PREFACE

International Energy Agency

The International Energy Agency (lEA) was established in 1974 within the framework of the Organization for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IBA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of forty-two Implementing Agreements, containing a total of over eighty separate energy RD&D projects. This publication forms one element of this programme.

Energy Conservation in Buildings and Community Systems Programme

The lEA sponsors research and development in a number of areas related to energy. In one of these areas, Energy Conservation in Buildings and Community Systems (BCS), the lEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Seventeen countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organizations, as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy research and development is recognized in the lEA, and every effort is made to encourage this trend.

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures that all projects fit into a pre-determined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (completed projects are identified by *).

Annex 1: Load energy determination of buildings *
Annex 2: Ekistics & advanced community energy systems *
Annex 3: Energy conservation in residential buildings *
Annex 4: Glasgow commercial building monitoring *
Annex 5: Air infiltration and ventilation centre
Annex 6: Energy systems and design of communities *
Annex 7: Local government energy planning *
Annex 8: Inhabitants behaviour with regard to ventilation *
Annex 9: Minimum ventilation rates *
Annex 10: Building HVAC system simulation *
Annex 11: Energy auditing *
Annex 12: Windows and fenestration *
Annex 13: Energy management in hospitals *
Annex 14: Condensation and energy *
Annex 15: Energy efficiency of schools *
Annex 16: BEMS 1 - User interfaces and system integration
Annex 17: BEMS 2 - Evaluation and emulation techniques
Annex 18: Demand controlled ventilating systems
Annex 19: Low slope roofs systems
Annex 20: Air flow patterns within buildings
Annex 21: Calculation of energy & environmental performance of buildings
Annex 22: Energy efficient communities
Annex 23: Multizone air flow modelling
Annex 24: Heat, air & moisture transport in new and retrofitted insulated envelope parts

Annex 25: Real time simulation of HVAC systems and fault detection
Annex 26: Energy-efficient ventilation of large enclosures
Annex 27: Evaluation and demonstration of domestic ventilation systems
Annex 28: Low-energy cooling systems

Annex 21: Calculation of Energy and Environmental Performance of Buildings The objectives of Annex 21 are to:

1) develop quality assurance procedures for calculating the energy and environmental performance of buildings by producing guidance on:
   - program and modelling assumptions
   - the appropriate use of calculation methods for a range of design applications the
   - evaluation of calculation methods
2) establish requirements and market needs for calculation procedures in building and environmental services design;
3) propose policy and strategic direction for the development of calculation procedures;
4) propose means to effect technology transfer of calculation procedures into the building and environmental services design profession.

The subtasks of this project are:

A. Documentation of Existing Methods
B. The Appropriate Use of Models
C. Reference Cases and Evaluation Procedures
D. Design Support Environment

The participants in this annex are: Belgium, France, Germany, Italy, the Netherlands, Switzerland and the United Kingdom. Canada, Finland and Sweden also participated in the early part of the project. In addition, Finland, Spain, Sweden and the United States participate in Subtask C as a collaborative research activity between Task 12 Subtask B of the lEA Solar Heating & Cooling Programme.

The UK Building Research Establishment acts as Operating Agent of BCS Annex 21.

Solar Heating and Cooling Programme

Initiated in 1977, the Solar Heating and Cooling (SHC) Programme was one of the first lEA R&D agreements. Its objective is to conduct joint projects between the 20 member countries to advance solar technologies for buildings.

A total of eighteen projects or "Tasks" have been undertaken since the beginning of the Pro-gramme. The overall programme is managed by an Executive Committee composed of one representative from each of the member countries, while the leadership and management of the individual Tasks is the responsibility of Operating Agents. These Tasks and their respective Operating Agents are (completed projects are identified by *, tasks in planning stage are identified by #):

Task 1: Investigation of the performance of solar heating and cooling systems - Denmark * Task
2: Co-ordination of research and development on solar heating and cooling - Japan * Task 3:
Performance testing of solar collectors - United Kingdom *
Task 4: Development of an insulation handbook and instrument package - United States * Task 5:
Use of existing meteorological information for solar energy application - Sweden *
Task 6: Solar heating, cooling, and hot water systems using evacuated collectors - United States * Task
7: Central solar heating plants with seasonal storage - Sweden *
Task 8: Passive and hybrid solar low energy buildings - United States *
Task 9: Solar radiation and pyranometry studies - Germany *
Task 10: Material research and testing - Japan *
Task 11: Passive and hybrid solar commercial buildings - Switzerland *

Task 12: Building energy analysis and design tools for solar applications - United States
Task 13: Advanced solar low energy buildings - Norway
Task 14: Advanced active solar systems - Canada
Task 15: Advanced central solar heating plants #
Task 16: Photovoltaics in buildings - Germany
Task 17: Measuring and modelling spectral radiation - Germany
Task 18: Advanced glazing materials - United Kingdom
Task 19: Solar air systems - Switzerland
Task 20: Solar retrofit systems - Sweden

Task 12: Building Energy Analysis and Design Tools for Solar Applications

The scope of Task 12 includes:

(1) selection and development of appropriate algorithms for modelling of the interaction of solar energy-related materials, components, and systems with the building in which these solar elements are integrated;

(2) selection of analysis and design tools, and evaluation of the algorithms as to their ability to model the dynamic performance of the solar elements in respect of accuracy and ease of use; and

(3) improvement of the usability of the analysis and design tools, through preparation of common formats and procedures and by standardization of specifications for input/output, default values, and other user-related factors.

The subtasks of this project are:

A) Model Development
B) Model Evaluation and Improvement
C) Model Use

The participants in this task are: Denmark, Finland, Germany, Norway, Spain, Sweden, Switzerland, and the United States. In addition, Belgium, France, Italy, and the United Kingdom participate in Subtask B as a collaborative research activity between Annex 21 Subtask C of the lEA Energy Conservation in Building and Community Systems Program.

Architectural Energy Corporation serves on behalf of the US Department of Energy as Operating Agent of SHC Task 12.

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Overview

This Volume describes part of the empirical validation work undertaken under the auspices of the group formed by combining International Energy Agency (IEA) Building and Community Systems (B CS) Annex 21 Subtask C and IEA Solar Heating and Cooling (SHC) Task 12 Subtask B.
The work was directed by the UK Building Research Establishment (BRE), and managed by the Environmental Computer Aided Design and Performance (ECADAP) group in the School of the Built Environment at De Montfort University Leicester, and by the Energy Monitoring Company (EMC), Newport Pagnell, UK. The latter two participated via sub-contracts from the BRE.
This Volume is part of a 3-Volume set, produced by the UK participants:

Volume 1: Final Report
Volume 2: Empirical Validation Package
Volume 3: Working Reports

This empirical validation work complements the work using other evaluation techniques under-taken within the IEA BCS Annex 21/ SHC Task 12 group. These activities resulted in the production of a set of Building Energy Simulation Tests (BESTESTs), based on inter-model comparisons. These tests, based on domestic scale buildings, are structured such that reasons for a program not properly predicting a building's performance can be diagnosed. Other tests based on intermodel comparisons relate to commercial buildings. Some work was also under-taken to develop analytic tests.

The Working Reports

This Volume is a collection of reports which were used in IEA BCS Annex 21 / SHC Task 12 between March 1992 and September 1993 to evaluate the predictions from over 25 combinations of detailed thermal simulation program and user. The reports are reproduced without modification as they were distributed to the participants in the exercise.

- Availability of data for validating dynamic thermal simulation programs of buildings
- IEA SHC Task VIII Empirical Validation: A critical appraisal
- Summary and appraisal of high quality data sets in the UK

Examples of Newssheets

Three other reports which were also distributed during the exercise (Site Handbook, Validation Guidebook and Quality Assurance Report) are not reproduced in this Volume. They were, with some updates and modifications, consolidated to form Volume 2 (Empirical Validation Pack-age) of the 3-Volume set describing the work.

Summary As part of an SERC/BRE sponsored exercise to develop tools for validating dynamic thermal models, Leicester Polytechnic undertook a review and evaluation of monitored structures to identify data sets suitable as the basis for empirical validation tools. This was subsequently extended thanks to BRE support. Over 580 monitored buildings located throughout the world, were classified and assessed; all had produced hourly building performance data and had associated weather data. Data from only 27 structures, located at 8 sites in Europe and the USA were deemed to be of sufficiently high quality that they could be used for validating a wide range of complex dynamic, and simpler, thermal models. This Note gives an overview of the evaluation procedure, the types of data available and the major conclusions of the research.

Availability of Data for Validating Dynamic Thermal Simulation Programs of Buildings.

K J Lomas, BSc, PhD, CEng, MInstE

1. Introduction

Leicester Polytechnic was one of four UK institutions collaborating in the joint Science and Engineering Research Council (SERC) and Building Research Establishment (BRE) project; 'An investigation into analytical and empirical validation techniques for dynamic thermal models of buildings', Bloomfield'. This group was interested in models which predict the dynamic (hourly) variations in plant loads and energy fluxes rather than those which are aimed at simulating HVAC or active solar systems. Such programs are often termed 'building load' or 'building envelope models'. It is programs of this type which are the subject of this Note. The group worked with ESP, SERIRES, and HTB2. The primary thrust of the work at Leicester Polytechnic was to generate tests (or tools) based on Empirical Validation, that is, the comparison of model predictions with data collected from monitored buildings.

To be of real value, these validation tools should be capable of revealing internal errors' in the programs themselves, such as inappropriate simplifications of the real world, invalid mathematical approximations and coding errors. To do this, it is necessary to minimise 'external errors': in the data input to the programs; in the measurement of the buildings thermal behaviour; and in the procedure used to compare measured and predicted values. This, however, is no easy task, indeed, in a recent review[2] the author of this note concluded that: "the presence of external errors (and the consequent uncertainty in model predictions) has meant that none of the empirical validation studies undertaken using ESP, SERIRES, DEROB and BLAST would have produced conclusive evidence of internal errors in the models themselves" and that "only the highest qualify building construction and data-gathering techniques can hope to produce conclusive evidence of internal errors in dynamic thermal models". An exhaustive search and evaluation procedure was therefore undertaken to try and uncover data sets which would enable a suite of validation tools to be generated covering the widest possible range of building types, modes of operation and climatic types. The work has been documented in detail elsewhere[3,4]. The aim of this Note is to give an overview of the four phase evaluation procedure, the data sets available, the information about each data set which has been collated and the overall conclusions of the research. It also covers data sets developed more recently in the UK.

2. Phase 1: Identifying Acceptable Data Sets

in Phase 1, preliminary acceptance criteria were devised to eliminate data sets which could not be of value for validating any dynamic thermal program.

Criterion 1 : Structures must not include operative active solar space heating or cooling systems.

Criterion 2 : The weather data must have been collected at the site of the building.

Criterion 3 : The measured building performance data, and the weather data, must be available at hourly, or more frequent intervals.

Only data sets which fulfilled all three criteria were considered as a possible basis for empirical validation tools. These were termed as 'Acceptable Data Sets'.

3. Phase 2: The Search for, and Classification of, Acceptable Data Sets

In Phase 2, the widest possible range of Acceptable Data Sets were identified using a variety of methods. These included:

(i) interrogating 14 computerised literature data bases;

(ii) a questionnaire survey of the 21 members of the International Energy Agency Executive Committee for Buildings and Community Systems;

(iii) visits to data collection sites in the UK and North America; and

(iv) an extensive search of other standard sources, conference proceedings, journals etc.

The search revealed 599 different structures from which acceptable data had been gathered. As most of these had been monitored in a variety of configurations and modes of operation and under different weather conditions, the total number of Acceptable Data Sets was very much larger. Detailed information was sought for 231 of these structures. Based on the limited information to hand at the time, these were thought likely to have yielded the best data. The details of the 231 structures were classified and tabulated individually[3,4] .

The remaining 368 structures were either residences or commercial buildings which had been monitored at, what is commonly known in the USA, as the Class B level. At this level, the basic 'building system level', parameters such as internal temperatures and power consumptions are recorded but not 'mechanism level' data (i.e. the temperatures and heat fluxes which permit validation of individual program algorithms). These 368 structures were evaluated in Phases 3 and 4 based on their common group characteristics.

The 231 classified buildings ranged in size from 1m^3 boxes through to *very* large multistorey commercial buildings, so six structural categories were devised. Data from structures in all six categories have been used for program validation. In general, the structures increase in complexity from Category 1 - Test Cells, to Category 6 - Commercial Buildings.

The detailed reports[3,4] provide the following information:

(a) an overview of the structures in each category, including their location, the purpose for which they were monitored, and an appraisal of the strengths and weaknesses of the data;

(b) photographs depicting structures which typify those in each category;

(c) detailed tabular information about each data set with further textural information where necessary.

The tables are the key to the classification process. They contain the same type of information about each structure to the same level of detail.

(if General information about the institution responsible for the monitoring and the name and location of the experimental facility.

(ii) A description of the building, its constructional features, the mode of operation (the heating, cooling and venting strategy) and where appropriate, the type of occupancy, the number of rooms, the number of storeys and the plan area.

(iii) Details of the monitoring such as the recording period, the climatic and building response parameters recorded, and the media on which the data was stored.

(iv) The source references describing the experiments, the purpose of the monitoring and the uses which have been made of the data. Any usage of the data for empirical validation, especially by persons other than those who undertook the monitoring, is identified.

The compilation of information is thought to be the largest of its type ever assembled. In this Note it is only possible to give a brief overview (Table 1) and quantification (Table 2) of the structures in each category.

4. Phase 3: Identifying Useful Data Sets

In this phase, criteria were derived to identify data sets which appeared to have deficiencies rendering them unsuitable for validating any dynamic thermal program. (The criteria were not therefore specific to any particular dynamic thermal program or group of such programs). The data sets which pass these criteria were termed 'Useful Data Sets'.

In the course of compiling the information about Acceptable Data Sets, details of over 130 exercises involving comparisons between measured data and values predicted by thermal programs, of varying complexity, were examined. In the vast majority of these exercises, a small number of factors were repeatedly highlighted as sources of major uncertainty. One or more of these external errors posed problems irrespective of the program being used and the type of structure from which the data had been collected.

The criteria were devised to eliminate data sets with these sources of external error.

Criterion 4 : All three major elements of the weather, air temperature, wind speed, and the direct and diffuse components of solar radiation, must be measured at the site of the building for the whole comparison period.

Criterion 5 : The structure must be unoccupied, it must not contain design features which cannot be explicitly modelled and each zone in the building must have independent heating and/or cooling plant and controls.

Criterion 6 : Measured infiltration and, where appropriate, interzonal air flow rates, must be available for the whole comparison period.

As the plant and air flow modelling capabilities of dynamic thermal programs develop it should be possible to relax the restrictions imposed on the heating/cooling regimen (criterion 5) and the air flow date (criterion 6) so that currently unacceptable data sets may become Useful.

At this stage, only data sets which definitely failed any one of the criteria were rejected (published sources of information often lacked crucial details). In total, 100 of the 231 individually tabulated structures and 33 of the structures assessed on the basis of their group characteristics definitely passed the criteria. (Table 2)

Data sets from Residences and Commercial Buildings suffered a higher than average rejection rate; in fact, none of the Commercial Buildings passed all the criteria.

Since care was taken to try and avoid bias towards structures of a particular type or from a particular part of the world, it is reasonable to assume that the data sets examined are a representative (and large) sample of all those which have been gathered. It may be concluded, therefore, that of all the data sets which appear to be Acceptable for validating dynamic thermal load calculation programs, only about 20% are actually likely to fulfil this purpose. This is unfortunate particularly as many of the data sets which did not pass the criteria were gathered from experiments in which a major objective was to generate data suitable for program validation.

The main reason for the high failure rate stems from a conflict between the objectives of experiments where data was gathered for more than one purpose; there were many experiments of this type. It is clear that the limitations imposed by validation needs are, in general, far more stringent than those imposed by other objectives, e.g. building or component testing, energy use or energy saving evaluation, or thermal comfort assessment. Therefore, if data sets are to be used for program validation, the experimental constraints imposed by this objective should be given the highest priority. Any other approach is highly likely to produce data which will fail to fulfil this aim.

5. Phase 4: Identifying High Quality Data Sets

In Phase 4, the aim was to select, from the Useful Data Sets, those which were most appropriate as the basis for validation tools. The programs used in the SERC/BRE research programme were deliberately chosen to cover a wide range of modelling capabilities and they are very demanding in their input requirements. Therefore, data sets which satisfy all three of these programs are likely to be of use for validating many other programs as well, especially simpler programs. Conversely, it may be possible to use a useful data set (one which fails the Phase 4 criteria) to evaluate less demanding programs.

Criteria were devised and applied to the Useful data sets, and those which definitely passed these new criteria were termed `High Quality Data Sets'.

Criterion 7 : The structure must not contain features, or environmental control systems, which cannot be modelled explicitly by ESP, HTB2 or SERIRES.

Criterion 8 : The data medium must be of a type which is readily usable, and close liaison with the monitoring institution must be possible.

Criterion 9 : Data which, due to external errors, has introduced unacceptable uncertainty into previous validation work, must not be used.

The Phase 4 criteria eliminated all the remaining structures except for test cells and experimental buildings at just eight sites in Europe and North America (Table 2). These 27 structures were therefore deemed to have produced data sets which were of sufficiently high quality that they are likely to be suitable as the basis for widely applicable empirical validation tools.

For use in the BRE/SERC projects, data was acquired from test cells in Peterborough (monitored by the Polytechnic of Central London) and the Passive Solar Test Facility experimental buildings (monitored by National Bureau of Standards in Washington DC). These data sets are now being used to empirically validate the dynamic thermal programs at Leicester Polytechnic. Comparisons between these data and the predictions of the programs are the subject of other publications.

6. Conclusions

1. A four phase methodology has been devised to identify data sets suitable for validating dynamic thermal simulation programs. The classification procedure will also be useful to those who assess hourly on-site weather and building performance data for many other purposes.

2. An extensive literature search revealed over 599 structures which have been monitored in such a way that the data could be valuable for validating dynamic thermal simulation programs. These structures, located throughout the world, were all monitored in the last twenty years. They covered a wide variety of built forms and modes of operation. The structures were divided into six distinct categories and 231 of them are described in detail. This is thought to be the largest compilation of this type every assembled.

3. Reference material, describing over 130 exercises in which thermal models have been compared with measured data, has been examined. In the vast majority of these exercises, the presence of a few, easily-identifiable, sources of external error has severely undermined the value of the work, irrespective of the model being used, or the type of building from which the data were acquired.

4. Criteria have been devised to exclude data sets which contain external errors which prevent them being useful for validating any dynamic thermal model. Only about 20% of the data sets reviewed passed these criteria, although many had been gathered for validation purposes. In future, monitoring experiments should be much more carefully conceived and executed if the data is to be of value for validating dynamic thermal programs.

5. The limitations imposed of experimental designs by the requirements for validating dynamic thermal simulation programs are, in general, far more stringent than those imposed by any other monitoring objectives. Therefore, if data sets are to be used for program validation the constraints imposed by this objective should be

given the highest priority.

6. Data from only eight sites in Europe and the U.S.A. appeared to be of sufficiently high quality to enable an accurate evaluation of the predictive ability of three of the programs that were used by the SERC/BRE validation group, namely, ESP, SERIRES and HTB2. Data from the Polytechnic of Central London Test Cells and the U.S. National Bureau of Standards Passive Solar Test Facility were acquired as the basis for developing tools for empirical validation.

7. There are very few well documented high quality data sets suitable for validating dynamic thermal programs. In particular, there appear to be no such data from multi-zoned structures located in Western Europe.

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Structural Category and Description	Number of Data Sets Passing Criteria		
	Phase 1 Acceptable Data Sets	Phase 3 Useful Data Sets	Phase 4 High Quality Data Sets
1. Test Cells - Los Alamos Type	41	9	2
- Custom-Designed	27	15	10
2. Experimental Rooms	14	7	0
3. Indoor Structures	7	5	0
4. Experimental Buildings			
- Zoned[1]	21	19	11
- Thermally Integrated	41	25	4
5. Residenses - Conventional	49	15	0
- Passive Solar & Hybrid	24	5	0
- Various Groups[2]	313	33	0
6. Commercial Buildings			
- Individually Assessed	7	0	0
- Various Groups[2]	55	0	0
Totals	599	133	27

[1]Each structure may contain two or more thermally isolated zones; entry is total number of zones.

[2]Additional data sets, from data bases and compilations, which were evaluated as a group.

TABLE 2 Number of Structures Remaining After Each Phase of the Evaluation Process

Category	Sub-Category	General Description	Advantages/Disadvantages
1. Test Cells	Los Alamos Type	Based on original Los Alamos Cells built in 1976. All in USA except for cells in Peterborough, UK. Internal volume $11m^3$ approx. Insulated wooden frame construction. Insulated party wall separates cell pairs. In general, highly glazed, well sealed, south facing.	Cheap to build. Constructions well defined. Built form easily changed. Scaling problems in small cells. Easy to model. Frequently used for model validation.
	Custom-Designed	All in Europe except single cell in Colorado. Vary from $1m^3$ wooden boxes to $64m^3$ concrete cell.	
2. Experimental Rooms	-	Unoccupied, monitored zone within, or attached to, existing building. Wide variety of locations and built forms.	Cheap to monitor existing room. Uncertainty as to construction. Uncontrolled boundary zone behaviour.
3. Indoor Structures	-	Variety of structures located in large environmental chambers. Vary from full size to test boxes, all unoccupied	No true solar or wind effects possible. External temperature carefully controlled. Few ill defined structural features.
4. Experimental Buildings	Zoned Thermally Integrated	Unoccupied, built for research only. Virtually all data post-1980. Similar size to actual residences. Some buildings reconfigurable. Wide range of forms. Frequent source of good validation data.	Unoccupied, dedicated to research, scale typifies domestic buildings. Undesirable heat flow mechanisms suppressed. Good site handbooks for some sites. Expensive to construct.
5. Residences	Conventional	Typical of region in which located. — Single family dwellings not substantially modified for research. Most in USA but 6 in UK. Occupied, unoccupied and simulated occupancy. Only 3 monitored for model validation.	Typify design usage of models. Occupancy problematical. Ill-defined heat flow mechanisms cannot be explicitly modelled. Complex heating systems.
	Passive Solar	Contain overt passive solar (and hybrid) features.	
6. Commercial Buildings	-	Large, occupied, multi-zoned and often multi-storey. Complex HVAC systems. Sometimes used for validation.	Very large, and complex. Dominated by internal gains. Numerous ill-defined features. HVAC difficult to model.

Table 1 **Classification and General Description of Monitored Structues**

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1. Introduction

This report reviews a previous international empirical validation programme of work (IEA Task VIII) and explores the potential for future international collaborative validation work. The report has four main parts.

(i) To briefly describe the possible aims and objectives of empirical validation exercises (Section 2) and give the criteria which must be fulfilled for empirical validation to be successful.

(ii) To give an overview of the methodology adopted in IEA Task VIII and to comment briefly on this (section 3).

(iii) To critically appraise the three validation exercises undertaken in Task VIII (sections 4 to 7).

(iv) To suggest a more effective strategy as a possible basis for a future international empirical validation project (section 8).

At the time the data used in Task VIII was collected (a decade ago) the experimental design and monitoring techniques were far less well developed than at present. Also, when the IEA Task VIII work began, in 1983, the knowledge of thermal programs and validation techniques was much poorer than it is now. It is recognised that, with hind sight, it may be easy to be critical of this work. However, the appraisal leads to a wider understanding of the strengths, limitations, difficulties and cost (both in time and money) of empirical validation. If this review helps to establish a firmer foundation upon which future studies can be built, it will have been worthwhile.

The majority of the information on the Task VIII studies was taken from the final report of the Task VIII group (Morck 1986), and the poor quality of the figures and tables in that report is the reason for the poor reproductions contained here (sections 4 to 7).

Other related documents (Judkoff 1985, Gough 1984 and Dalrymple 1983) were studied but are not discussed at length. Additional comments by the author stem from visits made in 1985 to the data collection sites at Los Alamos in the USA, and the National Research Council of Canada (Lomas 1987).

2. Assessing Empirical Validation Studies

2.1 The Data

To be of real value, the empirical validation data sets should be capable of revealing 'internal errors' in the models themselves, such as inappropriate simplifications of the real world, invalid mathematical approximations and coding errors. To do this, it is necessary to 'minimise external' errors: in the data input to the models; in the measurement of the building's thermal behaviour; and in

the procedures used to compare measured and predicted values. This, however, is no easy task, indeed, in a review (Bowman 1985), it was concluded that "only the highest quality building construction and data-gathering techniques can hope to produce conclusive evidence of internal errors in dynamic thermal models".
To help identify high quality data sets suitable as the basis for tools to validate building envelope thermal load programs the following criteria have been devised (Lomas 1991).

The first three 'preliminary acceptance criteria' must be fulfilled if data is to be of value for validating any dynamic thermal model.

Criterion 1 : Structures must not include operative active solar space heating or cooling systems.

Criterion 2 : The weather data must have been collected at the site of the building.

Criterion 3 : The measured building performance data, and the weather data, must be available at hourly, or more frequent intervals.

Only data sets which fulfilled all three criteria should be considered as a possible basis for empirical validation. Data sets which pass these criteria have been termed 'Acceptable Data Sets'.

Data sets which do not comply with any of the following criteria ought not to be used for validating any dynamic thermal program since large sources of external error are likely to be introduced into the validation process.

Criterion 4 : All three major elements of the weather, air temperature, wind speed, and the direct and diffuse components of solar radiation, must be measured at the site of the building for the whole comparison period.

Criterion 5 : The structure must be unoccupied, it must not contain passive solar features which cannot be explicitly modelled and each zone in the building must have independent heating and/or cooling plant and controls.

Criterion 6 : Measured infiltration and, where appropriate, interzonal air flow rates, must be available for the whole comparison period.

Data which fulfil these additional criteria have been termed Useful Data Sets.

Finally, the data selection process can focus specifically on the programs being validated and on the credibility of the data as demonstrated by the 'track record' of the experimenters.

Criterion 7 : The structure must not contain features, or environmental control systems, which cannot be modelled explicitly by any of the programs being validated.

Criterion 8 : The data medium must be of a type which is readily usable, and close liaison with the monitoring institution must be possible.

Criterion 9 : Data for sites which have never produced data for model validation work, or data which, due to external errors, has introduced unacceptable uncertainty previous validation work, must not be included.

Data sets which pass these criteria as well have been termed 'High Quality Data Sets'.

Criterion 9 seems rather harsh given the historical context of IEA Task VIII since, at the time, hardly any attempt had been made to use data for model validation. Furthermore, the generation of a validation tool was not an explicitly stated objective. In assessing the Task VIII work, therefore, Criterion 9 will be ignored.

These criteria are seen as minimum requirements. Data sets which fulfil then should still be scrutinised closely to identify all the other sources of external error which may be present. In addition, the availability of mechanism level data, to test the operation of individual program algorithms and crosscheck the other measurements, should be considered.

2.2 The Methodology

From previous work (Lomas 1990) the author has concluded that:

'Ideally, program predictions should be made in ignorance of the actual measured building performance and uncertainties in the measurements and model data should be accounted for in a logical and systematic way. Certainly no attempt should be made to manoeuvre a fit between the measurement and predictions'.

This approach implies

(i) a thorough understanding of the sources of uncertainty in the monitoring experiments;

(ii) a qualification of these sources of uncertainty;

(iii) sensitivity analysis to assess the effect of the uncertainty on the predictions; and

(iv) data/program comparison techniques which account for the uncertainty.

This is now viewed by the author as merely the beginnings of a comprehensive methodology. More advanced techniques, for example, based on cross-correlation and co-variance analysis, may well extend the methodology and, in conjunction with the collection of detailed mechanism level data, permit the causes of errors in program predictions to be more easily identified.

3. IEA Task VIII Research Programme

3.1 Objectives and Methods

"The specific objective of the validation activities ... was to test the analysis capabilities of a number of simulation programs selected by the participants ..."

"The participants focused their collective effort on empirical validation studies and model-to-model comparisons". From a survey of monitored buildings, data sets deemed suitable for empirical validation were selected from three climatic regions; these also covered three passive solar design features.

(i) A test cell with a Trombe-Wall, located in Ecublens near Lausanne, Switzerland, monitored by the Emile Polytechnique Federale in Lausanne. (EPFL)

(ii) A test cell with a sunspace, located in Los Alamos, New Mexico, USA, and monitored by the Los Alamos National Laboratory (LANL).

(iii) An experimental building with a south facing direct gain room, located in Ottawa at the National Research Council of Canada (NRCC).

Participants from 10 countries worked with 14 programs, however, the Trombe-Wall cell and the sun-space cell were only modelled by three programs. The direct gain cell was modelled by 12 programs.

From the final report, it is possible to discern that each modeller was given a description of the building and the measured weather and building performance data. The predictions were then obtained by the participants and plotted alongside the measurements as a single (hourly) trace for each parameter. Parameters predicted were typically air temperatures, energy usage and, in the Trombe wall and sunspace cell some surface temperatures. No further analysis is presented in the final report. It is clear however, that some participants undertook detailed investigations when poor results were obtained to correct program problems and refine their predictions (e.g. Judkoff 1985, Morck 1986).

3.2 Critique

Comparing the Task VIII approach with the comments made in Section 2.2 about validation methodology a number of comments can be made.

(i) The study offered the participants the opportunity to 'tune' the program to fit the measurements. Thus it would be hard to make strong statements about the ability of the programs as distinct from the ability of the program users to manoeuvre a 'good fit' to the monitored data.

(ii) No attempt was made to incorporate rigorous error analysis procedures into the program/data comparison process. It is impossible to tell therefore, whether any observed program/data discrepancies are significant (and due to problems with the program) or not (being due to external errors).

(iii) It is not clear if there was a careful study of the programs to be used (their capabilities, their weaknesses, their input requirements, the outputs they produce) prior to selecting the data sets. It is more important to explicitly match the data sets to the programs being used than it is to try and cover a range of climate types and passive solar features. (Incidentally, climate is not necessarily a good indicator of the weather conditions which arise during a particular (short) monitoring period).

(iv) It is not clear whether the participants had the opportunity to visit the data collection sites. Such visits are extremely helpful since they enable:

(a) the general philosophy and rigour of the experimenters to be assessed;

(b) specific deficiencies in the data (when viewed from the perspective of the individual models) to be identified; and

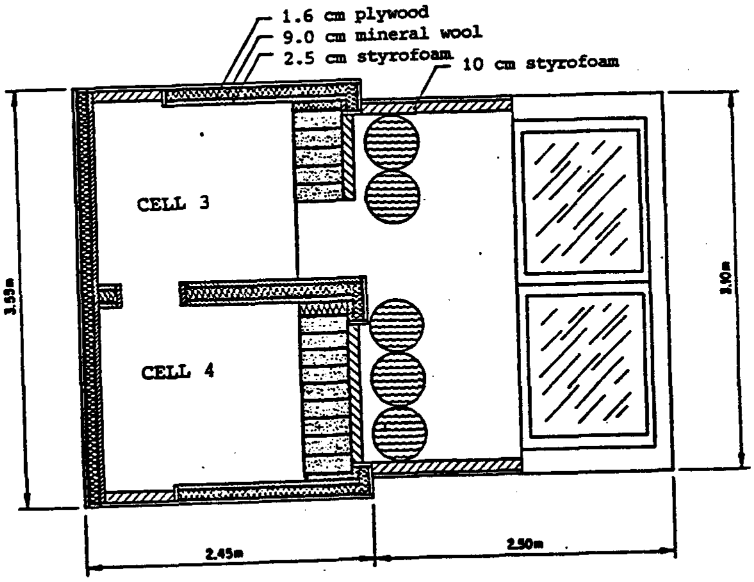
(c) observations to be made of other factors (to be considered in the modelling process) such as site shading, edge losses, self shading, exact sensor locations.

4. The Los Alamos Sun Space Building

4.1 Description of Data Set

The Los Alamos building consisted of a double glazed south facing sunspace in front of two cells of equal area (Fig 1 and Plate 1 which was taken in 1985 but externally the building is substantially the same as in 1981). Thermal mass was provided by water drums in the sunspace and, in each cell by concrete blocks. The building was monitored from February 14 to February 27 inclusive. The door between Cell 3 (East side) and Cell 4 (West side) was always open, whereas the door between the sunspace and Cell 3 was closed 'at night' from February 14 to February 22 and open at all other times. Insulation was placed over the sunspace glazing between 16.30 and 08.00 for the whole period. During this monitoring period the weather was "cold and sunny".

Both cells were heated by six 100W light bulbs which were controlled by relays in response to black-globe temperature measurements, to maintain a heating set point of 18.3°C. Both test cells were ventilated with ambient air by a mechanical fan at a rate of 3 air changes per hour.



CHARACTERISTICS OF TEST CELL

Inside measures:	
Room depth, m	2.18
Room width, m	1.57
Room height, m	3.05
Floor area per room, m^2	3.44
Heating set point, ^oC	18.3
Ventilation rate, ach	3.0
Sunspace width, m	2.87
Sunspace depth at the floor, m	2.26
Sunspace depth at the ceiling, m	1.22
Sunspace height at common wall, m	2.19
Sunspace floor area, m^2	6.49
Net sunspace glazing area, m^2	5.04
Thermal resistance of sunspace glazing, m^2K/W	?
Sunspace doorway area, m^2	1.06
Sunspace floor thermal capacity, MJ/K	1.7
Water drums thermal capacity, MJ/K	2.1
Common wall thermal capacity, MJ/K	3.1

Fig. 1 The Los Alamos Sunspace Building

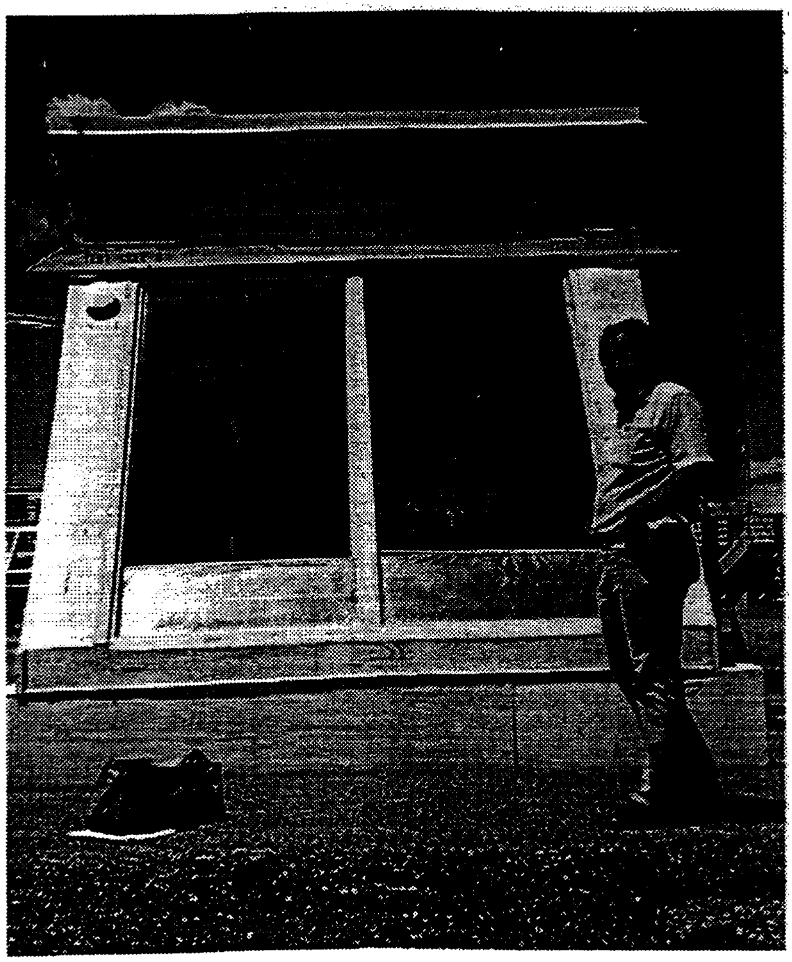


Plate 1. Los Alamos Sun Space Building as configured in 1985

Plate 1

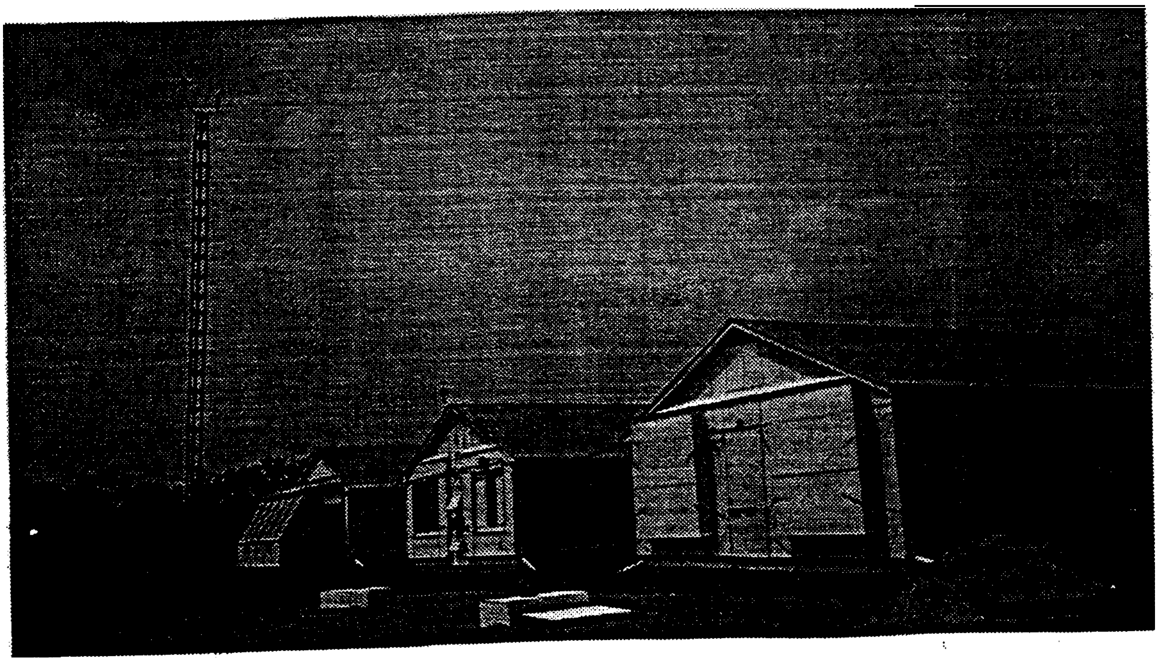


Plate 2. The Canadian Direct Gain Building photographed in 1985

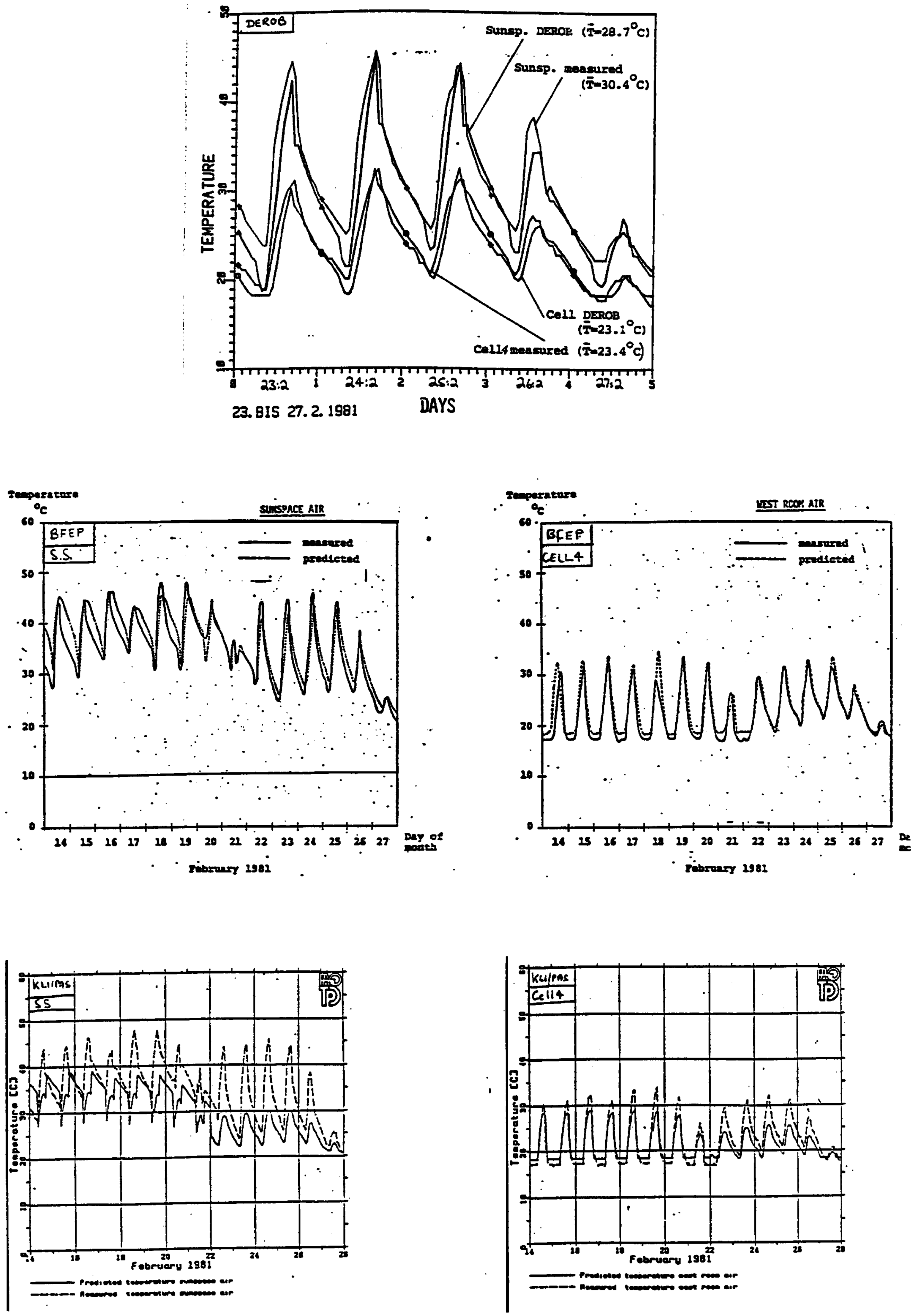


Fig. 2 Sunspace and Cell 4 Predictions for DEROB, BFEP, and KLI/PAS

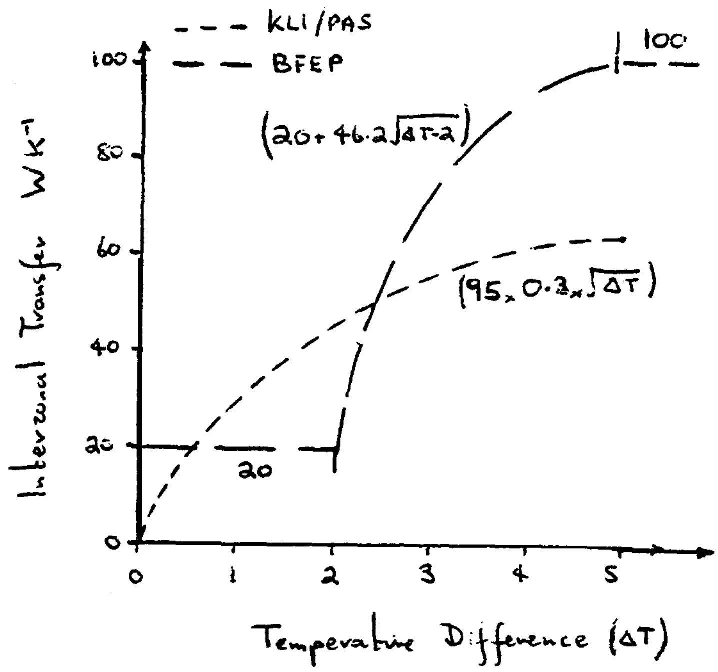


Fig. 3 Inter-zonal Conduction Modes Invented for the Los Alamos Cells

		DEROB[1]	BFEP[2]	KLI/PASS[2]
Air Temperature	Sun Space	*	*	*
	Cell 4	*	*	*
Power Input	Cell 3	-	*	*
	Cell 4	-	*	*
Water Drum Temperature		-	*	*

*Compared with measurements -No values predicted

[1] Last 5 days only
[2] Full 14 days

Table 1 Hourly Predictions Compared with Measurements for Los Alamos Sun Space Building

Country : Model Theoretical Basis	Modelling and Assumptions	Comments on Results
Switzerland: DEROB	Could not simulate door opening and closing Result for last 5 days only. Water drums considered as an additional layer to south wall.	"It can be seen that the DEROB predictions are in good agreement with the measure of data for this period"
Holland: BFEP Finite Element Program User-Modelling Flexibility	3 zone model Tried various methods for inter-zonal air flow modelling, chose best one.	"Whereas the temperatures are represented rather well .... the auxiliary loads show some significant deviations"
Holland: KLI/PAS	Sunspace modelled as rectangular. Water as layer of south facing wall.	"KLI/PAS dynamically tracks the performance of the test cell rather well, but generally predicts considerably lower temperatures and auxiliary power"

Table 2 Validation Using The Los Alamos Data

Building monitoring included: air-, black-globe-, opaque surface-, and intra-constructional-, temperatures, and power supplied. Weather data collected were: air and dew point temperature; wind speed and direction; and the total (global) irradiance on a horizontal surface and on south facing surfaces tilted at 90°, 60°, 45°, and 36° to the horizontal. All data was reported hourly.

