation of the internal daylight levels.
    (b) The interception of solar and daylight by the roof light opening and shutter.
    (c) The interaction between the lighting and thermal systems. For example, the operation of the rooflight shutters to control overheating will have an effect on both the lighting systems and the heat conduction through the rooflights.
3. What information could be generated to assess:
    (a) The influence of the lighting control strategy on the passive solar contribution.
    (b) Control strategies for avoiding summer overheating.

## 7.0 SOURCE CODE

Purpose: Confirm that the source code is available with adequate documentation and to establish the ease of modification.

### 7.1 Availability

Confirmation of the availability of the source code and the provision of one copy of the source code documentation.

YES/NO

### 7.2 Coding

An explanation of the coding technique and the authors view of the balance between elegance and efficiency versus clarity to unfamiliar users.

## 7.3 Updating

Description of the procedures adopted for updating and releasing new versions of the source code and the associated documentation.

## 7.4 Source Code Modifications

A detailed description of how a user could change an algorithm for the following cases:

(a) Any special facilities which do not interfere with main code, e.g. for temporary insertion of special algorithm or values

(b) Addition of algorithm, with and without additional I/O data.

Notes: Identify any relevant documentation including cross- referencing documentation to prevent unexpected results of software changes.

## 8.0 USER SUPPORT

Purpose: To gauge the support available to the user.

### 8.1 Availability

Confirmation of the availability of user documentation and the provision of one copy of the documentation.

YES/NO

### 8.2 Updating

Description of the procedures adopted for updating and releasing new versions of the user documentation.

### 8.3 User Experience

Describe the experience of buildings and simulation modelling expected of a user to enable them to understand the documentation and run the model.

## 8.4 Modelling Strategies

What is the nature of the advice given to the user on strategies for creating physical descriptions suitable for modelling different building types and patterns of usage?

## 8.5 Assistance

To what extent does the software, user or other available documentation assist the user in the translation from the chosen physical description to the input data set for simulation?

## 8.6 Support

Availability and cost of support within the model author groups to advise external users, particularly ETSU and the projected availability of this help over the next 3 years.

## 9.0 USER INTERFACE

Purpose: To establish the characteristics of the user interface

### 9.1 Data Input and Input Constraints

1. Describe the formal structure of the input data set.

2. Describe the methods of entering and editing data including links to other software such as architectural drawing packages, and comments on how appropriate different strategies are in different circumstances.

3. Input Requirements and constraints including:

   Climatic variables: Method of describing zone geometry and constraints on zone shape: Method of specifying window/door geometry, maximum number allowed: Maximum number of zones: maximum number of component elements per structure.

4. Databases of material properties and other 'guide book' data, and guidance on choice of inputs including information about default values generated by the model, and whether these can be overidden by the user.

5. Extent to which model attempts to ensure that input data are reasonable and consistent, including geometric visualization, topological analysis (eg air flow networks, zone linking), range checks on numerical quantities, and cross checking against QS bills of quantities.

## 9.2 Output Data Sets

1. Contents and structure of output data set(s) before processing, including options for varying number of data output during simulations. Is the input data reflected in the output?

2. Summary of statistical analyses (averages, regression, extrema, time series etc) and forms of presentation (graphical, spreadsheet, tabular etc) directly available to the user.

## 9.3 Training Period

An estimate of the training period necessary before a new user could run a simple simulation from raw data on a building and its usage pattern.

## 9.4 Free Comment on User Interface

## 10.0 FREE COMMENT

| | |
|---|---|
| Purpose: | To provide an opportunity for author groups to comment freely on any issues arising from the questionnaire or the use of their model in the context of the Passive Solar Programme. |
| Notes: | **It is ETSU's current intention to run SERI-RES for at least the next 12 months in conjunction with at least one other model.** |

# ANNEX 2

# SUMMARY OF QUESTIONNAIRE REPLIES FOR THE EVALUATION OF BUILDING SIMULATION MODELS

## ESP HTB2 SERI-RES

## FOR THEIR ROLE IN PASSIVE SOLAR DESIGN STUDIES FOR ETSU

In the summary it is not possible to cover much of the technical detail of the responses (equations, theory, etc.). This is a summary of the Questionnaire replies for all three models. The general format is a short paragraph about each model, followed in some cases by general conclusions comparing and constrasting the models.

It should be noted that this summary was written originally in the context of ETSU's requirements for the Passive Solar Programme.

For brevity, the models are referred to by the first letter of their names, and always in alphabetical order.

Since the original exercise was completed, significant developments have occurred to the models. These are indicated in the appropriate sections by text *in italics*. Note that, in the case of ESP, two distinct versions now exist: a research version at the Energy Simulation Research Unit (ESRU) at the University of Strathclyde, and a commercial version at ABACUS Simulations Limited (ASL) on the Kelvin Campus, Glasgow. All modifications referred to here are for the ESRU version.

## Table of Contents

## 1.0 MODEL DESCRIPTION

Purpose: To identify and describe the fully operational version of the model which could be released to ETSU in March 1987.

Notes: In the following questionnaire all comments should refer to this released version of the model.

The simulation models and the user interfaces should be identical for the alternative hardware implementations options cited in table 1.2 below.

### 1.1 Model Identifier

If relevant describe the structure underlying the identifier used to designate released versions of the model.

E - Designated format UNIT.DECIMAL.LETTER, eg 5.4b. The UNIT is incremented for major releases, DECIMAL is incremented for new features, and LETTER is incremented for bug fixes and general code management. Released version is 5.4.

H - Format is release number, version number, and version date. The version number indicates bug fixes. Released version is 1, version 12. 0. (Usefully) dated also.

S - Simple (1.0, 1.1, 1.2a, 1.2b) but not explained.

The identification of different versions is very important when comparing results produced by more than one version.

### 1.2 Model Details

E - ESP (Environmental Systems Performance)

H - HTB2 (Heat Transfer in Buildings 2)

S - SERI-RES (Solar Energy Research Institute - Residential Energy Simulator)

**Identifier:**

E - 5.4

*E* - *6.14a*

H - 1.12

S - 1.2

**Release Date:**

E - March 87.

*E* - *November 88.*

H - April 85.

S - March 87.

**Programme Languages:**

All F77, except E 'C' also for some recent code.

**Operating System:**

E - Vax/VMS, UNIX (preferred)

H - Vax/VMS, Prime/PRIMOS, Perkin-Elmer 0532

S - Vax/VMS, Prime/PRIMOS, MS DOS, Perkin-Elmer 0532

Continued over page

**Hardware Implementations:**

E - Vax, Sun, Apollo, Whitechapel

*E* - *Perkin-Elmer 3230*

H - Vax, Prime, Perkin-Elmer 3230

*H* - *Sun, IBM PC-AT*

S - Vax, Prime, IBM PC, Perkin-Elmer 3230

If there is an implementation of a given model on a given machine, major software upgrades may be very difficult unless the machine is fully supported (which probably means used) by the authors, or the upgrades are entirely machine independent. Implementation is generally simpler for S and H than for E.

**Memory Requirements:**

**Core:**

E - 1.5 Mb

H - 0.35 Mb data, 0.15 Mb program

S - 0.95 Mb

The core requirement is not very important as models can page in and out of disc.

**Disk:**

The minimum requirement for disc is a fraction of the minimum useful amount of storage, which is around 10 Mb; most of this is used for output data. All models produce similar volumes of output data; in general the more disc space available the better.

E - Widest hardware options but requires graphics screen.

## 2.0 STATUS OF RELEASED VERSION

Purpose: To provide a context in which the released version of the model can be evaluated.

Notes: Reference number refers to existing documentary evidence which should be listed on page 2.4.

### 2.1 Model Evolution

**Brief description of evolution of model indicating dates of key developments resulting in significant changes to the model.**

Brief descriptions of new features added over development are given but the models as they are now will normally be considered in other sections here. Where important new features exist on versions under development (principally Release 6 for ESP), the new version will be identified.

E - Continuous development since 1974. Key points are:

1980-2 graphics and geometric extensions

1984-6 plant and control simulation

1986-7 move to workstations and prototype intelligent front end (still under development).

H - 1971-83 Earlier model (HTB) developed

1983-85 HTB fundamentally rewritten to produce new modular architecture with new documentation, renamed HTB2.

S - The model was originally called SUNCODE. Version 1.0 received from Solar Energy Research Institute (SERI) in 1982. Major restructuring and additions by Polytechnic of Central London (PCL) 1985-7, leading to version 1.2b.

All models are likely to suffer undesirable features inherited from early versions as a result. However, more importantly, longer use means more bugs will have been ironed out and more expertise will have been built up. HTB2 is at a disadvantage in being the youngest.

## 2.2 Previous and Current Use

Previous use of model including both 'in house' consultancy and external users. This should cover when and for what purposes the model was used, distinguishing between academics and industry.

Difficult to give a breakdown as areas overlap (e.g. 'research' overlaps with 'external users') and groups have answered in different ways.

E - Too extensive to give much detail (e.g. 60 external users). International use for research and education. 'A number' of commercial users but limited success implied here. Also in-house consultancy service for difficult design problems. In particular, it was selected as the European passive solar reference model, and 'validated' as part of the EC PASSYS Project (1986).

H - All use in-house. Used for a variety of buildings (from domestic to factories). Small amount (in-house) consultancy (limited by resources). Total 12 projects identified.

*New Users : Three academic institutions; CAP for ETSU; British Gas.*

S - UK: mainly in-house consultancy for ETSU (15 projects). Fundamental work on accountancy (warmth indices, etc.). 4 external users given - only one for design in practice. Also software released to 9 other organisations in the UK, commercial & academic. Used extensively by CAP Scientific and others in ETSU studies.

USA: Earlier versions of model (SUNCAT, SUNCODE) used in the UK widely, but no details available.

E has had the largest use as a research tool and widespread use worldwide. S has been the main 'ETSU' model and has probably developed in tune with ETSU's previous requirements. The widespread use of earlier versions in the USA strengthens its credibility as a useful tool.

## 2.3 Model Verification

The nature and extent of verification exercises should be declared, but excluding the current SERC/BRE study.

E - Versions 1,3,4 used in IEA Annexes 1,4,8,10 and model subject to analytical tests by SERI. Cuurent version 5 is being tested against test cell data under PASYS programme. The model has also been very widely used and thus its assumptions have been subject to wide examination.

H - Some algorithms tested in IEA Annex and as part of development. Detailed validation of plant/control model as part of PhD project using measurements for an office.

S - Objective analytical testing of algorithms by SERI (more than H or E), and by CAP Scientific. Used in IEA Annex VIII and some intermodel comparisons.

Both E and S subject to much more external validation than H. In general, simulation models agree fairly well with empirical data, especially for overall energy requirements, but usually with wide disagreement for some more specific parameters. However, this is no guarantee of accuracy or applicability for other modelling which usually involves much greater complexity and many more assumptions by the user.

## 3.0 CURRENT AND FUTURE DEVELOPMENTS

Purpose: To anticipate current and future developments.

### 3.1 Current Enhancements

Enhancements already incorporated into the version of the model which is currently under 'in-house' development.

**E** - Several developments in plant simulation, lighting control, intelligent user interface, occupant behaviour. Major effort directed towards a more user friendly and intelligent interface.

**H** - Improved input-output formats and some more options. Rigorous checking of code.

**S** - Enhancements made with 'user port' only: - these were minor extensions, the most important being radiant/convective split for heat inputs but not for zone temperatures.

### 3.2 Current Funding

Current funding of model; sources and amount of support including ETSU funding.

All models involved in an ETSU funded inter-model comparison exercise (10K each). Also:

**E** - Total 120K current funding, plus involvement in other grants, 1 SERC, 2 EEC.

**H** - No other sources at present.

**S** - Scribe interface (no figures).

### 3.3 Short Term Enhancements

Enhancements planned within the next six months.

