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Data sets for validating thermal models of buildings

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Building Environmental Performance Analysis Club

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SUMMARY

Empirical validation, in which the predictions of a thermal model are compared with actual performance of a building, is the ultimate test of a model's accuracy. The data, against which the predictions are compared must, however, be of highest quality if 'internal errors' within complex simulation programs are to be revealed. This note describes around 600 monitored buildings located throughout the world, varying from single zoned test cells to multi-storey commercial buildings. For each of these, hourly on-site weather and building performance data were gathered so they were termed 'acceptable date sets'. This document contains detailed descriptions of over 200 of these which includes: the institution rsponsible for the monitoring; the building and weather parameters recorded; the use to which the data has been put; any particular strengths or weaknesses which the data sets may have; and an extensive reference list to further sources of detailed information. The 250 references listed include descriptions of over 130 comparisons between model predictions and measured building performance data. This is believed to be the most comprehensive review and compilation of its type ever assembled.

By progressively applying more stringent criteria, some of the acceptable data sets were reclassified as either 'useful' or 'high quality'. These criteria are seen as the minimum standards with which hourly data sets must comply if they are to provide credible `benchmarks' for evaluating a range of dynamic thermal models.

Only 20% of the data sets were classified as useful and only 23 buildings have provided high quality data. Those U.K. data sets for which the data is readily available are described in even greater detail.

DATA SETS FOR VALIDATING DYNAMIC THERMAL MODELS OF BUILDINGS

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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[1]. This group worked from 1983 to 1986 and was interested in models which predict plant loads and energy fluxes rather than those which were aimed at simulating HVAC or active solar systems, and worked with ESP[2], SERIRES[3] and HTB2[4]. The primary thrust of the work at Leicester Polytechnic was to generate tests (or tools) to assess the adequacy of dynamic thermal models 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 models themselves, such as inappropriate simplifications of the real world, invalid mathematical approximations and coding errors. To do this, however, 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 procedure used to compare measured and predicted values (examples of external errors have been published elsewhere[5]).

The elimination of external errors is no easy task, indeed, in a recent review of previous empirical validation work[5] 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 quality 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 of sufficiently high quality. This covered buildings of all types from small, single cell 'boxes' through to very large and complex multi-storey commercial buildings. The aim was to obtain suitable data sets to enable a suite of validation tools to be generated covering the widest possible range of building types, modes of operation and climatic types.

The strategy which was adopted to try and isolate such data sets consisted of four phases.

Phase 1 : Preliminary acceptance criteria were devised to define the minimum requirements which data sets must fulfil if they are to be of value for validating any dynamic thermal model. These were termed Acceptable Data Sets.

Phase 2 : The widest possible range of acceptable data sets were identified. These were classified by structural type and their salient features were tabulated to enable evaluation in Phases 3 and 4.

Phase 3 : Criteria were devised to screen out data sets which contain external errors which would prevent them being useful for validating any dynamic thermal model. Data sets which passed this phase were termed Useful Data Sets.

Phase 4 : Further criteria were devised to identify those data sets which should be useful for validating the widest range of dynamic thermal models. These were termed High Quality Data Sets. Since the end of the SERC/BRE research project a number of new high quality data sets have been collected in the UK. These, and others for which the data is readily available, are described in more detail.

This four phase methodology proved to be very workable and could be useful for classifying new data for a wide range of applications. For example, acceptable data sets which pass the Phase 1 criteria could be used for such things as the generation of control codes for building energy management systems or the production of energy design guides. Useful data sets which pass Phase 2 may be useful for generating and testing simple design tools which predict monthly average, rather than hourly, performance. High quality data sets which pass Phase 4 could, in addition to the foregoing uses, be useful for validating complex dynamic thermal models.

The criteria devised at each phase are discussed in this paper and the acceptable data sets identified in Phase 2 are described. The compilation covers around 600 buildings, and over 250 references to the source material are given. This is thought to be the most comprehensive compendium of information of its type ever produced. It will therefore form a useful text for building scientists who are seeking data on the relationship between the performance of buildings and the imposed climatic and occupancy conditions.

It is not possible to fully explain all the details of the work in this paper, however, it has been fully documented in one volume of the final report on the SERC/BRE validation project (Lomas[6]).

2. PHASE 1 : IDENTIFYING ACCEPTABLE DATA SETS

Most dynamic thermal models, and certainly those being used in the SERC/BRE validation exercise, cannot simulate active solar space heating systems, although some, such as SERIRES, purport to model hybrid systems such as rock bins and convective loops. The models require hourly, or more frequent, weather data gathered at the site of the building being modelled, in order to produce accurate predictions. Therefore, the preliminary acceptance criteria were defined as follows:

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.