4.2 Model Predictions

Hourly predictions were reported for three programs DEROB (by Swiss participants) and both BFEP and KLI/PAS by Dutch participants as shown in Table 1.

In all cases the results were shown as single traces of measured value versus predicted value (e.g. Fig 2). The programs, the modelling approach, the assumptions made and the comments about the predictions are given in Table 2. However, a number of additional points made in the Task VIII report are worth repeating. Because DEROB could not simulate night time door closing only the last 5 days of the period, during which the door was open all the time was simulated. "In order to keep the model simple the water drums were considered as an additional layer to the south facing wall".

For the BFEP predictions, various methods of modelling the natural inter-zonal air flow between the cell and the sunspace were attempted. The one which proved most accurate was chosen (Fig 3). It was noted that "whereas the temperatures are represented rather well by the computed results, the measured and computed auxiliary loads show some significant deviations". Possible reasons for this were given as:

(i) an inadequate inter-zonal air flaw model;

(ii) uncertain convection coefficients within the zones; and

(iii) doubts about the overall heat loss coefficient of the building.

For the KLI/PAS predictions: a different inter-zonal air flag conductance was chosen (Fig 3); the sunspace was modelled as a rectangular space (due to the program being limited to these geometries); and the water drums were modelled as an extra layer of south facing wall.

4.3 Critique

From the forgoing one can highlight the following limitations of the building, the data, and the validation procedure.

(i) None of the models had the capability to model all the features of the building. Furthermore, the features for which approximations had to be made crucially influence the performance of the building (inter-zonal airflow, scheduled door operation, sunspace geometry, and water wall shape and thermal history). Model users had to make crude approximations and the approximations made differed significantly from one modeller to the next (e.g. Fig. 3). The study was therefore testing the ingenuity of the modeller as much as the accuracy of the programs.

(ii) Since the inside door had to be opened and closed then the outside door of the cell must have opened (albeit briefly) during the first 9 day period. Also the time of placing the outside insulation is rather uncertain.

(iii) The diffuse and direct components of the solar irradiance could not be dissagregated as neither the direct normal-, nor the diffuse horizontal-, solar irradiance appear to have been monitored. The performance of the sunspace is strongly influenced by solar radiation.

(iv) The Task VIII modellers had access to the measured performance of the building prior to modelling so it was possible to 'tune' the model to reproduce the measured data. Because this validation methodology was adopted, the best one could say of the study is that "with appropriately chosen algorithms and input data the program(s) were able to reproduce observed behaviour". The statement concerning the predictive abilities of the programs have to be treated with some caution. (As it happened, even after some tuning, BFEP failed to reproduce both the measured air temperature and the measured energy usage).

(v) It may be that some of these problems could have been foreseen because researchers at the Lawrence Berkeley Laboratory (in a perceptive piece of work for the time) had already highlighted the sensitivity of the Los Alamos cells to the direct/diffuse split of solar irradiance and the uncertainty in the cell air infiltration rates (Anderson 1980, Bauman 1981, 1983). This highlights the value of a literature review.

(vi) The author visited the Los Alamos site in 1985 to assess the likely reliability of the data being produced. The Los Alamos researchers conceded that, in collecting data, they intend to look for "qualitative agreement" with model predictions only and they had never looked at error bands in a systematic way. It was also quite apparent that the mechanical ventilation system was extremely crude and relied on manual adjustments. The errors on the 3 ach-^{1} quoted for the period used in IEA Task VIII could therefore be very large (e.g. around +/- 1 ach-^{1} rather than +/- 0.1 ach-^{1}). The researchers also noted that the auxiliary power control and supply system (globe temperature, via mechanical relay, to electric light) was unreliable and the power input was estimated based on the 'on' period only rather than on direct measurement of the current and voltage supply. Therefore it would be assumed that any broken bulbs were producing heat. Again, the uncertainty on the power input parameters must be very large (e.g. around 400 to 600W rather than 590 to 600W).

These observations indicate the value of being able to visit the data site to assess, first hand, the quality of-the data.

(vii) There are likely to be numerous other sources of external error (e.g. uncertain thermophysical properties, ground reflectivity, shading from adjacent cells, edge effects, thermal bridges, self shading etc. etc.).

The Los Alamos sunspace building actually failed Criterion 4 and Criterion 5 and so in the SERC/BRE assessment was not deemed to be a useful data set (section 2).

5. The Swiss Trombe Wall Cells

5.1 Description of Data Set

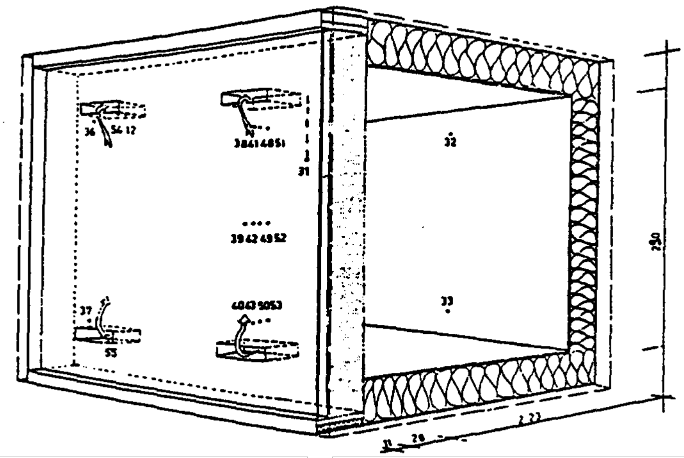
The building is only very briefly described, but consists of a massive vented Trombe Wall located between the south facing double glazing and the well insulated light-weight test cell (Fig 4). The measured cell performance was compared with that predicted by a number of models for the 10 day period from 25 March to 3 April, 1980. The measured values were the cell air temperature, the inner and outer Trombe Wall surface temperatures, the temperatures of the air at the upper and lower vents and the thermo-circulation air velocities. The weather data included the air temperature, the total horizontal and south facing vertical solar irradiance and the diffuse horizontal irradiance. Wind speed was only available for the 5 day period from 29 March to 2 April.

5.2 Model Predictions

BLAST 3.0 crashed during the simulation so no results were obtained. The results for the USA version of SERIRES are not shown but it is quoted as giving the same results as the Swiss version. SMP, the Italian program, generated limited results and then only for the 5 day period for which wind speed was available (Table 3). Thus, full sets of results were obtained for only the Swiss version of SERIRES (Fig 5) and the Dutch program BEEP (Fig 5).

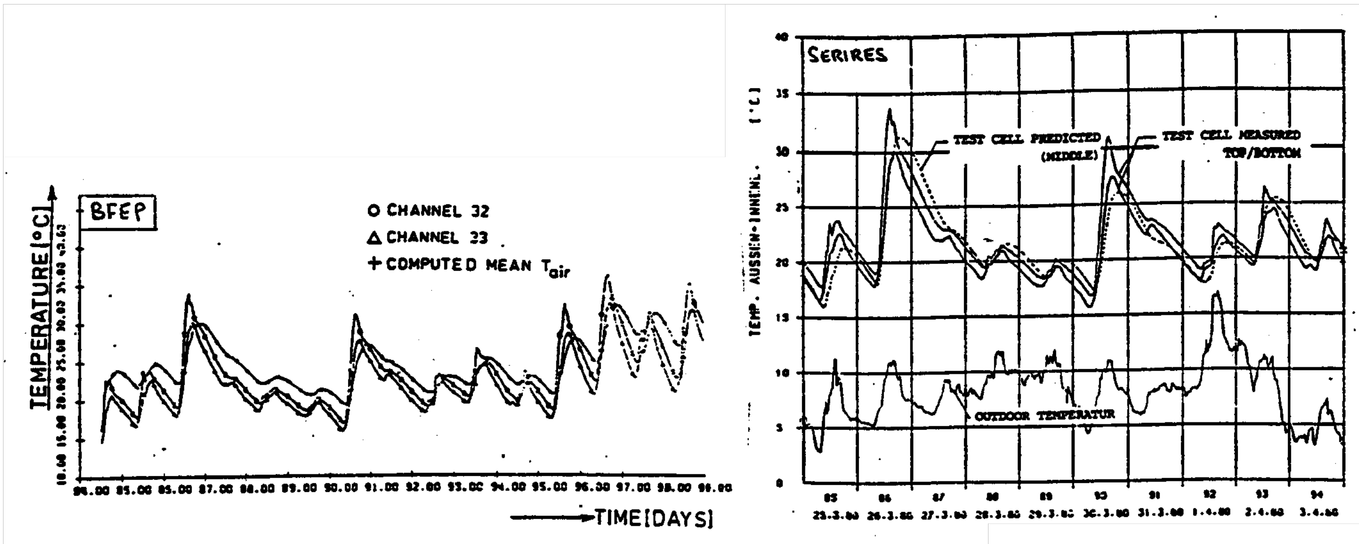
A. number of assumptions had to be made by the modellers (Table 4). The Swiss specifically quote a value of 0.3 as being chosen for the Trombe-wall venting coefficient. (This is a parameter [chosen by the modeller] which acts as a multiplier in the SERIRES thermo-circulation algorithm). The thermo-circulation gains are highly dependant on this parameter. The predicted cell temperatures (Fig. 5) show significant smoothing as compared to the measured values and they differ in magnitude by up to 2°C at some instances. The Trombe wall temperatures on the exterior side differ by up to 5°C and on the inside by 2°C. Nevertheless it is stated that, "Simulation of room air temperature *as* well as surface temperatures of the Trombe wall were in good agreement with measured data" (Table 4).

The Dutch results show similar discrepancies to the Swiss ones although the surface temperatures are marginally better after the first two

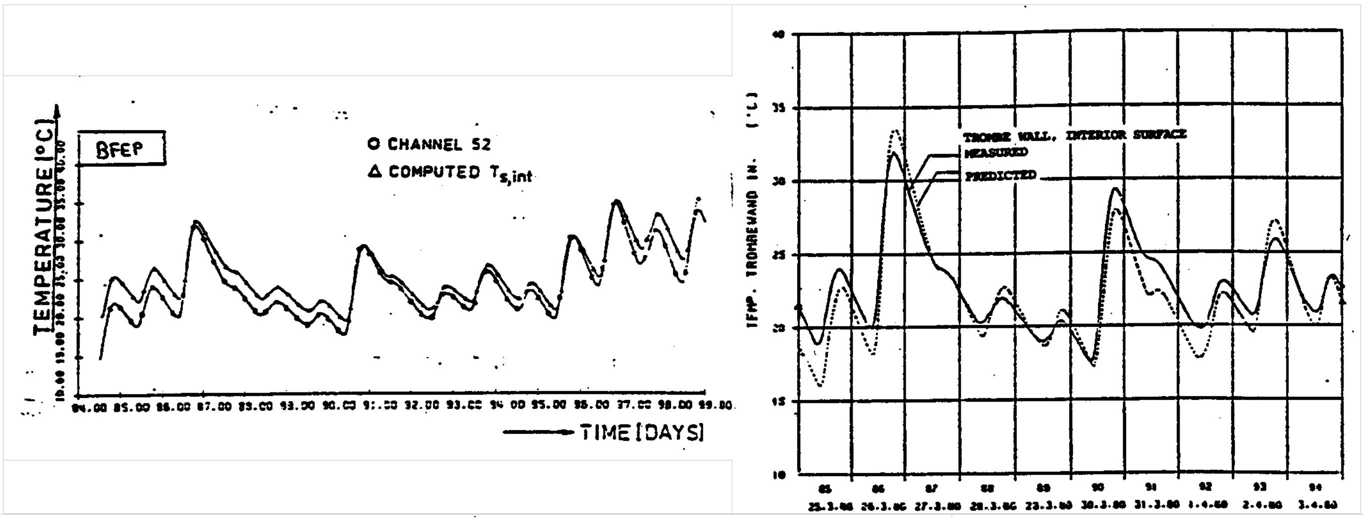


TEST CELL	
Indoor volume	12,2 m3
Area of the south aperture	5.06 m2
Insulation of the cell: mineral wool thickness	0,30 m
Thermal heat losses of the cell (without the Trombe wall)	5,2 + 0,2 W/K
Air changes	0,1 hr^{-1}
Auxiliary heating system (electrical with a fan)	600 W — no auxiliary
Thermostat setpoint	16°C — during test period
Fan, continously operating	12.5 W — (Heat source!)
TROMBE WALL	
<u>The wall</u>	
Area 2.76 x 2.76	7,62 m2
Thickness	0,28 m
Material: concrete blocks, Density	1920 kg/m3
Thermocirculation vents:	
Upper vents 2 x 0,38 x 0,1	0,076 m2
Lower vents 2 x 0,38 , 0,1	0,076 m2
Hight between the vents	1,80 m
Colour of the wall	dark blue
Absorption coefficient	0,75
<u>Glazing</u>	
Area 2.76 x 2.76	7,62 m2
Double glazing (8/12/8 mm)	
Normal transmission	0,68
U-Value	2,9 W/m2 K
Space between the wall and the glazing	0,11 m
<u>Night protection</u> (not used)	

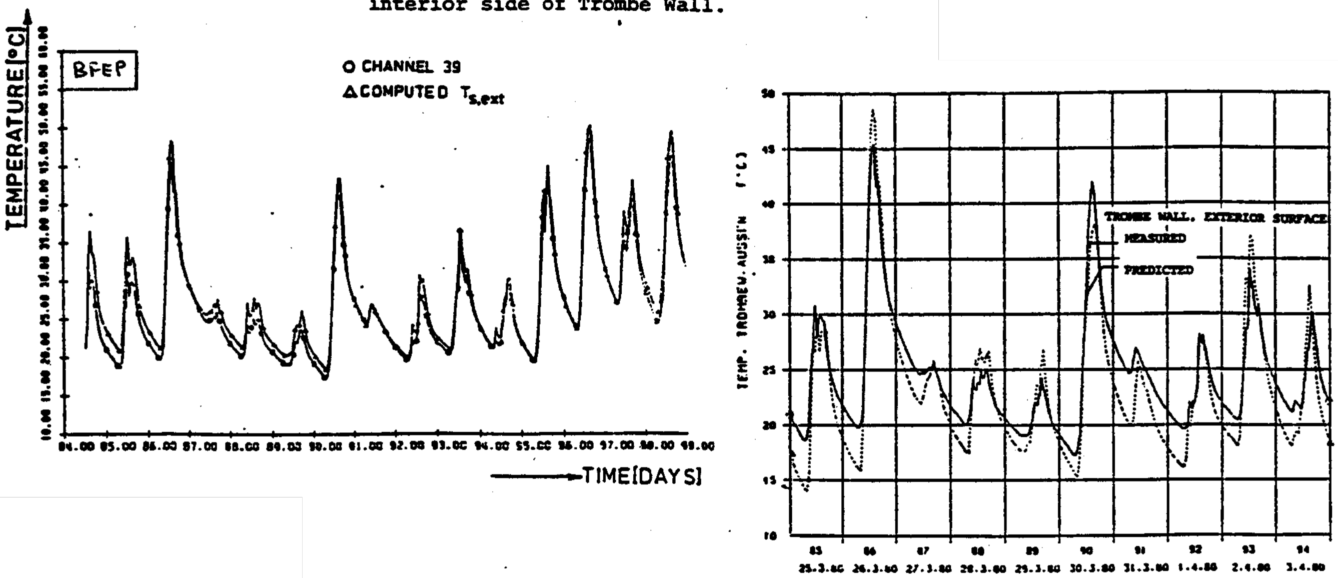
Fig. 4 The Swiss Trombe Wall Cell



Computed (---) and measured (——) room air temperature.



Computed and measured surface temperature for interior side of Trombe Wall.



Computed and measured surface temperature for exterior side of Trombe Wall.

Fig. 5 Trombe Wall Cell Predictions for BFEP and SERIRES 1.0

	Swiss SERIRES 1.0	USA BLAST 3.0[4]	USA SERIRES[5] -	Italy SMP -	Holland BFEP -
Temperatures					
Cell Air	*	-	-	*[6]	*
Trombe Exterior Surface	*	-	-	-	*
Trombe Interior Surface	*	-	-	-	*
Glass Temperature	*	-	-	-	-
Mass Flow Rate of Air[1]	0	-	-	-	0
Convective Heat Gain[2]	0	-	-	-	0
Conduction Heat Gain[3]	0	-	-	-	0

* Compared with measurements — 0 No corresponding measurements

[1] Between glass and Trombe Wall
[2] From vented Trombe Wall to room
[3] Through Trombe Wall to room
[4] Program crashed
[5] Quoted as identical to plotted Swiss results
[6] For 5 days only

Table 3 Hourly Predictions Published for Swiss Trombe Wall Cell

Country : Model Theoretical Basis	Modelling and Assumptions	Comments on Results
Switzerland:SERIRES Explicit Finite Difference	Single zone plus SERIRES Trombe-wall algorithm Venting Coefficient selection No reverse thermo-circulation	"Simulation of room air temperature as well as surface temperature of the Trombe Wall were in good agreement with measured data"
Holland:BFEP Finite Element Program User Modelling Flexibility	Lack of data on initial conditions Reverse Thermo-circulation allowed	No comments made

Table 4 Validation Using the Swiss Data

days. It is noted that this could be due to a lack of data on the initial state [temperatures] of the Trombe wall. A significant difference from the Swiss results is that reverse thermo-circulation was allowed in the simulations, in the Swiss simulations it was not. Although the programs produced comparable mass flow rate predictions (e.g. peak of $0.04m^3s^{-1}$ for BFEP and $0.045m^3s^{-1}$ for SERIRES on March 26) the convective heat transfers due to these flows differed from 300W for BFEP to 800W for SERIRES.

5.3 Critique

(i) The SERIRES modellers had to select the venting coefficient and this parameter critically influences predictions. Such necessities should be avoided, however, with such empirically derived parameters it is difficult to see how this should be done. One route is to leave the modeller to estimate the parameter, based on experience, other tests etc. (hut not based on the actual measured data) and then to undertake an error analysis to estimate the uncertainty in predictions due to the estimate. Indeed error analysis of this type is seen as important for all uncertain program input parameters.

(ii) As with the Los Alamos building results, various vague statements about model accuracy are made after comparing measured and predicted results for single parameters without a serious attempt to estimate the errors in either the experimental data or the predictions.

(iii) The wind speed and direction were not measured for part of the data period - these are key program inputs.

(iv) The cell was only capable of being modelled explicitly by two programs so the scope for inter-model comparison, in addition to program/data comparisons, was reduced.

(v) Lack of data to cover a sufficiently long program preconditioning period seems to be an issue.

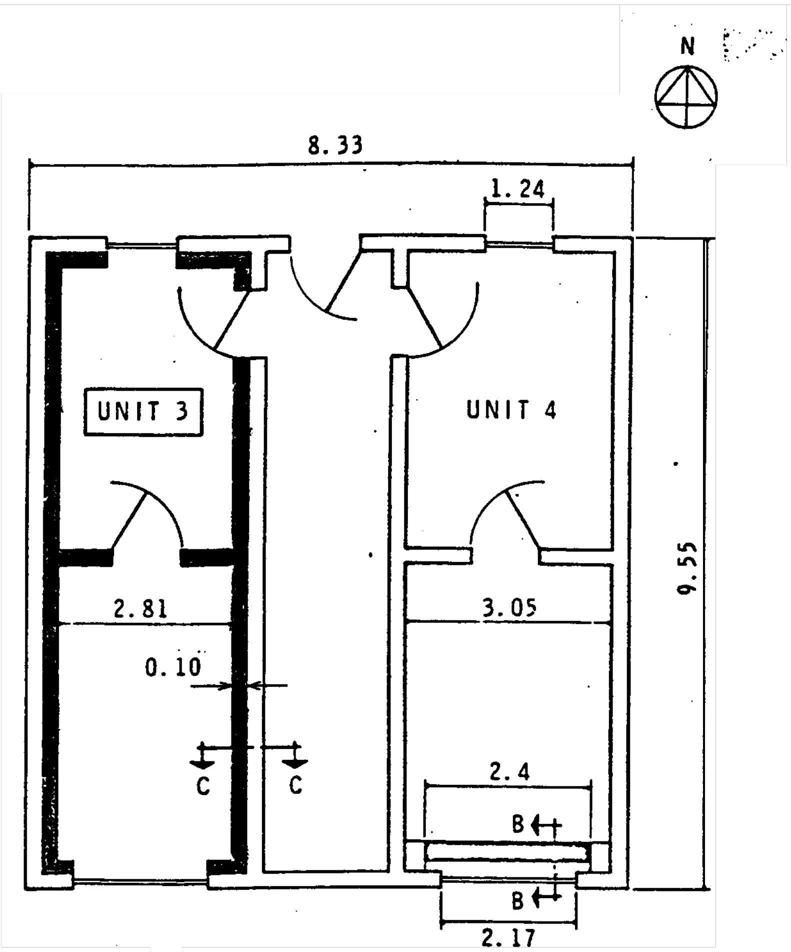
(vi) There are numerous other sources of uncertainty (e.g. thermo-physical properties, ground reflectivity, heat bridging, external shading, etc. etc.).

The Swiss Trombe wall failed Criterion 7 in the BRE/SERC review because all the programs being considered there could not model it explicitly. The data gathered when no wind speed was recorded also fails Criterion 4, the data would therefore not have been deemed a useful data set.

6. Canadian Direct Gain Buisding

6.1 Description of Data Set

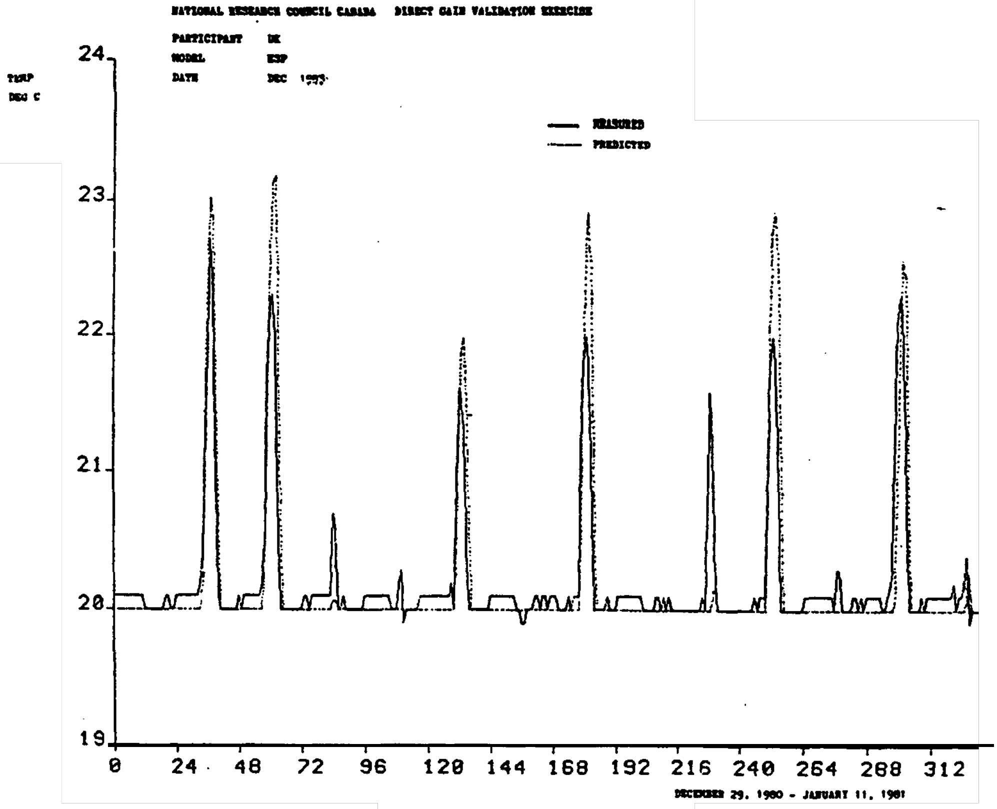
The building at the National Research Council of Canada (NRCC) in Ottawa consisted of two rooms. One with a large area ($3.4m^2$) of south facing double glazing, and the other, to which it is connected by an open door, with a smaller area ($1.4m^2$) of north facing double glazing



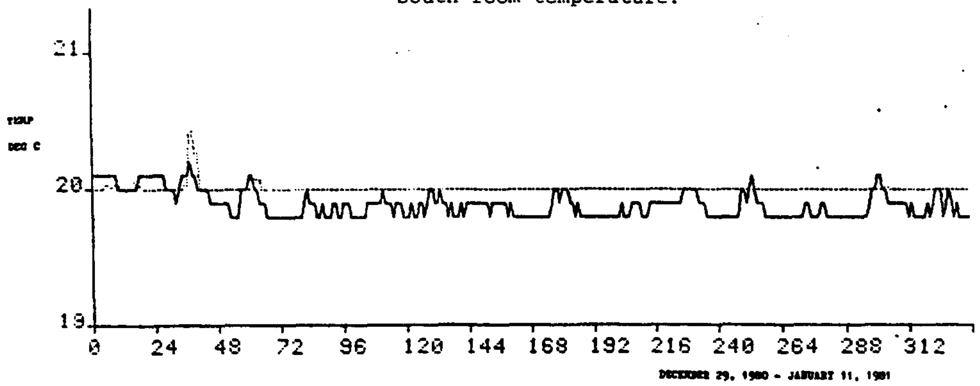
Room length, m	4.38
Room width, m	2.81
Room height, m	2.4
Floor area per room, m^2	12.3
Overall wall* thermal resistance, $m^2 \cdot K/W$	2.1
Overall ceiling thermal resistance, $m^2 \cdot K/W$	3.5
Overall floor thermal resistance, $m^2 \cdot K/W$	7.0
Gross south window area, m^2	3.4
Net south window glass area, m^2	2.6
Gross north window area, m^2	1.4
Net north window glass area, m^2	1.0
Window glazing thermal resistance, $m^2 \cdot K/W$	0.35
Window frame thermal resistance, $m^2 \cdot K/W$	0.37
Partition door area, m^2	1.65
Partition thermal resistance, $m^2 \cdot K/W$	0.44
Corridor door area, m^2	1.9
Corridor door thermal resistance, $m^2 \cdot K/W$	1.25
Circulation fan power, Watts	21
Heating set point, °C	20
Heating Controller deadband, °C	0.1
Ventilation set point, °C	27
Basement temperature, °C	21
Corridor set point temperature, °C	20
Thermal storage mass, kg	13,565
Heat capacity, MJ/K	11.55
Infiltration rate, ach	~ 0.0

* All walls are of wood frame construction, 38 x 89 mm studs at 0.6 m centres

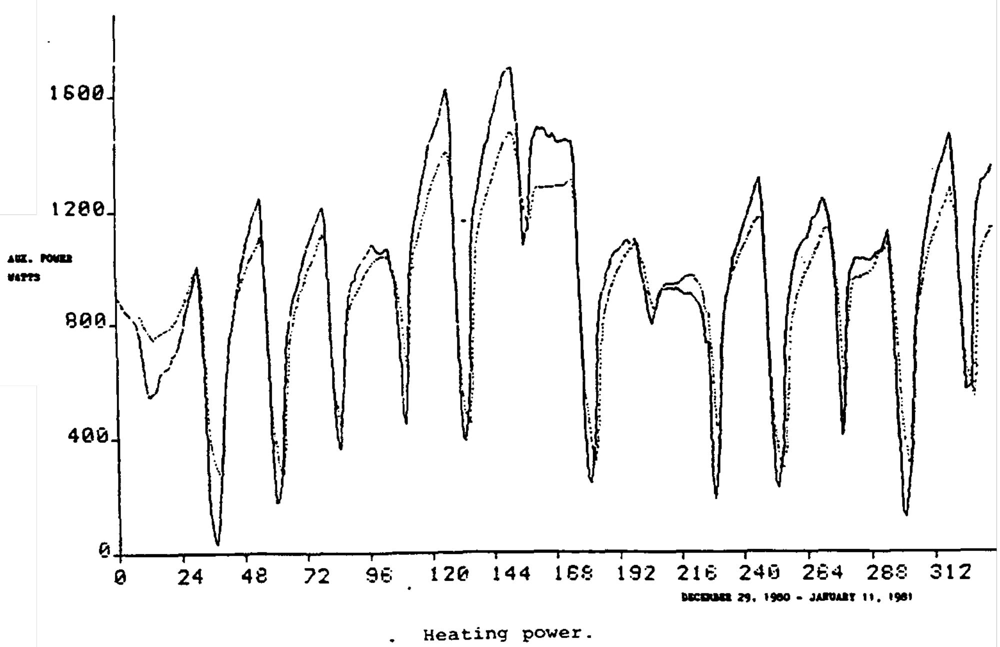
Fig. 6 The Canadian Direct Gain Building



South room temperature.



North room temperature.



Heating power.

Fig. 7 Canadian Direct Gain Room Results for ESP

Country : Model Theoretical Basis	Modelling and Assumptions	Comments on Results
Netherlands: BFEP Finite element program User-modelling flexibility	Great detail Absorptance walls assumed as 0.5 Half radiation to floor half to other surfaces	"Generally BFEP results are in very good agreement". Some of the differences "due to uncertainties in the input data supplied to the building".
Netherlands: KLI/PAS Multi zone energy analysis program	3 zone model Wall studs accounted for 90% radiation to floor Radiant/Convective split 50/50 External wall absorptivity 0.4, emissivity 0.9	"Temperature to within 1°C however, always on the low side". "Consistently under-predicted the peak power consumption and over-predicted the minima".
Norway: ENCORE Hour by hour "transfer function method"	2 room and 1 room modelling (Results for 2 room shown) Inter-zonal conductance $100 Wm^2K^{-1}$ Cloud cover estimated Used measured vertical irradiances	Considerable difference in the room heating power at noon". Good agreement between measured and calculated temperatures. calculated temperatures".
UK: ESP Finite difference approach	3 zones Studs modelled Inter-zonal air flow $4.84 ach^{-1}$ Attic air flow $10 ach^{-1}$ Solar radiation to floor Solar radiation assumed as on-the-hour	"Agreement generally fairly good, with local overheating maxima predicted to within 1°C in most cases". For power consumption, "agreement is reasonably good", "tendancy to under-predict peak loads", over-prediction of minimum loads by a similar margin", "available thermal mass may be too high". "Alternatively ... inaccurate assumptions about heating system control". "Predicted load minima often lay behind observed minima by 1-2 hours".
USA: BLAST Response factor method USA: DOE2.1A Response factor method USA: SERIRES-1.0 Finite difference approach	2 zone modelling Stud framing accounted for Infiltration $0 ach^{-1}$ Unlimited heating capacity (Various other minor assumptions which depended on program)	"The agreement between measured temperatures and power values is generally good", "maximum difference ... south room temperature is in the order of 1.0°C for SERIRES". SERIRES produced the best agreement with measured power data, both BLAST and DOE2 under-predicted the peaks".
Canada: Encore Canada Response factor model	3 zones (2 rooms plus attic) Attic $0.5 ach^{-1}$ Inter-zone conductance $34 Wm^{-2}K^{-1}$ Window shading coef. 0.88	"The agreement with the measured data is good". There is a tendency to underpredict the room air temperature by about 1°C, which could be due to the inaccuracy of the representation of convective heat flow mechanisms between the two rooms".
Denmark: BA4 Simplified method Half hourly predictions	Single zone model Attic temperature ambient Corridor and basement same temperature All heat accumulated at one theoretical layer	"The computer plots of temperature and auxiliary power show that the program does not predict the detailed dynamic behaviour of test rooms very well...". "It seems that the one zone simplification of the program is the major reason for these differences".
Denmark: PASOLE Thermal network method Research tool	2 zone model Solar processes did not reproduce given vertical solar irradiances	"Considerable effort was put into modelling the system" "When the work stopped, the predicted solar radiation on the south facade was still somewhat lower than the actual value" "The plots show that the dynamic performance of the test building was reasonably tracked by PASSOLE" "The higher peak temperature ... may be an air-node/mass-nodes distribution problem".
Denmark: SOLMAT General thermal network model 13 Node model used	13 node network model South facing vertical irradiance input to to program	"The model tracks the dynamic performance of the test building well".
Italy: SMP Finite difference model	2 zone model Exterior opaque surface absorptivity 0.4 Radiation 99% to floor R-value studs estimated	"The SMP predictions agreed well with measured values". "There appears to be a problem with the ability of the program to control the room at the fixed set point".

Table 5 Validation using the Canadian Data

(Fig 6, Plate 2). The insulated wood frame building is over a basement held at a constant temperature of 21°C, the corridor at the east side of the unit was at 20°C and there is ventilated attic space above the ceilings of the huts (Plate 2). The rooms were well insulated and sealed to produce a measured infiltration rate close to zero.

During the 14 day data period used in IEA Task VIII (29 Dec 1980 to 11 Jan 1981) the rooms were lined with a 100mm course of solid cement bricks. The door between the rooms was open and a small (21W) fan located above the door circulated air between the two roans. The electric base board heaters in each room were connected to precision controllers to maintain a constant temperature of 20°C. The south room was also equipped with an exhaust fan which ventilated the space with outside air whenever the temperature rose above 27°C. (This never occurred during the period of the IEA study).

The measured building performance parameters used for model validation were: average south room temperature; average north room temperature; and total heating power of the unit. Other parameters recorded were: average corridor air temperature; average attic air temperature and south room cooling (venting) energy. These were recorded hourly as were the following parameters: average ambient temperature; global horizontal irradiance and the total vertical south and north facing radiation; direct normal radiation; and average wind speed and direction. It was extremely cold but sunny during the two week period.

6.2 Model Predictions

Hourly predictions of 12 programs were compared with the total hourly power demanded by the two rooms. The programs also predicted either the mean temperature of the two rooms (for single zone models) or the separate north and south room temperatures (for multi-zone models). In the Task VIII report, south and north room temperature predictions are reproduced for multi-zone models, combined zone temperatures for single zone models and total power for all models (e.g. Fig. 7). The abridged comments from the IEA report about the level of agreement, plus statements about the method of modelling and the assumptions made about the building and the measured data, are given in Table 5. The level of detail with which the issue of errors was treated varied significantly from one participant to the next.

For 11 of the programs, 14 day energy use totals were produced; these ranged from 285KWh to 349KWh with a mean of 310.8KWh (Table 6). The measured value was 323KWh . The predicted results had a standard deviation of 16.8KWh (5.4%) but all the programs under-predicted energy use except ESP (+26KWh).

6.3 Critique

(i) The building was simple enough to be modelled closely by a wide range of programs thereby permitting an extensive inter-model comparison exercise as well as comparisons between the measurements and the predictions of individual programs.

COUNTRY/MODEL	TOTAL AUXILIARY HEATING ENERGY (KwH)	DIFFERENCE FROM MEASURE %
MEASURED	323	-
Canada - ENCORE CANADA	309.1	-4.3
Denmark - BA4	312	-3.4
- PASOLE	300	-7.1
- SOLMAT	323	-0.0
Italy - SMP	312	-3.4
The Netherlands - BFEP	307	-5.0
- KLI/PAS	297	-8.0
Norway - ENCORE	NOT REPORTED	
United Kingdom - ESP	349	+8.0
USA - BLAST	301.7	-6.7
- DOE-2	285	-11.8
- SERIRES	322.8	0.0
Mean	310.8	-4.7
σ_{n-1}	16.8 (5.4%)	
$2.33\sigma_{n-1}$	39.1 (12.6%)	

Table 6 Results of Canadian Building Validation Work

(ii) The building was reasonably well described by the NRCC and so the level of uncertainty is considerably less than that associated with the other two buildings. The errors in predictions could be estimated (although no attempt was made to do this in the IEA work). The uncertain attic air change rates and, more importantly, the uncertain inter-zonal air flaws are unfortunate.

(iii) The difficulty of the predictive task varied from one program to the next. Specifically, some programs were fed the hourly values for the radiation incident on the north and south windows; some (most) programs were left to calculate this for themselves. The empirical validation work should be managed in such a way that this cannot happen.

(iv) The modellers had access to the measured results and so there was the opportunity to 'tune' the programs, and/or to correct errors. The USA predictions in particular, were produced after a number of trials (Judkoff 1985). This is at variance with the preferred approach outlined in section 2.2.