**E** - Release of developments described in 3.1, more passive solar features.

**H** - Revision of documentation leading to new release level 1.2. Improvements to user interface.

**S** - Addition of Scribe interface and improved database and link to PC software (Symphony) for graphics results processing.

Uncertain how important these enhancements would be for passive solar modelling. Initial thoughts are:

**E** - Changes likely to make it better for outside users; all current developments likely to be important.

**H** - Impending new release likely to be significant improvement on current version.

**S** - Post-processing likely to smooth and speed up 'production runs' for Performance Assessments.

## 3.4 Future Developments

Anticipated future funding and plans for the development of the model.

| | | |
|---|---|---|
| E | - | Development and full commercial support for current versions of E will continue for several years. Eventually, model may be absorbed by the Energy Kernel System (EKS), now being given priority treatment by ESRU. In this, models would be constructed from object-oriented modules contributed by different groups. |
| H | - | No major funding at present, but will be sought; current need for funding to produce release 2 and develop plant and control simulation. |
| S | - | Improved comfort/temperature assessment algorithms, but these will still suffer the limitations of a combined 'zone' temperature. |

The structure of E and H both have potential for considerable development, but the structure of S is such that major software changes would be impracticable.

The EKS project is likely to take some years to affect modelling in the UK and ESP will remain an independent model for the foreseeable future.

## 4.0 MODEL STRUCTURE

| | |
|---|---|
| Purpose: | To establish the major structural features of the model. This is intended to provide an insight into the general approach adopted and to determine whether this results in fundamental limitations in the way in which buildings and systems may be modelled. |
| Notes: | Terms such as modularity, whose meaning may be in doubt, should be clearly defined.<br>Where possible reference has been made to the BRE/SERC Questionnaire. |

### 4.1 Primitives

Definition of any primitive entities fundamental to structure, such as 'zone', 'wall', etc. Words in upper case are given special meaning by the authors.

**(See detailed definitions in individual replies; the following are general comments)**

| | | |
|---|---|---|
| E | - | A ZONE is a volume of fluid (normally air) assumed to be fully mixed represented by one capacity node and bounded by surface polygons. More than one ZONE can exist within a pysical space by using 'virtual' surfaces. Windows and doors can be pure resistances or have capacitance nodes. |
| H | - | A SPACE is a mixed volume of air represented by one node.<br>A ZONE is a SPACE or collection of SPACES bounded by physical surfaces with radiation exchange between them.<br>A CONSTRUCTION is a single- or multi-layer sequence of material(s).<br>Windows and doors are always treated as CONSTRUCTIONS with capacity. |
| S | - | A ZONE is a room, part of a room or group of rooms which operate at the same temperature.<br>A WALL is an opaque connection between a ZONE and one of: another ZONE, ambient, ground.<br>A WINDOW is a transparent connection with resistance but no capacity between a ZONE and another ZONE or ambient. |

Note that a ZONE is normally identical with a room in each model, but can have a different meaning in each depending on how the building is configured in the model.

Geometric rigour of E demands more input data (vertex coordinates), and may make it more difficult to set up multi-room, single zone problems. One outside user has commented that the benefits of the geometric rigour (which includes the error checking involved in creating a geometrically meaningful form) outweighed the extra effort required in inputs. Another said that many problems did not require geometry; using geometry without visualization (not available always) was difficult, while the larger volume of input data required gave more potential for error.

## 4.2 Philosophy

Brief description of the philosophy underlying the software architecture and data structures.

All responses are clear and helpful. Briefly:

E - Rigorous physics approach; treating energy flows in a generalised way between finite volumes of matter and including full geometry. Authors claim it has a very modular, hierarchical structure.

A rigorous, comprehensive energy simulator tailored to buildings.

H - Based on the assumption that models need firstly an architecture allowing algorithms to be inserted, removed or modified independent of the rest of the model, secondly explicit and well documented, thirdly a good match to an intuitive feeling of how a building works.

To quote the authors, 'A flexible, adaptable research tool'.

S - Physics simplified to reduce calculations and input data. Easy to use, minimum resources needed for data input and to run, flexible and useful output structure.

A user's tool.

Regarding ease of understanding of the code, S was said by one external user to be difficult to follow because of the use of Fortran EQUIVALENCE statements (to reduce memory requirements, but effectively renaming arrays in different subroutines). Model H appears not to do this and has been deliberately written to be easy to understand and modify. Similarly E, despite its complexity, is well written and structured, so quite easy to modify code.

As with most philosophies, there is no 'right' one for a model. Each has strengths and weaknesses for different applications.

## 4.3 Data Transfer

Forms of data access and output at run time, distinguishing between main types of data and form of storage (eg ASCII, binary files).

All models use ASCII Input files. The models S and H also use ASCII output files, but E uses Random Access Binary output files attached to a database for fast access. These can be translated to ASCII format.

## 4.4 Geometric Representation

Principle underlying geometric representation including any limitations on spatial form.

(See also question 9.1, section 3 for detailed treatment.)

E - Is a true 3-D model - basic spatial input is vertices of planar surfaces, but wall thicknesses do not exist which can cause problems.

H - Has geometry of external surfaces in terms of orientation, tilt and size. No internal geometry.

S - Has geometry of external surfaces in terms of orientation, tilt and size. No internal geometry except for internal windows (for conservatories).

Lack of geometry and structure of H and S make it easier to construct unusual or unrealistic layouts, e.g. to test an algorithm.

## 4.5 Time

1. Is allowance made for the difference between mean solar time at the site and local solar time at site (ie the equation of time)?

Yes for E and H, no for S (user must do time shift on weather data).

2. Is it possible to represent a difference between mean solar time and local clock (time zone) time?

Yes for E and H, no for S (except by shifting schedules).

3. Is it possible to include British Summer Time, Daylight Saving Time and the like?

E - Not in current version, but in new version 6.
H - Yes: one period allowed in year.
S - No: schedules must be changed.

4. How does the program treat the time difference between the site and the location(s) at which weather data was recorded?

Not treated - all models assume data apply to site.

5. How does the program handle the effects of differences in latitude, and uncorrected differences in time and/or longitude between site and weather data, e.g. what does it do when the local sun has set but there is still direct solar in the weather file?

E - Uses sun position locally.
H - Uses sun position locally.
S - No allowance, user must modify weather data or block below - horizon solar with skyline.

6. Can schedules for casual gain depend on local solar time (e.g. for lighting) separately from clock time (e.g. activities)?

No model can.

7. Can schedules distinguish between different days of the week, in particular can Saturday and Sunday be different from Monday to Friday?

Yes, all models.

S also by season, and H by each day of week.

E distinguishes weekdays, Sat. and Sun, and can schedule at any frequency from one timestep upwards.

Not clear what S does for individual days; appears to distinguish between weekdays Mon-Fri, and weekends Sat-Sun.

8. How long can a simulation be; are there limits on the numbers of time steps, the length of each time step, the total period simulated? Can the program handle leap years?

E,S one year, H no limit.

Only H handles leap years. Note that single node layers (in particular windows) are unconditionally stable, so the nodal window modelling used in H (but not S) does not affect stability.

The maximum timestep is one hour for E, S, with no theoretical upper limit for H. However, in practice, stability normally limits the timestep to much less than 1 hour for H and S, typically to about one minute.

9. Does the program expect the weather data file to contain values that are averages over some time interval t, or spot measurements at some time T? If values are associated with T is the average taken between T-t and T; T-t/2 and T+t/2, or T and T+t? E.g. what does hour one mean in the weather file, the output and the schedules?

In summary:

| | | |
|---|---|---|
| E | - | Treats climate data (hourly) as if at spot times and uses data appropriate to the 'model' time. For short timesteps data are interpolated. |
| H | - | Allows control over met. data time interval and offset to alter averaged interval, thus fully flexible and able to utilise short interval met. data if available. |
| S | - | For consistency with local solar time, weather data should be average from x.00 to x.59 mins, conflicting with met data from x.30 to x.1.29 = offset needed. (See q 1,2,3 this section). But the previous inconsistency with schedules has now been resolved. |

10. How does the temporal resolution of the model output depend on the algorithms chosen to solve the heat conduction equations and on the timestep lengths used in the solutions and for schedules and weather data?

All maximum resolutions are for 1 timestep - limited also by schedule times, met. data (normally hourly).

11. Which parameters can be scheduled?

All models similar (ventilation, internal gains, etc.).

Only E appears to allow heat transfer coefficient to be scheduled.

Only S schedules ground reflectance; H and S allow ground temperature to be scheduled. Overall, in the treatment of time H has the most flexible approach, with major limitations for S.

## 4.6 Coupling of Air and Fabric

Way in which zones are coupled to the fabric; separate or combined radiation and convection treatment; meaning of zone or node point; and options for treatment of the transfer mechanisms in different ways.

E - Uses surface-air convection coefficients and explicit surface pair long-wave radiation exchange. Combined coefficients can optionally be used, as in S.

H - Uses surface-air convection coefficients and star equivalent network for long-wave radiation. Radiant inputs are given explicitly to surfaces. Combined coefficients can be simulated, as in S.

S - Uses combined radiant and convective star network with user-defined surface-zone node coefficients. The Zone node has no real capacity or strict definition but roughly represents a conductance-path weighted mean of = air + glazing + light furnishings temperatures.

Given the well-known and important effects of convective transfer on behaviour, the treatment used by S is a serious deficiency.

## 4.7 Coupling of Building and Controls

The interaction of the model with control and plant modelling software. Is this software contained within the model or does it use external routines? Describe the nature of the treatment of HVAC components (eg explicitly by node representation, or using 'black-box' algorithms) and the effects of control modelling on the numerical solution (stability, convergence, iterations).

( See also questions 5.10 and 5.11)

E - Explicit nodal modelling for plant (matrix solution) and air flow network (Newton-Raphson solution). Plant timestep any sub-interval of the building timestep, and changes during simulation to maintain stability.

H - Ranges from simple 'ideal' system, to detailed time- dependent model of plant, thermostats and cycling as 'black boxes'; no nodal plant modelling.

S - Explicit 'ideal' plant type adds / removes heat instantaneously to give desired control (zone) temperature; the radiant/convective split is fixed in the same ratio as the zone temperature. Maximum output can be specified.

Importance of this depends on what is being modelled - simple approach may be perfectly adequate in many cases and easier to use. The 'instantaneous' nature of S is a shortcoming, especially for popular wet systems in low heat loss buildings. Additional documentations and modifications to software are required to use plant modelling in E; it is not in a suitable form for the average user. The nodal approach is no guarantee of accuracy: no validation work has yet been published on plant modelling in E.

## 4.8 Multi-zone Treatment

1. Number of independently controlled zones which can be modelled.

E - 25, can be increased.

H - Limited only by memory size.

S - 40, can be increased.

2. How does the program solve the inter-wall and interzone interaction problem, eg. does it solve the equations explicitly by matrix inversion or implicitly by iteration?

Note: the words implicit and explicit are used here in a different sense from reference to numerical scheme used.

Long, technical answers again. In summary:

E - The building is partitioned into n zones in a way depending on the control structure, which are solved separately leaving n unknowns to solve for the n control loops. Backward substitution completes the solution. Several advantages are claimed, particularly in scope of control and speed. Iteration is used for the air flow network and certain controllers. The main disadvantage is that there is only one control loop per zone.

H - No iteration; as the model is fully explicit in its solution technique, changes to the thermal state are based on accummulated energy flows over the preceding timestep using the known conditions.

S - This is explicit, like H, so iteration may not be used, but when plant inputs, or Trombe walls, are involved in zones linked by direct flow paths (no intervening thermal mass), iteration is used.

The explicit approach used by H and S is conceptually very simple in contrast to the sophisticated partitioned matrix invertion of E.

Implications for control are left to sections 5 and 6.