Compiler, Title, Year, Reference	Objectives and Class of Data Included	Number, Location and Type of Structure Included	Contents of the Data Base
US DOE Passive Solar Class A Performance Evaluation Programme 1981>, [159,170]	To collect and archive Class A data for validating dynamic thermal models at the component/algorithm level.	Passive heating: 1 Test Cell; 2 Residences; 2 Experimental Facilities. Passive cooling: 4 Experimental Facilities. All located in the USA and unoccupied.	Data may still be being gathered at some sites. Site handbooks have, or will be, prepared. Data achived will cover one to two weeks. Comparisons between measured performance of three facilities and model predictions have been made [109].
SERI Data Base for Validating Passive System Computer Models 1980, [22]	To collect consistent and coherent data which can be used to validate computer models of passive solar systems through correlations with monthly performance data.	6 Test Cells: 1 direct gain and 1 Trombe wall cell at each of three sites. 5 Residences: All sites are in the USA. They cover 4 climatic regions.	The data bank contains a complete description of the building plus two weeks of measured data covering sunny and cloudy days.
NBS Selected Measured Data from Residential Housing for Use in Testing and Verification of Building Energy Analysis Programs 1982, [200]	Hourly weather and heating or cooling systems performance and hourly weather data has been gathered which, it is believed, is of sufficient detail for all existing computer programs.	Data was culled from that gathered in three large monitoring efforts: 6 Occupied Residences and 1 Unoccupied Residence in the USA.	Data tapes contain a description of the building and 10 successive days of hourly data.
AIAF Archive of Data from Passive Solar Commercial Buildings 1981>, [141]	To provide a unique resource of consistent data for evaluating the energy performance and cost effectiveness of passive solar commercial buildings.	18 Occupied Commercial Buildings in the USA. Including: 5 assembly buildings; 4 retail stores; 5 schools; 2 offices; 1 lodging and 1 health centre.	Documentation about the buildings and monitoring techniques. Monitored monthly and hourly energy use records, or monthly meter readings. An evaluation of the integration of occupants and systems. Individual buildings have been described elsewhere e.g. [152].
BRECSU/BRE for UK DOE Monitored Domestic Energy Use Archive 1975>, [23,24]	To extend the range of monitored data available to academics, designers and housing planners and managers.	507 Residences on 9 sites throughout the UK. 8 sites with between 28 and 56 houses and one with 196 [89]. Virtually all are occupied. Data collected for the Better Insulated House [91] and Energy Improvement Kit programmes.	Energy use available for virtually all houses and some hourly internal temperatures and weather data for most of them. Parameters measured and recording frequency varies between sites. Preparation of manuals, cataloguing the data available and data archiving, is in progress.

TABLE 1 Data stored in computer data bases for validating thermal models

Compiler Year and Reference	Purpose	Number, Type and Location of the Buildings Included	Format of the Information
Moore E., and McFarland R.D., 1982 [202,217]	To present the results of a survey of the use of test boxes, rooms, and buildings for passive solar research in the USA and Canada.	Includes: 2 twin box and 12 single box test modules, 17 twin room and 15 single room test modules, 9 buildings with between 1 and 6 attached greenhouses and 30 experimental buildings. Others are mentioned in the text.	A brief description of the buildings and the purpose of the experiments at each site is given. Compiled information about most of the sites is presented in matrix form. It includes: the monitoring period; the type of building and its size; the type of sensors used for monitoring the building and weather; the type of data acquisition system; the number of channels logged; and the format of these data.
L. Jones & Assoc., 1985 [7]	Table a: To identify data sets suitable for validating models which predict residential house performance in a Canadian context.	About 240 sites of monitored data from around the world are listed. Includes 34 test cells, remainder are single or multi-family residences.	Information about each site is given in matrix form. It includes an indication of: climate severity; building type; the design features; the heating system; level of monitoring; and data availability. Monitoring levels and occupancy information given for 133 structures only.
	Table b: To summarise post papers concerned with a quantitative assessment of the technical accuracy of models.	Lists 81 papers which detail empirical validation studies or inter-model comparisons using structures which range from test cells to commercial buildings and involving between 1 and 23 models.	Seventeen tables indicate: the type of validation; the programs involved; the models involved; the source of the data; and the reference source, year and subject matter.
Jones R.W., 1982 [188]	Present performance results from monitored passive and hybrid solar heated buildings.	Describes structure and performance of 6 residences in New Mexico, USA.	Each building and it performance is described individually.
Heidell J.A. et al, 1985 [154]	To provide a well-documented data base of measured end-use energy consumption.	Lists 37 data sets from individually monitored, occupied commercial buildings. All are in the USA.	Lists attributes of each data set and briefly describes the building, its use and measured energy consumption. Lists many other multi-building end-use monitoring projects in the USA. Notes lack of, "well-documented sources of metered end-use data in the public domain".