(v) No attempt was made by any of the participant to assess the errors associated with their predictions, or if such attempts were made, they are not described in the final report. Thus, it is difficult to assess whether the prediction errors can be apportioned to the programs, the uncertainty in the building description, or to errors in the monitored data.

(vi) The author visited the NRCC site in 1985 and one problem that was observed was that the many (linked) thermocouples suspended in the air (as a thermopile) were unshielded. Solar and long wave radiation would therefore impinge on the sensors warming them. They do not therefore record a pure air temperature.

(vii) A number of other minor error sources included: unknown thermo-physical properties; shading from adjacent buildings perhaps; uncertain radiant/connective split of heating system; imprecise glazing properties - including shading to frames. The magnitude of the uncertainty in predictions due to this could however be estimated.

The Canadian test cells passed all nine of the Criteria (section 2.1) and were therefore classified as High Quality data sets in the SERC/BRE review.

7. Task VIII - Management and Reporting

The final Task VIII report has a number of weaknesses.

(i) The report itself is poorly presented with results plotted on a variety of scales. It is therefore difficult to make comparisons between the results of one program and those of the next. The specific information given, and the level of detail, varies from one validation exercise to the next.

(ii) There is very little discussion in the main report about the assumptions, approximations, modelling techniques and usage of data so the reader gains little insight into their validation process. Thus useful validation experience is not passed on to others.

(iii) The buildings are in general poorly described and the weather data and building performance data is not made readily available to others. Thus, it is impossible for others to use the data sets as a benchmark against which to compare the predictions of other models.

(iv) The management of the information available to the participants does not appear to have been considered carefully. This led to different approaches both at a general level and at a detailed level. Consequently, the programs were not being assessed on an equal basis. Overall, the report (and the validation work itself) conveys the impression of a project where there was a lack of planning and co-ordination.

8. Proposals for Future Work

8.1 Aims and Objectives

Program/date comparisons can be made for many reasons, such as: to develop (improved) algorithms for individual thermo-physical processes; to evaluate individual algorithms; to validate whole models; to develop benchmarks for whole model validation. The research methodology (and the data) demanded by each one of these can differ significantly. (For example, for algorithm development, actual building-like structures may not be tested, when testing component algorithms within whole programs, buildings (or part buildings) may be used in which the magnitudes of the heat flows differ dramatically from those in real buildings).

At present there are very few properly documented whole program validation benchmarks, and even fewer (perhaps none) which have been tested on a wide range of programs. Given the nature of international collaboration it is probably appropriate that the aims of empirical validation work should be:-

Aim 1: To develop well documented, well tested, empirical validation benchmarks for detailed thermal simulation programs.

Without compromising this primary aim it will also be possible to achieve the following aims.

Aim 2: To assess the ability of a number of detailed thermal simulation programs to predict the performance of a number of simple buildings.

Aim 3: To test a methodology for developing empirical validation benchmarks.

Finally depending on the availability of data and resources it may also be possible to pursue a fourth aim.

Aim 4: To extend existing, and/or develop new empirical validation methods.

From these aims, and knowing the problems encountered in Task VIII (Table 7), it is possible to draw up a list of requirements which must be fulfilled by the validation methodology, the data sets, and the simulation models used.

8.2 Methodology

Based on the experience of the previous IEA validation work described above and that gained within the SERC/BRE validation project it is suggested that the following features should form the basis of any empirical validation work.

Methodology Requirement 1: The research methodology must be devised and agreed by all participants prior to the start of the work. The agreed methodology must encompass: management procedures; models to be used; data sets to be used; predictions to be made; reporting formats; and analysis techniques.

Methodology Requirement 2: The work should encompass as many models with a similar level of sophistication as possible. In the context of this paper these would all be detailed thermal simulation models of the building envelope capable of hourly, or more frequent, predictions of temperatures, and heat fluxes, examples are ESP, SERIRES, HTB2, BLAST, DOE-2, DEROB, Tas.

If the work failed to separate out effort on simpler, single-zone dynamic programs (such as BREADMIT, or SPIEL) or steady-state programs (such as BREDEM or Method 5000), it is likely that the research programme and the end products would be an unhappy compromise which would not fully service the needs of any of the program groups. (In any case, the principle used in IEA VIII, of using detailed models to generate benchmarks against which simpler models can be tested, is worth retaining at present.)

Methodology Requirement 3: Initial predictions will be made blind, that is, all program users will be given the same detailed information about the buildings, the operating conditions and the weather data and the measured building performance data will not be made available at an early stage. The model/data comparisons would then be made by an independent, third party, not responsible for any of the program predictions (see project management).

Methodology Requirement 4: The release of other (mechanism level) data to permit more detailed studies, the application of new (sophisticated) analysis techniques, and the refinement of the programs should follow the initial 'blind comparison' phase.

Methodology Requirement 5: The early stages of the work should incorporate a thorough review of the data input requirement of, and the outputs available from, the programs to be used.

Methodology	*Opportunity to 'tune' the programs so predictions fit the measurements *No analysis of errors in the predictions or the monitored data *Probably no careful study of the inputs and outputs of the programs used *Possibly no organised visit to the data collection sites by most of the participants
Los Alamos Sunspace Cell	*Complex operation could not be modelled by some programs *Structure could not be modelled by many programs *'Thermal history' of cell critical but unknown *Unreliable ventilation equipment *Unreliable heating power measurements *Incomplete building description *Incomplete weather data set *Unknown inter-zonal air flow *Overall building heat loss coefficient uncertain *Cell opened and (briefly) occupied during monitored period *Data never intended for detailed program validation
Swiss Trombe Wall Cell	*No site handbook *Could not be modelled by many of the programs *Missing weather data *'Thermal history' of wall uncertain *Many other thermo-physical inputs to models uncertain
Canadian Test Rooms	*Some uncertainty on thermo-physical inputs to models *Uncertainty about inter-zonal air flows *Air temperature sensors not shielded *Uncertain attic air change rate
Management and Reporting	*Poor statement of methodology *Poor reporting of modelling activities *Inconsistent coverage of the various validation exercises *Inconsistent and poor quality reproduction of results *Poor description of buildings *No validation package produced for use by others *Weak project management and data control

Table 7 Limitations of the IEA Task VIII Work

Methodology Requirement 6: There should be a thorough review and assessment of acceptable data sets to establish those-which are most suitable as the basis for the validations benchmarks.

Methodology Requirement 7: Careful consideration must be given to the way the benchmarks will be packaged, and managed. In particular so that 'blind' model/benchmark comparisons can be undertaken in the future.

8.3 Project Management

It appears that the IEA Task VIII project lacked strong management, and this led to a disjointed and poorly presented piece of work. It is suggested, therefore, that in future work, the following management requirement is satisfied.

Management Requirement: There must be strong centralized, project management which is responsible for: (i) ensuring that the agreed methodology and program time-scales are adhered to; (ii) interfacing between the data collection team and the modellers to ensure that the same information is available to all the modellers and that this information is consistent; (iii) analysing the results (e.g. receiving the digital program predictions and input files, undertaking the model, data comparisons and statistical analyses, and plotting/reporting the results).

8.4 Modellers

For the work to be manageable within a reasonable time-frame, the programs would have to be used by acknowledged experts who are familiar with the underlying assumptions, the data input requirements, and the outputs produced. The development of benchmarks is a high level and sophisticated usage of thermal models, and so it demands a high level of user expertise. The work should not be considered as a teaching activity for novice program users. Ideally, the modellers would already have attempted empirical validation work before

Modeller Requirement 1: The modellers should be experts in using the programs and be fully conversant with the underlying theory of the program, the inputs needed and the outputs produced. Whilst not a requirement, previous experience of model validation exercises would clearly be beneficial. By beginning from a strong experience base, the work would have prospects of significantly advancing the field of empirical validation. However, even with very experienced users, empirical validation is a very difficult, time consuming and computer intensive activity.

Modeller Requirement 2: Modellers should be strongly motivated and have adequate resources (time, manpower and computer power available). It is suggested that the task of developing benchmarks is more likely to succeed if a small experienced group of modellers work closely together to achieve the above aims.

8.5 Data Sets

As noted previously, a thorough review of data sets should be undertaken to identify those which are most suitable for use as model validation benchmarks. Criteria have already been defined (section 2.1) to help identify high quality data sets, but there are other requirements which must be fulfilled in the context of a benchmark development exercise.

Data Set Requirement 1: The data set(s) must fulfil all nine criteria and hence be classified as High Quality.

This is seen as far more important than trying from the outset of the project to try and cover a range of buildings and weather conditions and, in the process, accepting inferior data (as happened in IEA Task VIII).

Data Set Requirement 2: The data must be available for use both within the benchmark development project and for subsequent use by others.

Data Set Requirement 3: Ideally, the site from which the data was collected should still be active.

This will allow participants to have first-hand experience of the building and the monitoring (which will lead to more accurate use of the models). It will also permit any necessary peripheral investigations to be undertaken and any extra experiments to be commissioned. Furthermore, the monitoring team will be available to assist in resolving any uncertainties and ambiguities.

Data Set Requirement 4: The actual monitored performance of the buildings must not be widely known; otherwise 'blind' comparisons cannot be assured.

Finally, having fulfilled these criteria, it is possible to consider additional needs, in particular, the identification of the source of errors in the programs and hence the remedies to be effected; there are two possible routes, and both could be pursued. A single data set must contain mechanism level data to permit inspection of the predictions of individual algorithms (solar transmission, heat fluxes etc.), or a sequence of data sets (benchmarks) can be produced each of which differs in a specific way from the next (e.g. change in window area, surface emissivity, etc.). This latter approach is analogous to that which has been adopted in the previous IEA Task VIII inter-model comparison work (and which could be adopted in inter-model comparisons associated with the empirical validation study).

It is the author's view that these considerations should not at this stage form a data set requirement. It is likely that those already stated, and which are crucial, will so limit the number of data sets available that further, less important considerations, will not be needed as a basis for selection.

8.6 Documentation

Most previous validation work has had little benefit beyond the small group of experts directly involved - primarily because of the poor level of project reporting; the Task VIII empirical validation work is a clear example of this.

Documentation Requirement 1: The methodology by which the benchmark is to be conceived must be clearly stated before beginning the work. Modifications to the approach (and reasons for them) should be described and recommendations for approaches to be used in future should ensue.

Documentation Requirement 2: The benchmarks must contain a description of the building and its operating conditions, the weather data and the procedure to be followed when using these for validation. This documentation must be clear and unambiguous so other program developers can use it.

The development of this documentation can take a long time and the resources needed should not be understated. The objective of such documentation is to ensure that others, who did not participate in the development of the benchmark, could use it to assess their own programs. (The documentation should have a similar degree of rigour to that which is adopted by the medical profession for describing experimental procedures for testing drugs, etc.). A computer library is one obvious way to store benchmark data, building descriptions, and information on how to use them.

9. Conclusions

This report has outlined the shortcomings of the empirical validation work undertaken within the IEA Task VIII. As a result, outline proposals about how future international collaborative exercises in this field could operate have been devised. These suggestions are built around the idea of developing benchmarks against which existing, or future programs can be assessed. Requirements which ought to be fulfilled for this idea to be successful have been suggested. It is upon this outline skeleton that detailed proposals and related work could be framed.

01/IEATASK8/JW/MN

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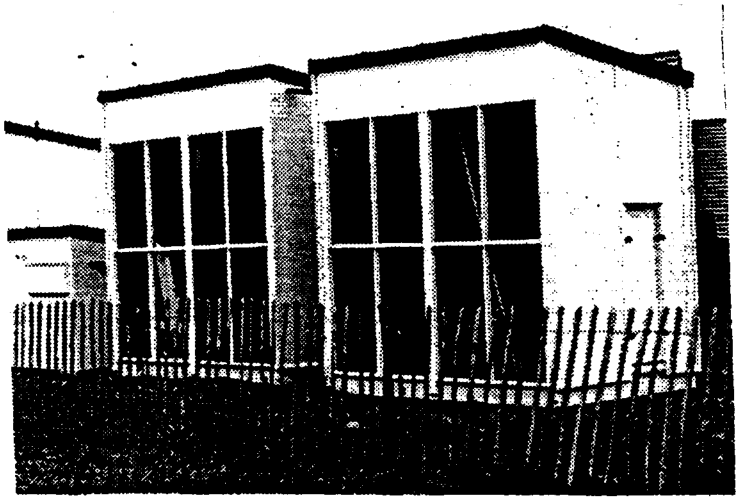

Plate 2. The PCL Cells

Plate 3. The ETSU Rooms

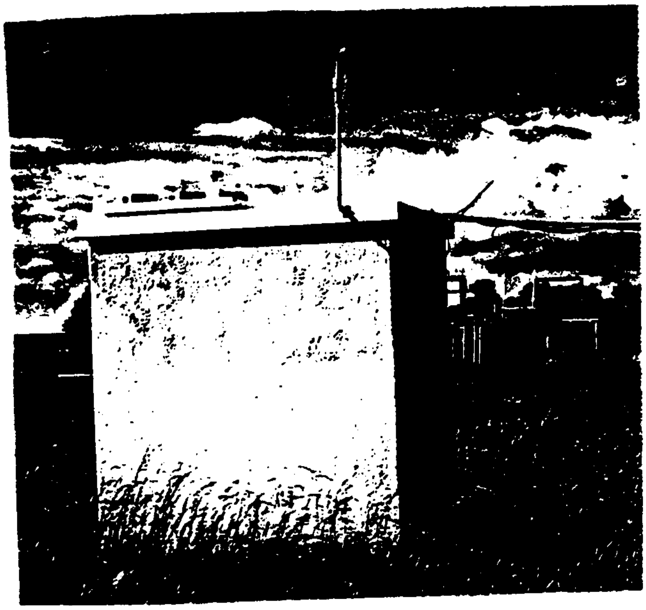

Plate 4. The British Gas Test Cells

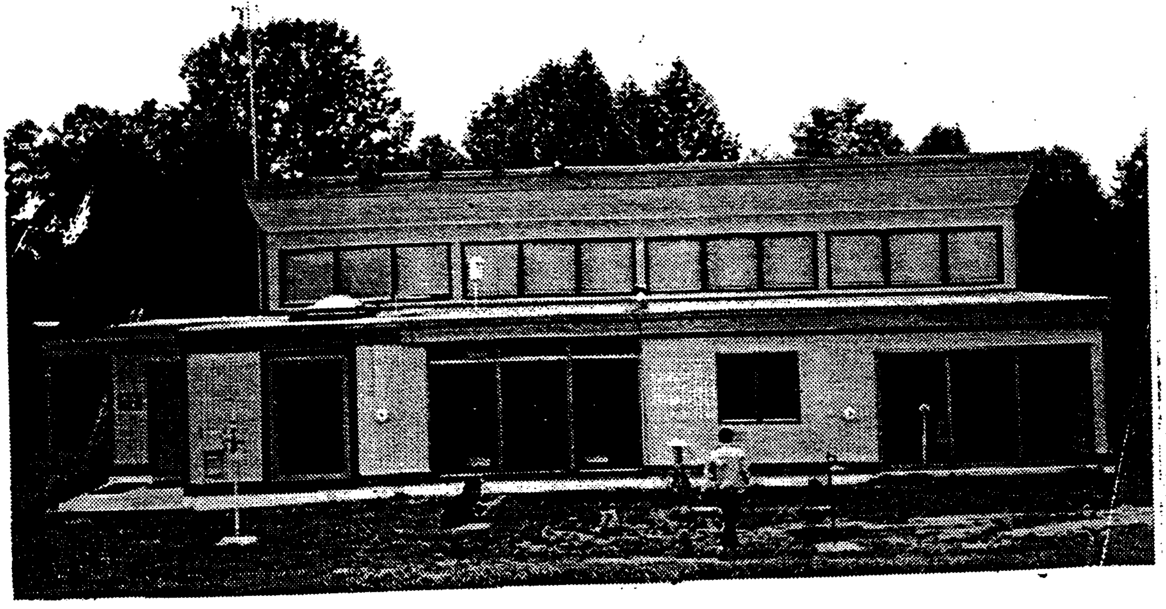

Plate 5. The NBS Passive Solar Test Facility

1. Introduction

Empirical validation is the ultimate test of the predictive abilities of a thermal model since it compares the predictions with measurements made in real buildings. Further, if the predictions are made without a knowledge of the actual measured performance, then the modelling process mimics the situation which arises when the program is actually used for building design.

There is renewed interest at the UK Building Research Establishment (BRE):

(i) to consider afresh the availability of suitable data for model validation;

(ii) review previous work in the field, especially within IEA Task VIII; and

(iii) to identify data sets upon which future empirical validation work should concentrate.

Previous reports (under the Leicester Polytechnic support contract to the BRE) have dealt with activities (i) and (ii) above (Lomas 91 a,b). This report looks more closely at item (iii) and, in particular, the high quality data sets available in the UK. It describes the buildings, the data sets available from them, and the empirical validation work (if any) undertaken with these. The monitored data, the comparisons and the results of the analyses are deliberately not given in this summary. Finally, the most appropriate data to use in any (international) collaborative empirical validation effort is identified.

The buildings from which data is considered, in the order studied, are:

The Polytechnic of Central London (PCL) cells at Peterborough; The British Gas cells at Cranfield;
The ETSU test rooms at Cranfield;
The PASSYS cells in Strathclyde; and
The National Bureau of Standards Passive Solar Facility in Washington D.C.

The buildings are illustrated in Plates 1 to 5 and the main attributes of the data sets currently available from them are given in Table 1, all are freely available. It is 'recommended that this Table is read in conjunction with the written information about each data set. All the data sets are available in the UK including that from the NBS facility (Table 1, column 1).

2. PCL Cells

2.1 The Test Cesls

The Polytechnic of Central London (PCL) direct gain test cells were located on a flat open grassland site in Peterborough. The cell block consisted of two adjacent cells with a common attic space above (Figs. 1,2). A separate hut housed the data acquisition system and the meteorological data collection equipment. They were monitored from late 1983 to July 1984 to compare the thermal performance of different thermal storage walls (Littler et al, 84). High quality data is available for two

Monitoring Institution [Location of Structure] Contact (and Number) [Major References]	'Name' and Code Number	STRUCTURE: Volume (m^3)	Primary Features: Opaque, Heavyweight	Primary Features: Opaque, Lightweight	Primary Features: Direct Gain, Lightweight	Primary Features: Direct Gain, Heavyweight	Secondary Features: Raised off Ground	Secondary Features: Night Insulation	Secondary Features: Clerestory Window	HEATING Type: None	HEATING Type: Fan Convector	HEATING Type: Natural Convector	HEATING Type: Panel Radiator	MONITORING: Start Date (Month, Year)	Duration (Days)	Recording Frequency (Mins)	OPERATION: Free Floating	Intermittent, T'stat Control[1]	Continuous, T'stat Control	Impulses	Pseudo-Random	AIR FLOW Intra-zone: Stratified	Intra-zone: De-stratified/Mixed	Ventilation: Negligible	Ventilation: Natural	Ventilation: Mechanically Induced	BUILDING MONITORING: Number of Sensors	Temperature: Air	Temperature: Globe	Temperature: Opaque Surface	Temperature: Window Surface	Temperature: Intra-fabric	Temperature: Below Floor	Temperature: Above Ceiling	Ventilation: Continuous Flow Meter	Ventilation: Continuous Gas Decay	Others: Auxiliary Heating Power	Others: Surface Heat Flux	Others: Interior Insolation	Others: Interior Longwave	Others: Some thermo-physical Props.	WEATHER MONITORING: Sensors	Temperature: Air, Dry Bulb	Temperature: Air, Wet Bulb	Temperature: Ground	Radiation: Global Horizontal	Radiation: Direct Normal	Radiation: Diffuse Horizontal	Radiation: Vertical Glazing Plane	Radiation: Ground Reflected	Radiation: Net Longwave	Wind: Speed	Wind: Direction	VALIDATION Data: High Quality Datasets	Data: Site Handbook Available	Comparisons: ESP	Comparisons: HTB2	Comparisons: SERIRES	Comparisons: DOE-2
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[A1-A5]	Test Cell 2	10.4			*		*			*				4:84	9	60																																											
Energy Monitoring Co.	British Gas									*[3]			*[3]	:85	16	3/20[2]	*[3]		*[3]																																										
[Cranfield UK]	Test Cell	9.7	*				*						*	:85	35[4]	3/20[2]			*																																										
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P Strachan (41-552-4400)																																																											

[1] Cycle of heating to a set point then free floating in between
[2] 3 minutes to first heater 'turn off' then 20 minutes
[3] Free floating followed by continuous heating
[4] 5 at 7 days each
[5] 3 at 7 days each
[6] Period of continuous heating followed by periodic heating followed by free floating period
[7] Complex operation including 28 hour cycle of 6 hours continuous heating, 2 hours free float, 6 hours heating, 14 hours free float
[8] Exact type of radiant source unknown
[9] Excluding service room

TABLE 1 Compiled information about high quality data sets in the U.K. up until June 1990

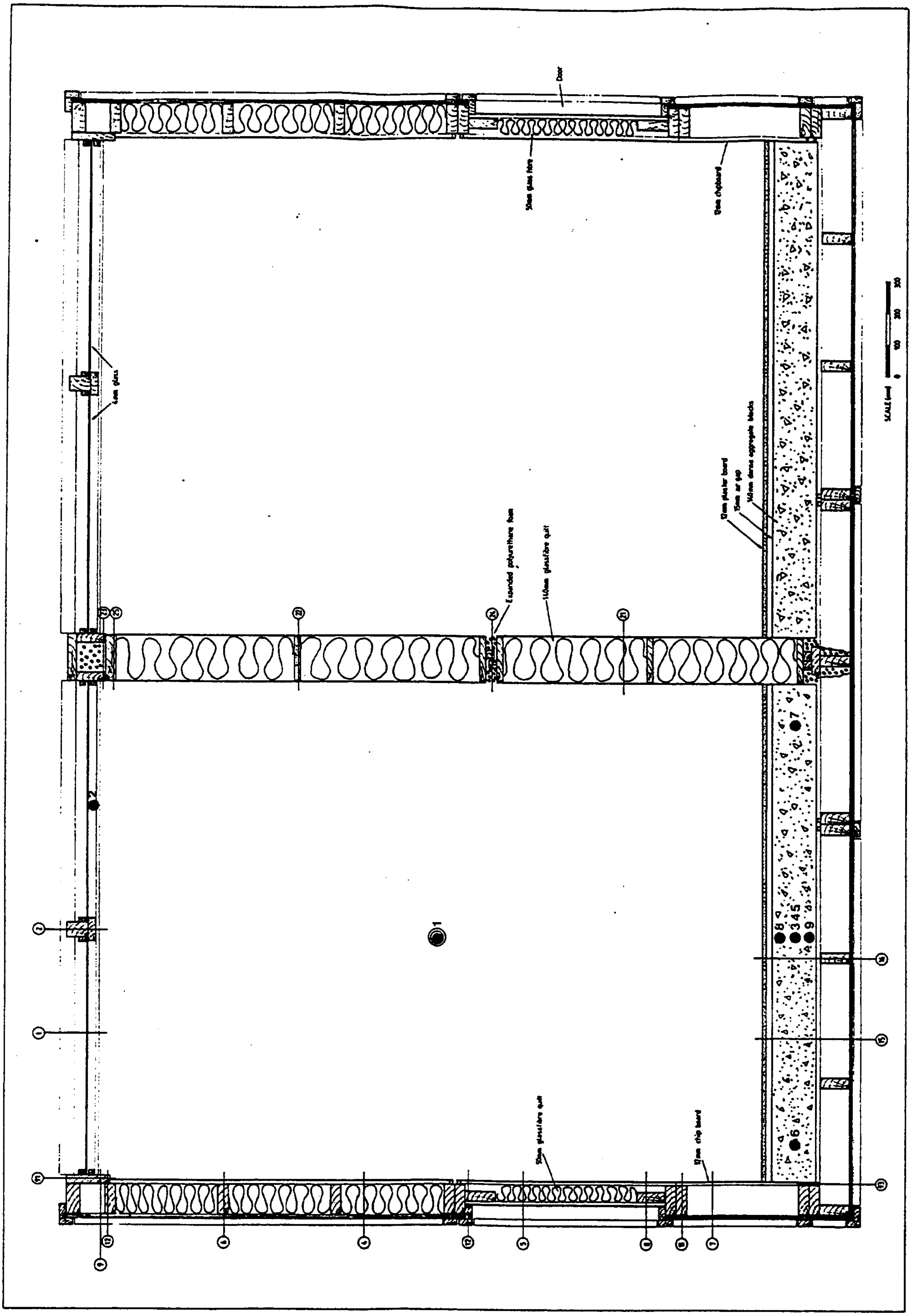


Fig.1. Plan view of the PCL test cells showing sensor locations for Cell 1

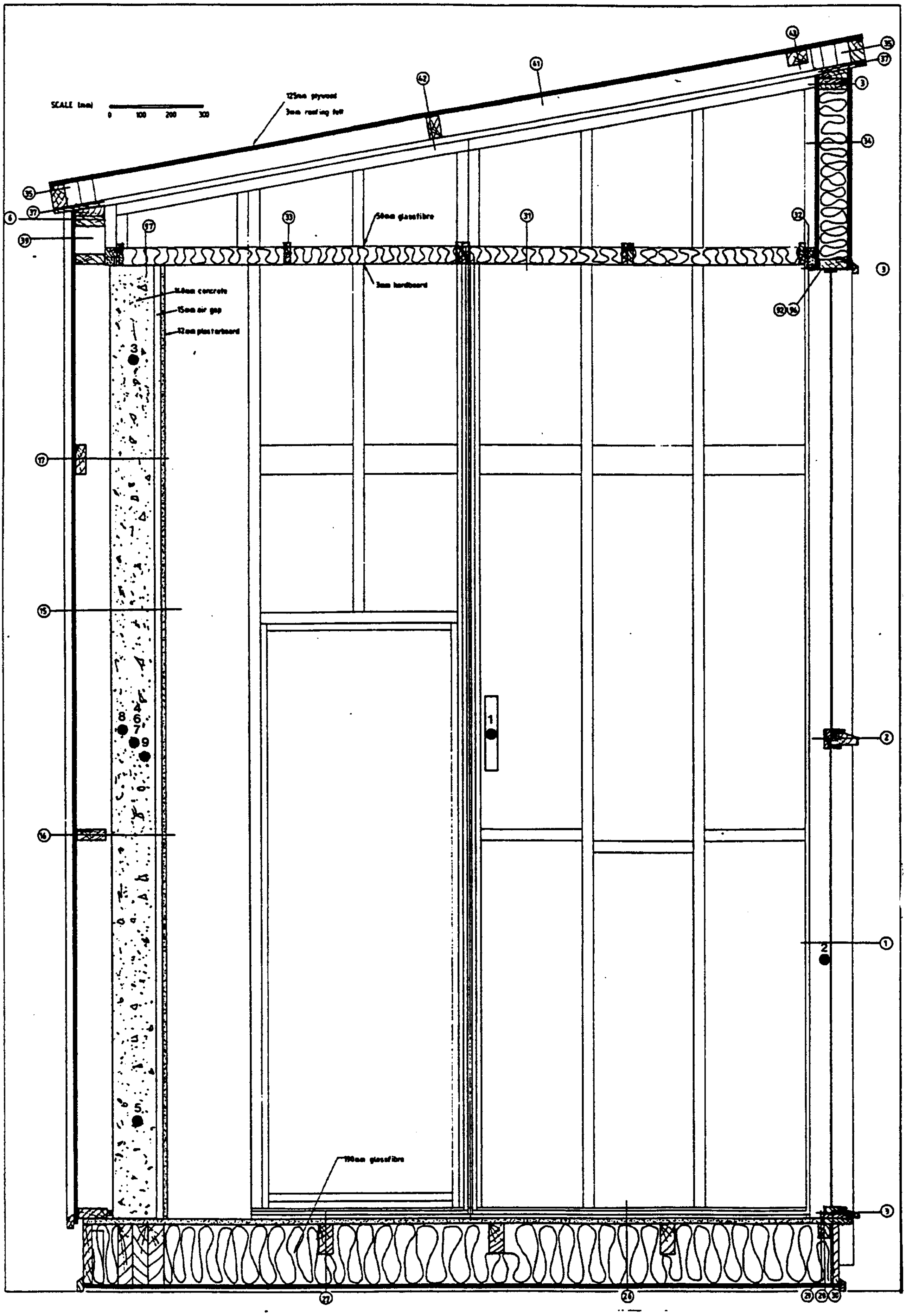


Fig.2. Vertical cross-section through Cell 1 looking east

nine-day periods: 25th February to 4th March 1984, and 4th May to 12th May 1984. Neither cell was mechanically heated or cooled and they were both well sealed to minimise infiltration. -

The cells were erected on site by bolting together prefabricated panels built in accordance with detailed working drawings (Watson, 85a). The exterior surfaces were of stud frame construction with a stressed skin plywood facing. An additional layer of waterproofing felt covered the roof. A suspended hardboard ceiling with insulation separated the attic from the cells below. The cells were of equal volume and separated by a well insulated party wall. The floor and side walls of each cell were well insulated (Fig. 1). The cells were supported on ground beams to enable free circulation of air below the floor (Fig. 2). Virtually the entire south face of each cell was glazed using four sheets of single thickness 4mm clear float glass. These were supported by a substantial mullion and rail. The thermal storage wall in cell 2 was made of dense concrete blocks whereas in cell 1 the blocks were of open textured, no-fines, concrete.

During the May experiments, an insulating blind was located behind the windows of Cell 1 from 7.p.m. (19:00) to 7.a.m. (07:00) Greenwich Mean Time. After 12:00, the west side of Cell 2 was shaded by the adjacent cell block located 0.8m to the west (Plate 2). The window shading caused by the mullion and rail and the slightly protruding cell sides was the same for both cells.

The only building description parameters measured (Table 2) were:

(a) the U-values of the window and the window and blind combination;

(b) the density, specific heat and conductivity of the concrete blocks;

(c) the infiltration rates in the cells (less than 0.05ach^{-1}).

The overall heat loss coefficients of the cells were also determined by heating them to a fixed temperature of 25°C whilst shading out solar radiation. The values measured were 32.1 W°C^{-1} for Cell 1 and 32.5 W°C^{-1} for Cell 2; these values were accurate to +/- 5%.

2.2 Data Acquisition

The external meteorological conditions and temperature at nine points within each cell were recorded using a data acquisition system (Table 2, Figs. 1 and 2). The air temperature sensors were shielded to eliminate radiant effects but allow free circulation of air. The temperature at the internal surface of the window was recorded using a thermocouple which had a small cross-section and hence absorbed minimal solar radiation. With the blind in place in Cell 2, the sensor was between the glass and the outer surface of the blind. Seven current transducers were used to sense the mass wall temperatures.

The data is available on floppy disk from Leicester Polytechnic, along with a site handbook and a guide to using the data.

Data Type	Parameter	Measurement Technique	Values Measured
Building Description	Cell Air Infiltration Rate	Tracer gas decay 100 hr. trials	0.03-0.05 Ach^{-1}
	Thermo-physical properties. No-fines concrete blocks	Values supplied by manufacturer	Density - 1685 Kgm^{-3} Spec.Heat - 1230 $JKg^{-1}\,^{\circ}C^{-1}$ Conductivity - 0.72 $Wm^{-2}\,^{\circ}C^{-1}$
	Thermo-physical properties. Dense concrete blocks	Values supplied by manufacturer	Density - 1900 Kgm^{-3} Spec.Heat - 1200 $JKg^{-1}\,^{\circ}C^{-1}$ Conductivity - 1.10 $Wm^{-2}\,^{\circ}C^{-1}$
	Window and blind -value	Guarded hot box, Cardiff University	1.5 $Wm^{-2}\,^{\circ}C^{-1}$
External Meteorological Conditions	Air Temperature	AD590 current transducer	Hourly values
	Global (Total) Horizontal Irradiance	Licor Pyranometer type L1-2005B	
	Global (Total) South Facing Vertical Irradiance	Licor Pyranometer type L1-2005B	
	Diffuse Horizontal Irradiance	Licor Pyranometer type L1-2005B	
	Wind Speed	3 cup Weathermeasure type W103-355	
	Wind Direction	Porton Windvane type W200	
Internal Temperatures In Each Cell	Air Temperature	Shielded AD590 Current Transducer	See Figs 1,2
	Window Inside Surface Temperature	Type t thermocouple	
	Interior of Mass Wall	Seven AD590 Current Transducers	

TABLE 2 Parameters measured in the PCL test cells

2.3 Thermal Performance

May was cold for the UK and the ambient temperature showed a greater diurnal variation than in February (between -2 and 16°C). Throughout the May period it was also much sunnier than in February/March (GH between 340 and 810 Wm^{-2}). The wind speeds in both periods varied in the range 0 to 9 ms^{-1}. The May period provides the data set which stresses the dynamic capabilities of the programs the most.

The most striking feature of the performance of the two test cells was the similarity of the temperatures within them. During the February/March period all the temperatures in Cell 2 were within 0.5°C of the corresponding temperature in Cell 1. In May with the blind in place, the evening temperatures in Cell 1 were less than 2°C greater than those in Cell 2.

The measured wall temperatures also lagged behind the cell air temperatures. The temperature gradient from the top to the bottom of the walls differed between Cell 1 and Cell 2. Although the gradient in both increased as the solar gain increased, the gradient in Cell 2 was under half that in Cell 1 at all times. On 12th May at 15:00 hours the top of the wall in Cell 2 (dense concrete) was 2.8°C above the bottom but, because the no-fines concrete blocks in Cell 1 tended to allow air to circulate, whereas the dense concrete blocks did not, the vertical gradient in Cell 1 was greater at 7.7°C. These figures suggest that the floor to ceiling air temperature stratification in the cells may exceed 10°C.

2.4 Empirical Validation

The data from the cells was used as the basis for empirical validation using the programs ESP, HTB2 and SERIRES (Lomas 87, 90, 91c). This work concentrated more on the May data. Initially, this involved making simple graphical comparisons of measured and predicted values, cross-correlation analysis to detect any time shift between the measured air temperatures and the predicted values, and the calculation of simple statistics to describe the overall level of agreement between the measurements and the predictions. Window surface and internal mass-wall temperatures were also analysed in this way.

In the second stage of the work, simple differential sensitivity analysis was undertaken for one day (12th May) to study the influence on the air temperature in Cell 2 of the uncertainty in the input parameters to the programs. Because of the large area of single glazing, it is not too surprising that uncertainty in the ground reflectivity, window U-value (and, in SEETHES, the external combined surface coefficient) had the greatest impact on the internal air temperature.

The validation work concluded with a comparison between the external south facing vertical irradiances predicted by the three programs and the measured values.

The most important products of the work were the three level empirical validation methodology and the empirical validation tool. This consisted of a detailed site handbook, a disk containing the measured weather and

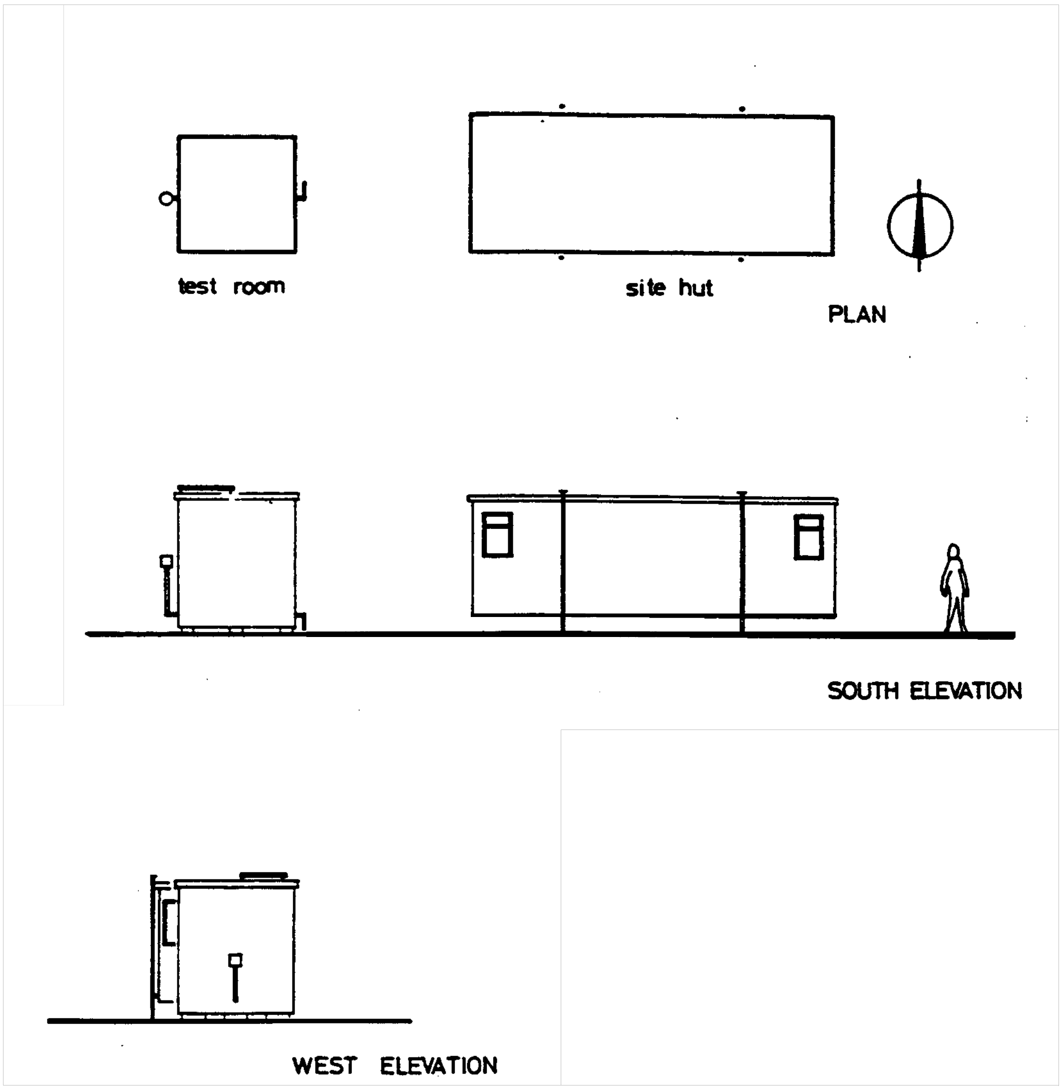


Fig. 3. Site layout for the British Gas test cell

building performance data and a guidebook explaining ho^w to use these for validating programs. These are currently being used by researchers in Ireland and has been distributed to two Australian research groups for program validation.

2.5 Critique

Because the test cells were prefabricated under the scrutiny of the monitoring group and then assembled on site from these units, the construction is very well defined. The data was high quality and complete, and it is well documented and easily accessible. The original research/monitoring team is still active in the field, although the cells no longer exist, so first hand inspection is not possible.

The cells stress the glazing conduction and solar gain algorithms strongly. However, whilst there is thermal mass in the cells, it is not closely linked to the air and so the temperature swings (and peak temperatures) are untypical of those found in the occupied spaces of real buildings. (This is advantageous for stressing the algorithms, but not if 'realism' is seen as important). A limitation is that the data only represents one type of cell (highly glazed, light weight, unheated), so many other very important issues and program sub-models cannot be tested.

The data set is one of the most rigorously studied for use in empirical validation. The validation tool which resulted is one of only a handful that exist and it has succeeded in identifying errors in the predictions of an early version of ESP (version 10:84). The monitoring was, however, not sufficiently detailed, at the mechanism level, to identify unambiguously the source of these discrepancies.

3. EMC - British Gas Test Cells

3.1 The Test Cels

The British Gas test cell was monitored by the Energy Monitoring Company (EMC) which was established by the same individuals who monitored the PCL cells. (An earlier British Gas cell was in fact located in Peterborough; Watson, 85b). The current British Gas cell is located on the same site, at Cranfield, as the Company's other six (ETSU) rooms (see section 5). The British Gas cell has a very well insulted stud frame construction but with a single layer of bricks covering the floor and the walls on the inside. Like the PCL cells, the construction is very well defined. The cell is completely opaque with internal dimensions 2.034m x 2.034m x 2.334m high, and raised off the ground to allow a free flow of air underneath (Fig. 3). It is well sealed to preclude uncontrolled infiltration (less than 0.01ach^{-1}), but it is mechanically ventilated to about 2ach^{-1}. The air flow rate, the internal air and opaque surface temperatures, the heating system power consumption, the opaque surface heat flux, and the weather data were continually recorded. The type of heater, the ventilating system and the exact location of the sensors varied from year to year. In general, in successive years, the heating and ventilating system became more sophisticated, with better controls and the number of sensors gradually increased (see sections 3.2 and 3.3, and Fig. 4).