The explicit formulation has the major disadvantage of an upper limit to the timestep imposed by stability criteria. This can be very short (e.g. less than 10 seconds, but typically about 1 minute) and hence lead to a large amount of computation for a given simulation period. In this case, the inherent complexity of E compared to the other models is offset by its longer timestep to some extent.

3. Treatment of adjacent but unmodelled zones.

E - Modelled with fixed or variable temperature and radiation field, or declared identical to modelled zone, or adiabatic.

H - Assigned a fixed temperature which can be step-changed in a user defined schedule, or declared like modelled zone.

S - The ground is at a user-defined temperature but there is no other explicit treatment for unmodelled zones.

4. If one space is divided into zones, for example to handle stratification, is interzone radiation transfer possible?

E - Short-wave only.

H - Long wave and short wave, although this is not clear from the manual.

S - Only crudely for solar radiation, using solar transfer coefficients. Long wave radiation does not exist in model explicitly.

## 4.9 Numerical Solutions

1. Brief description of solution technique (implicit, explicit or mixed) used at each timestep, and how iteration is used if at all.

(See also section 4.8, question 2)

E - Equations of energy and (up to 2 phase) mass balance formulations vary automatically between fully implicit and mixed implicit/explicit to ensure stability. Timestep may be varied automatically.

H - No iteration used; energy balance based on previous timestep values and energy flow calculation.

S - See 4.8, q.2.

2. Criteria used to establish timestep(s) for solution.

E - A timestep controller can be invoked to monitor accuracy and adjust timestep accordingly. The default solutions are unconditionally stable (in effect by automatic adjustment of formulation, see question 1 above).

H - Explicit formulation stability criterion, typically resulting in timestep of the order of 60 seconds

S - As for H.

3. Is it possible for the user to specify the computational (iteration) accuracy required for a particular variable (eg, wall surface temperature or heat flux). Does the program tell the user the accuracy achieved for particular variables? Can the user always rely on achieving some known level of accuracy for some variables.

Interpretation of this question depends on the meaning of 'accuracy'. Here it does not mean actual truth - model accuracy (this is normally unknown). Accuracy relates instead to the differences between successive approximations and closeness to convergence (not necessarily to the correct answer!) of a numerical solution.

E - For iterations, absolute and relative error bounds are set. For control sensors a set point deviation tolerance is set. For heuristic timestep control a maximum relative error is set internally.

H - No; no iteration so no convergence tests needed.

S - Specified for zone or Trombe wall air gap temperatures only.

4. Treatment of non-linearity in equations, including effects of both non-linear terms in equations and the effect of these when an implicit solution technique, is used (e.g. iteration required).

E - For air flows (highly non-linear) a Newton-Raphson technique is used.

For long wave radiation, model uses values of surface temperature one timestep in arrears for cubic term. Otherwise (e.g. some controllers) iteration is used.

H - Non-linearity handled without problem due to explicit formulation.

S - Non-linearity not treated explicitly.

## 4.10 Preconditioning

Default and user-controlled preconditioning of state variables for typical simulation, and advice to user.

E - Fluid nodes set to 15°C, plant 20°C, linear interpolation to external conditions for wall temperatures. A preconditioning time is recommended to the user before a run from time control calculations inside model based on the lowest diffusivity value found, but can be over-ridden.

H - All nodes set to one value (default 10°C). Start-up of several days is recommended.

S - All nodes set to one value (default 18.3°C). No pre- conditioning as such but users are recommended to use results after 9 days simulation.

Clearly no concensus on best initial node value! - but little difference in practice: user can do what he wants. Pre-conditioning times recommended by E sometimes seem unreasonably long; the prediction method is unreliable because the material with the lowest diffusivity may form an insignificantly small fraction of the total building mass.

## 4.11 Limitations

A statement which indicates possible limitations inherent in the formulation of the model.

E - Each zone can only be assigned one control loop, requiring one zone to be split in two if it has two heating systems.

H - Computationally intensive due to explicit formulation which demands a short timestep. No detailed internal geometry. Internal reflections or sun tracking only possible by dividing windows into sections and using time series data supplied by user.

S - No detailed internal geometry. Hence solar gain specified by user defined constants; no internal reflections or sun tracking. Combined radiation and convection transfer.

## 5.0 COMPONENT ALGORITHMS

Purpose: To establish the major simulation algorithms of the model.

Note: This draws heavily on the BRE/SERC Questionnaire with some additional enquiries concerning issues of particular importance to ETSU's Passive Solar Programme.

## 5.1 Solar Radiation

1. Determination of external diffuse and direct radiation and specification of reflectivity of ground and surrounding buildings.

**Direct:**

**E** - Direct radiation from climate database of real or synthetically generated data, then normal geometric calculations.

**H** - Calculated geometrically from weather data.

**S** - Calculated geometrically from weather data, but with addition of circumsolar component.

Diffuse:

**E** - Ground reflectivity is input parameter. An anisotropic model is used for the sky, an isotropic model for the ground. However, all the diffuse radiation is lumped together and assumed to be incident at 51°; this is correct for vertical surfaces but not for other angles. The anisotropic model is only used to derive the total.

**H** - Sky is isotropic. A different ground reflectivity can be specified (but remains fixed) for each external surface.

**S** - Ground reflectivity is input parameter common to all surfaces and can be scheduled. An anisotropic model (Hay's) is used for the sky.

2. Shading of direct and diffuse radiation by surroundings and building itself, window geometry, blinds, shutters, etc.

**E** - (Optional) program module generates time series of direct shading factors for each external surface separately by projecting surrounding and facade obstructions geometrically. Diffuse shading also possible but not routine.

**H** - Uses masking templates for external surfaces in which user defines attenuation factors for sky vault divided into $10^{\circ}$ sectors. These can be scheduled but are not automatically changed with time. A preprocessing program is available for calculating them.

Blinds are modelled by using 2 transmission characteristics for each transparent element, swopped by scheduling.

**S** - Each window has shading coefficient (value<1) which multiplies solar heat gain through window and can be scheduled. A separate blind shading coefficient is also used, multiplied by the overall shading coefficient. In addition, skyline shading is defined in terms of azimuth and elevation 'blocks' of shaded sky, effectively turning the sun off. This cannot deal with localized shading.

Sidefin and overhand shading is calculated quasi-geometrically by producing a shading factor from the geometry of the shade, but assumes these to be infinitely long.

## 3. Treatment of single and multiple glazing systems including the use of special coatings and materials and dynamic or 'smart' glazing systems.

E - For each window, shortwave response curves for 5 angles of incidence held as data to give linear interpolation for angles of incidence. For direct radiation, the actual angle is used - for diffuse, the (average) value of 51° is used. Transmission, absorption and reflection are calculated using spectral analysis theory (given in detail). Calculations can include multiple contiguous layers.

H - Transmission and absorption coefficients are specified by the user in 10° steps for the whole glazing system.

S - User provides refractive index and extinction coefficient of glazing materials and number and thickness of layers. Program assumes all layers are same material, hence special materials and coatings are difficult to model. In effect, only multiple glazing systems with standard 4 mm glass can be modelled with the standard model.

Only E attempts to model the physics of special materials. However, the complicated algorithms are not fully tested or necessarily always appropriate and may sometimes give the wrong answers. All models rely on manufacturers' data.

## 4. Distribution of diffuse and direct solar radiation on room surfaces and component retransmitted through the window.

E - Radiation absorbed in glazing;

Added to air node (U-value treatment) or to glazing nodes if these are used.

Direct beam transmitted;

If sunpatches are used, tracked to first reflection. However, these are precalculated for the middle day of each month and change discontinuously at each new month. The direct beam radiation is assumed to fall on one, two or all surfaces only.

Diffuse beam transmitted and first reflection direct;

Spread over surfaces, biased against window wall, with any incident on glazing treated as incident at 57°.

H - Radiation absorbed in glazing;

Added to glazing nodes.

Direct;

Apportioned by fixed, user-specified weightings to any number of surfaces.

Diffuse and reflected direct;

Added and spread over area - weighted surfaces.

S - Radiation absorbed in glazing;

Goes to zone point and outside air in inverse ratio of surface resistances.

Direct and diffuse combined;

Apportioned by user-specified factors to air and separate walls with remainder spread over walls by area.

Loss through windows;

Given by a fixed, user-defined 'fraction lost' factor.

The user-defined values (which mainly apply to S and H) may be difficult to estimate but have a large effect on behaviour.

## 5. Treatment of furnishings, internal walls and movable thermal insulation.

**E** - Window coverings can be 'in place' as function of solar intensity, ambient temperature or time.

Internal non-structural mass can in principle be included by creating a 'nested' zone(s) inside the room with appropriate thermal properties but this may be difficult to do in practice. The consequent long and short wave radiation effects are not clear.

**H** - Internal objects can be specified as internal walls with both faces within zone. (No geometry involved). The thermal properties for windows cannot be scheduled, so movable insulation cannot be modelled.

*Thermal properties of materials (e.g. conductivity) can be scheduled.*

**S** - Neither reflection nor absorption modelled for opaque surfaces.

Surface furnishing can be modelled as wall layers.

Fraction of radiation going directly to zone point can be adjusted to include proportion of energy assumed converted quickly to heat, but this involves very broad assumptions by the user in choosing values.

Alternatively, extra walls can be put in zone with both faces within zone (no geometry involved). The transmissivities and U values for windows can be scheduled to model movable insulation.

The lack of a separate air point for S is a disadvantage. The 'feedback' facilities of E could be important for some passive solar designs with fabric properties varying automatically.

## 6. Treatment of transmission through two windows into (i) another zone, (ii) directly to outside (e.g, across the corner of a conservatory).

**E** - See question 4, internal windows treated as other surfaces, i.e. explicit treatment for this using geometry for direct beam.

**H** - Can be explicit by specifying short wave radiation going to particular surfaces (e.g. another window) or implicitly by making total solar distribution factors add up to less than 1.

**S** - Treated as an interzone component of solar gain from 'exterior zone' (e.g. conservatory) to 'interior zone' (e.g. adjoining room).

Radiation across corner could be included as part of fraction (short-wave) lost but not as function of time/geometry explicitly.

Only E treats internal direct beam geometrically. For H and S a large amount of work to get appropriate inputs would be needed by user to give time-varying treatment for sunny conditions. In all cases, the coarse temporal resolution of meteorological data combined with the 1-D treatments of wall conduction introduce errors additional to the geometric approximations. This is probably important for passive solar design, particularly domestic conservatory/sunspaces.

## 5.2 Building Fabric

### 1. Method used for wall conduction.

All models use a basic nodal finite difference method assuming uni- directional flow for normal constructions with thermal mass and multiple nodes for one layer.

All represent cavities as pure resistances.

E - Multi-dimensional flow can be handled (e.g. for floors) with multi-dimensional nodal scheme using plant simulation facility.

Apart from glazing, modelling very thin low capacitance layers which could have a large effect on resistance (e.g. cork tiles) using nodes would severely reduce the timestep for H and S. No suggestions are given for avoiding this problem, but a surface resistance could be used.

### 2. Method used for windows.

E - Can be modelled as U-value elements without mass or as transparent layers using nodes.

H - Always treated as transparent layers with nodes.

S - Always treated as U-value elements without mass. Inconsistency in using U times the difference between internal zone temperature and external air temperature.

In many passive solar applications, the inability to model the thermal capacity of glazing could be a serious defect, for example in modelling loss to the outside by long wave radiation. Knowing quite when it matters is the problem.

### 3. Method used for ground floor conduction.

E - Floor treated as wall, with monthly-varying below-ground temperatures either taken from typical profiles provided in model or defined by user.

H - Floor treated as wall with ground temperature, one of:

constant value;
external air with time lag;
deep ground temperature, if available, in met data.

S - Uni-directional flow as a wall connected to user specified ground temperature which can be scheduled.

All essentially the same treatment.