TABLE 2 Publications containing compiled information about data sets (continued)

Compiler Year and Reference	Purpose	Number, Type and Location of the Buildings Included	Format of the Information
AIA Research Corp., 1978 [153]	To collect articles detailing the thermal performance of monitored passive solar buildings.	Sixteen test cells, rooms or greenhouses, 44 residences, and 6 commercial buildings. All in USA.	Sixteen climatic zones in the USA are identified. For each zone, previously published information and supplementary notes about each building are compiled along with a matrix of their attributes: solar features included: level of monitoring; and the values monitored.
Littler J., and Watson M., 1981 [27]	To precis the use already made of scale models and component tests in the design of passive solar systems and recommend further work.	Includes about: 25 test cell or test box sites and 4 residences in the USA, and Europe and Australia.	Gives a written review of previously published information classified according to the passive solar features they include: mass walls, water walls, phase change material, thermosyphon systems, attached sun spaces, direct gain etc.
A.D. Little Inc., 1982 [25]	To identify high quality data from one or more residences for comparison with the predictions of five thermal models.	Identifies 12 sources of potentially usable test data in the USA. Data from 6 sites which included 30 residences was deemed suitable. Subsequently, data from 2 residences at one site were used.	Limited information is tabulated on all sites. With a more detailed discussion of the data from the site which was finally chosen for the study.
Wagner B.S., 1984 [11]	To collate information from studies in which the predictions of models have been compared with monitored data in order to dertermine the accuracy of models.	Over 24 validation studies using data from USA or Canadian buildings are identified. These include: 1 experimental house, 3 buildings tested in an environmental chamber, 556 residences, and, 12 commercial buildings.	Tabulated information describes: the buildings, its location, its mode of operation, fuel and HVAC type, the class of the data recorded, and the method of comparing measured and predicted values.
IEA Task VIII, 1985 [9]	To identify and index sources of monitored performance evaluation data for passive solar residential buildings in countries participating in Task VIII.	Includes 177 residences or similar sized experimental buildings for which automated monitoring of critical performance variables has been undertaken for at least six months. Fourteen are denoted as Class A sites, the remainder are Class B. Their locations are: Belgium, 3; Canada, 2; Denmark, 3; Norway, 8; Sweden, 7; Switzerland, 6; and the USA, 148.	Fourteen tables detail: location, type of building, construction, area, passive heating and cooling components, auxiliary system and fuel type, and the climate severity. There is, in addition, a single page entry for each site.

/continued

TABLE 2 Publications containing compiled information about data sets

Only acceptable data sets which pass all three criteria are described in this paper.

A three-tier classification system is often used to describe the overall level of detail with which a building has been monitored[7,8,9,10,11]. The above criteria effectively eliminate data which do not conform to the Class A or B requirements, ie. which have not been monitored at the mechanism or building system level (Burch[8,12]). Although Class C data, which involves assessing building energy use via utility company meter readings is excluded, attempts have been made to validate thermal models using such data[13,14]. Information on over 700 other buildings monitored at the Class C level can be found elsewhere[15,16,17,18,19,20].

3. THE SEARCH FOR ACCEPTABLE DATA SETS

The search began by interrogating fourteen computerised literature data bases (the majority of which are listed in a directory published by the Commission of the European Communities[21]). This work revealed numerous North American data sets but few in Europe and the rest of the world. Therefore, to broaden the number of regions covered, a questionnaire survey was conducted via the 21 members of the International Energy Agency (IEA) Executive Committee for Buildings and Community Systems. Information on monitoring work in Europe as well as in Japan and Australia was thus acquired. Finally, direct contact was made with researchers who appeared to be undertaking particularly relevant work. This included making site visits to eight research institutions in North America and two in the UK.

The literature search revealed the existence of five computer data bases containing monitored data for validating thermal models (Table 1). However, data in the Solar Energy Research Institute (SERI) data base[22] and from five of the sites in the BRECSU/BRE database[23,24] do not comply with the Phase 1 acceptance criteria.

Nine publications were discovered which contain compilations and evaluations of monitored building performance data (Table 2). Two of these, both by North American institutions, Littler Inc[25] and Jones and Associates[7], were specifically concerned with evaluating the worth of data for validating thermal models. The IEA compilation[9] contained many residences monitored at the Class B level which were part of large multi-building monitoring projects in North America (Table 3).