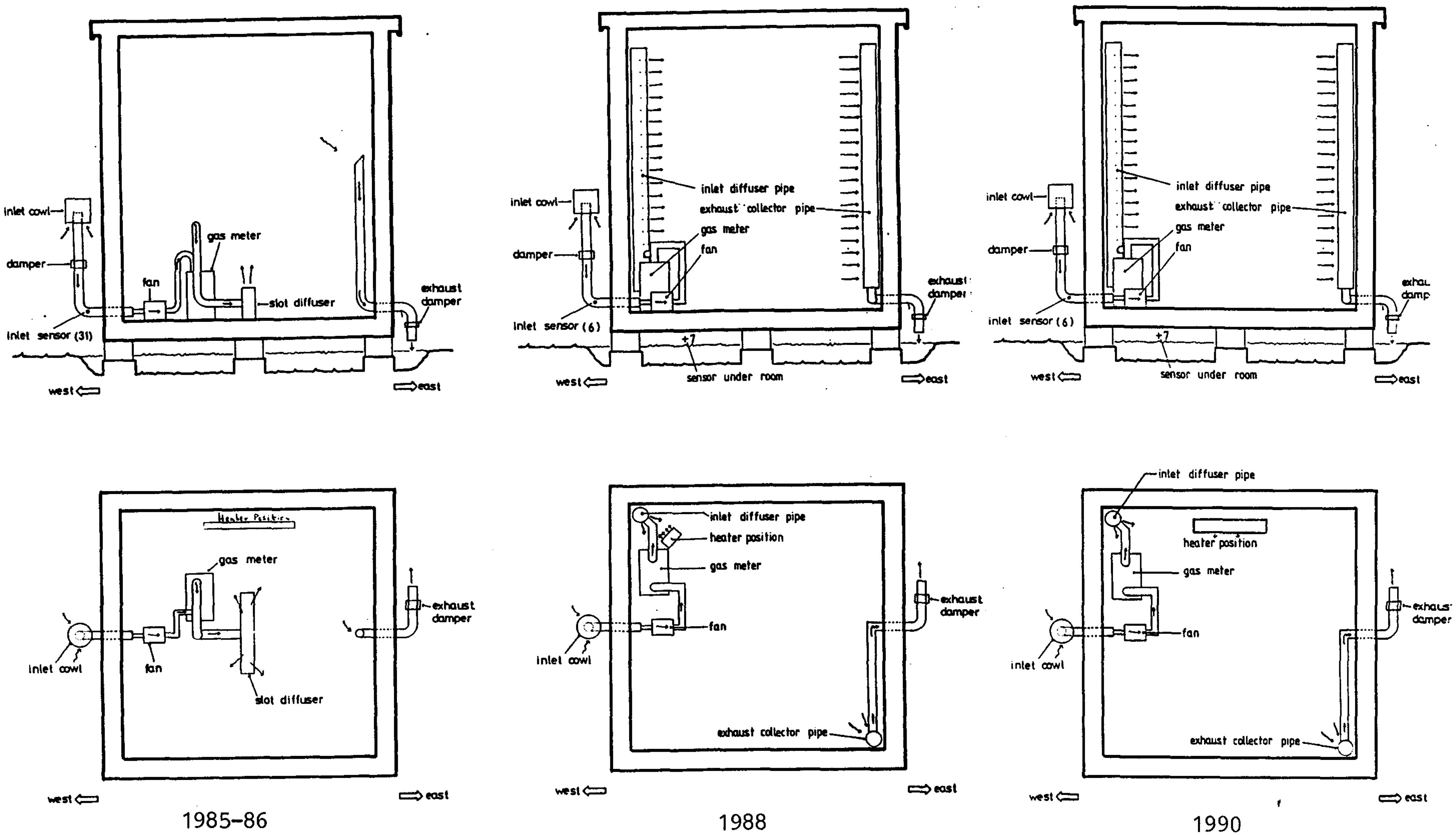


Fig. 4. Evolution of ventilating and heating system in the British Gas test cell

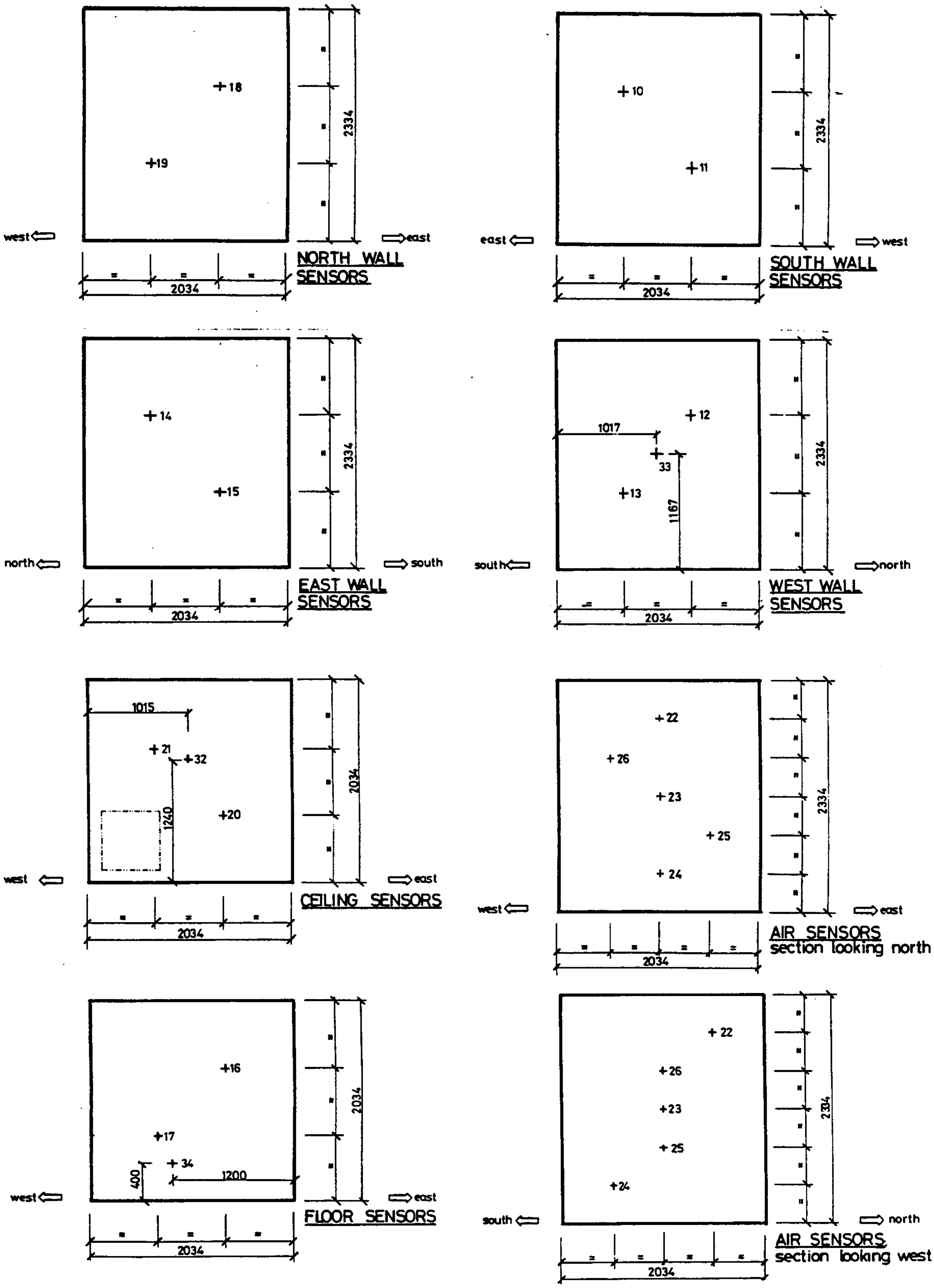


Fig. 5. Sensor locations in the British Gas test cell during the winter of 1985-86

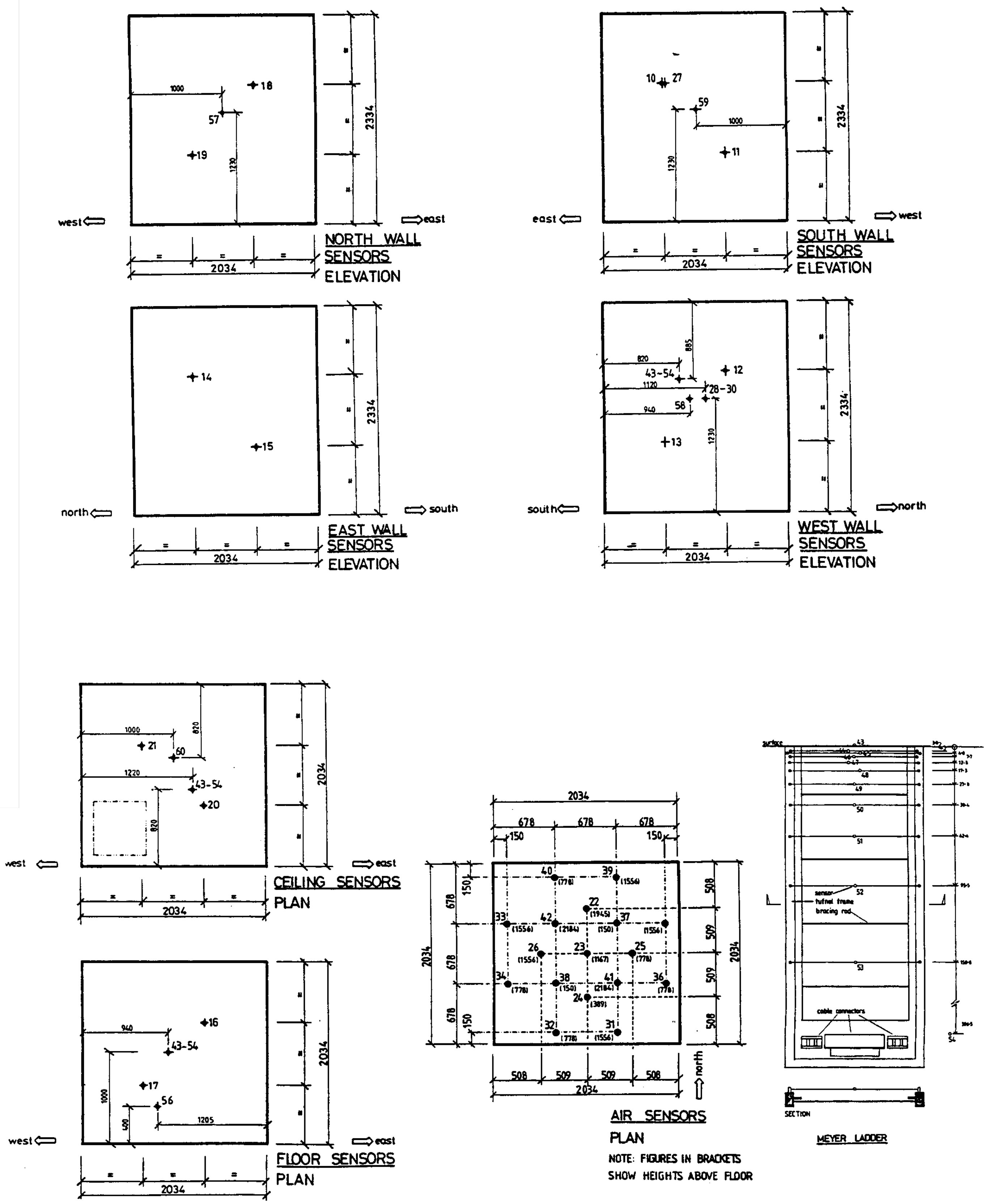


Fig. 6. Sensor locations in the British Gas test cell during the winter of 1990

3.2 Monitoring

The data collected by the MC, is used exclusively by British Gas to examine the interaction of heating systems and building fabric. British Gas report that the data is consistently completely uninterrupted and error free (Hitcher, 91).

Reports describing the monitoring of this cell cover the winters of 1985-6 (Anon., 86), 1988-9 (Martin, 89a,b) and 1989-90 (Martin, 90a). These are reports from EMC to British Gas describing the experimental procedure, they contain no details of the actual values recorded or the use which was made of the data. The following sections highlight the main features of the experiments and the differences between the three winter periods. Synoptic information is given in Table 1.

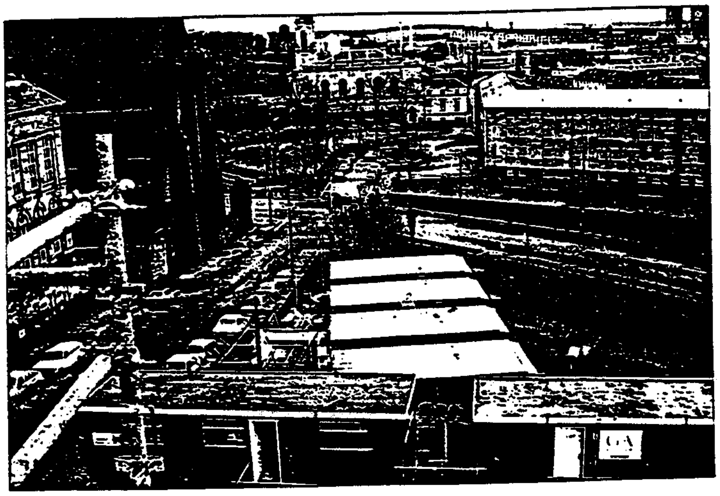
3.3 Data Sets

During the winter of 1985-6, a series of tests (10 different heating regimes) in which the cell was heated by an oil filled panel radiator, was planned (Fig. 4). In the first and last test (Table 1), the continuous heating period of 7 days was to be preceded by 7 free-floating days and followed by 2 more free-floating days. In all the other tests, the cells were to be intermittently heated to a fixed set point, but the 'on period' was to be varied for each test. In tests 7 to 10 (lasting 21 days), the panel radiator was to be covered with a polished metal cover to reduce the radiant component of the heat output. The weather and building performance data was to be recorded every 3 minutes from the time the radiator switched on to the time at which it first turned off and at 20 minute intervals thereafter. The sensor locations are illustrated in Fig. 5.

During 1988-9, the cell was heated with a fan convector rather than a radiator, and a more sophisticated, proportional integral and derivative controller replaced the on/off device used previously (Fig. 4). Ventilation air was supplied and extracted via sparge pipes to reduce inlet jet speeds and more detailed monitoring was used within the cell (Fig. 6). This included electrical heater power, 12 surface temperatures, 16 air temperatures, Meyer Ladder, 5 heat flux measurements, 3 intra construction (brick) temperatures, and a Net radiometer to try and record long wave exchange. The data was recorded at 5 minute intervals.

There was an initial block of three experiments (Table 1) which began with a period of continuous heating, followed by a period of intermittent heating, and then finally a period with unheated operation. The Meyer Ladder (Fig. 6), which is a series of 11 temperature sensors placed at right-angles to the wall, to measure air temperatures near the wall, was moved from one series of experiments to the next. Following a single day in which the cell free-floated the fourth and final experiment was undertaken (Table 1). In this test a pseudo-random heating sequence was used for a 20 day period. Statistical techniques were then used to extract the underlying relationships between the driving force (heat injection) and the building response (heat fluxes and surface temperatures etc.).

During 1989-90, the same British Gas cell was used with the only changes from the previous year being the installation of natural convector heating, an additional Meyer Ladder, and minor changes to three air



General view of the test site

General view of the test cells

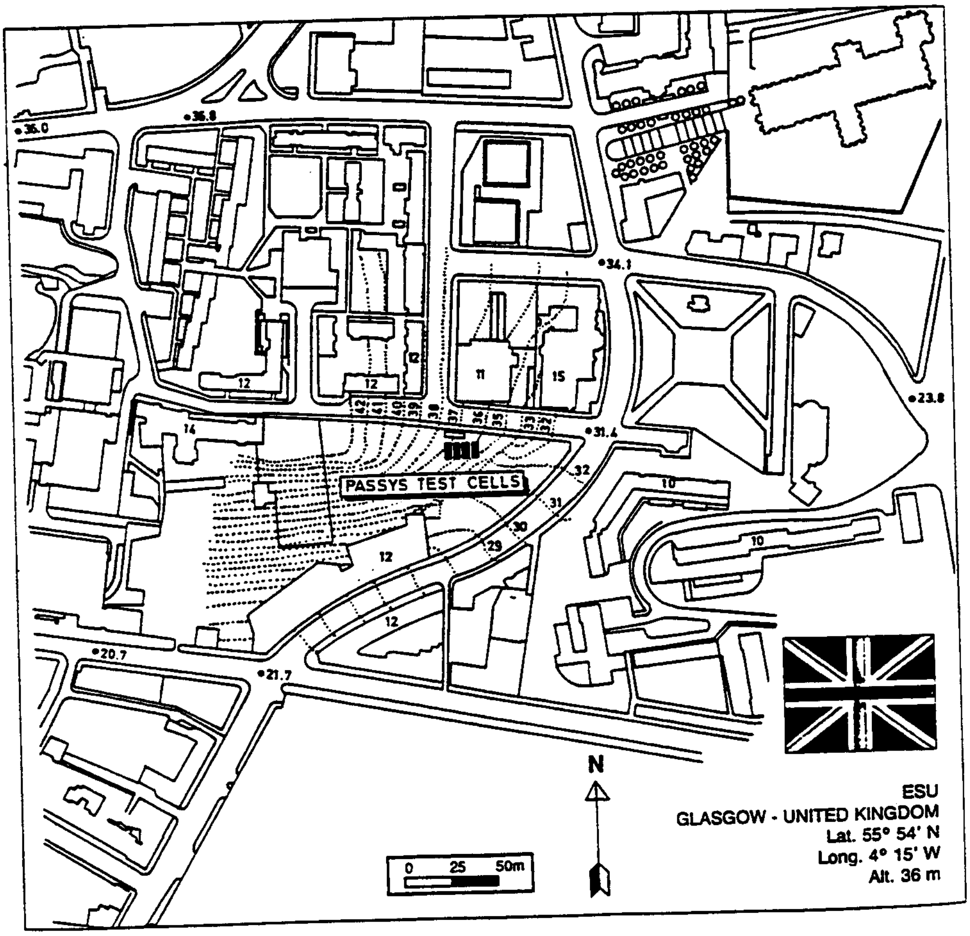


Fig. 7. The PASSYS test site in Glasgow

temperature sensor positions. The data was collected at 5 minute intervals for a $13^1/_2$ day period (Table 1), although the mode of operating the cell was changed during this period. The series started with a 3 day continuous heating period, this was followed by a free-floating period of 12 hours, then 7 days of intermittent heating (6 hours heating on, 2 off, 6 on, then 14 off) giving a 28 hour cycle, and finally a 3 day free-floating period.

3.4 Critique

All the experiments in the British Gas cells have the following general characteristics.

(i) The data was recorded by an experienced team with a track record of producing high quality error free data. The British Gas data was of this expected high standard.

(ii) The data was recorded at frequent intervals, typically 5 minutely or less, to a high level of accuracy.

(iii) The cells were completely opaque and heavy weight to test the interaction of heating plant and the thermally massive opaque elements of the building fabric.

(iv) The data cannot test aspects of the models dealing with glazing, solar irradiance or natural infiltration.

(v) The Meyer Ladder permits the variation with time of internal surface convection coefficients to be calculated. The surface and intra-constructional temperatures, plus the heat flux sensors, permit heat flows within the mass to be examined.

(vi) The infiltration was mechanically introduced in such a way that it could be accurately measured. The addition of sparge pipes within the cell in 1988-9 resulted in better diffusion of the incoming air and lower air velocities.

(vii) The control of the heater was improved in 1988/89 over that used in previous years. This produced very close control of the set point temperature in the cell (+/-0.1°C in 1988/89 and 1990 compared to around +/-1°C in previous years).

(viii) The pseudo-random (1988-9) and 28 day (1989-90) hourly sequences provide the opportunity to test novel statistical parameter estimation techniques to assess the underlying relationship between the response of the building, the heating system, and the weather data, and to compare this with the underlying relationship predicted by thermal models.

4. PASSYS

4.1 The Research Programme

The Passive Solar Systems (PASSYS) research programme involves eight research institutes in seven EEC countries. The activities focus on test cells located at nine sites (Table 3). "These test cells are identical test facilities spread over Europe, equipped with a common set of

Country	Test Center	Location	Responsible	Number of cells
Belgium	BBRI	Limelette	P. Wouters	4
Denmark	TIL	Lyngby	B. Saxhof	2
France	CSTB	Sophia Antipolis	L. Bourdeau	1
	CEA	Cadarache	M. Chantant	4
F.R. of Germany	ITW	Stuttgart	N. Fisch	4
Italy	CONPHOEBUS	Catania	M. Antinucci	4
The Nether-lands	TNO - TPD	Delft	D. van Dijk	4
United Kingdom	ESU	Glasgow	J. Twidell	4
CEC	JRC	Ispra	H. Bloem	2

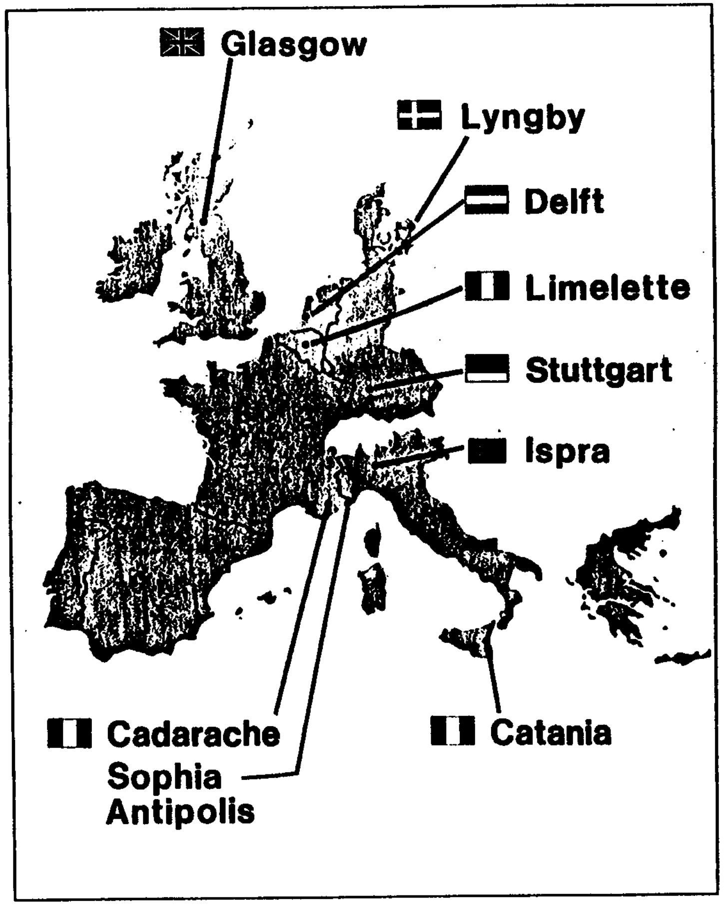


TABLE 3 Location of the PASSYS test sites

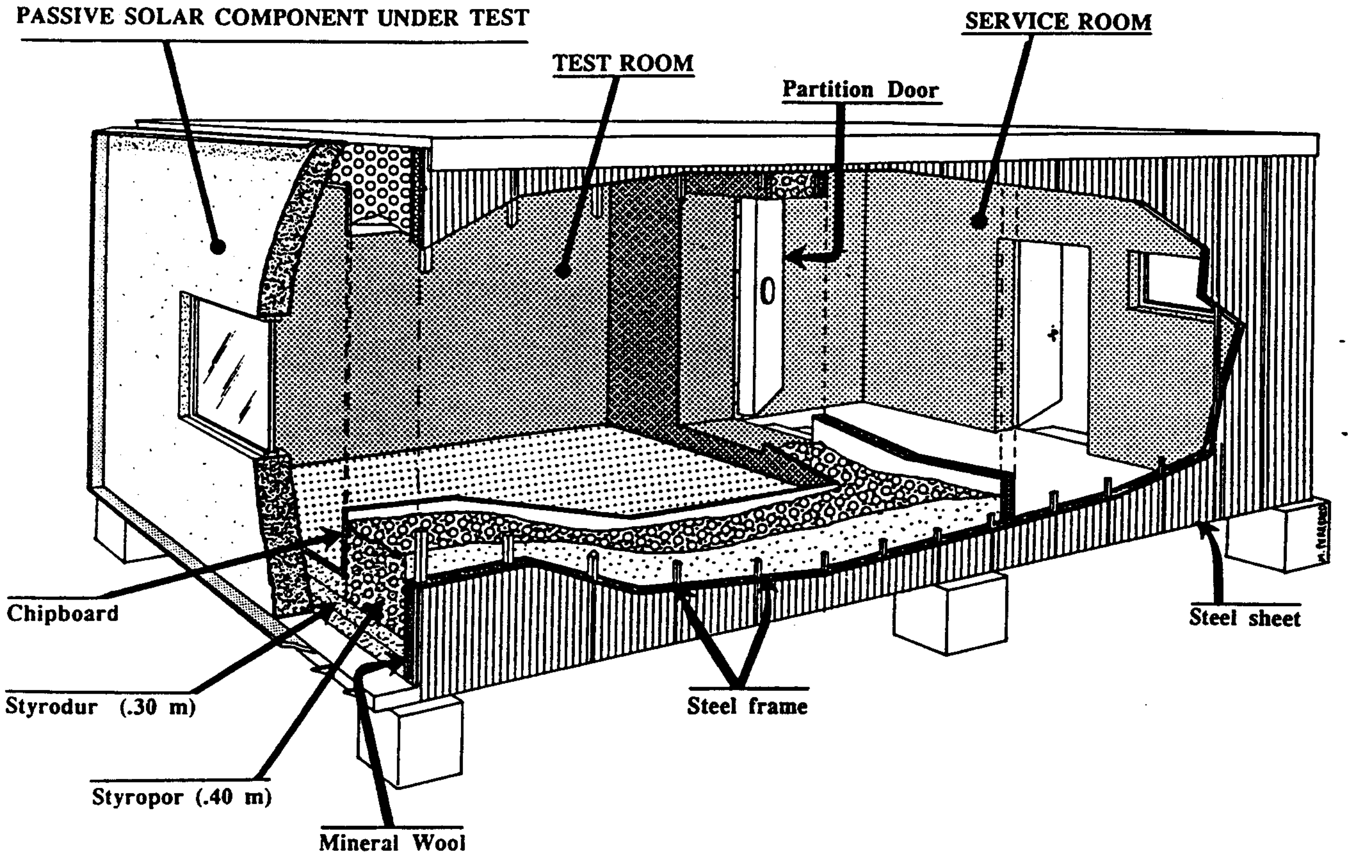
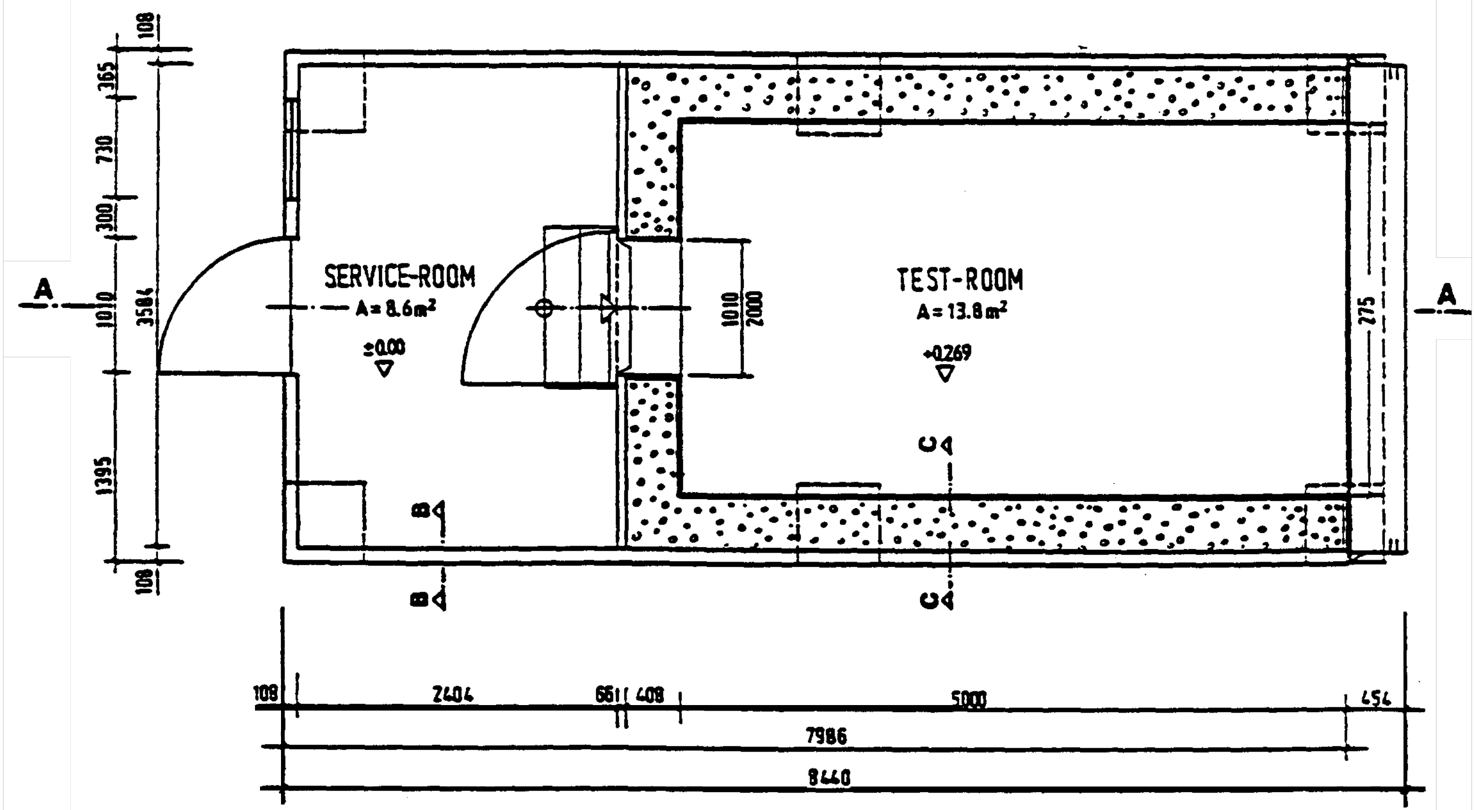
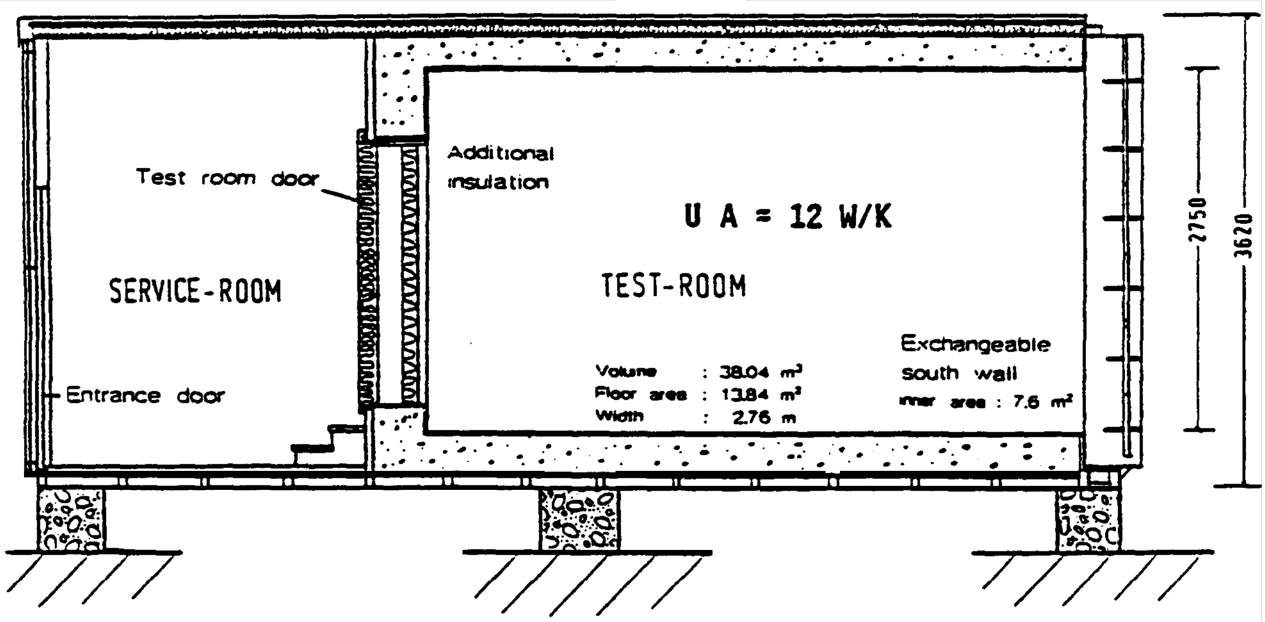


Fig. 8. Sketch of the PASSYS test cell



Groundplan



Sectional view A-A

Fig. 9. The construction of the PASSYS cell

measurement instruments and control devices" (Anon. 90a).

At the time of writing, PASSYS 1, which lasted from 1986 to mid-1989, was finished and PASSYS II (January 1990 to December 1992) was under way. Final reports from PASSYS 1 have been produced by each subgroup, but no PASSYS II results have been released (Strachan, 91b). Of particular importance is Chapter 15 of the PASSYS 1 report by the validation subgroup (Pinney, 90) as it contains details of the only useful (for validation) empirical data set to emerge from PASSYS 1. These emerged from the cells located in Glasgow (Fig. 7, Plate 1). A recent overview paper (Strachan, 91a) describes more recent experiments on comparisons between ESP and measured data. The PASSYS 1 data has also been used to aid the development of statistical tools for the time-series analysis (Palomo, 91). The 'glossy' brochure which gives a general overview of the PASSYS 1 activities was also used to assist in producing this report, (Anon. 90a).

4.2 The Test Cells

The PASSYS cells conform closely to proposals made by Nick Baker, now of Cambridge Architectural Research Limited. They were all prefabricated by the same German manufacturer (CADOLTO in Cadolzburg) using a rigid steel-frame construction. They are delivered complete, except for the south wall to each cell. (This southern aspect holds the component being tested). Each cell has two zones, the test cell, and a smaller service room which houses the monitoring and air temperature control equipment (Fig. 8). On site, the cells are mounted on plinths to allow free circulation of ambient air below the floor.

The cell is airtight producing an infiltration rate of $0.5ach^{-1}$ at 50Pa which will equate to a working rate of less than $0.1ach^{-1}$. The walls are well insulated internally (Fig. 9) to give a U-value of less than $0.1Wm^{-2}\,^{o}C^{-1}$ and an overall heat loss coefficient (with the calibration wall on the south facade) of $12W^{o}C^{-1}$. (Actually $11.9W^{o}C^{-1}$ and $12W^{o}C^{-1}$ in cells 1 and 2 in Glasgow which produced data for validation. With such high levels of insulation uncontrolled infiltration of up to $0.1ach^{-1}$ can represent 10% of the heat loss for the cell).

The high levels of insulation also mean that most of the one dimensional fabric heat loss takes place through the south wall. This is not typical of the heat flows in actual UK buildings but may have some advantages for stressing selected program algorithms (Strachan, '91c).

Unfortunately, "the protective steel sheets on the inside of the walls are in thermal contact with the stainless steel sheets on the outside of the walls and the partition door frame. Therefore, thermal bridges occur (Anon. 90a). This is a potentially serious problem from the point of view of model validation. A further problem is the large difference between the inside and outside surface areas of the cells and hence the large contribution that 'edge and corner effects' may make to the overall heat loss (Strachan, '91c). This is multi-dimensional heat flow whereas thermal models typically assume one-dimensional flow). Attempts are being made to derive theoretical modelling solutions to this problem (Hassid, '91). These effects were estimated at 20% during the validation experiments in the Glasgow cells (see below) although in other tests values up to 35% have been deduced.

Two standard south walls are available at all PASSYS sites. A calibration wall, consisting of a sandwich of plywood/400mm rigid insulation/plywood, giving a U-value of about 0.1Wm-^{2} °C-^{1}, and a reference wall, consisting of a concrete/100mm polystyrene/concrete sandwich with a wooden framed double-glazed window in the centre, this was manufactured by Gibat in France. The reference wall was tested on cells in many of the participating countries with the intention that cross-comparisons between different climatic sites could be made. However, a lack of uniformity in the wall construction undermined this intention (Strachan, 91a). Complex mechanical heating/cooling and ventilating equipment was installed in each cell, but this was not used during the validation experiments.

The same Hewlett Packard data acquisition system was installed at all the PASSYS sites, along with a standard set of weather data sensors. These were sufficient to provide the key data inputs to ESP. Numerous internal sensors to measure temperature, heat flux and comfort were used in various cells at various times. However, during the validation experiments, only internal air temperature and heating power input were recorded (Pinney, 90).

4.3 Monitoring

In PASSYS 1, the only potentially useful data sets for model validation were collected in two of the celss in Glasgow. These covered a 32 day period in which both cells had the opaque 'calibration' south-facing wall attached (Fig. 7, Plate 1). Cell 1 was free floating whilst Cell 2 was intermittently heated as follows: 4 days free floating; 4 hour radiant heat pulse of 2kW; free floating to within 0.5°C of corresponding cell 1 temperature (about 6 days, 16 hours); 2 hour convective heat pulse of 2kW; free floating to within 0.5°C of corresponding cell 1 temperature (about 4 days, 4 hours); constant heating to 30°C for 5 days; and finally, free floating decay (about 7 days, 12 hours). The only measurements were the air temperature in Cell 1 and the air temperature and heating energy input in Cell 2. The PASSYS II data is not openly available so will not be discussed further here.

Comparisons between ESP predictions and the measured air temperatures in both cells have been reported (Pinney, 90). Uncertainties arise primarily because of 'crude' attempts to account for heat bridging and edge/corner effects in the cells (which ESP was not simulating). Uncertainty in the air infiltration rate (0.1+/-0.1ach-1) and service room temperature (20.7+/-2°C) each lead to large uncertainties. Also worth noting is the degree to which the Cell 1 internal air temperature floats above ambient temperature, and the negligible response to external air temperature. A likely cause of this is the fact that the external surfaces are very well insulated (U<0.1Wm-^{2}K-^{1}) whereas the connecting door to the service room was not (U=1.5 Wm-^{2}K-^{1}). Since this room was held at around 20°C during the experiments, the cell was being slowly fed with heat from the service room. More recently, polystyrene insulation has been added to the service room door to reduce this adventitious heat gain. Nevertheless, it is likely that the service room must be modelled explicitly.