### 4. Method used for roof and roof spaces.

All models treated roof space (if any) as an unheated air zone. The roof itself is treated as a normal construction, like a wall.

### 5. Method used for doors, window frames (etc) conduction.

**E** - No distinct model. Either treated as resistance only, or as part of the zone geometry using nodal representation (i.e. as walls).

**H** - Treated as walls.

**S** - Can be treated as pure resistances, or walls.

No model has a special treatment for these. Probably ignored in most modelling but cold bridging could be important for detailed design; this would require additional modelling features.

### 6. Time step used for solution of conduction equation.

**E** - Any timestep, up to one hour.

**H** - User specified; typically 60 seconds, upper limit given by stability criterion.

**S** - Model gives upper limit (given by stability criterion); user can choose this or a lower one. As glazing is not modelled with nodes, these thin layers do not affect the timestep.

Resource (CPU time) implications:

Generally, stability limits H and S to a much shorter timestep than E. For many applications, accuracy is not improved significantly for timesteps shorter than about 15 minutes. Accurate control modelling requires a shorter timestep, in the order of minutes.

### 7. Method for determining node placement and number of nodes.

**E** - Nodes normally placed on layer boundaries and at centre for each layer. Also, nodes per layer can be increased by splitting layers.

**H** - Nodes placed at centre of each layer, with additional nodes on wall surfaces. Number per layer can be increased by specifying number of slices per layer.

**S** - Any number per layer, specified by user. 1 node only in a layer is placed in centre, 2 on surfaces, 3 or more on surface and interior.

### 8. Treatment of walls, partitions and furniture within zones.

See 5.1, q5.

### 9. Is there any facility to take into account moisture effects on fabric thermal behaviour, including latent load from evaporation from external surfaces, and changes in conduction due to moisture content of fabric?

**E** - No.

**H** - No.

**S** - No.

## 5.3 Ventilation, Infiltration and Interzone Air Movement

Treatment of infiltration and ventilation losses related to wind, temperature, occupant behaviour, mechanical systems and inter- zone exchanges within building.

Responses are long and technical as they involve several forms of air movement mechanisms and definitions. Briefly, these are:

**Infiltration:**

All models allow 'traditional' air change rates, fixed or time varying, or driven by algorithm using wind and inside-outside temperature difference, but S 'air' temperature is really Zone temperature. Only E has a user-specified leakage network which can be time varying to allow for user behaviour. Flows are functions of wind induced pressure differences and buoyancy flows. Models S and H rely on user-specified flow rates.

**Inter-zone flows:**

E and H allow this, S does not, except as two-way conduction path.

For S, Zone 1 → Zone 2 or Zone 2 → Zone 1 not allowed; Zone 1 ↔ Zone 2 allowed.

**Venting:**

E - Possible via air-flow simulation or thermostatic or time control of air flow rates.

H - As separate time or thermostatic control of ventilation rate.

S - Explicitly in terms of thermostat control (heat removal) to maintain set point Zone temperatures.

**Mechanical ventilation:**

E - Mass injection (e.g. of air) possible at any node for plant and air flow models.

H - Can be specified in terms of inter-zone flows, with up to 3 patterns (changed in schedule) possible.

S - Heat delivery using fans from source zone (Trombe wall or rockbin) as function of set points and other constraints.

**Air flow simulation:**

E - Allows this in terms of pressure and fixed or variable buoyancy- or mechanically-driven flows, solved using iteration.

H - Allows user-specified flows only.

S - Operates ventilation only in terms of heat inputs using set points; its lack of an interzone model seems a serious defect.

## 5.4 Heat Transfer Mechanisms

Note: For each of the following make explicit any difference in the treatment of opaque and window elements.

1. Internal convection coefficients.

**E** - User specified, or computed as function of surface and air temperatures, direction of heat flow and dimensions. These functions are empirical relationships derived from dimensional analysis.

**H** - Fixed user-specified values for horizontal, upward and downward flows. Normally the CIBSE values are used, in absence of consensus for calculated values.

*Internal surface coefficients can be specified and scheduled for each surface independently.*

**S** - Fixed combined transfer coefficients are used for horizontal, upward and downward flows, supplied by user.

None is given for windows - this must be taken into account in choosing U-value.

Several groups have reported the large effects of choice of convection coefficients on thermal behaviour. The correct choice (possible varying, as E) is therefore important. Suitable algorithms could easily be added to H but not S.

2. Internal long wave radiation exchange

**E** - 1. (By default), explicit surface-pair, linearized radiation coefficients; view factors calculated by area weighting.

2. A zone radiosity matrix is created and inserted at each timestep to give the net flux gain/loss based on latest temperature data, and supplied as excitations to main system matrix.

3. Recursive ray-tracing technique which accounts for reflections.

All these require view factors; these can be calculated previously by another routine for any geometry, (which takes a very long time to run) or if not, a simple area-weighting is used. (Detailed theory is given in the reply).

**H** - Approximate solution using star circuit based on area and emissivity weighted radiosity for each surface.

**S** - Combined coefficients, see 5.1, q1.

Treatment of H similar to E for most situations. Combined treatment of S precludes any explicit long wave modelling.

### 3. External convection coefficients

E - Can be user specified, but by default is based on an empirical relationship between wind speed, wind direction and surface orientation from dimensional analysis.

H - Uses standard ASHRAE formulae; coefficients are functions of windspeed, vertical/horizontal tilt and windward/leeward position.

S - Treated using fixed combined external resistance values, referenced to external air temperature. No explicit values in data file for exterior walls - implies held as fixed value for all walls within model.

For 'U' value surfaces, (including all windows in S), combined coefficients are implicit anyway.

The assumptions in SERI-RES need clarifying. External convective surface resistance is smaller than internal surface resistance due to much greater external air movement. However, it is still important, particularly for high loss surfaces such as conservatory single glazing; also, the uncertainty in external resistance values is much greater, so that the absolute error in estimating them may still be greater than for internal resistance values.

### 4. External longwave radiation

E - Calculated explicitly as functions of:-

cloud cover (estimated from direct and diffuse radiation fluxes);

sky temperature (estimated from screen air temperature);

surface, ground and sky emissivities;

scene view factors (estimated from table of values for different types of site);

ground temperature (estimated or calculated as part of model with a nodal scheme).

H - Calculated from air temperature, cloud cover and ground temperature distinguishing between vertical and horizontal surfaces. Cloud cover is user specified in meteorological data file.

S - Combined constant coefficient(s) (not given). In effect, ground and sky are assumed to be at the same temperature as the dry bulb. See 5.4, q3.

All fabric loss is, ultimately, by radiation and convection at external surfaces. External long wave radiation exchange has been found to be an important factor for buildings. This would be particularly important for large areas of glazing.

## 5.5 Stratification

Treatment of stratification within a zone.

E - Can be modelled with multiple fully-mixed air volumes within a physical space using 'virtual' walls which radiation can cross.

H - Can be modelled with multiple fully-mixed air volumes within a physical space using 'virtual' walls which radiation can cross.

S - Not modelled.

## 5.6 Casual Gains

Types of casual gain included and scheduled by time, zone and radiative/ convective split.

| | | |
|---|---|---|
| E | - | Time schedule of total casual gain for each zone, split by latent/convective/radiant ratio and by source. (Lights, occupants and equipment). Values given at each timestep. |
| H | - | Four categories: lights, occupants, small power, others, in terms of convective, radiant and latent inputs. Radiant inputs can be directed to user-specified surfaces. Lighting can be switched between 'day' and 'night' loads according to external illuminance. All scheduled by hours and minutes. |
| S | - | No distinction made between source types. All energy to zone nodes: radiant/convective split is implicit in zone temperature definition but latent gain is separate. Scheduled on hourly basis for Mon-Fri and Sat-Sun. A proportion of the gain from lighting can be scheduled to be 'vented' instead of going to zone node, but apparently only as proportion of total gain; lights not treated separately. |

## 5.7 Moisture

Treatment of moisture production and transfer and condensation risk.

| | | |
|---|---|---|
| E | - | Moisture balance performed at each timestep in terms of ventilation and generation by occupants and processes. Surface and dew-point calculations are also possible, but there is no dynamic modelling of phase changes. |
| H | - | Moisture balance performed in terms of ventilation and internal generation. Surface condensation (internal surface temperature <dewpoint) is flagged, but there is no dynamic modelling of phase changes. |
| S | - | Moisture balance performed in terms of ventilation and internal generation. The way the model handles ventilation suggests that moisture is assumed to move between zones as heat does via conduction paths. Cooling plant can also (crudely) model moisture removal. |

Models H and E are very similar and probably adequate for passive solar purposes. The lack of dewpoint calculation is a deficiency of S but could be rectified, but the treatment of moisture movement does not seem realistic.

## 5.8 Occupancy Effects

To what extent can occupancy effects such as the following be taken into account:

- operating window screens, such as curtains, blinds and shutters
- window and door opening and closing
- latent inputs from washing, cooking and metabolism
- manual lighting control

If these are scheduled what is the time increment?

Can occupancy effects be initiated from within the simulation?

These are treated under separate headings:

**Window coverings**

E - Operate as functions of time, temperature, or solar intensity, on a timestep basis.

H - Shading scheduled but thermal properties remain fixed.

S - Modelled by choosing schedules for shading coefficient and glazing U value. Also blinds can be operated automatically to maintain a maximum direct solar gain.

**Infiltration through openings**

E - Specified by time or temperature dependent leakage system; time on hourly basis.

H - A total of three ventilation patterns are available which can be scheduled to mimic user behaviour (e.g. window opening).

S - Schedule of infiltration, venting and inter-zone conductance (no interzone flows possible).

**Lighting**

E - By schedule (as casual gain; no daylighting model).

H - By schedule or external radiation level.

S - By schedule, or BRE lighting method which uses a stochastic, empirical model of user behaviour.

No model really mimics occupants' behaviour as such, e.g. in a stochastic way, except the treatment of lighting used by S.

## 5.9 Comfort

Calculation of indices of comfort as a function of: air movement; humidity; air temperature; radiant temperature; direct solar radiation; activity; clothing levels.

Are these calculated during simulation or from output data.

E - Calculates zone air and surface temperatures, humidity and direct solar radiation and a rough estimate of air movement. Standard Effective Temperature, Predicted Mean Vote and Predicted Percentage Dissatisfied (of occupants) are also calculated.

H - All data for standard indices (as in E) available in output but not calculated explicitly.

S - No comfort index, no separate air and radiant temperatures. Zone temperature used, approximately 1/3 air and 2/3 radiant in normal situation.

Comfort is an important issue; for accurate calculation, the air and surface radiant temperatures are essential, with solar radiation desirable. Thus S is severely limited in this respect. For H and E, calculation of other indices (given the data) is trivial, but inconvenient.

## 5.10 Heating and Cooling Systems

How are heating and cooling systems modelled?

(See also question 4.7)

| | | |
|---|---|---|
| E | - | Detailed plant simulation is possible via a linked piece of software. Alternatively, and adequate for most simulations, control loops can be used to control environmental conditions using heat inputs etc; simple plant characteristics can be included, such as part load efficiencies, convective/radiative split etc. |
| H | - | Flexible means of delivering heat to space; heating systems defined by maximum output, warm-up and cool-down characteristics, system time lag, output connections to air (convective) and surface (radiant) nodes and controller characteristics. |
| S | - | Very simplified treatment: all heat to zone point or (optionally) radiant fractions direct to specific surfaces. No plant modelling as such except maximum outputs. Controls are from ambient air, zone and Trombe wall or rockbin temperatures. To satisfy a load, order is: fans, rockbins, venting, heating/cooling equipment. |

The approach of S is more specific to solar systems than the other models (but the restrictions of zone temperature are a significant disadvantage) while the other models are capable of handling solar features, with more physical detail, if required.