The literature search revealed, in total, 599 different structures from which acceptable data had been gathered. As most of these had been monitored in a variety of configurations, modes of operation and different weather conditions, the total number of acceptable data sets was very much larger. Source references were sought for 231 of these structures which, based on the limited information to hand at the time, were thought likely to have yielded the best data. It is the details of these structures which are classified and tabulated below.

The remaining 368 were either residences or commercial buildings which had been monitored at the Class B level. These comprised of 18 commercial buildings in the AIAF database (Table 1) and 37 in the Heidell compilation (Table 2), 6 occupied residences in the National Bureau of Standards (NBS) database (Table 1), and a further 157 residences with known occupancy patterns listed in either the IEA compilation or by Jones and Associates (Table 2). Finally, there were about 150 residences, with on-site weather measurements, in the BRECSU/BRE database (Table 2). The common features of

Responsible Institution, Title of Project, Year of Monitoring, Reference	Purpose	Number, Location and Type of Structure	Data Obtained and its Usage
VITRO Laboratories Div., National Solar Data Network, 1979> [210,211,212]	To evaluate the performance of a large variety of solar systems in both residential and commercial buildings.	As of 1980, only 8 of the 148 data sites operating had passive systems [212]. A further two have been reported elsewhere [184,129] At least five of the residences were always occupied, as were the three commercial buildings. They are all in the USA and all but two are in the Northeast.	An average of 90 sensors were used per structure, monthly and seasonal performance reports are published for each site. Monthly energy usage from one house has been compared with that predicted by a simplified method [214]. So too have the monthly energy use and hourly temperatures predicted by two other simplified methods [129,76] Comparisons between superinsulation and passive solar designs have also been made [199,156].
US-SERI, Residential Class B Passive Solar Performance Monitoring Programme, 1981> [204,191]	To provide consistent measurements of the thermal performance of passive solar residences to evaluate their performance.	Data from about 70 occupied houses in the USA has been obtained. These include 11 houses being monitored by the Californian Energy Commission [205,206,207,208, 256,257].	The Class B system uses 20 to 25 sensors. The data is limited to that necessary to calculate the monthly building energy balance. Monthly, as well as hourly, data will be available along with site handbooks. The performance of 50 houses is reported in [182]. The measured hourly temperatures and/or monthly energy usage of at least one house have been compared with the predictions of simplified models and a dynamic thermal model [174].
Bonneville Power Administration, Class B Passive Solar Monitoring Programme, 1981> [209]	To assess the thermal performance of new passive solar houses in the Pacific Northwest.	Three occupied and four unoccupied houses in Hillsboro, OR, and nine occupied houses in Spokane WA, USA.	The SERI Class B methodology and equipment was used. The total energy use for one house over a five-month period has been compared with that predicted by a simplified technique [183].
NRC, Canada, NRC/Solar Energy Programme Intermediate Level Passive Solar Monitoring Work, 1982> [215]	To determine the performance of passive solar homes and establish the uncertainty in building analysis programs and design tools.	Eight occupied, passive solar homes in various parts of Canada. Fifty-six more residences will be monitored in 1984/85.	The Class B monitoring records up to 24 channels. Monthly energy usage and the contributions from various sources are determined. Six further residences were to be monitored between 9/84 and 10/85.

TABLE 3 Larger multi-building monitoring projects in North America

the buildings in each of these groups enabled them to be evaluated in Phases 3 and 4 based on their group characteristics.

3.1 The Classification of Data Sets

The 231 structures which were dealt with individually ranged in size from $1m^3$ boxes through to very large multi-storey commercial buildings. In order to evaluate the information about such a diverse range of structures, six structural categories were devised and each structure was allocated to one of these.

Category 1 : Test Cells

Category 2 : Experimental Rooms

Category 3 : Indoor Structures

Category 4 : Experimental Buildings

Category 5 : Residences

Category 6 : Commercial Buildings

In general, the structures increase in complexity from Category 1, Test Cells, to Category 6, Commercial Buildings, although the precise divisions are not always clear. In particular, the more complex test cells, Category 1, resemble the simplest experimental buildings, Category 4.

The descriptive information about the structures in each category is given in four formats:

(a) An overview of the structures in each category, giving their location, the purpose for which they were monitored and an overall appraisal of the advantages and disadvantages of the data (Sections 4 to 9).

(b) Photographs depicting structures which typify those in each category (Plates 1 to 9).

(c) Tabulated information about each data set necessary to effect the Phase 3 and Phase 4 evaluations (Tables 4 to 12).

(d) Additional detailed information about the individual structures in each category which is beyond the scope of either the overview or the tables (Appendix 1).