4.4 Critique

The PASSYS project has the potential to gather high quality data for validation, given the data acquisition system, the sensors and the expertise available. However, the data produced to date is limited and

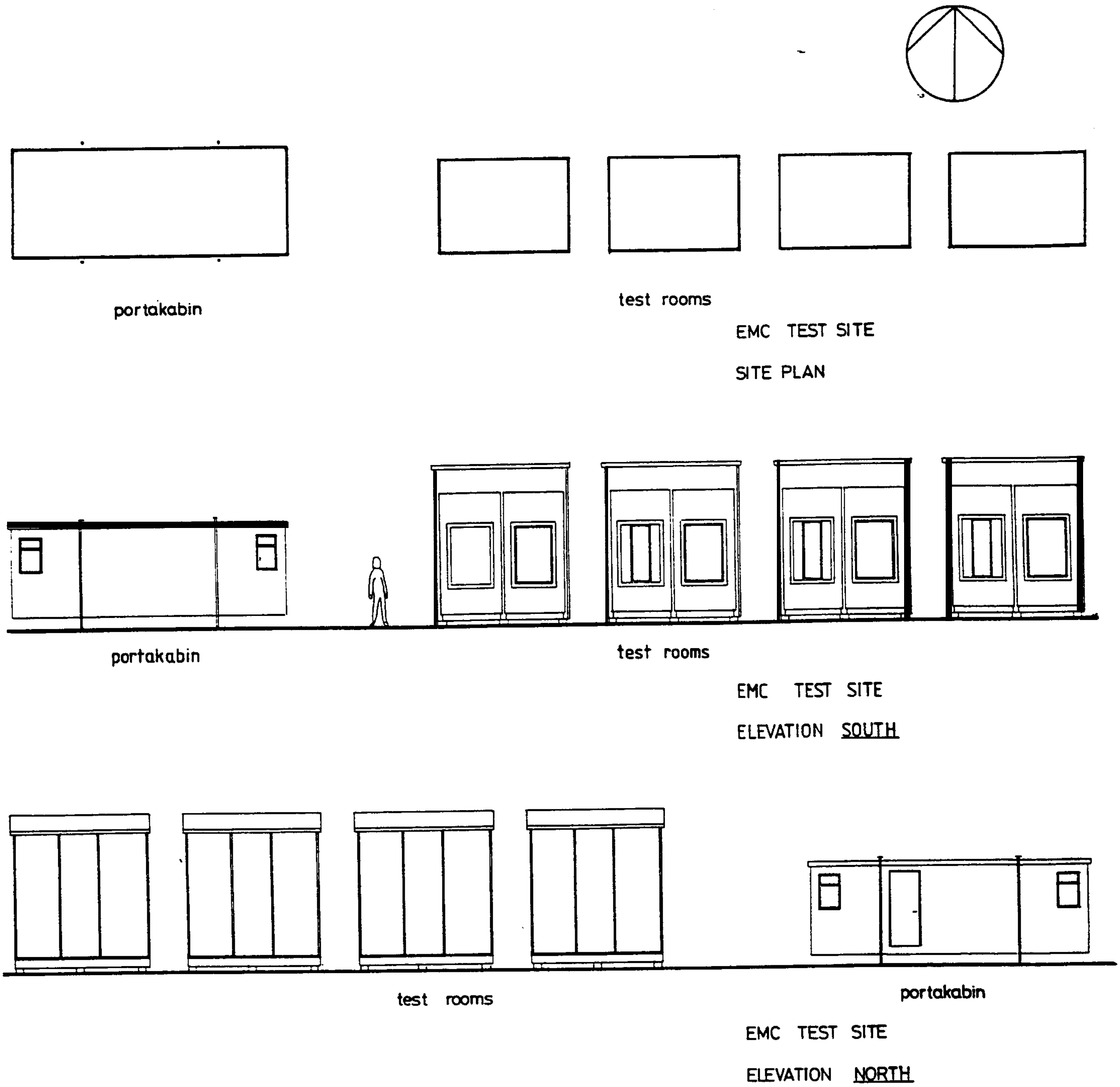


Fig. 10. The EMC Test Site

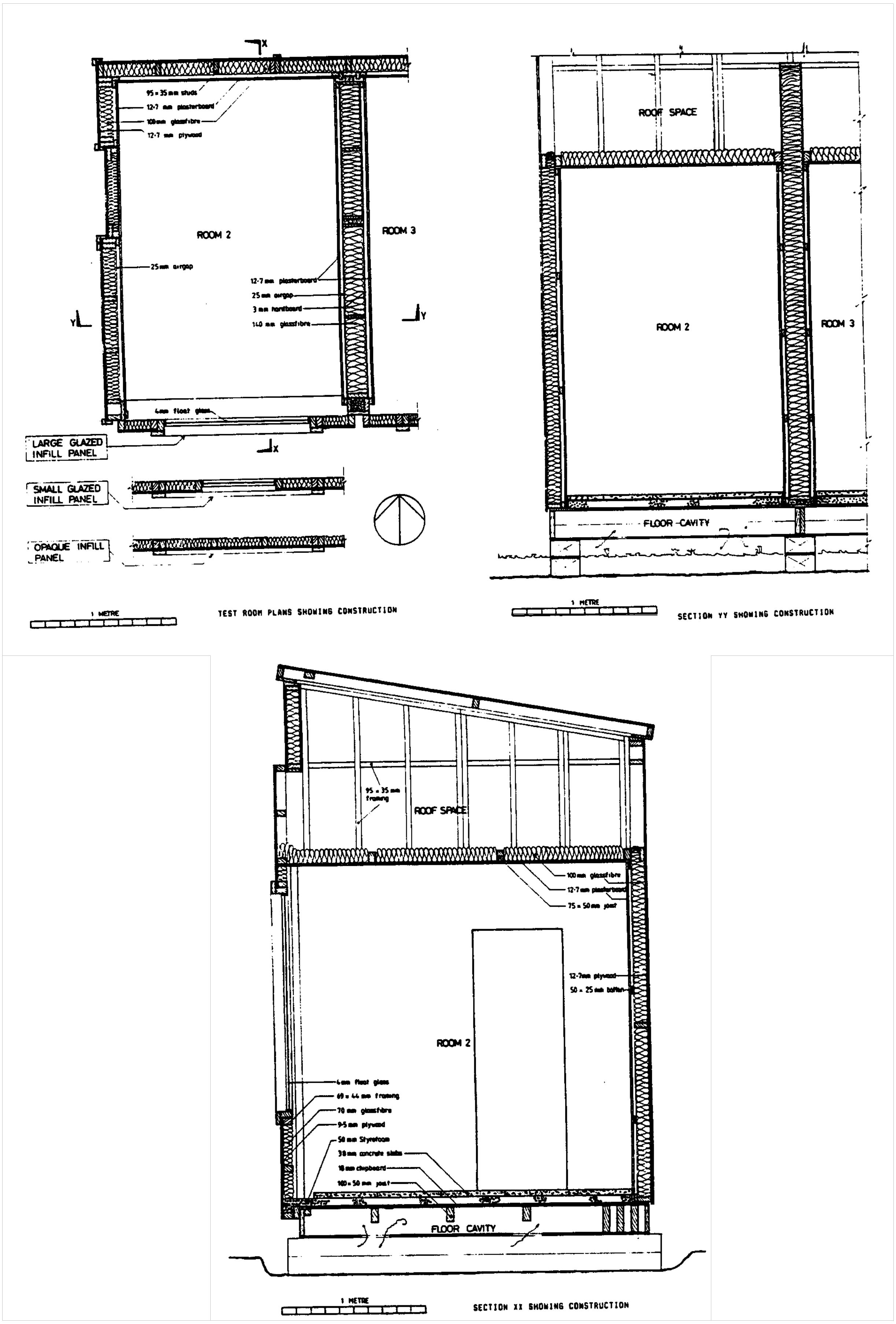


Fig. 11. Construction Details of the EMC Test Rooms

has a relatively high level of uncertainty. Future work may yield more valuable validation data than that already collected.

Validation work within PASSYS is however fundamentally constrained by the test cell itself. In particular, the very high levels of wall insulation which magnify the importance of heat exchange: through the south wall; by infiltration; due to edge and corner effects; and due to heat bridges. The latter three factors result in large uncertainty hands being attributable to the predictions of ESP, however efforts are being made to circumvent these difficulties. Even if these problems can be circumvented the heat flows through the south facing wall, opaque walls, and by infiltration are unlikely to match those found in typical dwellings. The problems stem partly from the PASSYS objectives to both validate and to test components and from the decision to use factory built cells. If cells are not built by the group which will monitor them, then there must be close co-operation between the two groups during the construction stage and close supervision of the manufacturing process. The Gibat reference wall problems are a further illustration of the problems which arise due to poor construction supervision. It is always possible that other parts of the PASSYS cells do not conform precisely to the specification and, where such differences are hidden (within the wall for example), they may not be detected, but have a major impact on the thermal performance of the cell.

5. EMC - ETSU Rooms

5.1 Test Rooms

The Energy Monitoring Company (EMC) simultaneously measured the thermal performance of six test rooms in a series of experiments funded by the Department of Energy, Energy Technology Support Unit (ETSU). The rooms were nominally the same and grouped in pairs, with an attic space above (Fig. 10). In fact, they are modified PCL test cells, (the ceiling is lower, reducing the cell height and south facing wall area) giving internal dimensions approximately 1.5m wide x 2.3m deep x 2.3m high. The outer shells are of stud-frame construction, and a layer of concrete slabs lines the floor. (Fig. 11). The cells were extremely well insulated and sealed, to reduce uncontrolled infiltration to less than 0.05ach-1. Manufacturers data were available for the thermophysical properties of some of the materials. The site handbook (Martin, 90b) describes the cells in great detail, care having been taken to include all the information needed by thermal models.

5.2 Operation of Rooms

For the program validation experiments described here, six rooms (RO, R1, R2...R5) were used. Each room had a different south facing surface and heating system (Tables 1 and 5). Eight blocks of experiments, six lasting 10 and two lasting 49 days, were undertaken over a four year period. Each set varied in terms of the thermostat set point, the thermostat type, the heating schedule, and the rate of mechanically induced infiltration (Table 4). This mechanical ventilation system was capable of delivering between 0 and 3 air changes per hour and recording the rate to within 2%. The radiant heaters used were 750W oil-filled electrical radiators. For sane experiments these were converted into convector heaters by housing them in a stainless steel shield. The heaters were placed close to the

EMC Code & Period	Room Code	Glazed Area m^2	Glazing Type[1]	Infiltration Rate ach^{-1}	Heater[2]	T'stat[3]	Set Point °C	Heating Period/hr	Models Compared to Data
v104	R0	1.5	D		Conv	↑	↑	↑	↑
4 Aug	R1	1.5	D	↑	Rad				
to	R2	0.0	B		Conv				SERIRES
13 Aug	R3	0.0	B	0	Rad	Air	40	06-18	ESP
1987	R4	0.75	D		Conv				HTB2
	R5	0.75	D	↓	Rad	↓	↓	↓	↓
v105	R0						↑	↑	↑
15 Aug	R1								
to	R2								SERIRES
24 Aug	R3	As for period 104					40	01-24	ESP
1987	R4								HTB2
	R5						↓	↓	↓
v110	R0						↑	↑	↑
17 Oct	R1								
to	R2								
26 Oct	R3	As for period 104					30	06-18	SERIRES
1987	R4								HTB2
	R5						↓	↓	↓
v111	R0						↑	↑	↑
28 Oct	R1								
to	R2								
6 Nov	R3	As for period 104					30	01-24	SERIRES
1987	R4								HTB2
	R5						↓	↓	↓
v116	R0			↑	Conv	↑	↑	↑	↑
6 Jan	R1	As for period v104			Rad				
to	R2				Conv				
17 Jan	R3			1.95	Rad	Mix	20	06-18	SERIRES
1988	R4	1.5	S		Conv				HTB2
	R5	1.5	S	↓	Rad	↓	↓	↓	↓
v118	R0					↑	↑	↑	↑
6 Feb	R1	As for period v104							
to	R2								
17 Feb	R3					Mix	20	06-18	SERIRES
1988	R4	1.5	S						HTB2
	R5	1.5	S			↓	↓	↓	↓
v202	R0						↑	↑	↑
13 Mar	R1	As for period v104							
to	R2								
1 May	R3						N/A	Random	SERIRES
1990	R4	1.5	S						
	R5	1.5	S				↓	↓	↓
v203	R0				↑	↑	↑	↑	↑
5 May	R1	As for period v104							
to	R2								
23 June	R3				None	None	None	N/A	SERIRES
1990	R4	1.5	S						
	R5	1.5	S		↓	↓	↓	↓	↓

[1]D = Double Glazing; S = Single Glazing; B = Blank (no glazing)
[2]Conv = approx. 100% convective source Rad = approx. 60% radiant source (see Section 5.2)
[3]Air = senses 100% air temperature Mix = senses approx 60% radiant heat

TABLE 4 Synopsis of EMC-ETSU Test Room Data Sets south wall. They were controlled by proportional + integral + derivative controllers, accepting input from either the air temperature sensor or a combination of this sensor and the black globe sensor. Thus, a thermostat sensing either pure air temperature, or a mix of air and radiant temperature, could be mimicked. This arrangement enabled the chosen set points to be maintained to within +/- 0.2°C.

Either continuous heating or intermittent heating (06:00 to 18:00) was used, although in the May 1990 experiment, the cells were free floating. The heating experiment in March 1990 is particularly interesting as a pseudo-random binary heater sequence was used. In such a regimen, the heating system is switched on (on the hour) to full power, it then remains on for a randomly chosen number of hours and then goes off, also for a randomly chosen number of hours. The approach is very similar to that described previously for the British Gas cell. It ensures that there is no correlation between the climatic driving forces and the internal driving forces. This permits the cross-correlation, and impulse response of the internal conditions to the internal and external functions to be studied independently of each other.

The site has therefore produced a large number of different data sets, 8 experimental blocks each with 6 rooms gives 48 data sets, 36 of these lasted for 10 days and 12 for about 49 days, all were monitored at hourly intervals.

5.3 Monitoring

The air temperature in each cell was recorded at three heights (Fig. 12) and also in the attic space, under the floor, and in the cells next to the thermostat. The black globe temperature in the centre of the room was also recorded. Surface temperatures were measured on all but the south wall (Fig. 12) and the ventilation rate (where applicable) and heater power output, were also recorded. Comprehensive weather data was also recorded (Table 1). The recording rates were: temperatures 6 minutes; solarimeters and wind 5 seconds; and any heat flux mats every 5 seconds; and energy consumptions continuous recording. All values were then reported as hourly total or averages.

5.4 Validation

Comparisons between the data collected in the rooms and the predictions of models have been documented in four reports (Martin, 90c,d,e; Anon. 90b). Earlier experiments, not recorded here, are described in (Anon. 90b,c).

The data from the six ten-day experiments in 1987 and 1988 (section 5.4.1) was used to compare the heating energy consumed by the convective heater with that consumed by the radiant heater (Martin, 90c). The data was also used to assess the influence of thermostat type (proportion of air and radiant temperature sensed) on the energy consumption of the cells (Martin 90d). Data/model comparisons were made using these data (Martin, 90e). The data from the two 1990 periods has been used to evaluate SERIRES (section 5.4.2), and more recently ESP (Anon, 91). A blind empirical validation package based on these data has been generated (Martin '91b) and has been used to assess Tas (Martin, '91a) and distributed to test Apache and Cheetah (Martin, '91c).

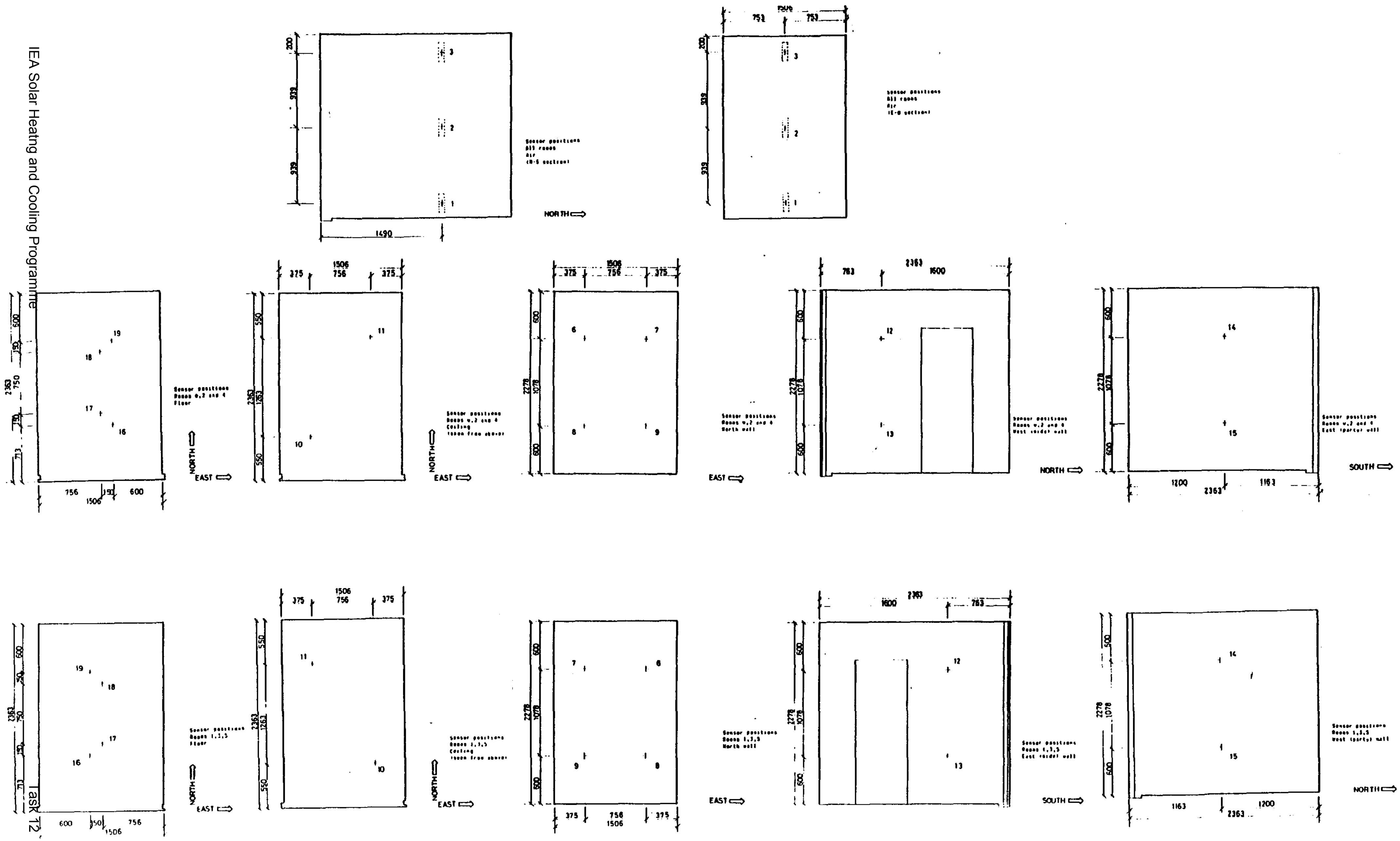


Fig. 12. Location of sensors in EMC/ETSU Test Rooms

5.4.1 Total Energy Consumption Comparisons

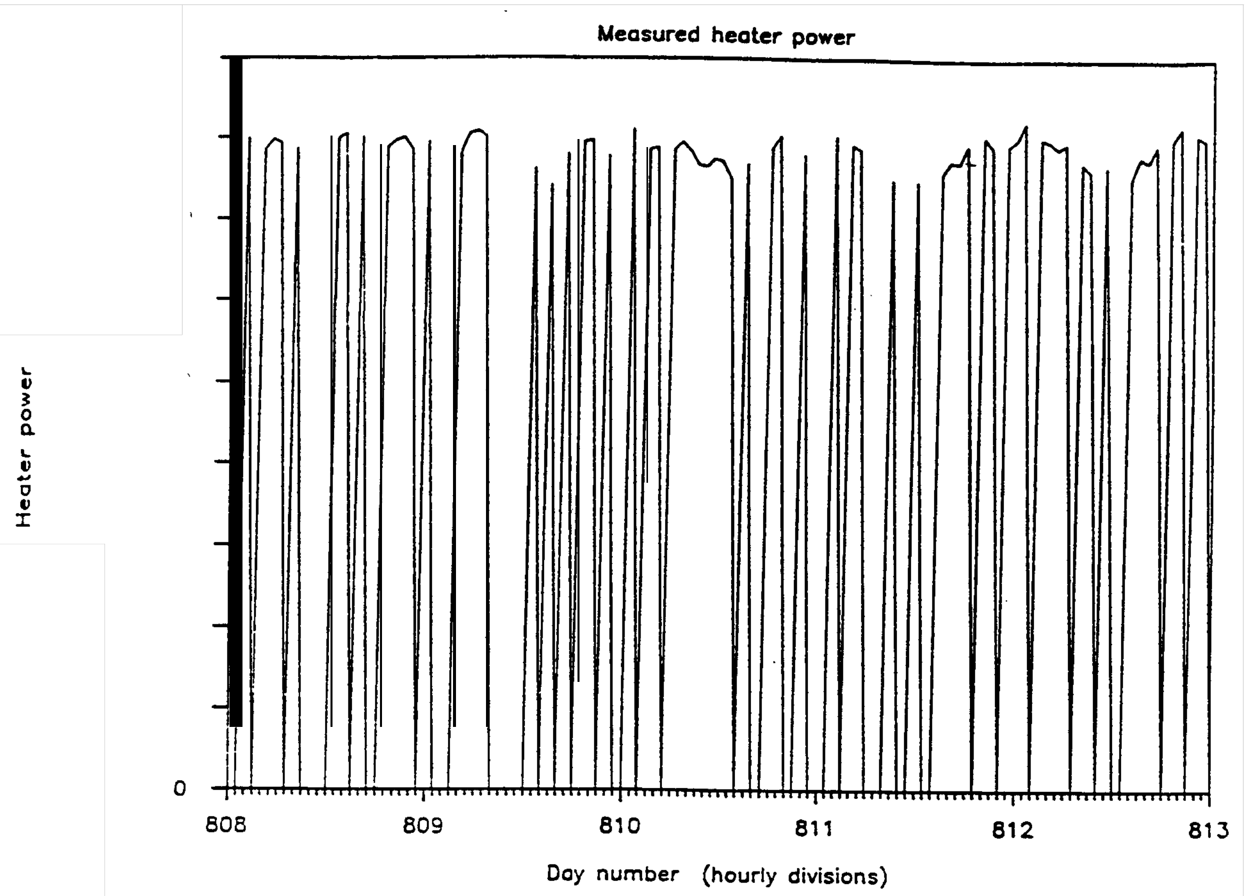
Comparisons were made between the total ten day energy predictions of ESP, HTB2 and SERIRES and the measured values for the two August 1987 monitoring periods. These comparisons were made 'blind', i.e. the model users were furnished only with a description of the test room and the measured data, they had no access to the measured performance data (Martin, 90c). In these studies, the rooms were modelled in a similar level of detail to that which would normally be used in a 'design' context. The trends in the predicted ten day energy consumptions as the glazed area changed were also compared with the measured trends. This study, even though it focuses on only one parameter (ten-day energy consumption totals), illustrated the value of being able to study the accuracy of predicted trends; and not just single sets of results.

In a second series of similar comparisons, only the programs SERIRES and HTB2 were used. The ten-day energy consumptions for the next four periods, v110 and v111, (1987) and v116 and v118, (1988), were compared with measurements in a similar way. The large volume of data made it possible to study predicted versus measured trends for variations in window area, window type, heating regimen (intermittent or continuous), thermostat type and ventilation rate. In these studies, the cells were modelled in much more detail, this included: the influence of the studs and framing on thermal conductivity and capacitance and corner/edge losses (via two-dimensional computer analysis).

5.4.2 Hourly Power and Temperature Comparisons

The more recent work (Anon. 90d), concentrated on using SERIRES and began by using the above (v110) data to make hourly comparisons between the predicted and measured hourly temperatures and power consumptions. Sensitivity analyses were undertaken to determine whether the differences between the observed and predicted values could be explained by the inherent uncertainty in the input data. Cross-correlation analysis was then used to try and find out which of the "driving forces" was correlated with the observed temperature error. However, because of the way the cell operated, the internal and external driving forces were themselves strongly correlated. This problem led on to the use of the pseudo-random binary heating sequence in order to ensure that energy input did not correlate with the other (meteorological) driving forces.

The pseudo-random binary heating trials lasted 50 days, beginning in March 1991 (3:90 in Table 1, v202 in Table 4). They involved switching the heater in every room (either convective or radiant) on at full power for a period of time and then off for a period of time; the on/off periods being pseudo-random (Fig. 13). Simulations were conducted in two modes: (a) with the actual measured hourly heater power being fed into SERIRES and the predicted temperatures being compared with measurements; and (b) with the actual measured hourly temperatures being fed into SERIRES and the predicted power demands being compared with measurements. These were termed respectively, 'heater power scheduled' and 'zone temperature scheduled' operation. In all the simulations for this period (and the period of free floating room operation, 5:90 in Table 1, v203 in Table 4), the measured values were also compared with the SERIRES predicted values of room air temperature; floor surface temperature and heat flux; back wall surface temperature and heat flux; and ceiling surface temperature. In both periods (v202, v203) the measured south-facing vertical irradiance



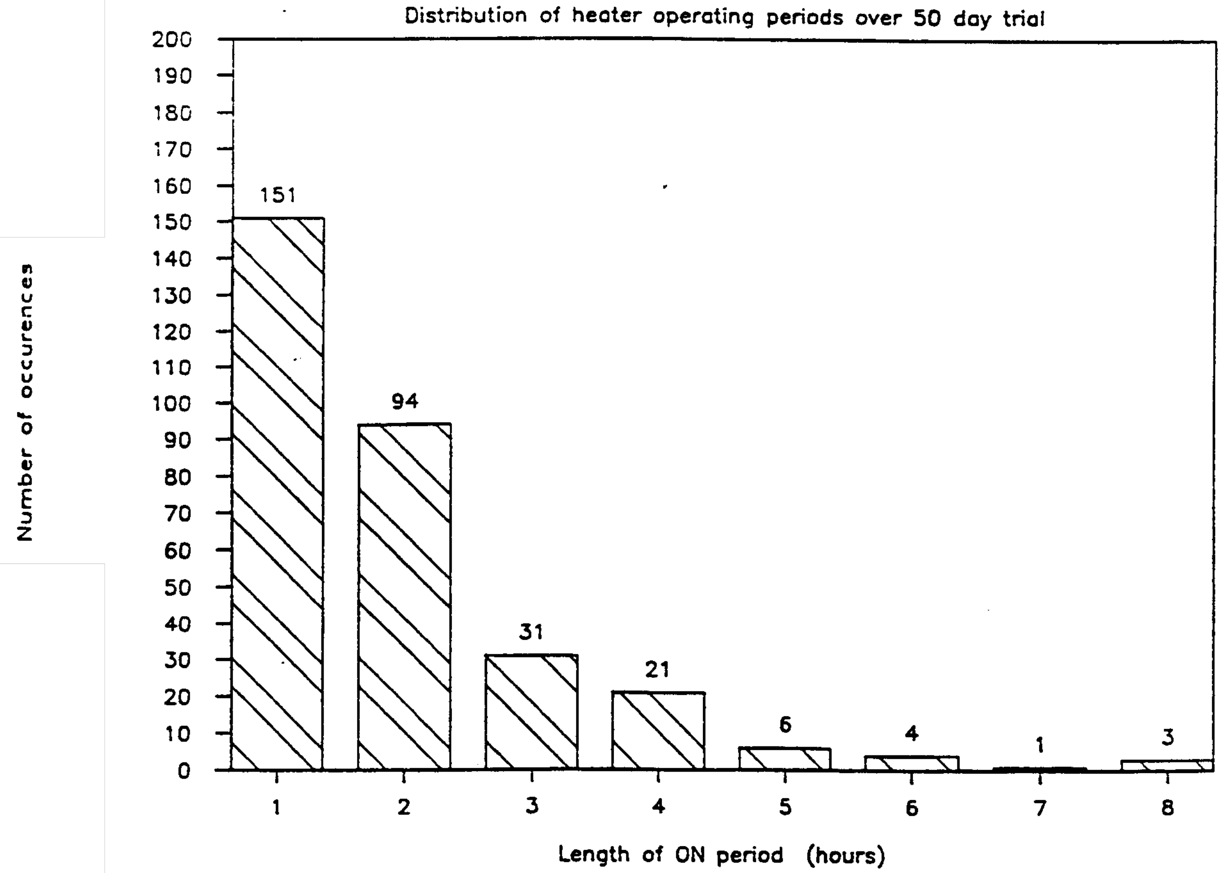


Fig. 13. Pseudo-random heating sequences: 5-day sample and 50-day distribution

was fed into SERIRES. The differences between the measured and predicted results were compared to the total uncertainty in the evaluation process.

The v202 data was also analysed by studying the cross-correlation between the errors and the primary driving forces and by extracting the corresponding impulse response functions. The impulse response of the measured Room 1 air temperature due to heater power input was also compared with the corresponding predicted zone temperature response. (The difference from the previous analysis being that the impulse response of actual, temperatures rather than temperature errors are examined). The free floating simulations (Table 1 and v203 Table 4) were also compared with the measured room temperatures. Data from both the v202 and v203 periods has been produced in the form of a 'blind validation kit' (Martin, '91b) and has been used to test Tas (Martin, '91a). It has also been distributed for testing APACHE (UK) and Cheetah (Australian).

5.5. Critique

The EMC test rooms have been used to collect a wealth of high quality data which has proved useful for validating a number of detailed thermal simulation models. The rooms themselves are well described in the site handbook, their thermal features (in particular, their interior construction, corner and edge details) are well understood as are the uncertainties in their properties. The rooms cover a range of glazing sizes, glazing types, heater types, thermostat types, ventilation modes and operating conditions. They can be used to look at the accuracy of predicted trends as well as daily or hourly absolute predictions.

The rooms themselves are reasonably well instrumented and the monitoring experience of the EMC group (since 1983) means that the data collected is reliable and error free: the trouble-free use made of the data for model validation by third parties is testimony to this. The data collected has been used to study the validity of three detailed programs (ESP, HTB2 and SERIRES) although not in the same level of detail in all cases. Because all six rooms are similar, except for the south face, once a building model has been established over 48 sets of data are available for validation with little modification to the basic description. The basic description itself is sufficiently simple that simulation times are not prohibitively long. This permits more computationally demanding validation techniques, such *as* Monte-Carlo analysis, to be undertaken.

In addition to the 'conventional' 10 day data sets, which have scheduled and thermostatically controlled heat input, larger, 50 day free floating and, more interestingly, pseudo-random heating periods, are available. These open up the possibility of trying more sophisticated analysis methods such as cross-correlation and covariance analysis. Because the data from the rooms has not been circulated beyond one or two research teams in the UK, the possibility of conducting true 'blind' simulations remains. A validation kit for undertaking such validation has been produced. These features are seen as the key to credible empirical validation.

Because the EMC group are still active in this field of work and because the rooms are still available for monitoring work, any uncertainty or ambiguity in validation work can be resolved easily. It may also be possible to commission further work in the rooms.

6. NBS Passive Solar Test Facility

6.1 Introduction -

The National Bureau of Standards' Passive Solar Test Facility was constructed as part of the U.S. Department of Energy's Experimental Systems Research Programme (Plate 5). The aim was to collect data for use in: (a) detailed building energy analysis and model/algorithm validation; and (b) performance characterisation of various passive solar subsystems. The building was made operational in October 1981 and data was collected during February 1982, 1983 and January 1984. The Leicester Polytechnic researchers visited the site in 1984 (Lomas, 87) and retrieved the data for the 1984 period of 20 days (24:1 to 12:2). It is therefore available in the U.K. and is useful for validation.

The building is well described in the NBS site handbook (Mahajan, 84) and one part of it (the direct gain cell) is in a document published by the Los Alamos National Laboratory (Anon., 83). Work on the data available in the U.K. has been described in an internal Leicester Polytechnic (LP) report (Eppel, 89).

6.2 The Building

The NBS site handbook gives an excellent description of the building so only an overview will be given here. The building is a rectangular one-storey, slab-on-grade, timber-framed structure with the long axis running east to west. It is divided into four 'cells' by heavily insulated partition walls (Figs, 14, 15, Plate 5). Each cell is considerably deeper (N to S) and of larger volume than the test cells described in sections 3, 4 and 5 (see Table 1). All the cells are virtually the same except for the south facing walls. These have either, a large area of double glazing (direct gain , cell 4), a smaller area of glass (control, cell 3) or a vented Trombe wall collector (cell 2); the remaining cell, number 1, houses the data acquisition system (and a component calorimeter). The cells have a clerestory window and a small north facing window, although the internal shutters were closed over these during the February '84 period. The site is essentially unobstructed to the south.

At LP use is being made of data from cells 3 and 4. Each cell has a 135mm concrete floor directly overlying a gravel base (i.e. the floor is not insulated); this is the only significant thermal storage in cell 3. In cell 4, additional thermal mass is provided by a wall of concrete blocks against the back wall of the cell. The U-values of the other main constructional elements are: roofs 0.18 $Wm^{-2}{}^{\circ}C^{-1}$; end walls 0.2 $Wm^{-2}{}^{\circ}C^{-1}$; inside partition walls 0.29 $Wm^{-2}{}^{\circ}C^{-1}$; and north and south walls 0.36 $Wm^{-2}{}^{\circ}C^{-1}$. The site handbook gives a detailed breakdown of the construction, including the area of framing and the area between the framing for each construction type. All the windows are double glazed. Virtually all the thermophysical properties quoted are the ASHRAE values. Using these values, the calculated overall heat loss coefficients for cells 3 and 4 (excluding infiltration) are 27.8 $W^{o}C^{-1}$ and 56.7 $W^{o}C^{-1}$ respectively (with clerestory insulating shutters closed); the measured value of cell 4 was 67$W^{\circ}C^{-1}$ (Anon., 83).

Auxiliary heating is provided by a 3.76 kW fan coil unit under the north window of each cell. The control is "by positive offsetting thermostats with a +/-0.5°C deadband". In the experiments, the fan in the heater was operational at all times (supplying, on average, 52.4W heat input), two destratifying fans (14W) were also in operation in cell 4 to assist in reducing air temperature stratification. The only other casual gains were from the 120W ice point reference (for the thermocouple temperature sensors).

6.3 Monitoring

There were 20 thermocouples to monitor the floor surface temperature in cell 3 (control) and two unshielded thermocouples to monitor the 'air' temperature. The auxiliary heat input was recorded by a watt-hour meter as were the consumptions of the other electrical appliances in the cell. The instrumentation in cell 4 is far more extensive consisting of: 22 shielded and 3 unshielded thermocouples in the air; 5 black globe and 2 pink globe sensors; 2 heat flux mats and 18 thermocouples on the north thermal storage wall; 2 heat flux mats and 14 thermocouples on the floor;
1 heat flux mat and 13 thermocouples on the ceilings; 6 heat flux mats and 19 thermocouples on the east wall inside surface; 13 thermocouples on the inside of the west wall; 46 thermocouples in the concrete floor and the earth below it (plus additional thermocouples round the foundations); watt-hour meters to record separately heater power and other adventitious heat-gains; and a pyramometer mounted vertically behind the glazing to record the solar transmission (e.g. Fig. 15).

In addition to the weather data needed for the thermal models, the following were recorded; infra-red sky radiation; ground reflectance; total irradiance on the south facing vertical surface; 4 air temperatures;
2 east wall surface temperatures; 12 ground temperatures; and 1 north wall surface temperature (Table 1).

The infiltration rates were continuously monitored in both cells using the tracer gas decay method. The gas was injected into the stream of air emerging from the fan in the fan/coil heater unit every 3 hours and sampled automatically every 10 minutes. The 5 measures in each hour were used to estimate the infiltration rates on an hourly basis. Over the experimental period, the values ranged from 0.1 to 0.6 ach-^{1}.

A data acquisition system records solar radiation and weather data at one minute intervals, the watt-hour data at hourly intervals, and all other data at 10 minute intervals. These values are integrated or averaged over the hour and merged with the infiltration results to produce a single magnetic tape of the data.

6.4 Validation

Validation of ESP, SERIRES and HTB2 has begun at LP using, initially, data from cell 4 only. The comparisons made were at the whole model, building system (rather than mechanism) level, and only 'first pass' or base-case predictions have been reported (Eppel, 89).

Some preliminary comparisons between the measured temperatures in the direct gain cell and the predictions of DOE-2 have been reported by others (Hunn, 83), however this was for an earlier data set (collected in 1981) and an in depth analysis was not undertaken.

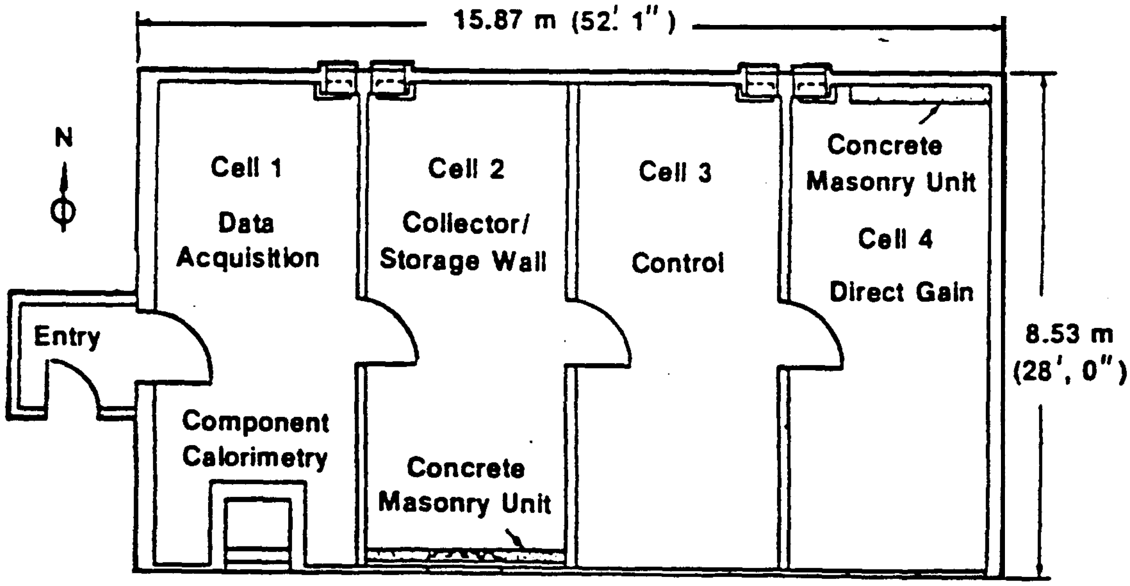


Fig. 14. Floor plan of the NBS passive solar test building

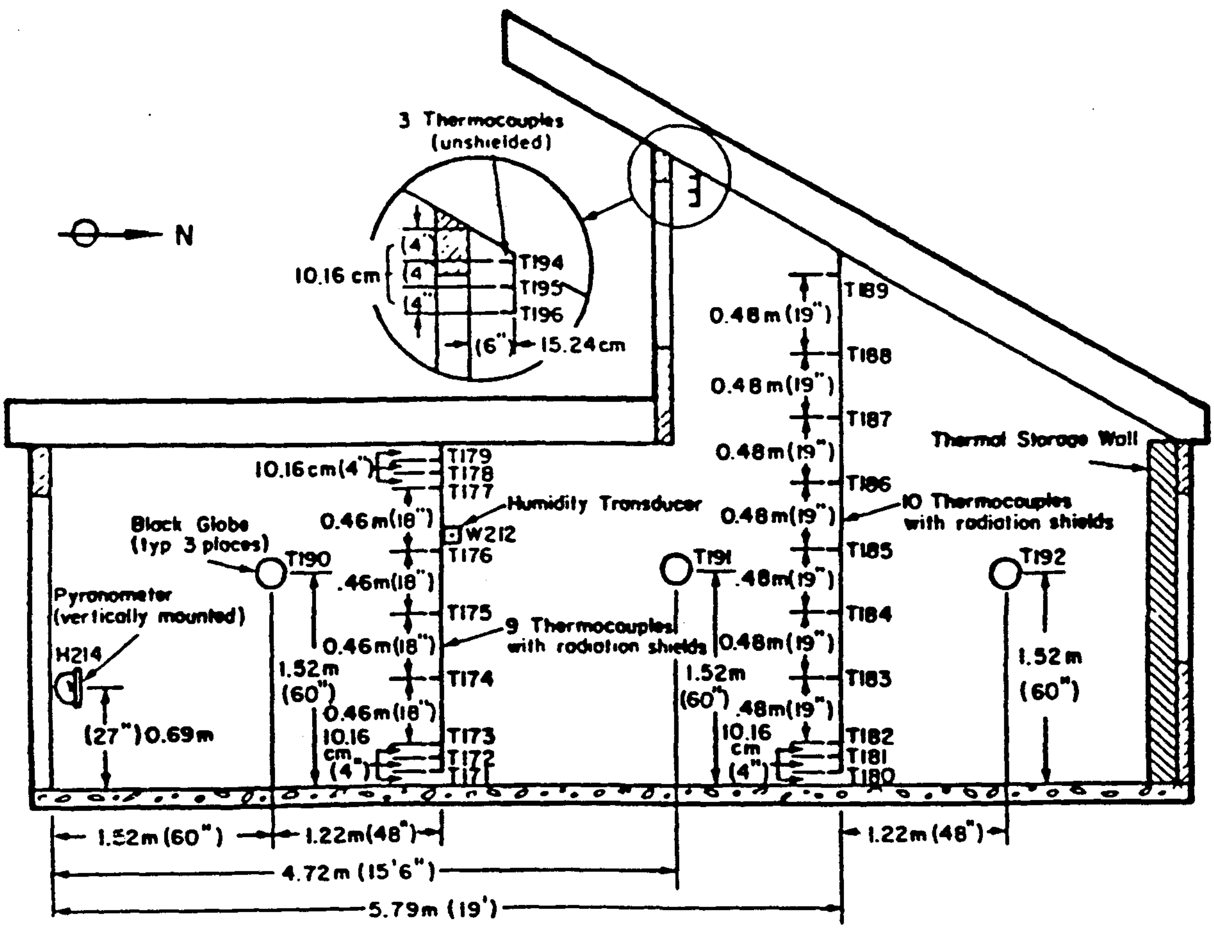


Fig. 15. Longitudinal section and air temperature sensors in the direct gain cell 4

6.5 Critique

The NBS data, in particular that from cell 4, appears to hold promise for empirical validation: the building and the data collection were devised with this objective in mind; the building is well defined by the site handbook; the instrumentation, particularly in cell 4, is very rigorous; whole model as well as algorithm validation is therefore possible; the data set has the capability of fulfilling the input requirements of a wide range of programs; the data set is long and unbroken (20 days); the data is being used by LP with some success.

Measurements of particular note (in cell 4), which set these data apart from the others are: continuous natural air infiltration records; internal south facing vertical irradiance records; numerous surface temperatures and heat flux measurements; numerous temperature measurements below the floor slab; and ground reflectivity measurements.