## 5.11 Plant Controls

How is control of heating and cooling systems implemented? How can the control points for the systems be defined.

(See also 5.10)

| | | |
|---|---|---|
| **Sensors** | | |
| E | - | Defined by location, condition sensed (e.g. temperature) and characteristics (e.g. deadband). Some data available in model. |
| H | - | Defined by location, times active, condition sensed (e.g. temperature) and characteristics, which may include frost protection. Data supplied by user. |
| S | - | Zone temperature only, as a 'perfect' sensor. |
| **Actuators** | | |
| E | - | Any nodal variable as output from a control law. This can include flux, temperature, valve position, etc. |
| H | - | Not treated separately from heating/cooling system. |
| S | - | Not treated separately from heating/cooling system. |

## 5.12 Daylighting Systems

Treatment of daylight levels within zones and control of daylighting and artificial lighting installations. Can the interaction between the lighting and thermal systems be modelled.

E - Not in released version.

*A lighting algorithm has been incorporated which calculates Daylight Factors and allows control of internal heat gains from lighting according to daylight level.*

H - Lighting level can be altered in response to external solar radiation as a step-response between fixed lighting patterns, or scheduled.

S - Daylight levels are predicted (fairly crudely) using BRE daylight factors (calculated independently before simulation and designed for UK climate). Strictly, this only applies to diffuse radiation, but direct radiation is added (after shading) in the model which gives a good approximation. Control can be manual or automatic and continuously variable or in steps.

The current versions use essentially empirical semi-manual methods 'tagged on' to the models.In general, the realistic modelling of plant, control and daylighting require short timesteps of a few minutes. This is inherent in S and H due to stability criteria, but not in E; it is not clear to what extent the timestep controller in E could reduce this effect by restricting the use of short timesteps to the relevant parts of the model only.

# 6.0 MODEL FEATURES

Purpose: To identify how closely the model maps on to ETSU's simulation requirements.

Notes: Within the passive solar programme, simulation models are used for the following purposes:

Understanding the behaviour of new designs

Relative performance of alternative designs

Absolute performance of alternative designs

Optimisation of performance

Design and interpretation of field trials

Design and interpretation of test cell experiments.

## 6.1 Performance Assessments

In evaluating the models their ability to assess performance in the following areas will be considered. An opportunity is therefore provided to comment freely on capabilities of the model in this respect.

Note: Reference number refers to existing documentary evidence which should be listed in section 6.2.

1. Energy accounting: What accounting methods are available? Procedures for assessing utility of casual and solar gains. Breakdown of energy flows by time and type.

E - Allows recovery of all parameters in tabular and/or graphical form. Statistical summary, regression and graphics plots of these can be selected from the output modules. Most parameters can be integrated and other data can be derived if required. However, only certain parameters are available in tabular form and then only in fixed parameters.

H - Energy gains and losses to each space at any time interval. Comprehensive breakdown by energy type, radiant/convective split, surface exchanges. No assessment of 'utility' of gains; authors feel no agreed, credible procedure exists for this.

S - By default, produces a comprehensive breakdown (described in manual) of heat flows of all types, including solar flows in great detail. Uses the concept of 'useful loss' as difference between actual loss and loss for zone temperatures exceeding 21°C. (This value is set within program code). Another approach is to compare simulations with and without solar gain for the same building.

E uses a different approach from H and S; this reflects their overall natures. E offers selection and could be set up to produce what S and H produce and is inherently more flexible for producing other data, but H and S give the information likely to be needed without any extra work by the user. The database approach of E is limited to pre-set formats and gives much less flexibility than a general database. The 'controlled experiment' approach with two simulations given for S could of course be used with any model.

## 2. Plant Performance: Plant sizing, Demand profiles, Etc.

E - As covered in answer to 6.1, q1, most data available for user to analyse as required.

H - No assessment of plant performance or operating efficiency; energy calculations based on net heat delivered to space. Demand profiles (total gain/space in specified time), and individual system outputs are available. See also 5.10.

S - Produces time series data (resolution chosen by user) for maximum load, fraction full load, number hours on, etc. of plant operation.

It would be fairly simple to add an analysis for plant sizing, operating efficiency, etc. to any model at a simple level.

## 3. Overheating

E - See section 6.1, q1 answer.

H - No special assessment is made, but see 6.1 q4.

S - Zonal temperatures recorded to form a frequency distribution, with possibility of removing invalid periods (e.g. unoccupied) with schedule. Apparently uses only zone temperature. Maximum zone temperature is also recorded.

Overheating is an important issue in passive solar design, but there is no generally accepted standard for assessing overheating. Therefore all models just rely on user interpretation of normal data.

## 4. Comfort Assessment

E - See 5.9. A set of standard comfort indices is offered and the data (e.g. air temperature, mean radiant temperature) to calculate others.

H - No explicit comfort assessment, but air, mean surface and mean radiant temperatures are available for simple comfort indices.

S - Uses a 'warmth' index as a simple function (not specified) of the zone temperature. Other measures are under investigation, but S faces the fundamental problem that radiant and air components cannot be disaggregated, so most standard indices cannot be derived. As the zone temperature is roughly 2/3 radiant, 1/3 air, it is not far from the simplest comfort index of 1/2 of each, but could be a long way out in many common situations, especially with large glazing areas.

For a proper assessment of comfort, separate radiant and air temperatures are needed. This is likely to be more pertinent to solar architecture than to conventional designs.

## 5. Utilization of Daylight and Artificial Lighting

E - No daylighting algorithms in released version.

*A lighting algorithm calculates daylight factors and can be used to switch lights according to internal illuminance, thus enabling calculation of daylight savings.*

H - No daylighting algorithms, but see 6.4 q6.

S - Outputs hourly illuminance levels (artificial and natural), using simple daylight factors.

A simple calculation of illuminance level, as used in S, could easily be added to E and H. A more detailed treatment would require internal geometry only available in E.

6. Site Layout

No specific algorithms except those described elsewhere, the main ones being for shading.

All models assume weather data is for site. The site affects microclimate, including solar obstruction, and only the latter can be modelled explicitly. The geometric approach of E makes this possible e.g. for partly shaded sites, but it is still difficult.

## 6.2 Documentary Evidence

(NOT GIVEN HERE)

## 6.3 Building Features

The determination of the scope of the model by establishing the physical features that can be handled. Additional items to be added if required.

Note: Type (n) Not Modelled
Type (s) Steady State
Type (e) Empirical Relationship
Type (qs) Quasi Steady
Type (f) First Principle
Type (d) Dynamic

Reference number refers to existing documentary evidence which should be listed in section 6.5.

1. Features: Direct gain, conservatory, atria, isothermal storage etc.

| | | |
|---|---|---|
| E | - | States that using first principle, energy and mass balance mechanisms, any passive solar feature can be modelled. As part of E.C. Passy's project, 12 passive solar entities are offered in pre-defined form, these include all the main passive solar features. |
| H | - | Most common passive solar features modelled; only air can be used as transport medium. Only solar transmission treated for shading and curtains. |
| S | - | States any feature can be modelled empirically via user 'port'. For example, 'stack effect' ventilation was modelled for an atrium in this way. Isothermal storage and Trombe walls are modelled within the existing model. Little scope for first principle modelling of other features other than as zones and walls. |

Most passive solar features can be modelled as part of a normal fabric/ventilation/window/space interaction; this is greatly facilitated by interzone air flows as air is the normal transport medium. Although S originated as a passive solar model, it has no significant advantage over the other models which can include passive solar features quite easily. S is at a disadvantage in its cruder modelling of some 'conventional' features such as direct gain and sunspaces, and (importantly) lack of interzone air flows. (This is only to be expected from its reduced parameter approach).

## 6.4 Plant and Control Features

The determination of the scope of the model by establishing the plant and control features that can be handled. Additional items to be added if required.

Note: Type (n) Not Modelled

Type (s) Steady State

Type (e) Empirical Relationship

Type (qs) Quasi Steady

Type (f) First Principle

Type (d) Dynamic

Reference number refers to existing documentary evidence which should be listed in section 6.5.

1. Heat Sources and Emitters: Fires, Boilers, Electric Storage Radiators, Wet Radiators, etc.

E - At a first principle, predefined level (all f) using plant model nodal representation: gas fired boiler; water radiator; electric storage radiator; air heating and cooling coil.

H - At a dynamic, empirical level: fires; boilers; electric storage; wet radiators; warm air; fan heaters; calor gas heater (including latent input); underfloor; 'ideal' heating without load limit.

S - 'Effective' model of hot air system (f) Model of electric storage radiator as zone with appropriate characteristics (e/f)

Empirical boiler with wet radiators, using one zone as heat source and fans/rockbins for transport to other zones (e/f).

The systems modelled by S seem somewhat crude - for example, modelling wet radiators (mixed convective and radiant in reality) by inputs to zone point in same way as fans (convective only in reality). S has no real plant simulation, see 5.10, 5.11. E and H handle a wide range of devices but in different ways; neither method has been well tested within the model.

2. Distribution Systems: Air, water, fans and pumps etc.

E - Defined at the first principle, dynamic level (all f) using plant model nodal representation: air duct, water pipes, air fan, water pumps, air and water psychrometrics.

H - Air flow patterns can be specified and altered over time but water, fans and pumps not modelled explicitly.

S - Ventilation modelled in schedules (e)

Inter-zone air flow modelled as conductance (no control) (e) between zones

Thermostatic fans (f)

Rockbins (f)

Water distribution using effective flow rates for fans/rockbins (i.e. semi-first principle) (e/f).

The use of thermostatically controlled fans for distribution in S is a major simplification neglecting effects such as hysteresis. As with most plant modelling, little field trial data is available in this area. Only E offers actual plant modelling of distribution systems, but this recent extension is not readily accessible to the user and is not well verified. The realism of using other built-in features, as in S, is open to question.

### 3. Heat Recovery Systems: Run around coils, cross flow heat exchangers, thermal wheels etc.

E - Heat exchanger only (f)

H - Not modelled.

S - Heat exchangers, empirically as reduced effective (e) infiltration rate.

Pre-heat, empirically by redirecting infiltration through conservatories, rock-bins, etc. However, as time interzone flows are not modelled, this must be crude (e).

### 4. Plant Controls: Thermostats, radiator valves, proportional, integral, digital control etc.

E - Modelled in terms of characteristics. 12 types active (e).

*New controller types added.*

H - Comprehensive thermostat modelling in terms of thermostat characteristics. Includes one thermostat controlling several spaces and thermostat responding to several spaces, thermostatic radiator valves, and timeclock (3 periods/day) with override in schedule.

S - Ideal thermostatic control (no hysteresis) (e)

Time switching

Hysteresis empirically by incrementing heating set points (in schedules) at each end of heating cycle, but no feedback response (e).

Realistic control is important, particularly in energy-efficient buildings where energy inputs are small but have a proportionally larger effect on conditions than in inefficient buildings.

### 5. Domestic Hot Water Supply.

E - No DHW systems modelled; individual components can in principle be modelled from first principles (f).

H - Not modelled.

S - Hot water tank modelled as homogeneous zone (e/f)

Instant hot water as latent and casual gain inputs (e).

This is not of great importance except in plant modelling when DHW could significantly affect boiler load profiles.

6. Lighting Controls: Manual, Photo electric, Dimming.

**E** - Not in current version.

*Lighting control added (see 5.12, 6.1 q5).*

**H** - By timeclock, schedule (for thermal input) and switching between 2 specified loads according to external horizontal surface illuminance.

**S** - Switching (f)

Dimmer (f)

Manual; uses BRE switching probability function which is a function of natural illuminance derived from experimental data (e/f)

Blinds; effectively external, controlled by direct solar gain (f).

The algorithms for the actual switching are trivial (on/off switching or simple dimming), but the measured value for illuminance is difficult to model or determine. No model does this perfectly, but the appropriate facilities in E offer a potentially greater range of possible measures by virtue of the geometric treatment.