The tables, which are the key to the classification process, are divided into four sections:

Section 1 : General Information - The name of the institution responsible for the monitoring; the name and location of the experimental facility; a code number, and whether the data set is acceptable, useful or high quality.

Section 2 : Building Description - The name by which the individual structure, or zone, is known; its constructional features; a description of the mode of operation of the structure (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.

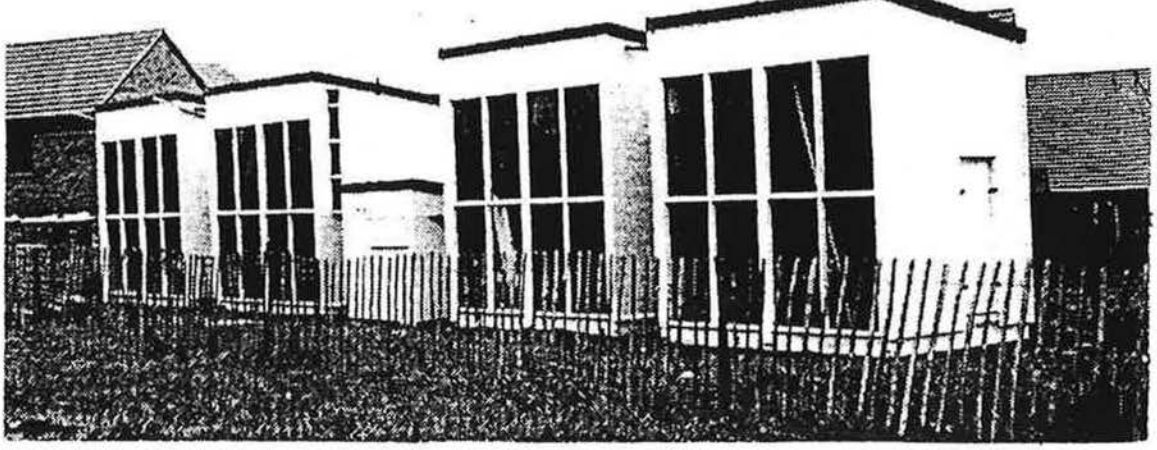


FIG 1 Test cells - Los Alamos type:
Cells monitored by the Polytechnic of Central London in Peterborough, UK. (Cells 37 and 38 in foreground).

Section 3 : Monitoring - The period during which the structure was monitored; the building response parameters recorded; the climate data recorded; and the media on which the data was stored.

Section 4 : Reference/Subject - Source references to the information tabulated and either, the purpose of the monitoring or, the uses which have been made of the data, in particular, any uses for empirical validation especially by persons other than those who undertook the monitoring.

The information in Sections 2 and 3 is presented in coded form. This enables the maximum amount of detail to be included whilst maintaining clarity. It also enforces an even-handed treatment of each data set and thus an objective assessment of their relative merits.

Section 4 enables inferences to be made about the likely availability, documentation and usefulness of the data, as well as an indication of how 'clean' the digital data may be. For example, data gathered for the purposes of model validation, which has been used widely for this purpose, and for which a site handbook is available, is likely to be of greater value for model validation than data which has been gathered, and used, only to evaluate the annual energy use of a building.

A key to the coding adopted in the tables is given in Appendix 2.

4. CATEGORY 1 : TEST CELLS

Test cells are unoccupied, rectangular, single zoned cells. The 60 structures in this category can be sub-divided into two groups:

Group (a) Cells which are based on the original Los Alamos National Laboratory (LANL) cells built in 1976[26]; for example, the cells monitored by the Polytechnic of Central London (PCL) (Plate 1).

Group (b) Cells which have a unique, customized, single zone design; such as those monitored by the EMPA (Plate 2).

Except for the cells built and instrumented in the UK by the PCL, or the Energy Monitoring Company, the cells in Group (a) (Table 4) are all located in North America. All the cells had an internal volume of about $11m^3$ except the EMC cells which were $8m^3$. All the cells were built, from wood, as a pair with a central, well insulated, party wall separated each pair to ensure that they were thermally isolated from each other. In general, each cell had a single, highly glazed, south facing surface and was well sealed to prevent either infiltration of outside air or exchange of air with the adjacent cell. However the EMC cells and, since 1979, the LANL cells were equipped with a fan and flow meter to induce ventilation at a controlled, measured rate.

Except for a cell monitored at Colorado State University, all the cells in Group (b) were built and monitored in Europe. They vary in size and construction from the $1m^3$ wooden boxes, monitored by the Centre Scientifique et Technique de la Construction (CSTC), through to a $64m^3$ reinforced concrete cell monitored by the Polytechnic of Turin. Model validation work using test cells has been conducted in Switzerland at the Ecole Polytechnique Federal in Lausanne (EPFL), in the UK by the University of Strathclyde (UOS) and also at the EMPA where the effect of changing the long wave radiative properties of the external surfaces was studied (Table 5).