Given these attributes, the data is worth using as a source of model validation data. There are, however, a number of sources of uncertainty which must be addressed. These include: intimate ground contact (with the ensuing multi-dimensional heat flows); the dead-band associated with the thermostat and the uncertainty about the temperature (pure air or air and a radiant component) which is sensed; the strong stratification (up to 6°C) in the cells; the poor shielding devices in cell 4 and, in cell 3, the lack of any shielding around the air temperature sensors; the need to feed hourly infiltration rates and casual gains into the programs; the mixing of air in the cell which could influence internal surface coefficients; the uncertainty over the impact of edge and corner effects (although in a true room-sized building these are less significant). It may be difficult to resolve these problems because the site is no longer active and the principal researcher in 1984 (B. Mahajan) no longer works for the NBS (now NIST).

7. Overall Assessment

The aim of this section is to assess the data sets described in terms of their use as a basis for future empirical validation work. In assessing these data sets, it is possible either, to adopt a 'validation led' approach or a 'data led' approach. A validation led approach would involve firstly determining what the aims and objectives of any empirical validation exercise should be (e.g. whole model validation of temperature predictions or testing solar radiation algorithms, etc.) and then searching for data to fulfil these aims. A data led approach would involve finding good data sets (which are high quality, reliable, error free, etc. etc.) and then making the best possible use of them for validation.

It is the author's view that the validation led approach is superior but, at the present time, it has two serious draw backs: (i) most program users are unlikely to be able to devise credible programmes of empirical validation work; (ii) even if a programme could be devised, it is unlikely that the extant data would satisfy all the demands of the programme; (iii) the generation of data to fulfil the demands is invariably prohibitively expensive. The data led approach has the advantages that: (i) many extant data sets are likely to be acceptable since the validation programme will be fitted around them; (ii) given the shortage of suitable U.K. data, every attempt should be made to maximize the potential of the

	PASSYS Strathclyde	EMC PCL	EMC British Gas	EMC ETSU	NBS Washington DC
General:					
Total number of data sets	2	4	16	48	2
Site Active	Yes	No	Yes	Yes	No
Access to Experimenters	Yes	Yes	Yes	Yes	Difficult
Site Handbook etc.	No	Yes	No	Yes	Yes
Use for Validation:					
Currently being used	Yes	No	?	Yes	Yes
Used as third party for validation	Yes	Yes	?	Yes	Yes
Sensitivity analyses conducted	Yes	Yes	?	Yes	Yes
Correlation/covariance analysis conducted	Yes	No	?	Yes	No
Validate predictions of:					
Daily energy consumption	No	No	Yes	Yes	Yes
Hourly energy consumption	No	No	Yes	Yes	Yes
Daily average air temperatures	Yes	Yes	Yes	Yes	Yes
Hourly air temperatures	Yes	Yes	Yes	Yes	Yes
Side-by-Side Comparisons of:					
Effect of glazing type	No	No	No	Yes	No
" " size	No	No	No	Yes	Yes
Effect of heater type	No	No	No	Yes	No
Effect of infiltration rate	No	No	No	Yes	No
Effect of thermal mass	No	No	No	No	No
Algorithms Stressed:					
Thermal storage	No	Limited	Yes	Yes	Yes
Solar gain	No	Yes	No	Yes	Yes
Glazing conduction	No	Yes	No	Yes	Yes
Opaque conduction	Yes	No	Yes	Yes	Yes
Ground conduction	No	No	No	No	Yes
Sky model	No	Yes	No	Yes	Yes
Infiltration prediction	No	No	No	No	Yes
Internal heat transfer coefficients	No	No	Yes	No	No
Plant/building interaction	Yes	No	Yes	Yes	Yes
Interzonal couplings	No	No	No	No	No
Total Yes responses	8	9	10	21	17

Table 5 Attributes of Data Sets for Empirical Validation

PCL Test Cells

Probably only one 9-day period of data worth using.
Hourly data only.
Free floating operation only.
Large vertical stratification.
Very limited cell monitoring.
Sensitive to unmeasured ground reflectivity.
Cell inspection not possible.
Very limited mechanism level data.
Relative heat flow paths untypical of 'real' buildings.

EMC - British Gas Test Cell

Completely opaque - solar effects limited.
No data/model comparisons published.
Adequacy of cell description unknown.
Sensitivity to uncertain inputs unknown.

PASSYS 1

Only one data set currently available.
Edge and cover effects large and unresolved.
Hourly data only.
Thermal bridging could be a problem.
Limited cell monitoring.
Heating regimen untypical of 'real' buildings.
Adequacy of site handbook and cell description unknown.
Relative heat flow paths untypical of real buildings.
Cells completely opaque - solar effects limited.
Large sensitivity to air infiltration and service room temperature.

NBS - Passive Solar Test Facility

Little used for rigorous validation.
Intimate ground contact.
Thermostat and heater characteristics uncertain.
Sensitivity to unknown ground reflectivity.
Time varying infiltration rates.
Destratification fans operational.
Single data period only. Unshielded air
temperature sensors.
Access to experimenters not practical.
Hourly data only

Table 6 Identified problems with the data sets

sets which are available; and (iii) validation techniques are still being developed and these can be tested even on data sets which may be less than ideal.

In the context of this report, there is no particular programme of validation work, or any particular computer programs, which are to be validated. Indeed, one valuable objective of future research would revolve around archiving data sets such that others wishing to validate programs have a source of suitable data readily to hand and guidance on how to use the data and interpret the results. The assessment undertaken here is therefore data led.

The general validation attributes of the data sets are listed in Table 5; this table is the key to the assessment procedure. In this table, a 'yes' indicates a 'favourable feature' of the data sets and any other response is less favourable. At a crude level therefore, one may simply add up the 'yes' responses in order to find out which are the most favourable sources of data. An additional, and important factor, is the number of sets of different data (weather, operating conditions, window-sizes, etc.) which are available for the same basic building shell, since this will permit the maximum amount of validation work with the minimum amount of effort from the program user (Establishing the basic, error free, building description is time consuming). The number of favourable features and the number of data sets (Table 5) were as follows:-

PASSYS	8	2
PCL	9	4
British Gas	10	16
ETSU	21	48
NBS	17	2

On this basis, the ETSU data sets are clearly superior to the others, closely followed on a Yes count basis by the NBS data. This ranking is by supported by the detailed discussions in the earlier sections (2,3,4,5 and 6) and the list of problems given in Table 6.

There is little point in reiterating all the arguments concerning the ETSU data sets (they have been fully explored in section 5) but, it would seen that the maximum insight into model behaviour can be obtained, with the minimum effort on the part of the modellers, and with a minimum of problems to be resolved, if the ETSU data are adopted as the starting point of any new empirical validation effort.

Validation work is however currently being undertaken using data from, in particular, the NBS, but also from the PASSYS cells. Given the paucity of good work in the field of empirical validation these efforts should be observed since, even if the data itself is not entirely suitable, useful techniques for conducting program/data comparisons may emerge.

JMW/2/RR4SUMM

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IEA 21C Empirical Validation
Hotline Newssheet No. 1

1. Introduction

The intention of this, and following newssheets, is to keep participants up-to-date with the state of the empirical validation exercise, and to disseminate our responses to any queries we had from other participants.

The response to the empirical validation exercise has been very good. So far 13 institutions have agreed to participate, using 10 different programs. We are currently soliciting participation for several other institutions/programs. A list of the participants and the programs they are using can be found in Appendix 1.

Same programs are represented by more than one institution. This will be useful for checking the input files and will also enable us to evaluate consequences on predictions of variations in the modelling approach. In particular, it might shed some further light on certain discrepancies revealed by the IEA BESTEST exercise.

2. Hotline News

The following is a chronological account of information exchange since the start of the exercise. Please read the information carefully and check whether it is relevant to the program you are using. This will help to avoid inconsistencies and confusion at an early stage.

March 31 - Enquiry from Eduardo Rodriguez regarding some inconsistencies in the specification. The following modifications were sent to all participants on 3 April and incorporated in the specification.
With regard to the opaque infill panel in roan 3 (constructions C45 and C48), the order of the layers *as* given in Table 5.8 of the site handbook is wrong. The order should be as shown in Figure 5.1, i.e. from outside to inside, Plywood then Rockwool for C45, and Plywood then Wood for C48.
Regarding construction C10R in the roofspace, the specific heat of wood given in Table 5.11 of the site handbook is wrong and should be 1380J/kgK, not 840J/kgK.
Another error occurred in Table 5.1. The external solar absorptivity of the test room ceiling should be 0.4, not 0.16. Obviously, this should not influence the program predictions, since there is no solar radiation in the roofspace.

Lastly, a point of clarification. Section 4 of the validation guidebook specifies the program outputs required. One of the outputs is the mean hourly inside surface temperature of the back wall (construction C16). However, in Table 3 this is only referred to as the inner surface of construction C16. This could be confusing, since there are two C16 wall elements, one in the north wall and one in the east wall. The output required is indeed the temperature of the inner surface of the north wall (construction C16) as specified in section 4.

April 6 - Enquiry from Foroutan Parand:

Q: "Is your general approach that the implementors should find for themselves the data that is required by their program but not specified in the handbook and guide? I think some of these, like surface coefficients and window U-value could cause a major difference in the results. It would be useful to give some values for these but ask user to give priority to data recommended by their program (or its manual) if the latter existed".

A: A conscious decision had been made not to include information in the validation guidebook that is required by some programs because of the simplifying assumptions they make about certain physical processes. Surface coefficients and window U-value would fall into this category. The aim of the exercise is to mimic the conditions which exist when the programs are used to predict the performance of an actual building. Any unavoidable approximations should be reported on the Empirical Validation Report Dorm (included at the back of the validation guidebook & spare copy supplied with validation pack). Any inconsistencies can then be resolved at the feedback phases of the project. Sensitivity to key program inputs will be investigated.

Q: "I have not seen these test cells. Are they made of fairly shiny metals? Because the external absorptivities of 0.16 seem to be too low (Aluminium paint has an absorptivity of 0.4 and polished aluminium's is 0.12, SERI-RES manual page III-44)".

A: The cells are painted bright white, which, according to British Standard BS4800, can have an absorptivity of about 0.16. The internal wall and ceiling absorptivities were actually measured (see reference 3 of the site handbook).

Q: "For most programs using the given absorptivities may lead to a different share of absorbed radiation for different surfaces and definitely for 'solar lost'. In fact one has to solve a set of 7 simultaneous linear equations to find the absorptivity of surfaces and then calculate 'solar lost'. The magnitude of 'solar lost' depends on how the program deals with the reflected diffuse. In TRNSYS one can choose an appropriate value for glazing reflectance to achieve the specified value.

Have you considered the above points? If not I suggest you solve the above equations for required distribution of solar and supply new figures for absorptivities if they are different from the ones already specified".

A: You Should model the internal distribution of solar radiation in the way you consider to be the most accurate, using the specified solar absorptivities. Please report any differences in the distribution that your program may produce, ca pared to table 5.17 of the site handbook.

Q: "Is floor construction OK for the Test Room? (Looks odd to have concrete inside and timber outside)".

A: The floor construction is OK, see figures 5.2 and 5.3.

Q: "Is there any reason for calling the roof of 'roof space' ceiling in caption of Table 5.16?".

A: No.

April 3 - Enquiry from Doug Hittle:

Q: "Has the construction data been modified to account for joists and other framing or only the corner effects?".

A: Separate construction elements have been specified within each surface to account for joists and other framing, e.g. constructions C16 and C15a in the north wall of the test rooms. No attempt has been made to account for two- and three-dimensional heat flows near joists and wood frames, other than the corrections for corner effects described in Appendix 1 of the site handbook.

Q: "For the V110 data, was the space heated from 6:00 to 18:00 or through hour 18:00? Also, how was the heater controlled (on/off, proportional, PI, etc.)? If the room temperature varies, I need to be able to determine the relationship between room temperature and heat addition rate".

A: The space was heated from 6am to 6pm, i.e. for 12 hours. Using our hour numbering convention (hour no. 1 = midnight to 1 am), this means that the space was heated through hour number 18, i.e. 5pm to 6pm, hut not through hour number 19, i.e. 6pm to 7pm.

Chris Martin of EMC has sent some further information about the heater control: "Following your telephone call on Friday, I have extracted the control parameters from the test room temperature controllers. The control units are industrial PID (Proportional + Integral + Derivative) units manufactured by Gulton, type 2070. The control parameters that we used were chosen after a simple system identification/controller tuning experiment. They are:

Proportional band (PB%/Xp%):	4.0°C
Integral time (RESET/Tn):	99 minutes 59 seconds
Derivative time (RATE/Tv):	15 minutes

I hope that this information is sufficient to allow the control systems to be modelled. If not, I can supply a full manual for the control boxes." Once attained, the setpoint is controlled to better than ±0.2°C.

April 22 - The first results were received from Eduardo Rodriguez - well done. May I remind the other participants that June 1st is the target date for receiving the first set of results for all six cases (see timetable, Appendix 2).

April 24 - Enquiry from Shirley Hammond concerning timing conventions. This is an important point, since the timing conventions adopted in different programs can be quite divergent. For example, some programs expect the first entry in the climate file to be spot values taken at 1pm (e.g. ESP), whereas other programs expect averages from half an hour before midnight to half an hour after midnight i.e. hour-centred on midnight (e.g. SERI-RES UK Version 1.2). Other programs might expect climate data to be averages centred on the half hour, as indeed are the measurements taken by EMC.

Please check the conventions used by your program and ensure that the climate data are consistent. Report any data conversions, assumptions and approximations on the Validation Report Form.

3. Naming conventions

A seven letter code will be used to identify each program/institution combination (Appendix 1). For example, ser_bre represents SERI-RES simulations carried out at BRE.

A two letter code will be used to identify each of the six simulations.

Weather Period	Room	Glazing Type	Heating	Code
099	1	Double	No	fd
099	3	Opaque	No	fo
099	5	Single	No	fs
110	1	Double	Yes	hd
110	3	Opaque	Yes	ho
110	5	Single	Yes	hs

The first code letter refers to the test room operation (f = free floating, h = heated), the second letter referring to the glazing type (d = double, o = opaque, s = single). It would be helpful if all participants could name their results files according to this latter convention, i.e. name the six results files fd.res, fo.res, fs.res, hd.res, ho.res, and hs.res.

4. Hotline

If you have any further enquiries, please do not hesitate to contact the IEA Hotline:

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List of Participants and Programs

Participant	Institution	Program	Code	Comments
Shirley Hammond	BRE, UK	APACHE SERI-RES	apa_bre ser_bre	
Foroutan Parand	BRE, UK	TRNSYS	trn_bre	
Eduardo Rodriguez	Escuela Superiore Ingenieros Industriales, Sevilla, Spain	S3PAS	s3p_esi	First set of results received April 22
Timo Kalema	Tampere University of Technology, Finland	TASE	tas_tut	
Augusto Mazza	Politechnico di Torino, Italy	BLAST	bla_pdt	
Bertil Fredlund	Lund Institute of Technology, Sweden	DEROB	der_lit	
Peter Verstraete	Vrije Universiteit Brussel, Belgium	TRNSYS	trn_vub	
Doug Hittle	Colorado State University, USA	BLAST	bla_csu	
Fred Winkelmann	LBL, USA	DOE-2	doe_lbl	
Sandy Klein	University of Wisconsin, Madison, USA	TRNSYS	trn_uwm	
Mike Holmes	Arup, UK	BEANS	bea_arp	Confirmation awaited
Francisco Arumi-Noe	University of Texas at Austin, USA	DEROB	der_uta	Confirmation awaited
Mike Kennedy	Ecotope, USA	SUNCODE	ser_eco	
Herbert Eppel	Leicester Polytechnic, UK	ESP	esp_lpo	

Appendix 2:

Empirical Validation IEA21 Subtask C
Phase I: Schedule

June 1st	**First set of results for all 6 cases to LP**
June 30th	Feedback on results
July 31st	**Second set of results to LP**
August 14th	Feedback on results
September 4th	**Third and final set of results to LP**
End September	Report and presentation of results at next IEA meeting

IEA 21C Empirical Validation
Hotline Newssheet No.2

1. Introduction

The Empirical Validation exercise is progressing well. We now have 23 participants from 10 countries, using 17 different programs (see appendix 1). In total, there are 24 user/program combinations. The first set of results has been received from 12 of these.
Some participants joined the exercise at a later date, and an individual deadline for the submission of their first set of results was agreed. However, from some potential participants we have not heard, despite two reminders about the June 1 deadline. It has to be made clear that the absolutely latest date for the submission of the first set of results is July 31. It will not be possible to include results which arrive after this date, or to include the program in any follow-up work with the data.

2. Hotline News

The following is a chronological account of information exchange since Newssheet No.1. Please read the information carefully (particularly the section about timing conventions) and check whether it is relevant to the program you are using. You may wish to modify your input data and submit a revised set of results, or undertake certain sensitivity studies, based on the information given here.

May 15 - Enquiry from Peter Pfrommer.

(i) The thickness of the plywood in construction C50 of the roofspace south wall construction (0.010m, Table 5.14) differs slightly from the other three instances where C50 is used. Strictly speaking, this construction should have been given a different code, i.e. C52.

(ii) Similarly, the conductivity of the material WoodA used in Tables 5.3 and 5.5 is different. The material of construction C02A (Table 5.5) should therefore be called WoodC.

(iii) The relative humidity values for data volume 099 were queried - 100% humidity during daytime with high solar radiation and higher air temperatures, lower humidity at night. However, Chris Martin confirmed that these values were actually measured and should therefore be used. The relative humidity was not measured for data volume v110. Suit-able assumptions should be made and reported by each participant. Perhaps a sensitivity study could be undertaken to assess the influence of the relative humidity.

June 6 - Enquiry from Paul Strachan.

(i) The timing convention issue mentioned in Newssheet no.1 was raised again.

The problem is that programs expect the climate data to be either hour-centred (UK convention) or half-hour-centred (US convention), an additional problem is that some pro-grams following the UK convention start with the period 23:30 to 00:30, others with the period 00:30 t0 01:30. The EMC data files follow the US convention, with the first line of data containing the average values for the period midnight to lam (hour number 1). Chris Martin investigated the issue and produced a brief document about it (appendix 3). As a result, we have produced alternative climate files for use with programs that expect climate data centred on the hour. The following action is suggested for all participants:

a. Check the conventions used by your program, i.e. whether the program expects climate data to be hour-centred or half-hour-centred, and check the starting time.

b. If your program expects data to be centred on the half hour, then no further action is required, since the original climate data files are correct for your program.

If your program expects data to be centred on the hour, then request alternative climate data files from the Hotline. Check what climate file starting time your program expects. If the starting time is midnight, then delete the last line of the new climate files. If the starting time is lam, then delete the first line of the new climate files.

Repeat your simulations and submit new results. It may mean that your program output does not exactly conform with the convention described in the validation guidebook (i.e. the first line of data in the results files is expected to contain values for the period 00:00 to 01:00). Please say so in the validation report form, if this is the case.

(ii) Paul queried the apparent mismatch between the time scale of the heater characteristics (time constant 22 minutes) and the fact that climate data are only available at hourly intervals.

In reply we note that hourly climate data were used because most thermal programs of buildings can only deal with such data. The heater time constant was merely supplied as additional information, should anybody wish to try and model it in more detail. For the heater surface, the same emissivity and absorptivity can be assumed as for the surrounding walls, i.e. 0.9 and 0.16 respectively.

(ii) Paul noted that the transmissivity, absorptivity and reflectivity of the glazing at different angles of incidence are not given in the site handbook.
Our response is that participants are expected to calculated these values from the basic glazing properties given in Table 5.9, and to report the values they are using in the simulations in the empirical validation report form.

(iii) The distance between the test cells is not given in the site handbook. It is 0.9m.

(iv) Figure 5.2 shows insulation in the roofspace south wall construction. This is incorrect, Table 5.4 gives the correct construction details.

3. Naming Conventions

Please stick to the file naming conventions described in Newssheet no.1, if you are submitting new results. The two letter codes to identify each of the six simulations are as follows:

Weather	Room	Glazing	Heating Code Period	Type
099	1	Double	No	fd
099	3	Opaque	No	fo
099	5	Single	No	fs
110	1	Double	Yes	hd
110	3	Opaque	Yes	ho
110	5	Single	Yes	hs

The six results files to be submitted are therefore fd.res, fo.res, fs.res, hd.res, ho.res and hs.res

4. **Feedback**

All participants who have submitted results will receive individual feedback in the next two weeks. The aim is to eliminate any user-introduced errors. Its has to be stressed that the exercise is still totally blind, i.e. not even the co-ordinators (ourselves) have access to the measured data. We will try and identify any obvious errors in the program input files. However, this should not be seen as quality assurance by us, which thereby divests .any responsibility on you to conduct in-house checking. All participants are advised to have their input files checked independently prior to submission.

The deadline for the submission of revised sets of results, if this is required, is July 31st (appendix 2).

Please remember, whenever you submit results, to supply your input files as hard copies as well as ASCII files on floppy disk. This greatly assists us when trying to provide feedback.

5. **Hotline**

If you have any further enquiries, please do not hesitate to contact the MA Hotline:

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Appendix 1:

List of Participants and Programs

Participant	Institution	Program	Code	Comments
Shirley Hammond	BRE, UK	SERI-RES	ser_bre	First results received
Foroutan Parand	BRE, UK	TRNSYS V.12 TRNSYS V.13	tr12bre tr13bre	First results received First results received
Eduardo Rodriguez	Escuela Superiore Ingenieros Industriales, Sevilla, Spain	S3PAS	s3p_esi	First results received
Timo Kalema	Tampere University of Technology, Finland	TASE	tas_tut	
Augusto Mazza	Politecnico di Torino, Italy	BLAST	bla_pdt	First results received
Bertil Fredlund	Lund Institute of Technology, Sweden	DEROB	der_lit	First results received
Peter Verstraete	Vrije Universiteit Brussel, Belgium	TRNSYS	trn_vub	First results received
Doug Hittle	Colorado State University, USA	BLAST	bla_csu	First results received
Fred Winkelmann	LBL, USA	DOE-2	doe_lbl	
Sandy Klein	University of Wisconsin, Madison, USA	TRNSYS	trn_uwm	
Mike Holmes	Arup R&D, UK	ENERGY2	ene_arp	First results received
Francisco Arumi-Noe	University of Texas at Austin, USA	DEROB	der_uta	
Mike Kennedy	Ecotope, USA	SUNCODE	ser_eco	
Pascal Dalicieux	Electricité de France	CLIMA2000	cli_edf	
Peter Pfrommer	FHT Stuttgart, Germany	HTB2	htb_fht	First results received
Don Alexander	University of Wales College of Cardiff, UK	HTB2	htb_uwc	First results received
Steve Irving	Facet Ltd., UK	APACHE	apa_fct	First results received
Paul Strachan	ESRU, Univ. of Strathclyde, UK	ESP	esp_esr	
Pete Moors	Leicester Polytechnic, UK	TAS°	tas_lpo	
Malcolm Munro	Swinburne Institute, Australia	BUNYIP	bun_sia	Confirmation awaited
Lorenzo Agnoletto	Institute di Fisica Technica, Udine, Italy			
Don McLean	Abacus Simulations Ltd., UK	ESP+	esp_asl	
Herbert Eppel	Leicester Polytechnic, UK	ESP	esp_lpo	First results received

Appendix 2:

Empirical Validation IEA21 Subtask C
Phase I: Schedule

June 1st	**First set of results for all 6 cases to LP**
June 30th	Feedback on results
July 31st	**Second set of results to LP**
August 14th	Feedback on results
September 4th	**Third and final set of results to LP**
End September	Report and presentation of results at next IEA meeting

Appendix 3:

IEA Task 21: Timing of weather data supplied for validation exercise

1 The problem

The weather data supplied for this exercise consists of average values accumulated over the course of each hour, that is from x:00 to (x+ 1):00. At EMC this value would be labelled with hour number x +1. Data thus refers to the hour preceeding the point at which it is recorded, a convenient assumption when that data is being gathered in real time. This is the convention normally used in the US.

In the UK, however, met. data is generally averaged from one half-hour point to the next, ie from (x-1):30 to x:30. Such a value will normally be labelled with hour number x, as it is centred on x:00.

A query has arisen about the use of the data as supplied with certain UK programs, most notably ESP, which requires data in the UK format.

2 Background

The data sets being used in this exercise were originally gathered for use in two ETSU validation projects in which SERI-RES was to be tested. SERI-RES has been modified to accept data recorded to the UK convention, but the modification was not comprehensive and introduced a series of bugs into the program. Accordingly, the modification was removed from the EMC copy of the model, and weather data in the US format is always used.

Of the two data sets currently being used, v099 was constructed from five minutely data, and a version of that data can thus be constructed using the UK timing convention.

The data in v110, however, was averaged on the site data acquisition system and then recorded at hourly intervals. In this case the UK version of the data is not directly available.

Previous sensitivity studies have indicated that, in one particular configuration, changing data type caused a 4% change in predicted energy consumption. It is therefore clear that something should be done about the problem.

3 A solution

One (approximate) solution to this problem is to use a moving average filter (MAF) to correct the US data, that is the required average value between (x-1):30 and x:30 is approximated by:

$$D_{(x-1):30 \rightarrow x:30} \approx \tfrac{1}{2} [D_{(x-1):00 \rightarrow x:00} + D_{x:00 \rightarrow (x+1):00}]$$

This solution is, however, only an approximation to the required information. In particular, the averaging process is likely to 'smooth' any high frequency fluctuations in the data.

4 Data disk

The files on the attached disk are described in the table

Filename	Contents	First line hour number	First line averaging period
v099.met v110.met	Original (US format) data files	1	0.00 → 1:00 am
v099.smt v110.smt	Data files adjusted to UK format using MAF	0	23:30 → 0.30 am
v099.emt	Data file built to UK format from recorded data	0	23:30 → 0:30 am

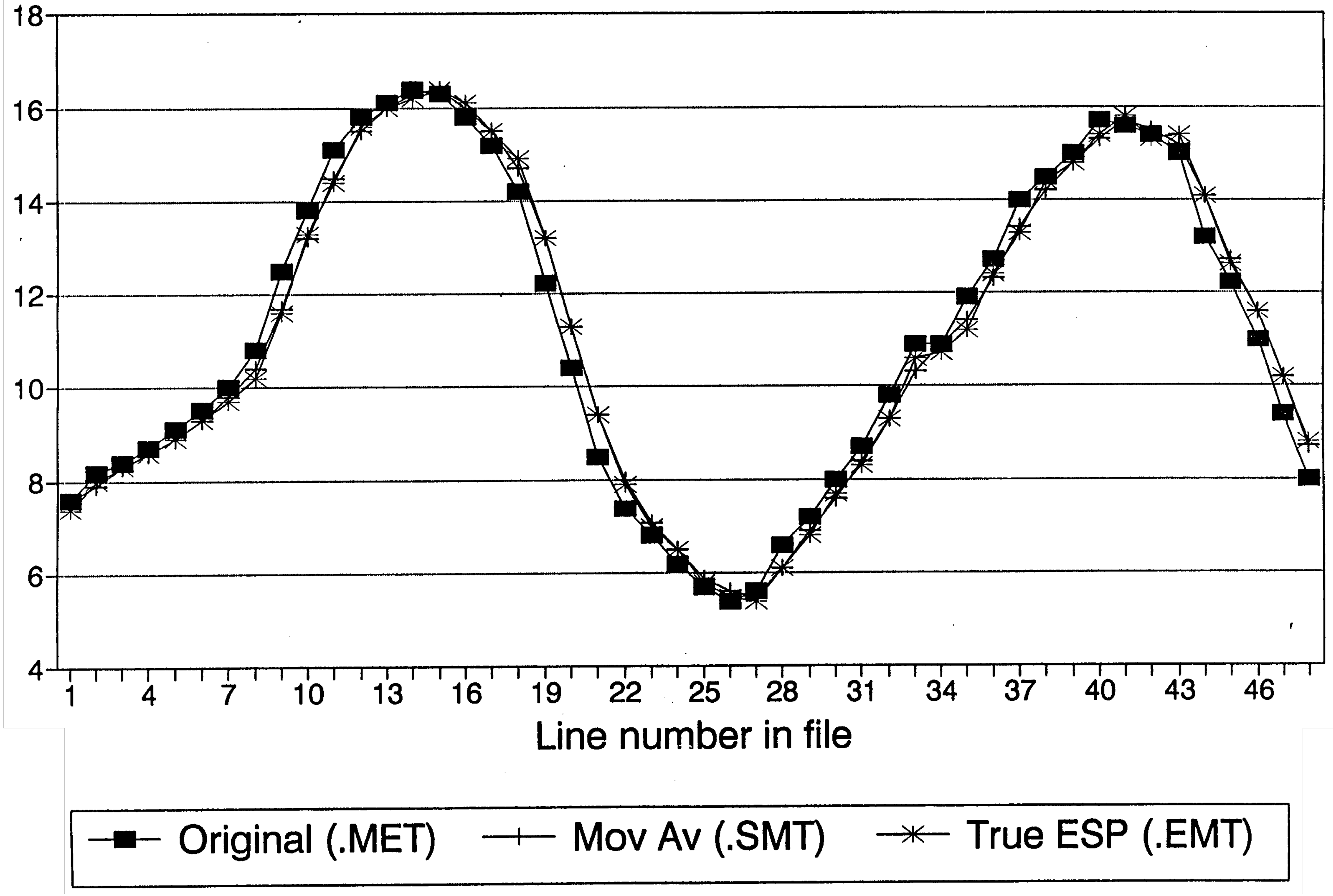
The attached graphs, all plotted starting from the first line in the v099 data files, show the effects of using the MAF and of building the data from the measured results. Points to note are:

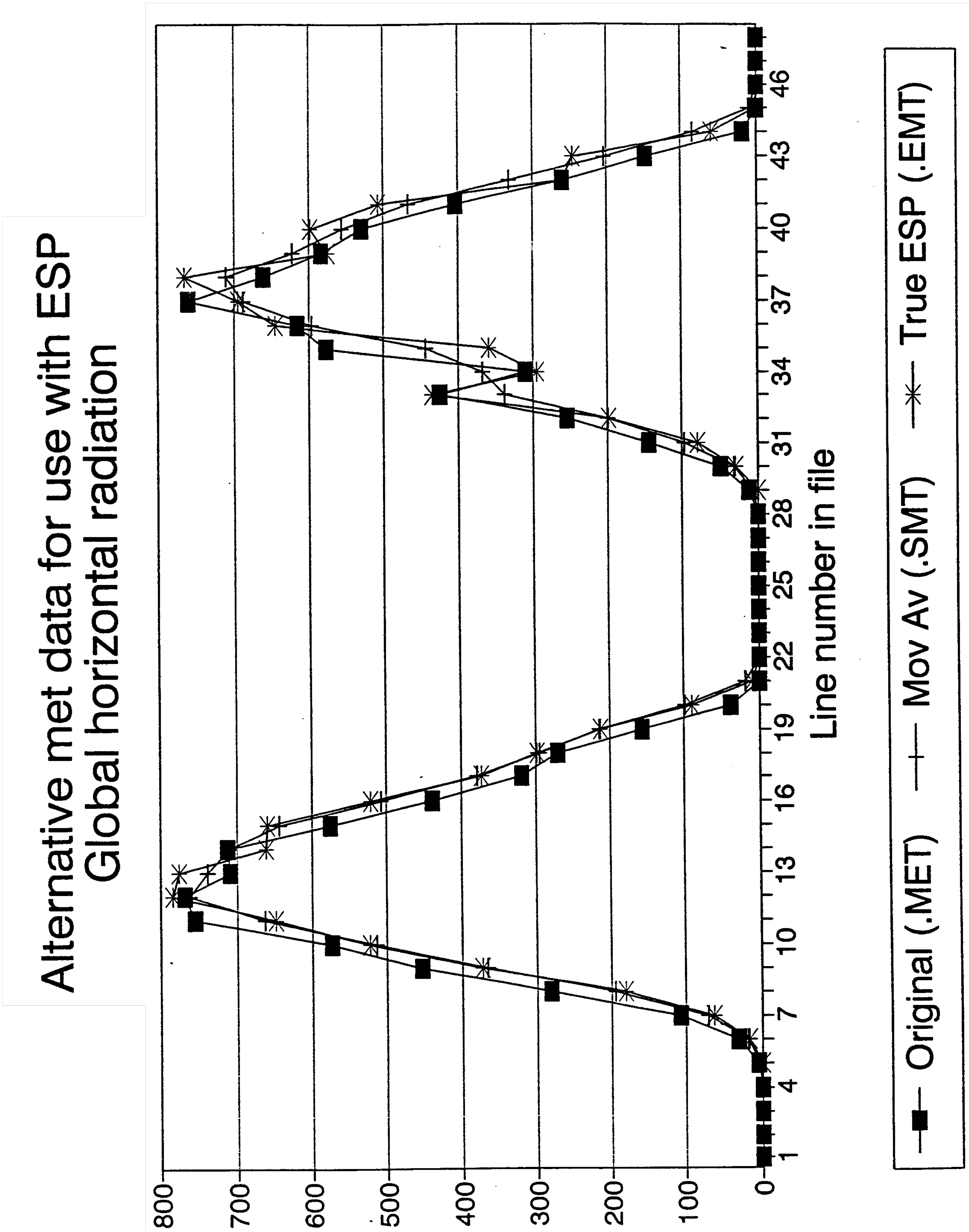
- for ambient temperature, which is a slow moving quantity and therefore immune to further smoothing, the MAF gives good results,
- on the first day, which is clear, the MAF provides good results on solar radiation data except at noon when there is a momentary error as the curve changes direction, and
- on the second day, when variable cloud cover has caused some fluctuations in radiation level, the MAF gives poorer performance due to the smoothing effect described earlier. Even so, a large amount of the potential 4% difference will have been corrected.

5 Conclusions

Data sets 'corrected' using the MAF have been supplied for both periods. A data set averaged from the original data has been provided for one of those periods. Initial qualitative comparisons indicate that the MAF performs acceptably. If there are further concerns these may be resolved by performing a sensitivity study using the MAF and correctly averaged data sets.

Alternative met data for use with ESP
Ambient temperature





Alternative met data for use with ESP
Global horizontal radiation
800
700
600
500
400
300
200
100
0
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
Line number in file
Original (.MET)
Mov Av (.SMT)
True ESP (.EMT)

IEA 21C Empirical Validation
Hotline Newssheet No.3

Introduction

We now have received the first set of results from the majority of participants (see appendix 1), and we are in a position to give individual feedback. This feedback is provided for each participant in a personal appendix to this Newssheet (appendix 2), without reference to the performance of the program relative to other programs. We stress again that the exercise is still totally blind, i.e. not even the co-ordinators (ourselves) have access to the measured data.

Deadlines

As mentioned in Newssheet No.2, the latest date for the submission of the first set of results is July 31. It will not be possible to include results which arrive after this date, or to include the program in any follow-up work with the data.
Since our feedback on the first set of results is somewhat later than originally planned, we will extend the deadline for the re-submission of the results to 17th of August, should this be necessary. Hopefully you will be able to accommodate any repeat simulations that you may wish to undertake within this time frame.

3. Hotline News

There was only one more enquiry in addition to the points that were clarified in the two preceding Hotline Newssheets.
Paul Strachan criticized the direct normal radiation values given in the two climate files. As ESP gives the user a choice between global horizontal radiation and direct normal radiation, Paul tried both options and the results were slightly different. One possible reason 'for the discrepancy is the use of different algorithms for calculating the solar altitude (the direct normal radiation values given in the climate file were calculated from the measured values of global horizontal radiation and diffuse horizontal radiation). Paul is carrying out a sensitivity study, which will give us a feeling for the impact of this uncertainty on the results, which we expect to be quite small. In the meantime, we advise participants to use global and diffuse horizontal radiation, rather than the derived direct normal radiation values, if their program permits this.

4. Re-submission of Results

Before re-submitting any results, please ensure that you have implemented any modifications that may be appropriate as a result of the feedback given in appendix 2, or in response to the clarifications given in the Hotline News sections of Newssheets Nos. 1 to 3. We repeat that in the personal feedback we tried to identify any obvious errors in the program input files, which should not be seen as quality assurance by us, thereby divesting any responsibility on you to conduct in-house checking. All participants are again advised to have their input files checked independently prior to re-submission of results.
Please remember also to supply your input files as ASCII files on floppy disk, together with your results. It would also be helpful if you could use the file naming conventions given in the two previous Newssheets.
You MUST report ALL changes that you have made to your input files as a result of

your personal feedback, or any other changes that were made.
Please let me know if you are not planning to submit a second set of results.

5. Hotline

Please note the change of name and address of our institution. If you have any further enquiries, please do not hesitate to contact the IEA Hotline:

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Appendix 1: **List of Participants and Programs**

Participant	Institution	Program	Code	Comments
Shirley Hammond	BRE, UK	SERI-RES	ser_bre	First results received
Foroutan Parand	BRE, UK	TRNSYS V.12 TRNSYS V.13	tr12bre tr13bre	First results received First results received
Eduardo Rodriguez	Escuela Superiore Ingenieros Industriales, Sevilla, Spain	S3PAS	s3p_esi	First results received
Timo Kalema	Tampere University of Technology, Finland	TASE	tas_tut	First results received
Augusto Mazza	Politecnico di Torino, Italy	BLAST	bla_pdt	First results received
Bertil Fredlund	Lund Institute of Technology, Sweden	DEROB	der_lit	First results received
Peter Verstraete	Vrije Universiteit Brussel, Belgium	TRNSYS	trn_vub	First results received
Doug Hittle	Colorado State University, USA	BLAST	bla_csu	First results received
Fred Winkelmann	LBL, USA	DOE-2	doe_lbl	**No response to dead-line reminders**
Sandy Klein	University of Wisconsin, Madison, USA	TRNSYS	trn_uwm	Withdrawn
Mike Holmes	Arup R&D, UK	ENERGY2	ene_arp	First results received
Francisco Arumi-Noe	University of Texas at Austin, USA	DEROB	der_uta	**No response to dead-line reminders**
Mike Kennedy	Ecotope, USA	SUNCODE	sun_eco	First results received
Pascal Dalicieux	Electricité de France	CLIM2000	cli_edf	First results received
Peter Pfrommer	FHT Stuttgart, Germany	HTB2	htb_fht	First results received
Don Alexander	University of Wales College of Cardiff, UK	HTB2	htb_uwc	First results received
Steve Irving	Facet Ltd., UK	APACHE	apa_fct	First results received
Paul Strachan	ESRU, Univ. of Strathclyde, UK	ESP	esp_esr	First results received
Pete Moors	De Montfort University Leicester, UK	TAS°	tas_dmu	Results expected by July 31st
Malcolm Munro	Swinburne Institute, Australia	BUNYIP	bun_sia	Confirmation awaited
Lorenzo Agnoletto	Institute di Fisica Technica, Udine, Italy	WG6TC	wg6_ifu	First results received
Don McLean	Abacus Simulations Ltd., UK	ESP+	esp_asl	Simulations may be undertaken at Leicester
Herbert Eppel	De Montfort University Leicester, UK	ESP	esp_dmu	First results received

IEA 21C Empirical Validation
Hotline Newssheet No.4

1. Current Status

An up-to-date list of participants of given in appendix 1. As you can see, the number of participants in the exercise is very large, much larger than we expected. We hope we can fully analyse the results before the end of September. As things stand, we believe that this is the largest empirical validation exercise ever undertaken, and it is very encouraging to have so many of the key state-of-the-art thermal programs involved.

2. Results Presentation

The plan for the Portland meeting (Sep 28 to Oct 2) is to concentrate on the following parameters for comparisons of the programs with each other and with the measurements:

- Total heating energy consumption for the heated cases.
- Total south facing vertical radiation for the heated and free-floating periods. Maximum and minimum air temperatures for the free-floating cases.

The program predictions and the measured data will be presented at the meeting, including some initial statistical analysis.
After the meeting, we expect that the hourly predictions will be scrutinized in order to get further insight into the performance of the participating programs. Feedback will continue to be given, and there will be opportunity for further refinement. The exact details of this phase of the exercise will be worked out in Portland.
We are planning to publish the background to the exercise, the results, and statistical analyses in an IEA report, which you will receive, and also at the CIBSE / BEPAC Conference in May 1993.