## 6.5 Documentary Evidence

(NOT GIVEN HERE)

## 6.6 Design Cases

Many aspects of modelling have already been addressed. However, it is difficult to appreciate how these would all come together when the model is used. This section presents some design cases which are judged as being of importance to the passive solar programme. The authors are requested to outline the modelling techniques which they might adopt for simulations incorporating a high level of detail. It should be emphasized that the primary concern is with the capabilities of the model and not with issues related to performance assessment methods. Particular attention should be paid to the following:

(a) How the building and plant would be represented and the assumptions and approximations.

(b) The specification of the required user inputs.

(c) The modelling techniques that would be adopted to undertake the performance assessments necessary to evaluate the given design options.

(d) The output that can be generated to indicate the thermal and lighting conditions of the building to provide understanding of the mechanisms involved as an aid to design evaluation and decision making.

(e) An assessment of the time it would take a user with a good basic experience of the model to input the data for a simulation. Three examples have been selected from Energy World 1986 at Milton Keynes with the fourth example coming from the ETSU Non-domestic design studies:

1. CASE STUDY 1: WINDOW SYSTEMS
2. CASE STUDY 2: CONSERVATORY
3. CASE STUDY 3: AIR FLOW NETWORK
4. CASE STUDY 4: DAYLIGHTING

## CASE 1: WINDOW SYSTEMS

This looks at the Haslam Homes courtyard houses at the Milton Keynes Energy World, featuring very high performance 100% south facing glazing.

Choice of Issues for Assessment

Although there are many features in this design the area selected for study is restricted to a consideration of the performance of the glazing system to the kitchen and dining area.

The following issues have been chosen:

1. The representation of the high performance glazing system (including internal and external shading, reveals, glazing) and all associated solar processes.

2. Particular features of interest are:

(a) The ability of the model to cope with the operation of the blinds within the glazing over short time periods (less than 1 hour) and the consequent effect on light, solar radiation and heat transmission.

(b) Facilities within the model to control the operation of the blinds as a function of parameters such as internal temperature or comfort conditions.

(c) Control of window openings for ventilation and how possible interactions with the operation of the blinds may be modelled.

3. What data could be generated by the model to investigate the energy balance of the window system?

| | | |
|---|---|---|
| E | - | Glazing modelled explicitly using radiation transmission and thermal properties for each layer. Blinds and curtains 'moved' by changing thermal properties of window layers.<br>Blind and curtain control by changing window properties as function of internal conditions and/or time. Ventilation control can be time dependent or by using air flow model with vent opening (i.e. increased infiltration rate) operated according to internal conditions.<br>Evaluation from zonal energy flows and, for windows, heat flows via short and long wave radiation and conduction. |
| H | - | Glazing as wall element with transmission properties from manufacturer's data or preprocessor. Blinds 'moved' by changing absorption properties (see below). Glazing gap resistance lower than air due to argon filling; need to modify software for this. Thermal curtains could be crudely modelled by changing surface resistance (as S) but this ignores curtain-window gap; no facility for fabric with variable properties.<br>No automatic blind control but this could be achieved by modifying software (estimated 1 man week); short time step gives high time resolution for this. Ventilation rate can be made a thermostatic function of internal temperature.<br>Evaluation from standard output option of heat flux and surface conditions in each zone. |
| S | - | Glazing represented by separate single and triple glazed units (assuming normal glass) with air gap as zone between. Blinds attached to triple glazed unit. Thermal curtains modelled by scheduling window U values according to season.<br>Blinds can be operated (using Port) as function of internal temperature. Venting in hot conditions operated by thermostat to change ventilation rate (fixed values only) - but only on zone temperature, no separate air mass.<br>Evaluation of heating energy from calculating idealized auxiliary requirement: glazing evaluated using incoming solar and outgoing heat flow through it (but with no differentiation between radiant and convective). |

## CASE 2 : CONSERVATORY

This is for the C.P. Roberts home at the Milton Keynes Energy World, with a double-height, double glazed conservatory in one corner of the plan with rooms opening into it.

Choice of Issues for Assessment

The area for study is the performance of the double height conservatory and the following issues have been selected:

1.The representation of the energy flow paths between the house and conservatory including conduction and air movement.

2.The particular features of interest are:

(a) The facilities within the model to handle the solar input to the house and conservatory taking into account the form of the building.

(b) Longwave radiation exchange between house, conservatory and outside.

(c) Stratification within the conservatory.

(d) Control and representation of ventilation and/or shading mechanisms to prevent summer overheating in the conservatory.

3.What information could be generated to assess:

(a) The environmental conditions within the conservatory, especially the effect of direct insolation on comfort.

(b) The net energy flow between house and conservatory.

E - External windows as normal; solar processes treated geometrically, particularly relevant for radiation in conservatory and through internal windows. If sunpatches are used; solar radiation can only be directed to two surfaces in this way. Explicit long-wave radiation (highly assymetric radiation field). Vertical subdivision of conservatory into zones for stratification using air flow model and variable convection coefficients (important for this problem); venting as Case 1.

Evaluation from standard comfort indices (no evalution of direct radiation effects except via heated surfaces affecting radiant temperature), and energy flows as Case 1.

H - External windows as normal. Radiation to internal window using sunpatch to that surface from external windows. Long-wave radiation using star network (takes account of assymetric field). Stratification as multi-zone space with user-specified flow rates; authors believe no algorithm exists for modelling air flows in a conservatory properly. Fixed convection coefficients. Venting as Case 1.

Evaluation from internal air, surface and radiant temperatures and surface and zone heat flux(no evalution of direct radiation effects except via heated surfaces affecting radiant temperature).

S - Conservatory as one zone. External windows as normal, internal windows similarly but with internal walls as sidefin shading. No long-wave radiation exchange possible. Stratification not easy (model not suited) but could split zone vertically and estimate combined conduction paths between these zones. Fixed combined heat transfer coefficients. Venting as Case 1.

Evaluation from combined radiant+air energy flows to/from conservatory, house and outside, and zone temperature profiles.

## CASE 3: AIR FLOW NETWORK

The house was designed by Phippen Randall & Parkes, and was at the Milton Keynes Energy World. It features a tightly-sealed structure with mechanical ventilation and heat recovery.

Choice of Issues for Assessment

The area for study is the performance of the air flow network within the house and the heat recovery system and the following issues have been selected:

1. The representation of the air flow network, heat recovery and heating systems.

2. The particular features of interest are:

(a) The ability of the model to handle latent energy in the heat recovery system.

(b) The facilities to handle energy exchanges within the house given zonal control of the heating system.

3. What information could be generated to assess:

(a) The effect of the operation of the heating system and the redistribution of solar gains via the air flow network on solar utilization.

(b) The benefit of the heat recovery system and its dependence on the airtightness of the house.

| | |
|---|---|
| NOTE: | Authors of E and H comment that, in an air flow model, there are large uncertainties in the input data of opening and crack dimensions and external pressure distribution resulting from wind. Authors of E consider this (paradoxically) results in a robust design as a range of possibilities are explored; in contrast, authors of H believe assuming design or intended flow patterns a more robust and useful approach.<br>This neatly illustrates how methodology affects choice of physical representation. |
| E - | Air flow model in terms of cracks, openings, inter-zone flow resistances and external pressure distribution. Heat recovery system as special zone; latent recovery "difficult... but possible" using control loop with control law to represent phase change, or more fully using plant simulation. Heating as separate control loops for each zone.<br>Evaluation as subjective mixture of energy requirements, peak capacity and comfort indices. Peak load and energy demands matched zone by zone to air flows and short-wave flux to find causal factors. |
| H - | Untested air flow model exists for H but authors prefer user- supplied air flow data (see comment above). Heat recovery as two special zones connected by appropriate resistance, but no latent recovery model possible. Heating system as separate control for each zone equivalent to thermostatic radiator valves; additional control over several zones not possible.<br>Evaluation from normal outputs; normal short timestep gives high temporal resolution for solar and heating system interactions. |
| S - | No detailed answer, but brief explanation summarised here:<br>There is no model of air flow networks or heat recovery; these could be represented by interzone conductances or, in more detail, via the Port, but this would be a major task. Therefore use of the model for this study is not recommended by the authors. |

## CASE 4: DAYLIGHTING

This is a hypothetical wharehouse building for DIY retailing, and the case study concentrates on daylighting, thermal storage of heavy structure, and rooflight shutters to function as insulation and blinds.

Choice of Issues For Assessment

The design proposal contains a set of passive solar design measures which have been evaluated as part of ETSU's Design Studies project to demonstrate which measures are successful and should be retained and which measures are not and should be either modified or removed.

Starting out from the design team's stated intent and their proposed solution, the following issues have been selected:

1. The representation of both the daylighting and artificial lighting installations and the control of the systems by (i) Photo electric on/off control and (ii) A continuous dimming system.

2. The particular features of interest are:

(a) The computation of the internal daylight levels.

(b) The interception of solar and daylight by the roof light opening and shutter.

(c) The interaction between the lighting and thermal systems. For example, the operation of the rooflight shutters to control overheating will have an effect on both the lighting systems and the heat conduction through the rooflights.

3. What information could be generated to assess:

(a) The influence of the lighting control strategy on the passive solar contribution.

(b) Control strategies for avoiding summer overheating.

E - No lighting control. Heating, venting and blind effects as Case 1.

*New release has lighting control algorithms using daylight factors and access to separate software with full lighting design features.*

Evaluation would start with reference case of no control and see the effects of different control strategies.

H - Skylights as Case 1 but shutter effects on daylight not modelled. Lighting modelled as series of lighting circuits in different areas. Control is on/off only, between two levels, with no dimming, but this could be added with software change. Shutter operation could be scheduled or, with software change, made automatic on internal conditions. Daylight level could be found using daylight factor (see S) but really needs direct beam model.

Evaluation from solar radiation, heating and lighting energy, and internal temperatures, compared with different control strategies.

S - Lighting level from user-supplied BRE daylight factor taking into account external obstructions, internal geometry and surface finishes, etc. Direct beam radiation added to diffuse for calculating illuminance as lumped total, effectively as if all diffuse. Control as on/off or dimmed in different zones. Overheating controlled by venting (see Case 1) and blinds on internal conditions; insulation by scheduling glazing U values.

Evaluation from hourly zone temperatures, heating and lighting demand, and solar radiation for different control strategies.

## Conclusions on Design Cases

These conclusions make no reference to specific models, as this would make the discussion too convoluted; the reader should refer to the above, the rest of the Summary, and individual Questionnaires. The design cases highlight the inherent difficulty of realistically representing physical situations with any model. They also reveal several points relevant to the Programme concerning the existing and potential states of the models. Cases 1 and 2 illustrate the problems associated with the large areas of glazing which typify passive solar design; these are principally the glazing system itself, the assymetric long-wave radiation field, comfort assessment incorporating short-wave radiation, and convective effects.

Air flow modelling, examined specifically in Case 3 but important throughout, is a major concern. Buoyancy driven flows and temperature stratification are important for sun spaces. Ventilation (natural and mechanical) is important for all buildings; while the benefits of a full air flow model to replace user-supplied flows are debatable, a model which treats air mass adequately would seem essential for many problems. Modelling plant and control at the simple level of characteristics can also have a large effect compared to an idealised treatment, so this too is important. Lighting control would appear to be easy to add to any model at the level of daylight factors, but a geometric approach which may be needed for sufficient realism in many cases would require a geometrically based model.

There is a clear need for "add-on extras" to software, either by modifying existing routines or inserting new ones supplied by the user. For the latter a formal mechanism is very useful and would be highly desirable for any model in the Programme; the latter depends on software structure, discussed in Section 4. However, it is sometimes difficult to interpret the meaning of phrases such as "...but could be included by a simple modification to subroutine XYZ".