General Information			Building Description		Monitoring				Reference/Subject
Monitoring Institution (Location of Cells)	Code and Test		Features	Plant and Schedule	Period	Building	Environment	Data Media	
Pennsylvania Univ. (Philadelphia, PN)	26[1]		WW	F	2-3:78	Tai	Ta	C	108 Bres
Iowa State Univ. (Ames, IA)	27[1]		TV/TU/NI	F	1-3:80	Taoi	Ta Iv	D	102 Bres
	28[1]		WW/NI						113 Smod
Solar Energy Research Institute (Golden, CO)	29,30[1]		WW						
	31,32[1]		WW NI	F?	?	Taoi Fo	?	D?	
	33,34[2]		TV						65 Ci
	35,36[2]		TV NI						51 Bres
Polytechnic of Central London (Peterborough, UK)	37[3]	a	DH		10-19:12:83				
	38[3]	b			12-21:1:84				
		c			24:2-5:3:84	Taow	Ta		27 Ci
		d	DH NI	F	3-12:5:84		Id Ivh	D	201,56,57 Des
	39[2]	a	TU		10-19:12:83	C	Wsd		58 Bres
	40[2]	b			12-21:1:84				230 SERI
		c			24:2-5:3:84		Id		
		d			3-12:5:84				
	41[2]	a		F HFtc	13-24:12:84				
		b	OH	HFtp	24:12:84-11:2:85	Tao Eh	Ta Ih Wsd	D	252 Des
		c		F HFtc	15:2-19:2:85				
Energy Monitoring Company (Cranfield, UK)	42[3]	A a		F-HFtc					
		b-i		HFtp	10:85-3:86	Tao			253 Des
		j		F-HFtc					
		B	OH	Vm		Eh Af Fo	Ta Ihd Ws		
		C a		Hftcp-F	21:12:88-10:1:89	Taoi Oi		D	
		b			19:1-27:1:89				
		c			1:2-9:2:89				254 Des
		d		HFtp	12:2:89				
		e		HFp	2:3-21:3:89				255 Des
		D a		HFtc-F -HFtp-F	23:2-7:3:90				256 Des
		E a		HFp	25:12:90-25:1:91				264 Des
	43[3]	a-h		(a) HFtp	4:8-13:8:87				258 ASP,HTB2,SERIRES
	44[3]	a-h	DH	(b) HFtc	15:8-24:8:87		Ta		257 Des
	45[3]	a-h		(c) HFtp	17:10-26:10:87	Eh Taog			
	46[3]	a-h	OH	(d) HFtc	28:10-6:11:87		Ihvd		259 Bres
				(e) HFtpVm	6:1-17:1:88	Af Fo	Wsd	D	260 Bres
	47[3]	a-h		(f) HFtp	6:2-17:2:88				
	48[3]	a-h	DH	(g) HFtp	13:3-1:5:90	Fo	Tw Ol		261 SERI, ESP, TAS
				(h) F	5:5-23:6:90				