3. Hotline

If you have any queries please do not hesitate to make use of the hotline. Note the change in our e-mail address:

Herbert Eppel
School of the Built Environment
De Montfort University Leicester
The Gateway
GB - Leicester LE1 9BH
Tel: +44 533 577417
Fax: +44 533 577440
e-mail: edu@uk.ac.dmu (if you are connected to UK JANET) or edu@dmu.ac.uk

Appendix 1:

List of Participants and Programs

Participant	Institution	Program	Code	Comments
Shirley Hammond	BRE, UK	SERI-RES v1.2	ser_bre	Second results received
Foroutan Parand	BRE, UK	TRNSYS v12 TRNSYS v13	tr12bre tr13bre	Second results received Second results received
Eduardo Rodriguez	Escuela Superiore Ingenieros Industriales, Sevilla, Spain	S3PAS v2.0	s3p_esi	First results o.k.
Timo Kalema / Simo Kataja	Tampere University of Technology, Finland	TASE v3.0	tas_tut	First results o.k.
Augusto Mazza / Vittorio Bocchio	Politecnico di Torino, Italy	BLAST v3.0	bla_pdt	Second results received
Bertil Fredlund / Maria Wall	Lund Institute of Technology, Sweden	DEROB vLTH	der_lit	Second results received
Peter Verstraete	Vrije Universiteit Brussel, Belgium	TRNSYS v13.1	trn_vub	Second results received
Doug Hittle / Brian Miller	Colorado State University, USA	BLAST v3LVL143	bla_csu	Second results received
Fred Winkelmann	LBL, USA	DOE-2	doe_lbl	Withdrawn
Sandy Klein	University of Wisconsin, Madison, USA	TRNSYS	trn_uwm	Withdrawn
Mike Holmes	Arup R&D, UK	ENERGY2 v1.0	ene_arp	Second results imminent
Francisco Arumi-Noe	University of Texas at Austin, USA	DEROB	der_uta	Withdrawn
Mike Kennedy	Ecotope, USA	SUNCODE v5.7	sun_eco	Second results received
Pascal Dalicieux	Electricité de France	CLIM2000 v1.1	cli_edf	Second results received
Peter Pfrommer	FHT Stuttgart, Germany	HTB2 v1.2	htb_fht	Second results received
Don Alexander	University of Wales College of Cardiff, UK	HTB2 v1.10	htb_uwc	Second results received
Steve Irving / Andrew Tindale	Facet Ltd., UK	APACHE v6.5.2	apa_fct	First results o.k.
Steve Irving / Andrew Tindale	Facet Ltd., UK	3TC v1.0	3tc_fct	First results o.k.
Paul Strachan	ESRU, Univ. of Strathclyde, UK	ESP-R v7.7a	esp_esr	First results o.k.
Pete Moors	De Montfort University Leicester, UK	TAS°	tas_dmu	Results imminent
Lorenzo Agnoletto	Institute di Fisica Technica, Udine, Italy	WG6TC v1992	wg6_ifu	Second results received
Angelo Delsante	CSIRO, Australia	CHEETAH v1.2	che_csi	Results received
Herbert Eppel	De Montfort University Leicester, UK	ESP+	es+_dmu	Results imminent
Herbert Eppel	De Montfort University Leicester, UK	ESP v6.18a	esp_dmu	Second results received

part4.ms

IEA 21C Empirical Validation
Hotline Newssheet No.5

1. Portland IEA Meeting Report

Prior to the Portland meeting at the end of September, we had received 22 results sets from 10 countries, involving 19 participants. Of the 22 results sets, 15 had been produced by genuinely different programs. The other 7 were results from different versions of the same program or from variations of programs (Appendix 1).

The following participants were present at the Subtask 12B/21 C meeting: Foroutan Parand, Timo Kalema, Augusto Mazza, Peter Veistiaete / Rik van de Perre, Pascal Dalicieux and myself. Also present were Ron Judkoff (Subtask leader), Michael Holtz (Operating agent IEAl2), Dave Bloomfield (Operating agent IEA21) and Kevin Lomas.

Kevin and I reported the background of the exercise and its management, and we presented some eagerly awaited comparisons of total heating energy consumption over the 7 day period, total south facing vertical radiation, and maximum and minimum temperatures.

There was a strong feeling that, having had such an overwhelming response to the exercise, it would be worth trying to make the work even more comprehensive by soliciting participation from institutions which, for various reasons, had so far been unable to participate or had not been invited. These were: University of Wisconsin (Sandy Klein, author of TRNSYS), LBL (Fred Winkelman, DOE-2), CSTB (Louis Laret, CSTBAT, France), Gaz de France (ALLAN) and, funds permitting, the Danish Building Research Institute (Ole Jensen / Kjeld Johnson, TSBI4).

The group therefore decided to delay revealing any results until the end of December to give these organizations a chance to participate in this validation exercise while it is still 'blind'. All we can report at this stage it that there were large differences between the predictions.

2. Further Work

Between now and the next meeting (March 1993) we will co-ordinate the contributions of the new participants (3 or 4 have now agreed to take part, see appendix 1), and refine our estimate of the uncertainties to be attributed to the measurements and the predictions. Unfortunately, following a review of the available resources, it now seems unlikely that we will be able to conduct a full analysis of the hourly results.

A draft report of the empirical validation exercise will be produced for the next meeting, and some aspects of the work will be presented at the CIBSE / BEPAC Conference in May 1993.

3. Hotline

In the meantime, please continue to make use of the hotline if you have any queries:

Herbert Eppel
School of the Built Environment
De Montfort University Leicester
The Gateway
GB - Leicester LE1 9BH
Tel: +44 533 577417
Fax: +44 533 577440

Appendix 1:

List of Participants and Programs

Results received from	Institution	Program	Code
Shirley Hammond	BRE, UK	SERI-RES v1.2	ser_bre
Foroutan Parand	BRE, UK	TRNSYS v12 TRNSYS v13	tr12bre tr13bre
Eduardo Rodriguez	Escuela Superiore Ingenieros Industriales, Sevilla, Spain	S3PAS v2.0	s3p_esi
Timo Kalema / Simo Kataja	Tampere University of Technology, Finland	TASE v3.0	tas_tut
Augusto Mazza / Vittorio Bocchio	Politecnico di Torino, Italy	BLAST v3.0	bla_pdt
Bertil Fredlund / Maria Wall	Lund Institute of Technology, Sweden	DEROB vLTH	der_lit
Peter Verstraete	Vrije Universiteit Brussel, Belgium	TRNSYS v13.1	trn_vub
Doug Hittle / Brian Miller	Colorado State University, USA	BLAST v3LVL143	bla_csu
Mike Holmes	Arup R&D, UK	ENERGY2 v1.0	ene_arp
Mike Kennedy	Ecotope, USA	SUNCODE v5.7	sun_eco
Pascal Dalicieux	Electricité de France	CLIM2000 v1.1	cli_edf
Peter Pfrommer	FHT Stuttgart, Germany	HTB2 v1.2	htb_fht
Don Alexander	University of Wales College of Cardiff, UK	HTB2 v1.10	htb_uwc
Steve Irving / Andrew Tindale	Facet Ltd., UK	APACHE v6.5.2	apa_fct
Steve Irving / Andrew Tindale	Facet Ltd., UK	3TC v1.0	3tc_fct
Paul Strachan	ESRU, Univ. of Strathclyde, UK	ESP-R v7.7a	esp_esr
Pete Moors	De Montfort University Leicester, UK	TAS°	tas_dmu
Lorenzo Agnoletto	Institute di Fisica Technica, Udine, Italy	WG6TC v1992	wg6_ifu
Angelo Delsante	CSIRO, Australia	CHEETAH v1.2	che_csi
Herbert Eppel	De Montfort University Leicester, UK	ESP+	es+_dmu
Herbert Eppel	De Montfort University Leicester, UK	ESP v6.18a	esp_dmu
New Participants			
Fred Winkelmann	LBL, USA	DOE-2	doe_lbl
Sandy Klein	University of Wisconsin, Madison, USA	TRNSYS	trn_uwm
? Ole Jensen / Kjeld Johnson ?	Danish Building Research Inst.	? TSBI4 ?	tsb_dbr
Louis Laret	CSTB, France	CSTBAT	csb_csb

patt5.ms

IEA 21C/12B Empirical Validation
Hotline Newssheet No. 8

1. Introduction

The following table gives a summary of the key events in the empirical validation exercise so far.

Diary of Key Events	
March 1992	IEA Meeting in Copenhagen - Empirical Validation exercise is agreed.
March / April	Invitations sent to possible participants. Distribution of validation package.
May	Newssheet 1 distributed - 11 participants, deadline for first set of results set to June 1.
June	Newssheet 2 distributed - Results received from all original participants. Number of participants had grown to 20. Individual results deadlines set for participants who had joined later.
July	Newssheet 3 distributed including personal feedback on first results set. All results received from confirmed participants.
August	Revised results received where appropriate.
September	Newssheet 4 distributed - 22 different results sets had been received from 19 participants. Intention to present results at CIBSE conference stated.
Sep 28 - Oct 2	IEA Meeting in Portland, Oregon. Decision to invite several more institutions to participate who had so far been unable to do so or had not been invited. Some results shown at meeting. Revealing of results delayed until end of December to keep the exercise 'blind'. Doubts about availability of resources for full analysis of hourly results. Publication of results discussed.
November	Newssheet 5 distributed giving summary of Portland meeting. Intention to present work at CIBSE conference stated.
January 1993	Newssheet 6 distributed - 25 different results sets received. Comments invited on key sections of proposed CIBSE conference paper.
March	Newssheet 7 distributed - Revised version of key sections of proposed CIBSE conference paper circulated following comments from a number of participants.
March 29 - 31	IEA Meeting in Madrid - Decision to release measured data to give participants opportunity for follow-up work.

It has been decided that the paper discussed in newssheets 6 and 7 should not be published in its present form in the CIBSE Conference proceedings. Instead a verbal presentation will be made. It is likely that a more comprehensive paper will be published in a journal. The paper will include further analyses and explanations for the performance of many of the programs.

2. Can we trust the measured data used in this exercise ?

At the IEA meeting in Madrid (29th to 31st March) Chris Martin, of the Energy Monitoring Company (EMC), who was responsible for collecting the measured data used in this exercise, gave a presentation addressing the question of whether that data can be considered trustworthy.

The approach to Quality Assurance adopted at the EMC test site when collecting data was described. A short report was distributed to everyone present at the meeting, and a copy is enclosed with this newssheet for those of you who were not at the meeting. The intention is that this report (updated if necessary) should be added to the original validation package so that if anyone uses the package in future they will have access to a document which should give them confidence in the data contained therein.

3. Further analysis of simulations and measurements

At the meeting some preliminary graphical comparisons of hourly simulated and measured data were presented. Graphs of temperature and energy consumption on a particular day are attached to this newssheet as Appendix A. There is obviously a great deal of insight to be gained from inspection of hourly results. In particular it is quite possible that a model may give a good long term average prediction, but that this may be as a result of over-prediction at one time of day being cancelled out by a corresponding under-prediction at other times. Such an effect can clearly be identified by analysing hourly predictions, and generating relatively simple error statistics. We will be compiling tables of such statistics for all of the participating models for inclusion in the final report, and further graphs showing more detailed comparisons.

The second extension of the analysis was the inspection of some mechanism level data - specifically the predicted solar radiation on the plane of the test room glazing. The graphs in Appendix B show the predictions of all the models and the measured values over the two periods studied, and hourly values for a particular day. This type of analysis is valuable in two respects:

- it allows individual parts of the models to be compared and tested (in this case, the solar radiation processors);
- it allows us to spot cases where errors in different parts of the models are cancelling out - for example a model which overestimates the heat loss of the building but also overestimates the incident solar radiation may, by chance, produce very good predictions of mean temperature and total energy consumption on a particular dataset. Examining the mechanism level data can reveal that such good agreement is purely fortuitous.

4. Further analysis: release of measured data

The UK team has put a very large amount of effort into this exercise, and does not have the resource to carry out more detailed analysis on all the simulation results. Indeed, the effort required to carry out such analysis could easily exceed the total effort to date.

In response to this, it was decided at the Madrid meeting that we should now release all the measured data to the participants. Enclosed with this newssheet is a 3½" diskette, which contains that data.

Unfortunately an error in the documentation which was supplied with the validation package means that we do not have data from the heated single glazed room described in those documents. The third heated test room was equipped with a completely different glazing option during that test. This error was discovered too late to ask you all to carry out alternative runs. This means that we have five sets of measured results to distribute. We apologise for any inconvenience or disappointment that this causes. The simulation results which are affected by this problem (and it is only one of the six sets) will still be useful in an intermodel comparison context, and we will be making these comparisons in the final report.

The diskette contains a total of eleven ASCII files. Five of these contain the measured values of the quantities which you were asked to predict, in the same format as that which you were asked to return your results. We felt that this would simplify *any* comparisons that you wished to make. In keeping with the original naming convention these files are named *fo.mes, fd.mes, fs.mes, ho.mes and hd.mes,* the *.mes* extension denoting that this is measured data.

Five of the remaining files contain more comprehensive data, and have extension *.exp.* They contain the measured temperatures from which the spatial averages in the .mes files were obtained, and thus enable you to assess, for example, the degree of stratification in the test rooms. They also contain the measured floorspace and roofspace temperatures throughout the trial. If you wish to use this additional data please refer to the text file *formats.txt* on the disk, which describes the layout of data in all the files.

It was decided at the Madrid meeting that you should each be allocated a maximum of three pages which will be reproduced in the final report to describe any data analysis or further simulation work which you have carried out. Appendix C contains a proposed format for these contributions. The closing date for return of these three page reports is 3lst July 1993. The sorts of investigations which you might choose to carry out and describe in your three page report include:

- more detailed statistical analyses of the hourly simulated and measured results.

- Studies of the sensitivity of the model to selected inputs. If it is found that some of the inputs required by the model can cause very large variations in predictions then model users should obviously be aware of this, and should also be aware of how those parameters should be selected in real applications.

- Sensitivity studies which yield the total output uncertainty of individual models, allowing a more rigorous comparison between simulated and measured results. To facilitate such studies a table of the uncertainties in the data provided to you (both recorded data and test room properties) will be sent out shortly.

- the results of further simulations, using input parameters modified with the benefit of hindsight. In this case special attention should be paid to explaining why the input parameters have been modified: it is well known that good agreement between simulations and data can almost always be obtained by systematic adjustment of input parameters. Indeed, this is the very reason that the exercise has been carried out blind up to this point.

5. Internal workings of models

At the meeting a number of inaccuracies were noted in the table of model features which has been drawn up from the questionnaire which you all completed as part of the exercise. Also, as possible reasons for the discrepancies between the results obtained from alternative models were discussed, it became clear that there were a number of other pieces of information which would be useful when trying to determine whether there are consistent patterns as to why some models do better than others.

Aided by Petter Wallentén of Lund Institute of Technology we have compiled a new pro-forma which is included with this newssheet as Appendix D. You are asked to enter details of the model you have used onto the form. Please return your completed form to the hotline by 31st May 1993 to allow us to collate the results.

6. Summary of deadlines

Please try to keep to the following deadlines:

31st May 1993: Return completed model information form to hotline

31st July 1993: Return three-page document describing further analysis/simulation to hotline for inclusion in final report.

APPENDICES

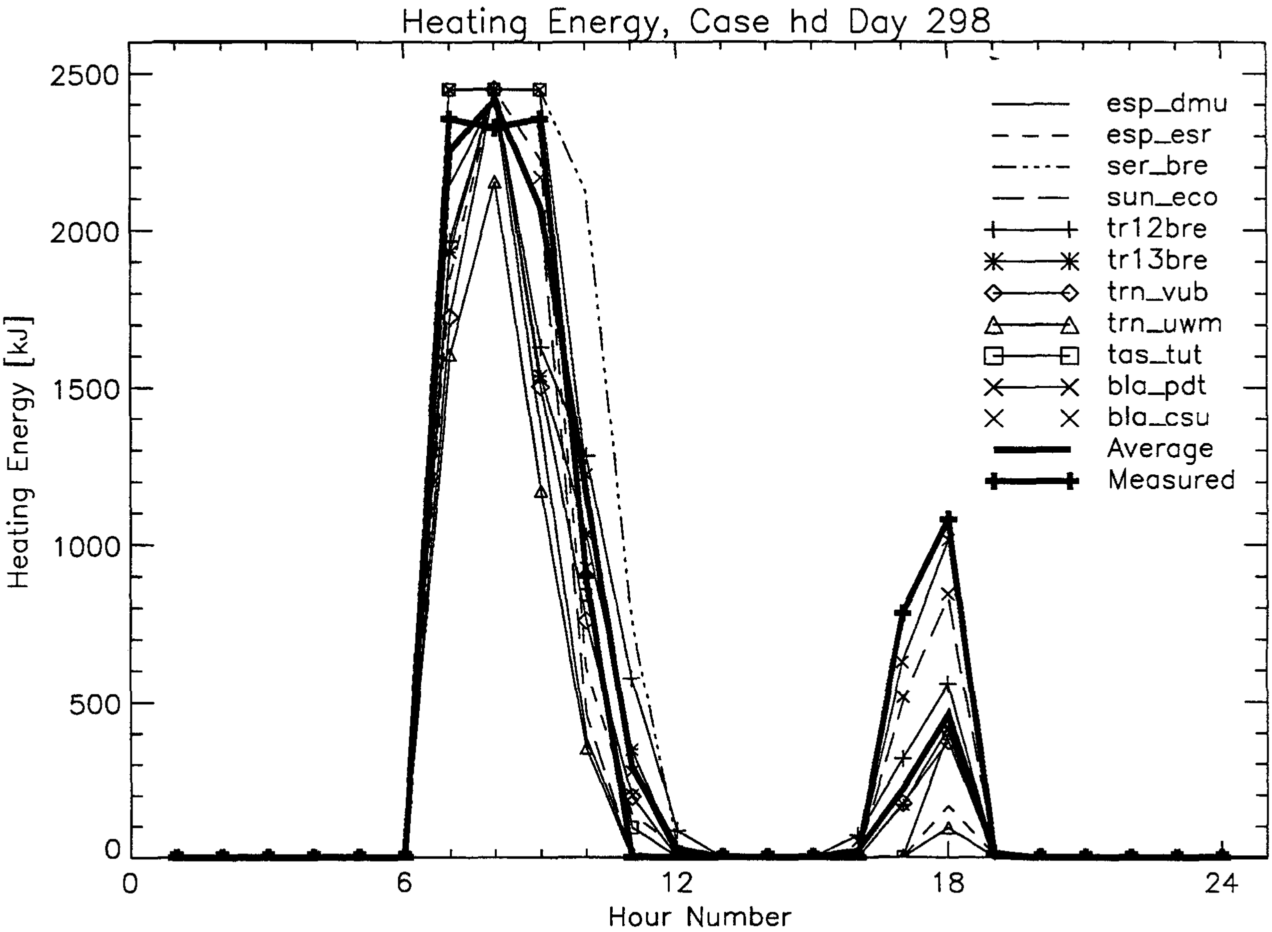
Appendix A Graphs of hourly energy consumption and temperature predictions and measurements for a particular day.

Appendix B Graphs of measured and predicted solar radiation on test room glazing (totals for both periods and hourly values for a particular day).

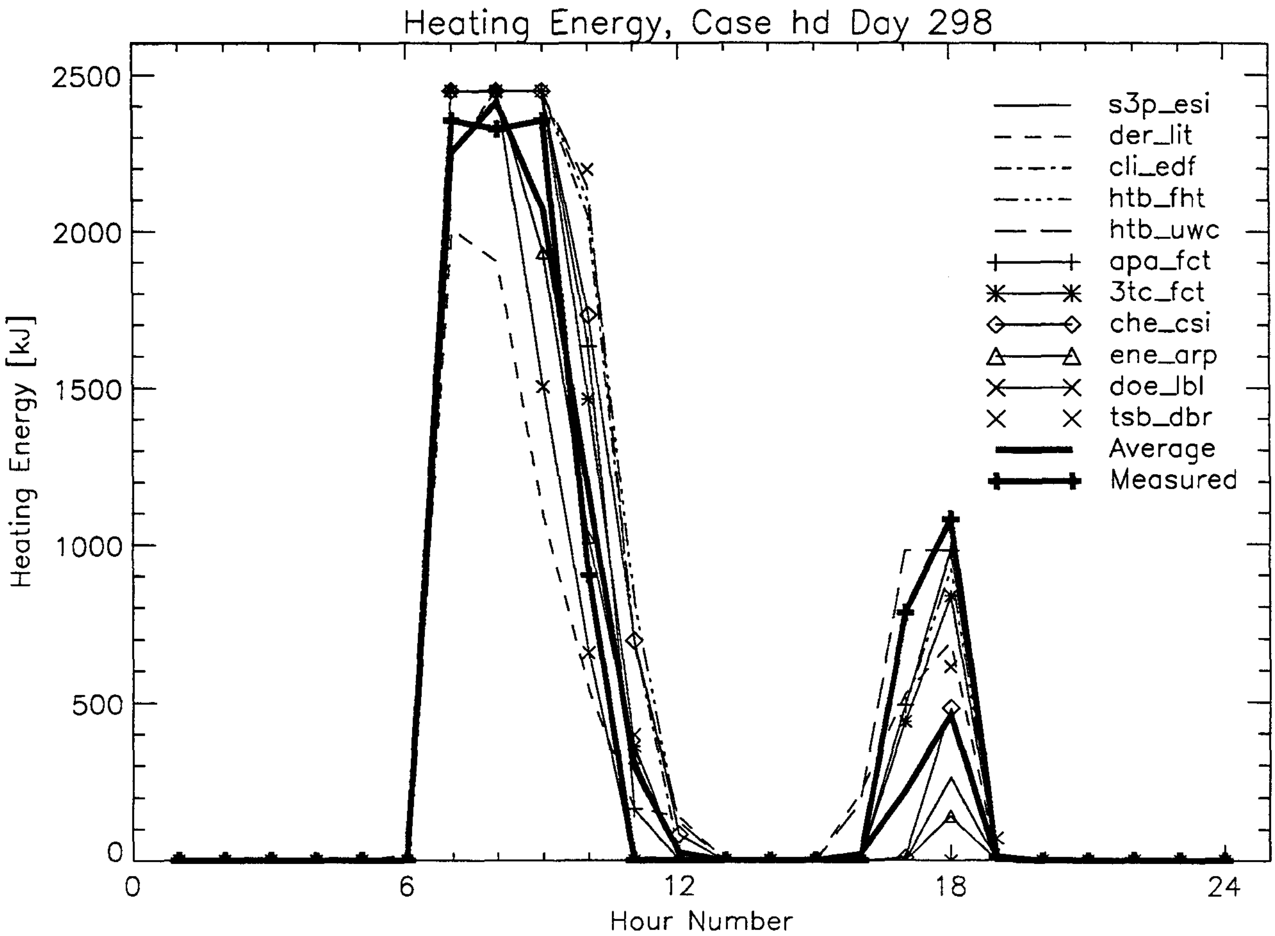
Appendix C Proposed format for 3-page report on further analysis.

Appendix D Model description pro-forma

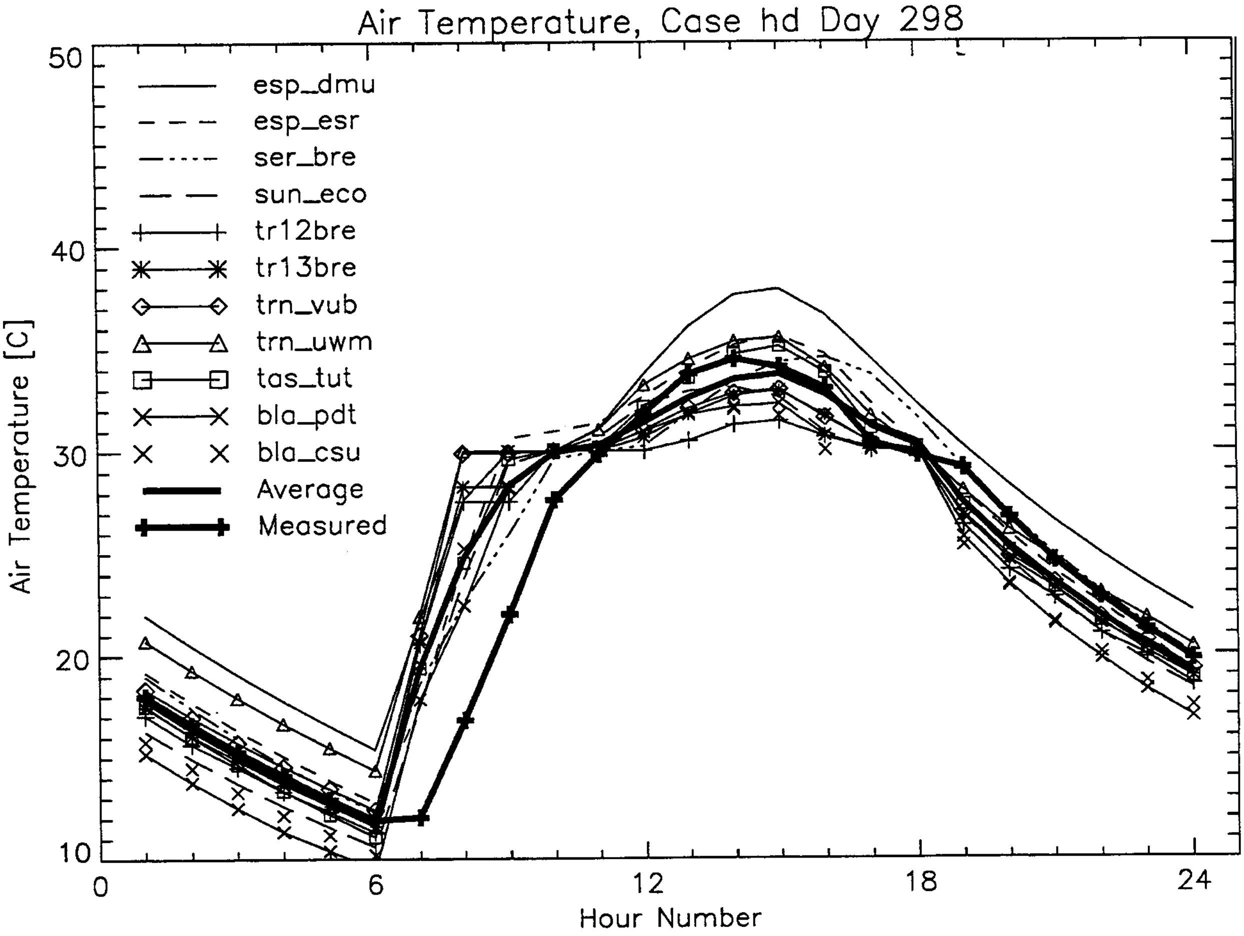
Appendix A

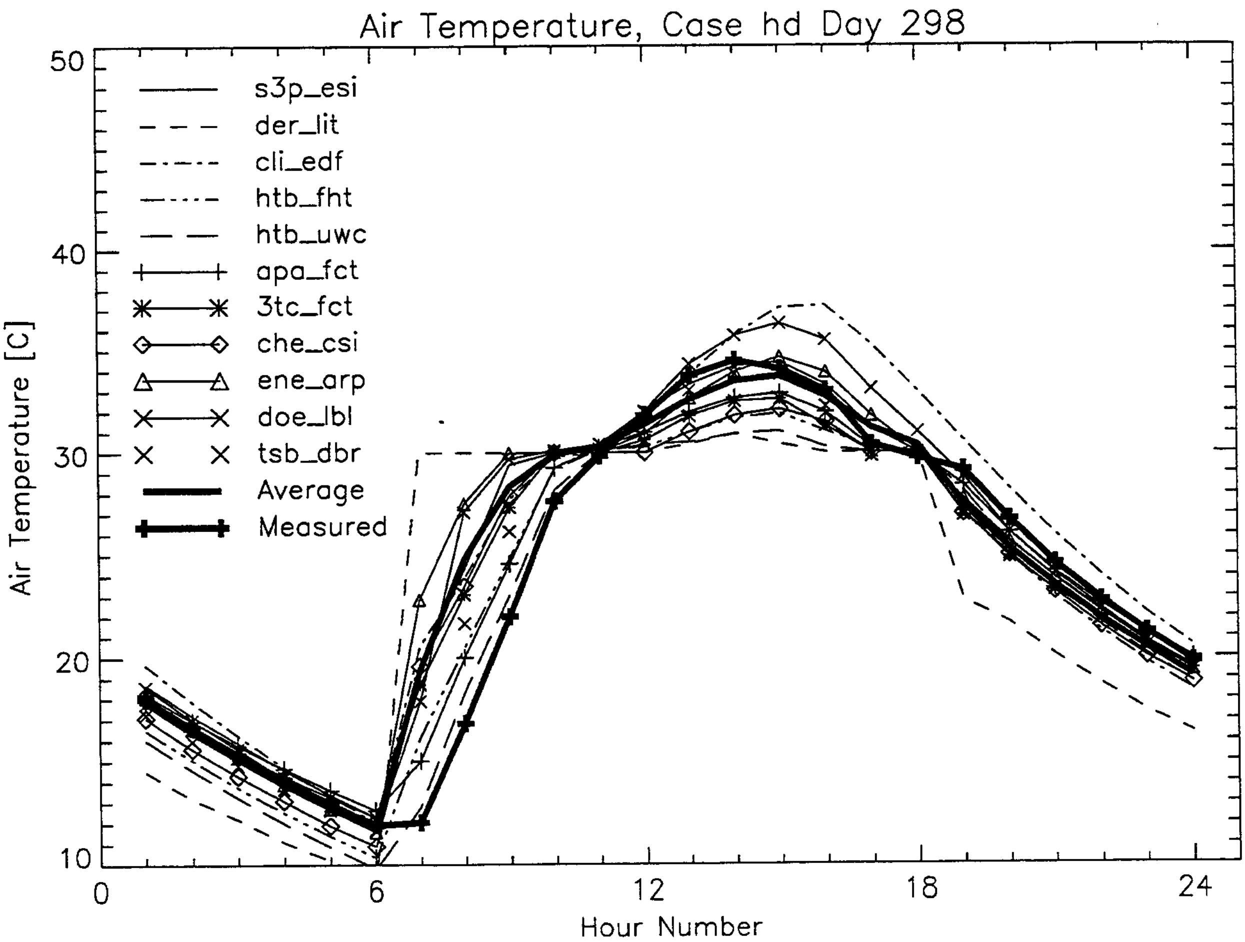


Heating Energy, Case hd Day 298
Heating Energy [kJ]
Hour Number
esp_dmu
esp_esr
ser_bre
sun_eco
tr12bre
tr13bre
trn_vub
trn_uwm
tas_tut
bla_pdt
bla_csu
Average
Measured

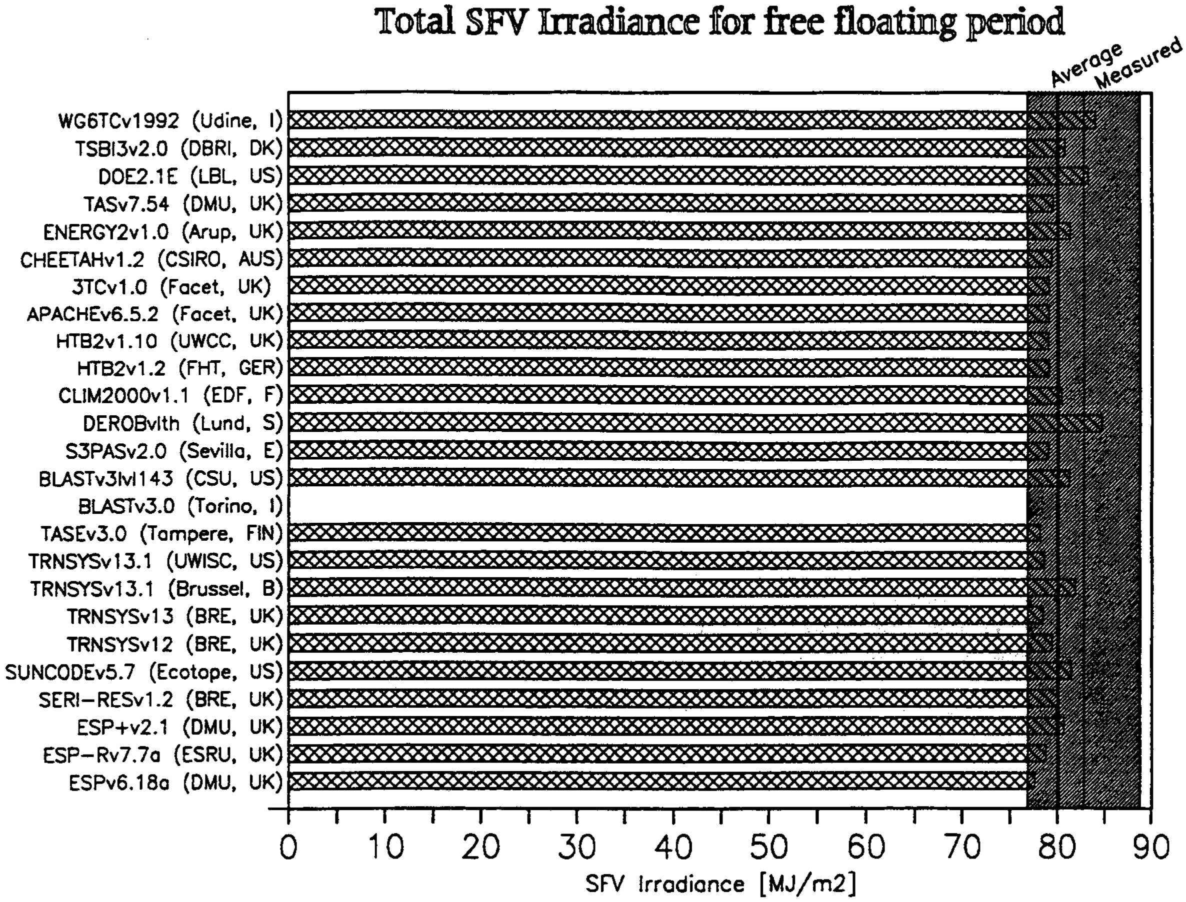


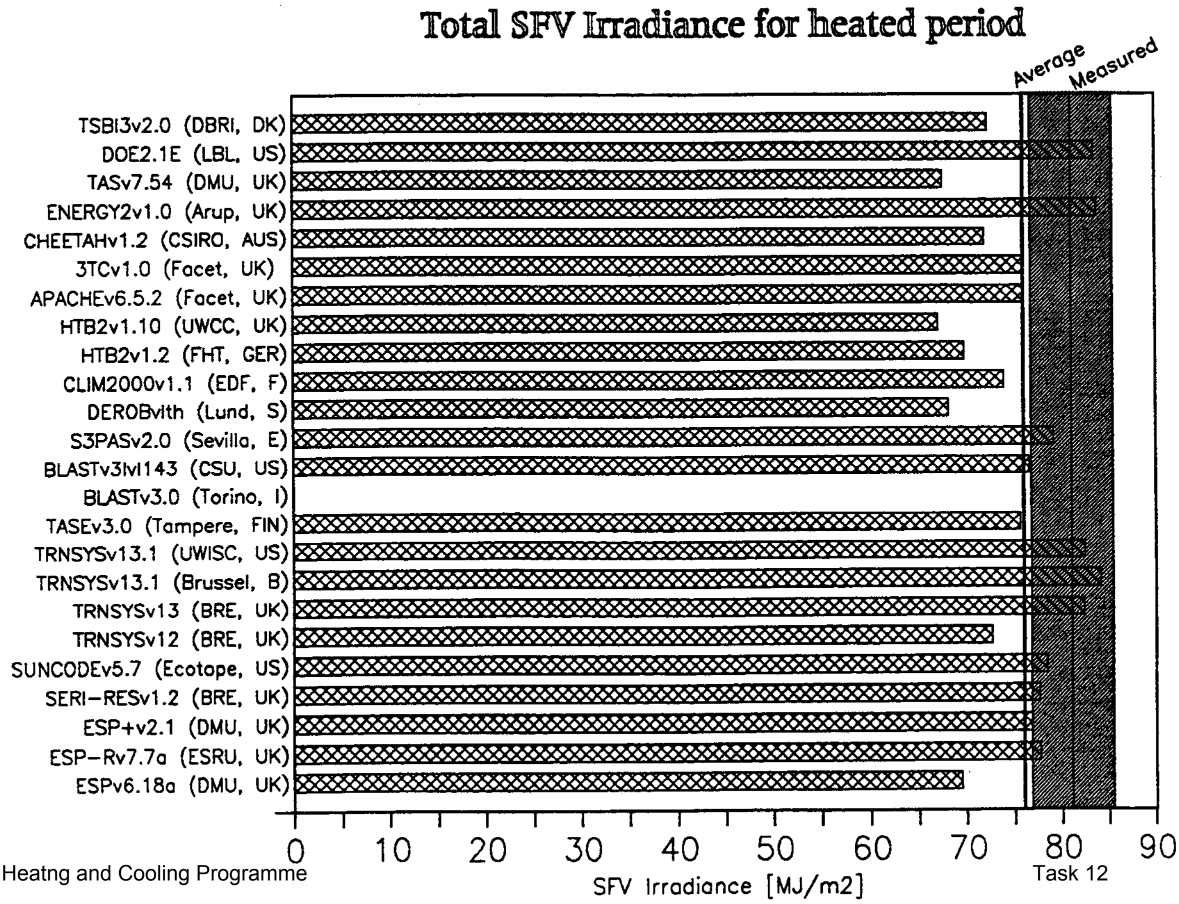
Heating Energy, Case hd Day 298
Heating Energy [kJ]
Hour Number
s3p_esi
der_lit
cli_edf
htb_fht
htb_uwc
apa_fct
3tc_fct
che_csi
ene_arp
doe_lbl
tsb_dbr
Average
Measured

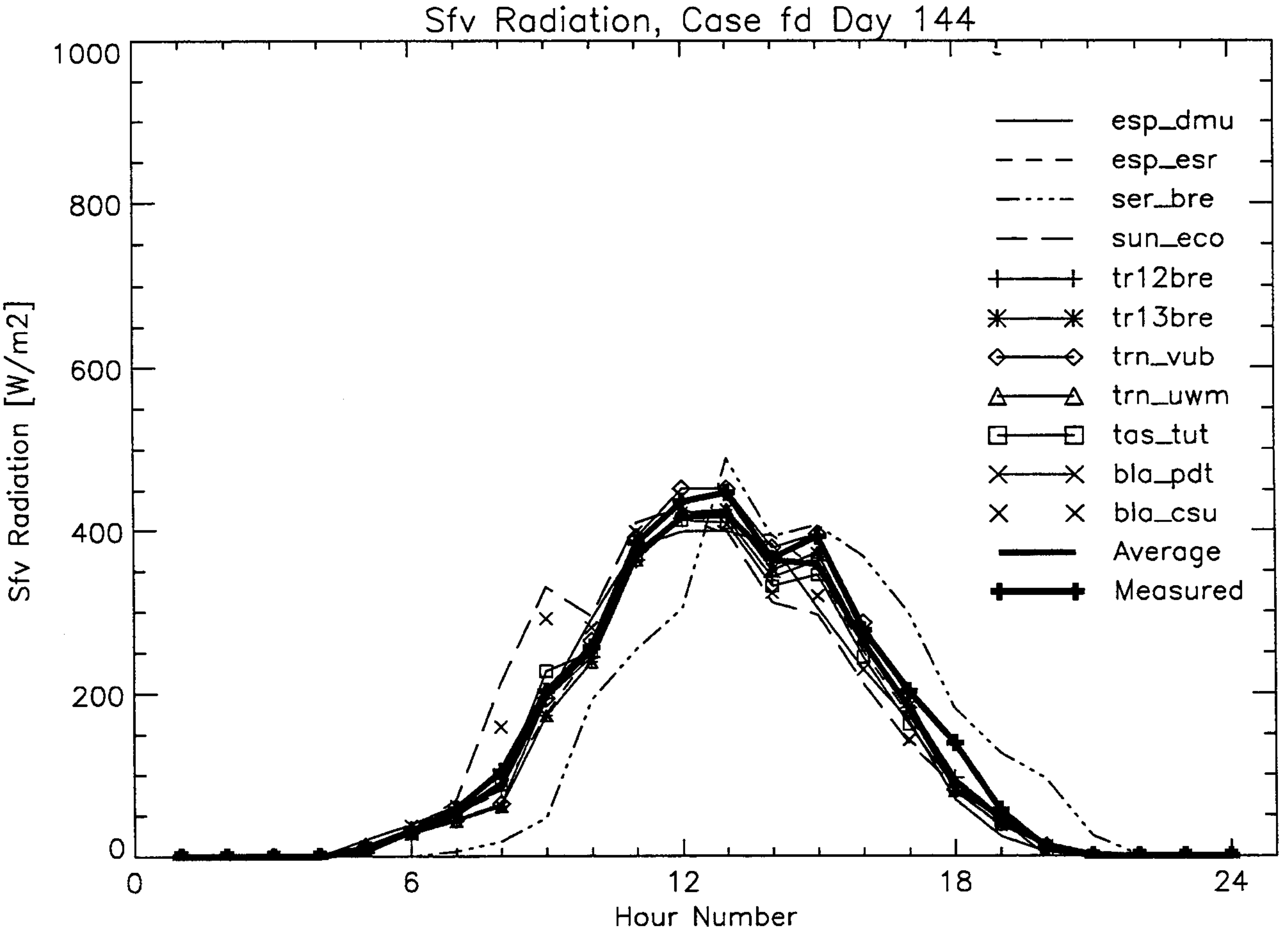

Air Temperature, Case hd Day 298
esp_dmu
esp_esr
ser_bre
sun_eco
tr12bre
tr13bre
trn_vub
trn_uwm
tas_tut
bla_pdt
bla_csu
Average
Measured
Air Temperature [C]
Hour Number
10
20
30
40
50
0
6
12
18
24