Much of the design evaluation given in the original replies was concerned with methodology, not of direct interest here, but it also highlights the need for an adequate range of output variables. For comfort, separate convective and radiant temperatures are needed to calculate accepted comfort indices, while for energy, the split between radiant and convective inputs is often important.

## 7.0 SOURCE CODE

Purpose: Confirm that the source code is available with adequate documentation and establish the ease of modification.

### 7.1 Availability

Confirmation of the availability of the source code and the provision of one copy of the source code documentation. YES/NO

Yes for all models

### 7.2 Coding

An explanation of the coding technique and the authors view of the balance between elegance and efficiency versus clarity to unfamiliar users.

E - Code is "liberally commented and well-documented". Input-output is divorced from procedural issues. Flexibility has always been chosen in preference to efficiency. To quote the jargon: "If a user is computer- literate and technology sympathetic, they will find it easy to effect changes to ESP. If not, they will be totally confused and lost."

H - To quote: "Code is structured and written for clarity, this generally at the expense of run-time efficiency." Authors place stress on ease of modification and clarity of code for users.

S - The program is, to quote: "reasonably well structured and documented (commented) although the documentation is probably inadequate for an unfamiliar user". Software structure is hierarchical with modules and transfer between modules well documented. However, a major deficiency is insufficient cross-referencing of variables between modules. Code is "neither elegant nor efficient but is self-evident and straightforward."

Outside users agreed with these comments. They felt that H was very clear and easy to understand, E slightly less so due to its complexity but still well structured, while the case coding of S was poorly written and documented.

### 7.3 Updating

Description of the procedures adopted for updating and releasing new versions of the source code and the associated documentation.

E - Regular updates. New manual twice a year. Outside users complained of delays in solving software problems and correcting bugs.

H - Updating for bug fixing available from authors. Funding awaited for full updating and release of new version 1.2.

S - New versions released by CAP to ETSU on request, with supplements to the manual.

## 7.4 Source Code Modifications

A detailed description of how a user could change an algorithm for the following cases:

(a) Any special facilities which do not interfere with main code, e.g. for temporary insertion of special algorithm or values

(b) Addition of algorithm, with and without additional I/O data.

Notes: Identify any relevant documentation including cross- referencing documentation to prevent unexpected results of software changes.

E - A document exists describing system at source code level using logic diagrams, subroutine trees, subroutine description, common block descriptions, subroutine and common block association matrices and file channels. Thus all the necessary information is available for modifying the source code and (in principle) knowing what the effects will be.

H - Temporary algorithms can be 'inserted' using 'Zipper points' which are essentially (normally dummy) subroutine calls which can be enabled or disabled as required. Otherwise, permanent changes can be made to existing subroutines or new ones inserted. The modularity of the input and output data sets, software, and manuals, facilitate code modification.

S - The user 'Port' allows quick alterations to code for special applications. It is a single subroutine called at strategic points in the main simulation module with access to most variables and spare arrays for outputs. The user creates new code and inserts it into the Port subroutine. This facility has been used for several things. Permanent minor changes can be made within the model, but this is more difficult to control and document in the long term.

All three models have at their cores a sequence of subroutine calls before the integration at each timestep, so a new routine can be inserted into the sequence in a similar way for any model. The 'Zipper' and 'Port' of H and S are merely dummy subroutine calls which formalize this, and are not really necessary for a competent programmer. However, CAP use the Port facility in S extensively and the formal arrangements of H & S are an advantage for users not familiar with the software. More important is the overall structure and ease of understanding; outside users who modified all three models found H by far the easiest.

## 8.0 USER SUPPORT

Purpose: To gauge the support available to the user.

### 8.1 Availability

Confirmation of the availability of user documentation and the provision of one copy of the documentation.

YES/NO

YES for all models

### 8.2 Updating

Description of the procedures adopted for updating and releasing new versions of the user documentation.

E - See 7.3

H - Currently no formal support or manpower available; bug fixes distributed to users as bugs are identified and corrected.

S - Supplements, released after major changes.

This is important.

### 8.3 User Experience

Describe the experience of buildings and simulation modelling expected of a user to enable them to understand the documentation and run the model.

E - Easy to 'drive' model for those with an aptitude for CAD but nevertheless this probably takes a few weeks to become proficient; tuition greatly speeds learning. The main problem is said to be in developing a personal methodology for using the model and interpreting the results. Author claims problems are compounded when model is simplified.

Little help given, except from examples in the manual.

H - Requires reasonable Fortran skills and knowledge of operating system features such as the editor and general building knowledge, but is quick to learn.

S - Fairly simple to understand for a new user; about 2 days of training required. Pro-forma sheets for inputs make input preparation easy, albeit old-fashioned. The main problem is user skill in developing a methodology, and understanding both the model limitations and buildings.

There is agreement that 'driving' the model is a minor part of the whole process, the rest of which remains an operation requiring human skills and experience which for all models includes knowledge of the theoretical and actual operation of buildings.

## 8.4 Modelling Strategies

What is the nature of the advice given to the user on strategies for creating physical descriptions suitable for modelling different building types and patterns of usage?

E - Refers to advice given in manual. This is mainly about the mechanics of setting up files, order of operations, etc. but does include some general advice about modelling. It is the opinion of the authors that use of simulation models is not developed enough for the "formulation of application paradigms" (this probably means methodology).

H - The details of preparing input data are explained in detail in the manual, but there is very little general advice on creating a physical description, except for the structure imposed upon it by the input data structure.

S - In the manual there is some useful general advice on the applicability and limitations of the model, the results of modelling exercises (e.g. what were found to be the important parameters), etc.

Modelling methodology is now a major research issue but little specific work has yet been done. No model manual would be expected to give more than brief advice on it. At present, it remains up to the skill and experience of the user.

## 8.5 Assistance

To what extent does the software, user or other available documentation assist the user in the translation from the chosen physical description to the input data set for simulation?

E - An input management program prompts, checks and coordinates inputs, but users have reported many bugs in this program. Some entries have assigned defaults. Access to multi-layer and material properties databases for walls and windows and plant item database. Most experienced users create and edit files using the system editor.

H - The manual explains very clearly how to input data with a simple example; the input files themselves require the names of most data items (the names must be put in by the user) so are easy to understand, but each file must be created and modified with the operating system editors without any assistance or data checking from the program. A file of material properties (but not constructions) is available. There are defaults for many parameters. The lack of assistance or error checking leaves a large potential for user errors going unnoticed.

S - The manual gives possible ways of describing a building, with example sets. An editor program manages and prompts for user inputs, with type and bound checks and defaults for most data and a demand for others if not given. Alternatively, pro-forma sheets can be filled in and entered into structured files. No files of materials or constructions available initially, but these can be built up by the user.

It is largely up to the user to map his description to numerical data; E and S, but not H, will prevent some obvious mistakes.

## 8.6 Support

Availability and cost of support within the model author groups to advise external users, particularly ETSU and the projected availability of this help over the next 3 years.

E - ESRU can supply any level of support, costed on a consultancy basis.

H - No funding or manpower available at present. Support is almost totally dependent on the continued involvement of the principal author.

S - Continuing at present level. (Not specified)

## 9.0 USER INTERFACE

Purpose: To establish the characteristics of the user interface

### 9.1 Data Input and Input Constraints

**1. Describe the formal structure of the input data set.**

E - Organized conventionally as records in files; these contain either numerical data, or other file names, in ASCII format. The file name appears as a heading; input files are difficult to read directly, but the data they contain can be listed clearly with headings from within the input management program.

H - In structured, readable command formats. These include the verbs ENABLE for program modules and SET for run parameters, file definitions in form Filename = .... etc., but all these must be set up by the user: see 8.5. The syntax takes a long time to understand.

S - Uses files for different input sections. These have 4 lines of header information and column headings for each table of input data, with indication of data type (text or numeric). They are thus easy to understand.

Rank order for ease of understanding: S H E.

Outside users agreed that S had the best input data structure.

2. Describe the methods of entering and editing data including links to other software such as architectural drawing packages, and comments on how appropriate different strategies are in different circumstances.

E - Various techniques. Normal inputs are with input management program responding to prompts, or for more experienced users editing files with operating system editors. Links to geometric CAD packages are possible, but authors consider no good data input technique yet exists anywhere.

E - A forms-driven on-screen editing facility has been added in Release 7.1.

H - Uses operating system editor to create and alter files. No built-in editor/input module or graphical inputs.

S - A module within the model is used as a line editor; arguments are entered separated by commas or spaces. Alternatively, any text editor can be used; this may be essential for making global edits when using large numbers of similar files. A facility exists (called SERILINK) to read geometry files from a CAD tool called SCRIBE, useful for checking geometric consistency or changing shapes, but the geometry is not used within the program explicitly.

As with most systems, a learning period is required, but once a user is familiar with the file structures, editing with an operating system editor is faster than a dedicated program designed for new users. In this case, the lack of description within input files (e.g. column headings) makes E slightly more difficult to use.

3. Input Requirements and constraints including:

Climatic variables; method of describing zone geometry and constraints on zone shape; method of specifying window/door geometry, maximum number allowed; maximum number of zones: maximum number of component elements per structure.

Climate: All models require normal climate variables : some are needed only for certain options.

Geometry:

E - The only truly geometric model. No constraints on zone shape as long as zone surfaces can be defined by vertex coordinates (so all surfaces are planar).

H - No real geometry so no constraints, but surface tilt and azimuth required.

S - No real geometry but a zone has a height and floor area, at least nominally, and surfaces have height, length, azimuth and tilt. This implies zones are rectilinear but there is no geometry to check this.

Sizes:

E - Upper limits on numbers of zones, constructions, etc., high enough for most work, but these can be increased if necessary.

H - No constraints except size of memory of machine.

S - Upper limits, but these can be raised by changing a Fortran statement.

No serious constraints except those inherent in models. Sizes can easily be changed.

4. Databases of material properties and other 'guide book' data, and guidance on choice of inputs including information about default values generated by the model, and whether these can be overidden by the user.

E - Construction database holds thermal and surface properties for approximately 100 products. A module exists for combining these to form project-specific constructions and produce information on U-values and condensation. Default values exist for many parameters. User can edit the database and add new constructions.

H - Database of standard material properties and users can create their own in parallel, together with databases of multi-layer constructions Many parameters have default values.

S - No databases supplied with code, but CAP have produced their own for materials and occupancy and heating schedules.

Rank order: All roughly equal.

All models use defaults, but it is not clear how much advice (if any) is offered to the user on when they are appropriate.

5. Extent to which model attempts to ensure that input data are reasonable and consistent, including geometric visualization, topological analysis (eg air flow networks, zone linking), range checks on numerical quantities and cross checking against QS bills of quantities.

E - Many checks on ranges of input data and consistency of derived data (e.g. zone volumes), and visualisation of building geometry.

H - To quote, "There is little checking on input data consistency". User warned of possible instability for inappropriate timesteps. Some checks deliberately omitted to allow full flexibility as research tool.

S - Simple checks on:

- illegal time and date data
- illegal fan placement
- correct data range and format
- certain values are not zero
- total internal solar distribution adds up to 1
- total window area does not exceed total wall area for any wall.

There are no other checks.

Rank order: E S H.

Data checking would seem very desirable for widespread use of any model, particularly for consistency which can be overlooked in checking raw data.

## 9.2 Output Data Sets

1. Contents and structure of output data set(s) before processing, including options for varying number of data output during simulations. Is the input data reflected in the output?

E - Entire input and output data sets are transferred to a database of random access binary files. This can be filtered to produce ASCII output files. There are 4 save levels for output. Graphical and statistical anslysis is offered (see section 6.1).