[1] Acceptable Data Sets which pass Phase 2

[2] Useful Data Sets which pass Phase 3 but

[3] High Quality Data Sets which pass Phase 4

TABLE 4 (continued) Test Cells - Los Alamos type

General Information			Building Description		Monitoring				Reference/Subject
Monitoring Institution (Location of Cells)	Code and Test		Features	Plant and Schedule	Period	Building	Environment	Data Media	
		Test							
Los Alamos National Laboratory (Los Alamos, NM)	1'	a	WW	F	31:12-21:1:77	Tgaoi	Taw Ihva Wsd	C	26 Smod
		b			24:2-3:3:78			D	78-35 DEROB
	2'	a	TV		31:12-21:1:77			C	26 Smod
	3'	b	WW		24:2-3:3:78			D	78-35 DEROB
	4'	b	CL WW						
	5'	b	TU NI						
	6'	b	TU						216Smod
	7'	b	DH						153, 202 Ci 161 Bres
	8'	b	TU						
	9	b	TU NI						
	10	b	PCM						
	11'	b	DH						78-35, 64 DEROB 203 DOE 249,118,196 Mod 22 Db
		c			24:2-13:3:78				216 Smod
		d			20-24:5:78				118 Mod
		e			15-24:9:78				40 BLAST
		f			5-11:12:78				169 Mod
		g			21-30:12:78				40 BLAST
	12'	a,b	TU NI	HLct F VMc	a)11:79-3:80 b)12:80-3:81 c)1:3-3:82	Tgio Eh	Ta Ihva Wsd Ohdl	D	a)153 Ci 70-73 Bres b)98,186 Bres c)162, 186 Bres
		c	TU						
	13'	a-c	TU						
	14'	a-c	WW						
	15'	a	WW NI						
		b,c	PCM						
	16'	a	TU NI						
		c	TU						
	17'	a,c	TU						
	18'	a	TU						
	19'	a	PCM						
	20'	a	PCM						
		b,c	WW						
	21'	a,b	DH			Ta			
		c	DH PCM						
	22'	a-c	OL			Tg Eh			
	23'	a,c	TU			Tgoi Eh			
		b		F		Tg			
National Centre for Appropriate Technology (Butte, MT)	24'	a	DH	F	2-5:78	Taio	Ta Iv	D	176-111 Mod 163 Smod; 22 Db 153 Ci 202 Ci
		b			11:78-4:79	Taowg Fw	Ih		47-83 SUNCAT
		c		HBct F	2:80	Taow Fw Eh	Ws Og		87-82 Bres
	25'	a	TV	F	2-5:78	Taio	Ta Iv		176-111 Mod
		b	TU/TV		11:78-4:79	Tago Fo	Ih		83 Bres
		c	TU	HBct F	2:80	Taow Fow Eh	Ws Og		82-87 Bres

/continued

'Acceptable Data Sets which pass Phase 1 but fail Phase 3 criteria.