Air Temperature, Case hd Day 298
s3p_esi
der_lit
cli_edf
htb_fht
htb_uwc
apa_fct
3tc_fct
che_csi
ene_arp
doe_lbl
tsb_dbr
Average
Measured
Air Temperature [C]
Hour Number
10
20
30
40
50
0
6
12
18
24

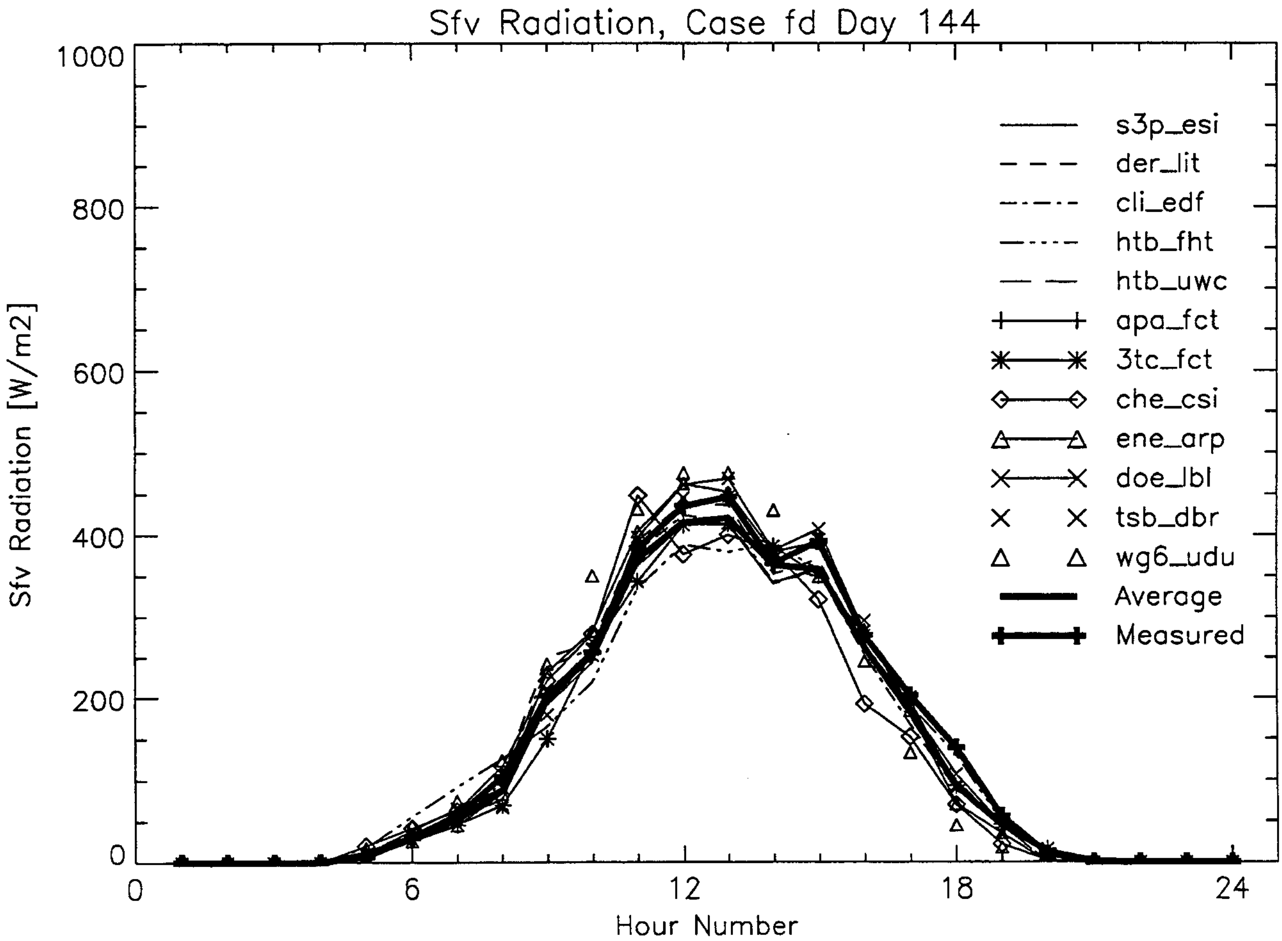
Appendix B


Total SFV Irradiance for free floating period
Average
Measured
WG6TCv1992 (Udine, I)
TSBI3v2.0 (DBRI, DK)
DOE2.1E (LBL, US)
TASv7.54 (DMU, UK)
ENERGY2v1.0 (Arup, UK)
CHEETAHv1.2 (CSIRO, AUS)
3TCv1.0 (Facet, UK)
APACHEv6.5.2 (Facet, UK)
HTB2v1.10 (UWCC, UK)
HTB2v1.2 (FHT, GER)
CLIM2000v1.1 (EDF, F)
DEROBvlth (Lund, S)
S3PASv2.0 (Sevilla, E)
BLASTv3lvl143 (CSU, US)
BLASTv3.0 (Torino, I)
TASEv3.0 (Tampere, FIN)
TRNSYSv13.1 (UWISC, US)
TRNSYSv13.1 (Brussel, B)
TRNSYSv13 (BRE, UK)
TRNSYSv12 (BRE, UK)
SUNCODEv5.7 (Ecotope, US)
SERI-RESv1.2 (BRE, UK)
ESP+v2.1 (DMU, UK)
ESP-Rv7.7a (ESRU, UK)
ESPv6.18a (DMU, UK)
0
10
20
30
40
50
60
70
80
90
SFV Irradiance [MJ/m2]


Total SFV Irradiance for heated period
Average
Measured
TSBI3v2.0 (DBRI, DK)
DOE2.1E (LBL, US)
TASv7.54 (DMU, UK)
ENERGY2v1.0 (Arup, UK)
CHEETAHv1.2 (CSIRO, AUS)
3TCv1.0 (Facet, UK)
APACHEv6.5.2 (Facet, UK)
HTB2v1.10 (UWCC, UK)
HTB2v1.2 (FHT, GER)
CLIM2000v1.1 (EDF, F)
DEROBvlth (Lund, S)
S3PASv2.0 (Sevilla, E)
BLASTv3lvl143 (CSU, US)
BLASTv3.0 (Torino, I)
TASEv3.0 (Tampere, FIN)
TRNSYSv13.1 (UWISC, US)
TRNSYSv13.1 (Brussel, B)
TRNSYSv13 (BRE, UK)
TRNSYSv12 (BRE, UK)
SUNCODEv5.7 (Ecotope, US)
SERI-RESv1.2 (BRE, UK)
ESP+v2.1 (DMU, UK)
ESP-Rv7.7a (ESRU, UK)
ESPv6.18a (DMU, UK)
0
10
20
30
40
50
60
70
80
90
SFV Irradiance [MJ/m2]



Sfv Radiation, Case fd Day 144
Sfv Radiation [W/m2]
Hour Number
esp_dmu
esp_esr
ser_bre
sun_eco
tr12bre
tr13bre
trn_vub
trn_uwm
tas_tut
bla_pdt
bla_csu
Average
Measured



Sfv Radiation, Case fd Day 144
Sfv Radiation [W/m2]
Hour Number
s3p_esi
der_lit
cli_edf
htb_fht
htb_uwc
apa_fct
3tc_fct
che_csi
ene_arp
doe_lbl
tsb_dbr
wg6_udu
Average
Measured

Appendix C

Suggested format for three-page report on further analysis

1. Problems encountered in representing the test rooms within the model.
2. Problems encountered with the documentation provided.
3. How useful was the hotline?
4. How useful were the newssheets?
5. How was Quality Assurance organised?
6. Results and conclusions from sensitivity studies.
7. Were any bugs found in the model as a result of this exercise?

Appendix D

IEA Task 21C/12B Empirical Validation Exercise:

Model Description Pro-forma

Thank you for taking the time to fill in this pro-forma. Although it looks rather long it should take little time to complete, as most of the questions are multiple choice.

In some cases you will find that several of the options given are available within your model. In this case please tick all the options available, and identify which one(s) you used in the IEA Empirical Validation simulations by circling it or them. For example, if your model can accept a user-specified internal heat transfer coefficient, or can calculate it as a function of orientation and temperature difference, and you used the latter option in the IEA runs, your entry in the section on internal convective heat transfer would be:

Convective heat transfer within zones

- ❑ coefficients fixed within code
- ❑ coefficients specified by user
- ❑ coefficients calculated by code as a function of surface orientation
- ❑ coefficients calculated by code as a function of temperature difference
- ❑ coefficients calculated by code as a function of surface finishes
- ❑ Other (please specify)______________________________

When you have completed the pro-forma please return it to the lEA Empirical Validation hotline:

Herbert Eppel
School of the Built Environment
De Montfort University
The Gateway
Leicester
LE1 9BH
UK

Phone: +44 533 577417
Fax: +44 533 577440

Once again, thank you for providing this information.

Program name (please include version number)

____

Your name and organisation

____

Program status

☐ Public domain
☐ Commercial
☐ Other (please specify) ____________________

Solution method

☐ Explicit finite difference
☐ Implicit finte difference
☐ Weighting factors
☐ Response factor
☐ Other (please specify) ____________________

Timing convention for meteorological data: sampling interval

☐ Fixed within code (please specify interval) ________
☐ User-specified

Timing convention for meteorological data: period covered by first record

☐ Fixed within code (please specify period or time which meteorological record covers) ____
☐ User-specified

Meteorological data reconstruction scheme

☐ Climate assumed stepwise constant over sampling interval
☐ Linear interpolation used over climate sampling interval
☐ Other (please specify) ____________________

Output timing conventions

☐ Produces spot predictions at the end of each timestep
☐ Produces spot output at end of each hour
☐ Produces average outputs for each hour (please specify period to which value relates) ____

Treatment of zone air

- ☐ Single temperature (ie good mixing assumed)
- ☐ Stratified model
- ☐ Simplified distribution model
- ☐ Full CFD model
- ☐ Other (please specify) ______________________

Heaters (dynamics)

- ☐ No dynamics assumed (output is instantaneous)
- ☐ Simple first order dynamics
- ☐ Detailed modelling of heat source dynamics

Heaters (output characteristics)

- ☐ Purely convective
- ☐ Radiative/Convective split fixed within code
- ☐ Radiative/Convective split specified by user
- ☐ Detailed modelling of heat source output

Control temperature

- ☐ Air temperature
- ☐ Combination of air and radiant temperatures fixed within the code
- ☐ User-specified combination of air and radiant temperatures
- ☐ User-specified construction surface temperatures
- ☐ User-specified temperatures within construction
- ☐ Other (please specify) ______________________

Control laws

- ☐ Perfect control
- ☐ On/Off thermostatic control
- ☐ On/Off thermostatic control with deadband
- ☐ On/Off thermostatic control with accelerator heater
- ☐ Proportional control
- ☐ More comprehensive control laws (please specify) ______________________

Heat transfer within zones

- ☐ Radiation and convection combined
- ☐ Radiation and convection treated separately

Convective heat transfer within zones

- ☐ coefficients fixed within code
- ☐ coefficients specified by user
- ☐ coefficients calculated by code as a function of surface orientation
- ☐ coefficients calculated by code as a function of temperature difference
- ☐ coefficients calculated by code as a function of surface finishes
- ☐ Other (please specify) ________________________

Longwave radiative heat transfer within zones

- ☐ Constant linearised coefficients
- ☐ Linearised coefficients based on viewfactors
- ☐ Linearised coefficients based on surface emmissivities
- ☐ Non-linear treatment of radiation heat exchange
- ☐ Other (please specify) ________________________

Number of nodes placed within each layer of walls and slabs

- ☐ Not applicable for this solution method
- ☐ Fixed number of nodes per layer (please specify) _______
- ☐ User-specified number of nodes per layer
- ☐ Other (please specify) ________________________

Airgaps within walls and slabs

- ☐ Resistance fixed within code
- ☐ User-specified constant resistance
- ☐ Resistance calculated within code as a function of orientation
- ☐ Resistance calculated within code as a function of temperature difference
- ☐ Radiation and convection treated separately across airgaps
- ☐ Treated as additional zones
- ☐ Other (please specify) ________________________

Windows (heat loss)

- ☐ Fixed resistance used for window element
- ☐ Dynamic treatment of window heat loss using same scheme as for opaque elements
- ☐ Other (please specify) ________________________

Airgaps within windows

- ☐ Resistance fixed within code
- ☐ User-specified constant resistance
- ☐ Resistance calculated within code as a function of orientation
- ☐ Resistance calculated within code as a function of temperature difference
- ☐ Radiation and convection treated separately across airgaps
- ☐ Airgaps treated as additional zones
- ☐ Other (please specify) ________________________

Windows (transmission of direct shortwave radiation)

☐ Fixed transmission used
☐ ASHRAE solar heat coefficients used
☐ Calculated by code as a function of incidence angle
☐ Calculated by code from user-specified function of incidence angle
☐ Other (please specify) ______________________

Windows (transmission of diffuse radiation)

☐ Diffuse radiation treated as direct from fixed altitude (please specify) ________
☐ Other (please specify) ______________________

Distribution of solar radiation within zones

☐ Fixed within the code
☐ Constant user-specified distribution
☐ Calculated once by code and used throughout (please describe algorithm) ___________
☐ Calculated as a fuction of solar position (please describe algorithm) ___________

Heat transfer betwen external surfaces and surrounding environment

☐ Radiation and convection combined
☐ Radiation and convection treated separately

External convection

☐ Coefficients fixed within code
☐ User-specified constant coefficients
☐ Calculated within code as a function of orientation
☐ Calculated within code as a function of surface finish
☐ Calculated within code as a function of wind speed
☐ Calculated within code as a function of wind speed and direction
☐ Other (please specify) ______________________

External radiative heat transfer

☐ Assumed to be to ambient air temperature
☐ Assumed to be to sky temperature read from met file
☐ Based on calculated sky temperature (please specify algorithm and requirements) _______
☐ Includes view factor of surrounding obstruction

Diffuse sky model

☐ Isotropic
☐ Other (please specify model used) ______________________

IEA 21C/12B Empirical Validation
Hotline Newssheet No. 9

1. Introduction

The main purpose of this newssheet is the distribution of a list of uncertainties in the data provided to you, as promised in Newssheet No. 8. This information will allow you to undertake sensitivity studies for inclusion in your report on further analysis (see Newssheet No. 8 for details). Please send your short report back by **31st of July** if possible.

Only about half of the participants have so far returned the model information proforma which was included in the last newssheet. **Could I ask anybody who has not returned the form yet to do so very soon.** It will only take a few minutes of your time, but will provide important information for the final report.

2. Table of Uncertainties in the Description of the EMC Test Rooms

The following table describes the uncertainties in the parameters supplied in the site handbook describing the EMC test rooms [1].

Table	Parameter	Nominal value	Uncertainty	Notes
Site Details				
3.1	Latitude	52.07°N	±0.05°	Note 1
3.1	Longitude	0.63°W	±0.05°	Note 1
3.1	Altitude	100 m	±5 m	Note 2
3.1	Ground reflectivity	0.20	±0.05	Note 3
3.1	Glazing orientation	9° W of S	±0.5°	Note 4
Test Room Surface Finishes				
5.1	External surface absorptivities	0.16	-0.06 +0.14	Note 5
5.1	Internal floor absorptivity	0.50	±0.10	Note 6
5.1	Internal other surface absorptivities	0.16	±0.02	Note 6
5.1	Internal and external emissivity	0.9	±0.05	esti-mate
Material Properties				
5.2	Styrofoam conductivity	0.027 W/mK	-0.002 +0.006 W/mK	Note 7
5.2	Concrete heat capacity	1840 kJ/K	±184 kJ/K	Note 8
5.3, 5.4, 5.5, 5.6, 5.7, 5.8	Rockwool conductivity	0.043 W/mK	±0.003 W/mK	Note 9
5.3, 5.4, 5.5, 5.6, 5.7, 5.8	Rockwool thickness	Various	±10 mm	Note 10
5.3, 5.4, 5.5, 5.6, 5.7, 5.8	Plasterboard heat capacity	937 kJ/K	±94 kJ/K	Note 11

5.3, 5.4, 5.5, 5.6, 5.7, 5.8	Wood conductivity	0.125 W/mK	±0.025 W/mK	Note 12
5.3, 5.4, 5.5	Edge effects	Various	-0 +50%	Note 13
Glazing properties				
5.8	Glazed area	1.500 m²	±0.02 m²	Note 14
5.9	Glass extinction coefficient	0.030 mm^{-1}	±0.005 mm^{-1}	Note 13
n/a	Glazing cleanliness	1.00	-0.02 + 0.00	Note 14
Test Room Heater Characteristics				
5.18	Heater power	680 W	±40 W	Note 15
5.18	Heater R/C split	60/40	±10/10	Note 16
5.18	Heater time constant	22 minutes	±2 minutes	Note 16
n/a	Test room ventilation rate	0.00 ac/h	-0.00 + 0.05 ac/h	Note 17
7.3	Setpoint	30°C	±0.2°C	Note 18

3. Notes to the Table

1. The location of the site was originally derived from the local Ordinance Survey sheet [2]. It has subsequently been measured using the satellite Global Positioning System [3] and this measurement found to agree with the figures derived from the map to within 0.002°. The figure given in the table thus represents a very pessimistic estimate of the uncertainty in the location of the test rooms.

2. The site is located in relatively flat countryside. A 100 m contour passes within approximately 200 m of the test buildings [2]. In addition to this, the height of the centre of the adjacent airfield main runway (which is 1700 m the other side of the test buildings) is known to be 111 m. Taken together, these pieces of information allow us to estimate the uncertainty in the site altitude as ±5 m.

3. The uncertainty assumed is in line with that chosen in previous studies [4].

4. The orientation of the test rooms has now been measured using several different techniques, and the figure given in the table again represents an extremely pessimistic estimate of the uncertainty in this figure.

5. The error band given is intended to account for the possibility of dirt on the external surfaces of the test rooms. In fact the surfaces were clean at the time these datasets were collected, and this therefore represents a very pessimistic estimate of the uncertainty in this parameter.

6. The solar reflectance of the white paint used on the test room walls and ceiling was measured by spectrophotometry, after conditioning the samples inside the test rooms [5]. The absorptivity of the test room floor was not measured directly, but the paint manufacturer's tabulated figure for the reflectance was 0.494 [6]. However the British Standard for paint colours [7] lists the reflectance of this shade as 0.42.

Subsequent comparison with other manufacturer's data for paints of ostensibly the same shade also produced a value of 0.42 [8], although this may, of course, have been taken directly from the Standard. For these reasons the relatively large uncertainty shown in the table has been assumed.

7. The conductivity of Styrofoam was supplied by the material manufacturer [9], who will have measured it to an accuracy of ±3% [10]. However, there is known to be some variation between batches of this material, and after further discussion with the manufacturer this was assumed to add a further -5% +20% to the uncertainty in the properties of the material actually installed.

8. The density of the concrete slabs used in the test rooms was measured on site by weighing a number of slabs. The density was then calculated assuming nominal dimensions, removing this source of uncertainty from the simulation process. The remaining uncertainty comes from the use of the manufacturer's figure for the material specific heat capacity.

9. The approach taken to assess the conductivity of the Rockwool installed in the rooms follows that for Styrofoam (Note 5). The manufacturer's quoted value [11] is again assumed to have been measured to an accuracy of ±3% [10]. Variations between batches of the material are assumed to add a further ±4% to this figure.

10. This value was determined by measurement. That measurement has subsequently been repeated [12] and the value originally obtained determined to be adequate.

11. The rationale behind the uncertainty assumed here follows that for the capacity of the concrete floorslabs (see Nate 6).

12. Estimate of softwood conductivity uncertainty is hard to derive. The value quoted (0.125) is the CIBSE A3 [13] value for DeaL CIBSE gives 0.13 for generic 'Softwood' and 0.105 for Spruce. ASHRAE [14] gives values for Spruce-Pine-Firs from 0.107 to 0.130. On seeing the large variation in quoted values a rather large uncertainty range was chosen.

13. The treatment of test room edge effects is acknowledged to be approximate in the site handbook. Not all edges are treated, and those which are have been assumed to be of only two types. The resulting uncertainty was originally estimated as ±30%. Subsequent discussions with Martin Gough, of EDSL Ltd, have identified a number of reasons why this may not be <u>sufficient</u>. In particular the front edge of the room adjacent to the party wall is likely to have a much higher loss than that assumed. Together with the fact that not all edges were treated this suggests that the published edge effects are very unlikely to be overestimates, and the uncertainty estimate has been modified to -0/+50%.

14. The area of the test room glazing is in some cases slightly reduced by the intrusion of the double glazing spacer unit into the window aperture [12], and this effect has been accounted for by assuming a small uncertainty in the size of that aperture. The glazing was cleaned every few days during data collection. However, a small allowance has been made for the fact that some dirt may have accumulated. This has been simulated by incorporating an additional uncertainty in the transmission, of between 100% (implying clean glass) and 98% (implying a small amount of dirt). The glazing extinction coefficient was deduced from the manufacturer's figure for the normal transmission of a single

pane of the glass, and the assumed uncertainty reflects the uncertainty in the measured transmission. The thickness of the glass has been measured to a high degree of accuracy, and the small uncertainty which remains is effectively absorbed into the uncertainty assumed for the extinction coefficient

15. The uncertainty in the measurement of the delivered heater power is small, at ±2% [1]. However, there are significant production tolerances in the power outputs of the heaters in different rooms, and there are variations in power output with the surrounding environment The figure shown has been derived by examining the peak power consumption of each room over the course of many days.

16. The heater R/C split and time constant were derived from a combination of calculation and measurement [14]. The radiative and convective outputs of the panel were calculated, and used to derive the R/C split.. The total power output at a given temperature was then compared with the result of this calculation and found to be within 2%, lending some credibility to the calculation. On the basis of this result the uncertainty in the proportion of the heat output which is, say, radiant, is believed to be less than ±10%. The heater time constant was derived by operating the heater pseudo-randomly and deriving the step response of the surface temperature to power input The step response was found to be well represented by a first order system with a time constant of 22 minutes. The uncertainty in determining this time constant was ±2 minutes.

17. The measures taken to ensure the airtightness of the rooms have already been described in detail in the validation package, [1] and [12).

18. The uncertainty in the measurement of the control temperature, from which the setpoint is maintained, is the same as the uncertainty in the other temperature measurements, ±0.2° C.

4. Further Comments on Parameter Uncertainty

The above table only contains uncertainties in fundamental physical properties (as does the sit' handbook [1]). It is a policy in this empirical validation exercise that we do not supply derived parameters which may be required by some programs, but let the program users make their own decisions about appropriate values for such parameters. The same policy applies for the uncertainty in derived parameters. We would, however, be happy to give advice on this issue. Parameters falling into this category are, for example, window U-value and air gap resistance.

The site handbook contains numerous materials, with 4 parameters used to describe each material (conductivity, density, specific heat, thickness). Each of these parameters has some uncertainty associated with it. However, it would be a huge task to undertake a complete sensitivity analysis, taking due account of the possible link between parameters, e.g. the conductivity of mineral wool is related to its density etc.

Fortunately, a great deal of work was done within the BRE/SERC study [4] in this area. Based on this work, and preliminary studies by Chris Martin using SERI-RES, it was clear that only selected properties of certain materials were significant in this context. This is particularly so when bearing in mind that the total sensitivity is approximated by the quadrature addition of individual sensitivities. Thus small sensitivities are suppressed. Only the key parameters are therefore listed in the table. However, if you wish to confirm that this list is appropriate, please do so.

Uncertainties for some parameters given in the site handbook are not listed in the table:

- site exposure - the input of this parameter is model specific
- area of surfaces - the sensitivity to possible errors is very small
- ceiling external absorptivity - this is irrelevant as there is no solar radiation in the roof space
- glass refractive index - uncertainty negligible

roof air change rate - parameter was estimated, a range between 1 and 3 air changes per hour has been used previously [4]
(The roof space has only very small ventilation openings. An infiltration rate higher than 3 is therefore very unlikely).

For the October measurement period, no information about **external relative humidity** was available. If your program uses this parameter, you may wish to undertake a sensitivity study, using values between 55 and 100%, which is an extreme range occuring in the UK at Kew during October. Values outside this range are very unlikely.
Concern had also been expressed in the past by some participants about the validity of the measured values for the May period. Again you may wish to include this period in your sensitivity analysis, using, as above, suggested values between 35 and 100%.

With regard to the **external solar absorptivity of the floor,** the information given in the site handbook could be misleading. An absorptivity of 0.5 is given in the site handbook. Whereas this is the correct value for chipboard, in reality it should actually be modelled as 0 in this case, because no solar radiation is falling on this surface.
This is particularly relevant if the cell has been modelled as 'floating in space', i.e. without connection to the ground and without specifying an extra zone for the floor space. A sensitivity study might be appropriate.

REFERENCES

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[2] UK Ordinance Survey Sheet 153: Bedford and Huntingdon.

[3] Sensitivity Analysis Techniques for Empirical Validation of Building Thermal Simulation Programs. K J Lomas and H EppeL Presented at Workshop: Validation of Building Energy Models, Electricité de France, June 9&10 1992.

[4] An investigation into Analytical and Empirical Validation Techniques for Dynamic Thermal Models of Buildings Vol. 4. K J Lomas and N T Bowman. September 1987. UK Science and Engineering Council Report GR/C/62871.

[5] Evaluation of the Solar Reflectance of Four Samples of Painted Cement submitted for test by Cardiff University Industry Centre. B M Cross. February 1986. EETS Ref no. 2.

[6] Sikkens, Permoglaze, Sandtex: Trade Colour Card. 1992. AKZO Coatings plc.

[7] British Standard 4800. Paint Colours. British Standards Institution.

[8] Colour Dimensions. ICI Paints Ltd.

[9] Dow Chemicals. Styrofoam for Cold Storage Insulation. February 1989.

[10] British Standard 874 Part 2: Section 2.1. Methods for determining thermal insulating Properties. British Standards Institution.

[11] Rockwool

[12] High Quality Data for Empirical Model Validation: Quality Assurance at the EMC Test Room Site. C J Martin and D M J Watson. March 1993. IEA Report no IEA21RN330/93.

[13] CIBSE Guide A3, Chartered Institution of Building Services Engineers, London, 1986.

[14] ASHRAE Handbook, 1989, American Society of Heating and Refrigeration Engineers, page 22.9.

[15] Detailed Model Comparisons: An Empirical Validation Exercise using SERI-RES. C J Martin. June 1991. Report to ETSU S1197-P9.

IEA 21C/12B Empirical Validation
Hotline Newssheet No.10

1. Introduction

The time-scales for the remaining work in the lEA 21 Empirical Validation exercise are dictated by the final IEA meeting which is to be held towards the end of September in Paris. We have therefore agreed a series of strict deadlines with Dave Bloomfield (BRE). We have tried to give you (the program users) as much time as possible to prepare your contributions, which leaves us a very tight schedule for collating all the information and preparing the IEA report on the exercise. Please adhere to the deadlines given in the table below. **Activities to be undertaken by you - the participant - are highlighted.**

2. The final IEA report on the Empirical Validation exercise

We intend to sort out Part 1 of the final lEA empirical validation report - the blind phase - very soon (see table of deadlines below).

Concerning Part 2, the non-blind phase, we have had some feedback suggesting, with some justification, that the deadline for submitting the 3-page follow-up reports was rather tight. A new but absolutely final deadline has been set. (Clearly, if you have already submitted a short report, which you would like, on reflection, to change, then by all means do so, provided you let us know and that the new version arrives by the deadline). Please note that the same dead-line applies for the return of the Model Information Proformas (see Newssheet 8). Most of you have returned this by now.

We intend to comment on all the 3-page submissions we received by August 13th. In this feed-back we will seek clarification where necessary, suggest editorial amendments and point out errors of fact. We also need a clear indication of what your new final results are and the error bands associated with them (if you have estimated these). It is possible estimating error bands using the uncertainties given in Newssheet no.9 and a simple differential sensitivity analysis approach. We would much prefer to receive your new results on a disk (or via E-mail) in the same format as before (see the Validation Guidebook, Section 4).

The agreed final versions of these model reports will be published without any amendment by us in the IEA report. We will add text in the main body of the report to highlight the main /recurring features in your reports and other aspects of interest. We will also produce a second set of graphs showing the amended results from the programs in this second, non-blind, phase.

3. Hotline

Please use the hotline to keep in touch and to seek clarification on any aspect of the exercise.

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Summary of Deadlines	
Date	Activity
August 6	Mailing of draft Part 1 of final IEA report
August 13	**Revised deadline for return of 3-page report**
August 13	**Final deadline for return of Model Information Proforma**
August 27	Feedback from DMU on 3-page report
August 27	**Feedback on draft Part 1 of final IEA report**
September 10	**Return of revised 3-page report**
September 13 week beginning September 20	Attempt to mail out draft of complete final IEA report, failing that: Draft of complete final report will be tabled at meeting

IEA 21C/12B Empirical Validation
Hotline Newssheet No.11

1. Final Report

As you know, we are 'running hard' to produce the final empirical validation report for the September IEA meeting. As outlined (Newssheet 10), we are circulating the first draft of the final report and look forward to receiving your feedback. Note that the draft is strictly **confidential** at present.

(a) We are particularly interested in your comments on the interpretation of the individual results (Section 2.3), specifically, the observations made about individual programs. Are these comments fair? Are there any features of the results which have been overlooked? Are there any general trends which begin to emerge but which have not been noted?

(b) Are the graphs and tables clear (or as clear as they can be) and does the data accurately reflect the results which you sent us?

1.1. Associated Documents

We plan to produce a new Validation Package in one volume as described in the Report. We are working on this and plan to circulate it soon (although it will not look much different from the version which you already have). Are there any changes you would like us to make?

1.2. Working Reports

The IEA working reports and Newssheets will be put together in one volume, without change, as a record of the progress of the exercise.

2. Phase 2

The deadline for the receipt of your 3-page reports is rapidly approaching (August 13). We want to be able to present a better set of results with **defensible** explanations of the reasons for the divergences shown in Phase 1. Ideally, this would take the form of a second set of figures and tables (and an appendix) just like that for Phase 1. Please send us your new results on a disk, following the same format as for Phase 1. Clearly, we can only plot and analyse what we get - no data, no plots!

3. Deadlines

Please refer to Newssheet 10 for deadlines up to the IEA meeting and contact the hotline if you have any queries.

IEA 21C/12B Empirical Validation
Hotline Newssheet No.12

1. New Hotline Fax Number

We now have a new, for us more convenient fax in our office. The number is +44 533 577449. However, you may continue to use the old number.

2. Program User Reports

The deadline for submission of the individual Phase 2 Program User Reports was August 27th; many participants have not yet sent a report (Table 1). Nevertheless, we are still prepared to accept a report at this stage but they must arrive by September 10th (see Newssheet No.10). It may however not be possible to provide feedback as planned. Please tell us whether or not you intend to try and submit one.

2.1. Feedback

For those participants who have submitted a Program Users Report, their personal and confidential feedback accompanies this document. A blank feedback form is attached for those participants who have not yet submitted a report to show them the style our feedback takes. The purpose of the feedback is to:

(i) eliminate information which is factually incorrect;
(ii) request clarification of important points, where necessary;
(iii) encourage expansion of interesting lines of argument; and
(iv) seek advice on how to improve the Validation Package and the conduct of empirical validation exercises.

We look forward to receiving amended versions of the reports where this is necessary by September 10th. Please use the Hotline to discuss our feedback if you wish. We intend to publish all the amended reports, without any modifications, but subject to (i) above, in the final IEA empirical validation report.

3. Final IEA Report

In the main body of the final IEA report we will produce new versions of Figures 2, 3, 5 and 7 containing the results from the Phase 2 modelling studies. We. also hope to produce new version of Figures 4 and 6. Please let us have the appropriate data, if you have not already done so (Table 1). We would also like feedback on our draft report from all participants (Table 1), and it would be helpful if the remaining participants could send us the Model Information Proforma, so that we can update and improve Table 7 of the final IEA report.

Table 1: Final IEA Report (Phase 2) Status

Name	Institution	Comments on draft report received	Model Information Pro-forma received	Intend to submit program user report	Program user report received	Intend to submit revised results	Revised results sets received
Michael Holtz	Arch. Energy Corp.	No	N/A	N/A	N/A	N/A	N/A
Ron Judkoff	NREL, USA	No	N/A	N/A	N/A	N/A	N/A
Martin Gough	EDSL, UK	Yes	Yes		Yes	?	
Shirley Hammond	BRE, UK	No	Yes		Yes		Yes
Foroutan Parand	BRE, UK	No	Yes	?		?	
Eduardo Rodriguez	ESII, Sevilla, E	No	Yes	?		?	
T. Kalema / T. Haapala	Tampere UoT, FIN	Yes	Yes		Yes	No	
A. Mazza / V. Bocchio	Polit. di Torino, I	No	Yes		Yes		Yes
B. Fredlund / Maria Wall	Lund IoT, S	No	Yes		Yes	No	
Peter Verstraete	VU Brussel, B	No	Yes	?		?	
Doug Hittle	CSU, USA	Yes	No	No		No	
Mike Holmes	Arup R&D, UK	Yes	Yes		-	?	
Mike Kennedy	Ecotope, USA	No	No	?		?	
Pascal Dalicieux	EDF, F	-	Yes	No		No	
Peter Pfrommer	FHT Stuttgart, D	Yes	Yes		Yes		Yes
Don Alexander	UWCC, UK	No	No	?		?	
S. Irving / A. Tindale	Facet, UK	No	Yes	Yes		?	
Paul Strachan	ESRU, UK	Yes	Yes		Yes	?	
Lorenzo Agnoletto	IdFT, Udine, I	No	No	?		?	
Glenn Stuart	ASL, UK	Yes	No		Yes	?	
Angelo Delsante	CSIRO, AUS	No	No	?		?	
Kjeld Johnson	SBI, Dk	Yes	Yes		Yes		Yes
Jeff Thornton	UWISC SEL, USA	No	No	?		?	
Fred Winkelman	LBL, USA	No	Yes		Yes	No	

Program User Report Feedback

Program:

User:

Text

1	Report has acceptable length	Yes / No
2	Report makes errors of fact	Yes / No
3	Report should/could include further results	Yes / No
4	Report should/could include points of clarification	Yes / No
5	Report contains (some) typographical errors which hinder understanding	Yes / No
6	Good quality copy of report on paper or on disk (PostScript or WordPerfect) would be welcome	Yes / No

Results

7	New digital results received (E-mail or disk)	Yes / No
8	Revised versions of Figures in draft IEA Report (IEA21RN372/93) can be produced from the information given:	
	Figure 2a	Yes / No
	2b	Yes / No
	2c	Yes / No
	Figure 3a	Yes / No
	3b	Yes / No
	3c	Yes / No
	Figure 5a	Yes / No
	5b	Yes / No
	5c	Yes / No
	Figure 7a	Yes / No
	7b	Yes / No

General

9	Views on specific aspects sought	Yes / No

Please see attached sheet for further details (where appropriate)

IEA 21C/12B Empirical Validation
Hotline Newssheet No.13

The Empirical Validation exercise within IEA 21C/12B is rapidly coming to an end. We plan to have the work written up by November for approval by the IEA Executive Committee.

The work will be published in three volumes:

Volume 1: Final Report

Volume 2: Empirical Validation Package

Volume 3: Working Reports

At the recent IEA meeting in Fontainebleau, France, it was decided that no more 3-page Model Users Reports can be accepted. However, we are still awaiting new, improved, results sets from some participants who have submitted a Model Users Report. Table 1 gives an overview of the status of the exercise. Please note that the **final deadline** for submission of new results is **Friday, the 8th of October.**
At the meeting it was also decided that we should get from participants the revised input files which form the basis of any new results. Only those revised results which are accompanied by such input files will be published in the final report.

During October, a draft of the complete final lEA report will be sent to participants for comment. Participants will have two weeks to make their views known.

Table 1: Empirical Validation Exercise (Phase 2) Status

Action Required	Name	Institution	Model User Report received	Modifications to Report required	Intend to submit revised results	Revised results sets received	Revised input files required
⇒	Martin Gough	EDSL, UK	**Yes**	**Perhaps**	**?**		
⇒	Shirley Hammond	BRE, UK	**Yes**	**Received**		**Yes**	**Yes**
⇒	Foroutan Parand	BRE, UK	**Awaiting**	**Yes**	**?**		
⇒	T. Kalema / T. Haapala	Tampere UoT, FIN	**Yes**	**Yes**	**No**		
⇒	A. Mazza / V. Bocchio	Polit. di Torino, I	**Yes**	**Yes**		**Yes**	**Yes**
~	B. Fredlund / Maria Wall	Lund IoT, S	**Yes**	**Perhaps**	**No**		
⇒	Mike Holmes	Arup R&D, UK	**Some comments**	**No**	**?**		
	Peter Pfrommer	FHT Stuttgart, D	**Yes**	**Received**		**Yes**	**Received**
⇒	S. Irving / A. Tindale	Facet, UK	**Awaiting**		**?**		
⇒	Paul Strachan	ESRU, UK	**Yes**	**Received**		**Need decision**	
⇒	Glenn Stuart	ASL, UK	**Yes**	**Yes**	**?**		
⇒	Kjeld Johnson	SBI, Dk	**Yes**	**Perhaps**		**Yes**	**Yes**
~	Fred Winkelman	LBL, USA	**Yes**	**Perhaps**	**No**		

For participants not listed in the table it is too late to submit follow-up work.

IEA 21C/12B Empirical Validation
Hotline Newssheet No.14

The intention of this brief Newssheet is to keep participants informed about the progress of the empirical validation exercise and the preparation of the final documents. As described briefly in Newssheet 13, the work will be published in three volumes:

Volume 1: Final Report

Volume 2: Empirical Validation Package

Volume 3: Working Reports

- **Volume 1:** Due to the international collaborative nature of the work, there have been some delays in the preparation of the Final Report. All participants can expect to receive a copy of the document, after approval by the IEA 21C/12B members.

- **Volume 2:** The final draft of the Empirical Validation Package has now been produced. It is mainly a collection of slightly modified versions of documents which have been circulated previously. The draft has been sent to IEA 21C/12B members for review. After final approval, the document will be sent to all participants.
  The intention is to make the package known as widely as possible, so that current and future program users and developers can benefit from it.

- **Volume 3:** The Working Reports are merely a collection of unmodified reports and documents which had been circulated previously. They will not be circulated again to all participants, but will be available on request from the Hotline.

Empirical Validation Status 9.11.93 (MUR in table = Model User Report)

Name	Institution	Comments
Martin Gough	EDSL, UK	sent **MUR + new results**
Shirley Hammond	BRE, UK	sent **MUR + new results**
Foroutan Parand	BRE, UK	no MUR, no new results
Eduardo Rodriguez	ESII, Sevilla, E	no response
T. Kalema / T. Haapala	Tampere UoT, FIN	sent **MUR**, no new results
A. Mazza / V. Bocchio	Polit. di Torino, I	sent **MUR + new results**
B. Frędlund / Maria Wall	Lund IoT, S	sent **MUR**, no new results
Peter Verstraete	VU Brussel, B	sent **MUR**, no new results
Doug Hittle	CSU, USA	no intention to send MUR, error in results reported, new results requested, no response yet
Mike Holmes	Arup R&D, UK	no MUR but some comments, no new results
Mike Kennedy	Ecotope, USA	no MUR just comments, **new results**
Pascal Dalicieux	EDF, F	no MUR, no new results
Peter Pfrommer	FHT Stuttgart, D	got **MUR + new results**
Don Alexander	UWCC, UK	no response
S. Irving / A. Tindale	Facet, UK	no response
Paul Strachan	ESRU, UK	sent **MUR**, no new results
Lorenzo Agnoletto	IdFT, Udine, I	no MUR just comments, **new results**
Glenn Stuart	ASL, UK	sent **MUR**, no new results
Angelo Delsante	CSIRO, AUS	no MUR, no new results
Kjeld Johnson	SBI, DK	sent **MUR + new results**
Jeff Thornton	UWISC SEL, USA	no response
Fred Winkelmann	LBL, USA	sent MUR, no new results

Total: 10 MURs, 7 new result sets

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