*Full list of input data and derived variables (areas, volumes, etc.) can be generated in readable format.*

H - Output can be turned on and off in schedules and the time resolution varied from one timestep to one day. Output is divided into 'blocks' by type; these are meteorological, spaces, surfaces, heating, water (i.e. latent), radiant. The output files, which contain a lot of commentary text, are very large but easy to follow. All these are optional and selected by the user, but there are no options for what appears within each block at each output interval. Indeed, outside users had to write their own post-processors to remove unwanted text, although this was not difficult. There is little reflection of input data in the output files.

*New output formats more compact with post-processors for standard tables and graphs.*

S - Output file contains an echo of the input file and entries used from library files, a summary section of static variables such as tables of areas, U values, etc. for walls, and blocks of user-selected output data; ambient, building, zones, windows, walls, surfaces, fans, rockbins, Trombes, or all.

The graphical facility in E is useful for rapid understanding. The echo of input data in S is a useful feature, especially for archived results. The output structure of H is not suitable for routine assessment at present.

Outside users found the clear structure and portability of S outputs the most useful format. For any model, it would be quite easy to change or extend the output formats.

2. Summary of statistical analyses (averages, regression, extrema, time series etc) and forms of presentation (graphical, spreadsheet, tabular etc) directly available to the user.

E - (See also section 6.1)

Summary statistics and other statistics e.g. regression (Link to NAG library)

Energy balance for defined point (pie chart of table)

Graphs of variable against time but not variable against variable in current version

Mappings to different comfort scales.

H - Output in basic readable tables. No post-processors in release 1, but some simple graphics being developed.

S - Basic statistics for pre-defined variables

Frequency distribution tables

Some post processing being developed by CAP;

Simple arithmetic and statistical functions in MANIP/MERGE, operating on output files

High quality graphics for reports produced by AUTOG

Graphs and tables from output files using SYMPHONY being developed.

Lack of graphical facilities in H (and to some extent S) could be a disadvantage in helping understanding of behaviour, but graphs could easily be added to any other model.

## 9.3 Training Period

An estimate of the training period necessary before a new user could run a simple simulation from raw data on a building and its usage pattern.

As reported by authors:

E - "Based on experience with students, it is estimated that a new user will acquire the skills necessary to simply control ESP within one week. To effectively apply the model in the real world will depend on a deep understanding of the issues underlying building energy and simulation. Therefore, to save energy in buildings may take a new user the rest of his or her life!"

H - "1 day to run examples in documentation

1 week to run simple building as modification to examples

6 months to full knowledge of both data and coding principles."

S - "A week."

Obviously a very difficult thing to define and dependent upon the natural aptitude of a user, but the answers reflect, perhaps, the complexities of the models. Outside users estimated that an initial, tutored training course would take about 2 weeks for H and E and 2-3 days for S. They considered S to be better suited to self-teaching with the manual.

## 9.4 Free Comment on User Interface

Summarized here:

| | | |
|---|---|---|
| E | - | Arguably advanced for its time when developed, but now, according to the authors, "badly in need of a retrofit" compared to the latest computer developments, but still advanced by the standards of current building models. A large effort is going into a new interface exploiting the latest technology. |
| H | - | Output facilities are limited.<br>Much in-house work has been going on since release to produce better output, including tabular post-processing and simple graphics. |
| S | - | The ideal interface is considered to be a function of the user and the application. Four main functions:<br>1. Creating input datasets<br>S is well suited to this<br>2. Checking data sets<br>S rejects all simple errors and echoes the input in the output which is essential for archiving for later analysis<br>3. Analysis of results<br>S produces simple, readable tables. Thus easy to analyse or input to other software, e.g. database<br>4. Communication of results<br>Probably unrealistic to incorporate report quality graphics into simulation software. The package AUTOG has been "invaluable" in producing high quality graphics. |

## 10.0 FREE COMMENT

Purpose: To provide an opportunity for author groups to comment freely on any issues arising from the questionnaire or the use of their model in the context of the Passive Solar Programme.

**E** - "ESP is a model for designers and researchers alike. Contrary to popular belief it has a very organised data structure which makes it easy to apply and to modify."

**H** - Felt to be "ideally suited to detailed investigative modelling of the energy and environmental performance of buildings, and for matching monitoring experiments of short time scale processes .... it is less suitable for general design assessment (e.g. annual fuel costs)".

Authors consider passive solar simulation "near to the forefront of modelling techniques and capabilities such that flexibility and ease of development should be a major consideration in assessing models for use in ETSU's programme".

**S** - There is a useful summary of the strengths and weaknesses of the model, upon which the selection of S for ETSU was made in 1982. The main strengths are widespread use, speed of running, good user interface and easy changes to code via 'Port'. The main weaknesses are due to the simplifications used in algorithms and complex data structures within the code making changes to this difficult.

In view of these, the role of the model is seen as complementary to more detailed models. It is considered that thorough comparisons with more detailed models will clarify the appropriate range of application of S.

# ANNEX 3

# COMPUTER RESOURCE REQUIREMENTS

## INTRODUCTION

As part of the evaluation exercise described in Section 1, a detailed comparison of the relative 'ease of use' of the three models was made by CAP Scientific [11]. For the study, the following working definition of ease of use was adopted:

- the 'ease of use' of a package is inversely proportional to both man and machine resources needed to yield a meaningful answer to a given problem.

This section is a summary of the main results and conclusions from the CAP report relevant to machine resources. The exercise was carried out for two problems; a simple two-zone model of a test cell (using all three models) and a 13-zone model of a three-bedroomed detached house (using just ESP and SERI-RES).

### Machine Resources

The following machine factors affect how quickly input data can be prepared, simulations run and output analysed:

- processor speed
- available core memory
- disk access and read/write speed
- operating system efficiency

Simulation speed is not the only important factor. If many simulations are carried out, particularly in batch mode with all results stored, the available disk space may be a limiting factor.

Improvements in processor speed and the operating system normally benefit each of the models equally. Increases in disk space and access speed have benefits which vary with the volume and frequency of disk access required by the model.

These results are for the simple two-zone model. The resources are divided into core memory space, disk space and running time.

Two simulations were run for each package;

- an annual run with an output file containing a monthly breakdown of the zonal heat flows and temperatures.
- a 'sample days' simulation. The model is run for a ten day period, outputting hourly data on the last two days only; again, a breakdown of zonal heat flows and temperatures are output.

All simulations were run in batch mode on a Perkin Elmer 3230 which operates at 0.7 MIPS, with an available core memory space of 1.85 Megabytes, and it has two 67 Megabytes fixed disks. On the Perkin Elmer, ASCII formatted files have a fixed length record. On most other machines (Sun, Whitechapel, Vax, IBM PC) they have variable length records. This means that the Perkin Elmer stores ASCII formatted files less efficiently than most other machines. Therefore the storage space for each model on an IBM formatted disk is given in brackets in table A3.1.

| | SERI-RES | HTB2 | ESP |
|---|---|---|---|
| Core memory | 706 kbytes | 658 kbytes | 1416 kbytes |
| Run time (minutes) | CPU elapsed | CPU elapsed | CPU elapsed |
| Sample day | 0.85 1.30 | 7.50 8.30 | 0.42 0.53 |
| Annual | 16.2 17.0 | 280 290 | 28.7 63.1 |
| Disk space: | | | |
| program | 2.9 Mbytes | 1.8 Mbytes | 14.4 Mbytes |
| | kbytes | kbytes | kbytes |
| Input files | 8(6.1)* | 60.3(11.8)* | 12.9(5.3)* |
| Yearly weather data | 240(239)* | 420(352)* | 240(239)* |
| Work files | 155 | 0 | 0 |
| Output | | | |
| sample day | 140 | 770 | 58 |
| annual | 70 | 5760 | 8400 |

* storage times on an IBM formatted disk are shown in brackets.

**Table A3.1** Comparison of computer resource requirements for the three models SERI-RES, HTB2 and ESP.

The following comments help to explain the results shown in Table A3.1.

**Core Memory:** The core memory required to run E is about twice that of S or H, but this is unlikely to cause problems on current machines.

**Disk Space:** The E suite of programs occupies about 10 times the disk space of S and 20 times that of H. Again, this should not cause problems on current machines.

**Weather Files:** The storage space required by weather files varies between models, but is a small part of the total.

**Output Files:** There is no output processing in H; data are stored for zones and elements at a maximum interval of one hour, and read directly from the output file. Output processing in S is done during the simulation and the maximum output interval is one day, with data stored on a zone by zone basis. In E, the maximum interval is one hour and data are stored for zones and elements in binary; they are subsequently extracted using a program separate from the simulation program. The times given for E are the sum of the simulation and output extraction times. The different output file contents mean that the output files for H and E require much more disk space than for S.

**Machine Time:** This is expressed in minutes of computer processing unit (CPU) time and elapsed time. Elapsed time (the total machine time from start to finish, including disk reading and writing) is the critical factor for a given machine, while CPU time is the best measure of computer time actually performing numerical calculations. In contrast to disk space requirements, it is not easy to estimate elapsed time for a many-zone simulation from a two-zone simulation, and the ratios between models will sometimes change completely. This is because the maximum timestep for H and S giving numerical stability (of the order of a minute) is determined by the construction, while E is always numerically stable and the maximum timestep is fixed at one hour.

Tables A3.2 and A3.3 summarise the manual effort and machine resources required for modelling the two-zone test cell, using all three models, and the 13-zone house using ESP and SERI-RES respectively.

For each of the simulation packages SERI-RES, HTB2 and ESP a simple two-zone model was input, checked, and run using the ETSU Perkin-Elmer 3230. The following table summarises the manual effort and machine resources required.

| **a: Manual Effort** (minutes) | SERI-RES | HTB2 | ESP |
|---|---|---|---|
| *Inputting the data* | | | |
| Construction | 20 | 30 | 40 |
| Geometry | 20 | 30 | 10 |
| Remaining parameters | 10 | 30 | 50 |
| **Total** | 50 | 90 | 100 |
| *Checking the data* | | | |
| Construction | 4 | 6 | 18 |
| Geometry | 5 | 14 | 5 |
| Remaining parameters | 1 | 10 | 7 |
| Total | 10 | 30 | 30 |
| Total manual effort | 60 | 120 | 130 |

| **b: Machine resources** | SERI-RES | HTB2 | ESP |
|---|---|---|---|
| *Elapsed time (minutes)* | | | |
| Ten days simulation | 1 | 8 | 0.5(1) |
| Annual simulation | 20 | 300 | 60 = 20(1)+40(2) |
| *Disk working space (kbytes)* | | | |
| Ten days simulation | 140 | 770 | 60 |
| Annual simulation | 70 | 5760 | 8400 |

(1) Simulation time
(2) Output post-processing time

**Table A3.2** Ease-of-use benchmarks (two-zone model).

For the two simulation programs SER-RES and ESP, the Linford house was input, checked and run using the ETSU Perkin-Elmer 3230. The manual effort and machine resources are summarised below:

| a: **Manual effort** (minutes) | SERI-RES | ESP |
|---|---|---|
| *Inputting the data* | | |
| Construction | 15 | 90 |
| Geometry | 100 | 500 |
| Casual gains | 30 | 30 |
| Heating system | 20 | 40 |
| Remaining parameters | 10 | 50 |
| Total | 175 | 710 |
| *Checking the data* | | |
| Total | 90 | 24 |
| Total manual effort | 265 (4.5 hrs) | 950 (16 hrs) |
| b: **Machine resources** | SERI-RES | ESP |
| *Elapsed time (minutes)* | | |
| Ten days simulation | 6.8 | 4.5(1) |
| Annual simulation | 44 | 480 = 260(1)(3)+220(2)(3) |
| Disk working space (kbytes) | | |
| Ten days simulation | 580 | 350 |
| Annual simulation | 260 | 56 000(3) |

(1) Simulation time
(2) Output post-processing time
(3) Extrapolated from a one month run

**Table A3.3** Ease-of-use benchmarks (13-zone model).

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# The documentation and evaluation of building simulation models

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