TABLE 4 Test cells – Los Alamos type

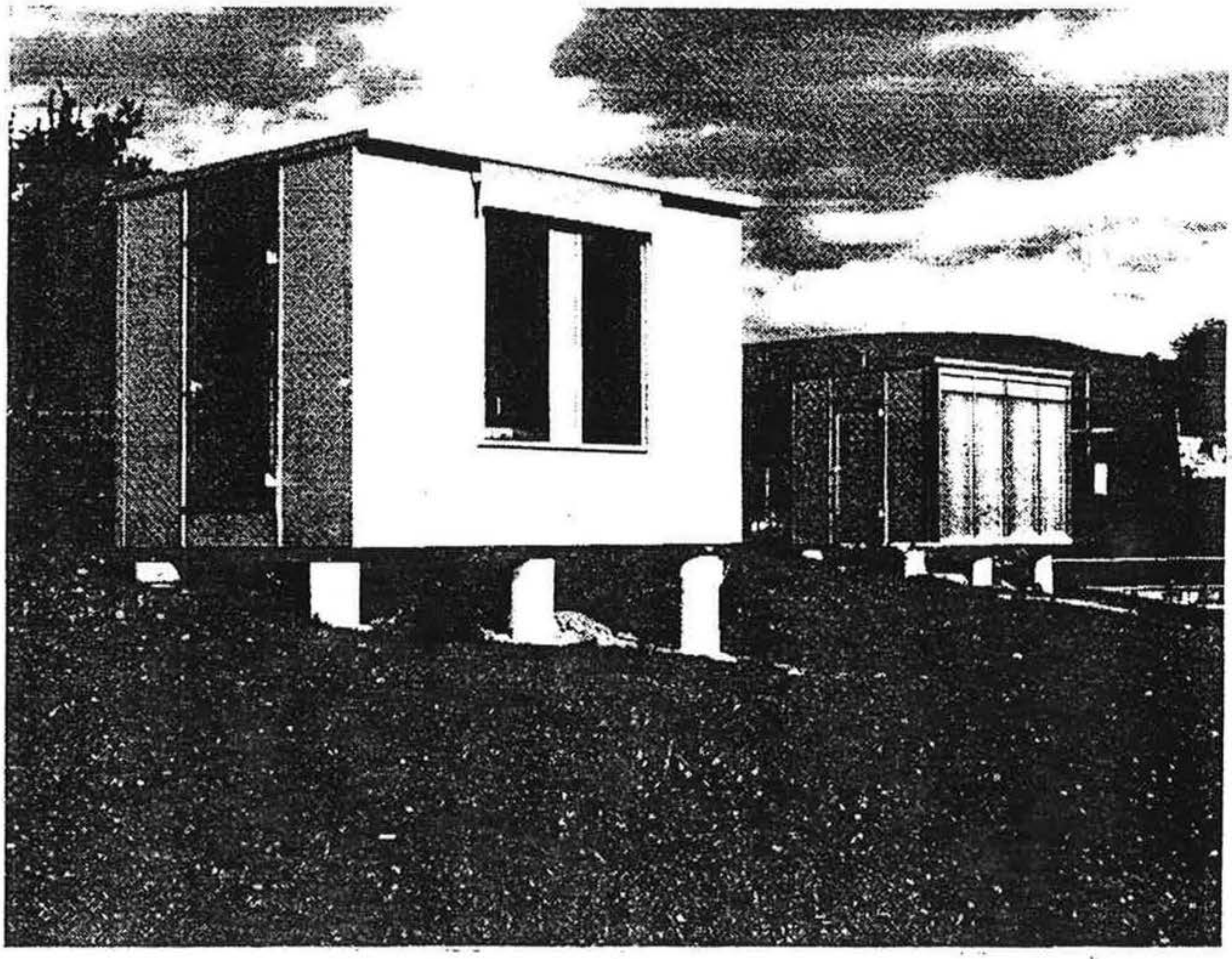


FIG 2 Test Cells - custom designed:
Two cells monitored by the EMPA Dubendorf in St Gallen, Switzerland (Cells 14 to 15).

General Information		Building Description		Monitoring				
Monitoring Institution (Location of Cells)	Code & Test	Features	Plant & Schedule	Period	Building	Environment	Data Media	Reference/Subject
Centre Scientifique et Technique de la Construction (Brussels, Belgium)	1-4[1]	DL	F VP	2:79>	Tag	Ta Ihvd Wsd	T	79,105 Bres
	5[1]	OL						
	6[2]	DL	F					
	7-10[1]		HLct F VP		Tag Eh			
	11[1]	OL						
	12[2]	DL	HLct F					
Colorado State Univ. (Fort Collins, CO)	13[1]	WW	F	7:79	Ta	Ta Id	?	112 Smod
EMPA Dubendorf (St. Gallen, Switzerland)	14[3] a	OL	HLct F	26:2-2:3:80	Tao Eh C	Ta Wsd Ihvd On	D	219 Des 220-221-222-104 Mod
	b		F	21-26:6:80				
	c-d	DH	HLct F	1:9-21:10:80				
	e-f	OH		6-21:12:80				
	g-h	DH NI		1:1-21:2:81				
	i	DH	F	14-21:4:81				
	15[3] a	OL	HLct F	26:2-2:3:80				
	b		F	21-26:6:80				
	c	OH	HLct F	1-30:9:80				
	d-h	TU		16:10-21:4:81				
Ecole Polytechnique Federal (Lausanne, Switzerland)	16[3]	DH	F	<81	Tao F	Ta Idn Wsd	D	151 Mod
	17[2]	TU/TV/NI		81	Taowi	Ta Iv		100 Mod 264 Des
	18[2]	DL	Hct F	79	Ta F Eh			153 Ci
	19[1]	DH WW NI						106 Bres
Politechnico di Torino (Turin, Italy)	20[2]	DH	F	1:81	Tao	Ta Ih	C	198 Mod, Smod
Univ. of Strathclyde (Glasgow, UK)	21[3] 22[3]	OL OL	F F.HFj,HFtc	7:2-10:3:89	Ta Eh	Ta Ihvd Wsd Ol	D	262 Des 263 ESP

[1]Acceptable Data Sets which pass Phase 1 but fail Phase 3 criteria.
[2]Useful Data Sets which pass Phase 3 but fail Phase 4 criteria.
[3]High quality Data Sets which pass Phase 4 criteria.

TABLE 5 Test cells - custom designed

Compared to the other categories of structure, test cells are relatively cheap to build and so are generally constructed specifically for conducting scientific experiments by the institution which will monitor them. The construction details can therefore be tightly controlled and troublesome mechanisms, such as heat bridging and uncertain air leakage, can be eliminated. Noteable exceptions are the UOS cells which are part of the pan-European PASSYS project.

Because the cells are small, they can be densely monitored and if necessary lifted clear of the ground to avoid the complex, multi-dimensional, heat loss associated with traditional building foundations. It is also relatively easy to alter the proportion or type of glazing, the amount and type of thermal storage, and the mode of heating. A sequence of experiments in structures of differing design can therefore be completed relatively quickly. Test cells are ideal for conducting carefully controlled side-by-side comparisons of alternative heating systems, solar collection methods and thermal storage devices. It is primarily for this purpose that they have been used; the work at the LANL and EMC exemplifies this approach.

The size and construction of test cells enables many potential sources of external error to be excluded from data sets acquired from them. This, together with their relative simplicity, which makes them easy to model, renders test cells an attractive and frequently used source of data for model validation (Tables 4 and 5).

Care must be exercised, however, when designing and interpreting validation tests using data from test cells. Very small structures, such as the CSTC cubes, are subject to severe scaling problems, such that the relative magnitude of thermal delays, edge effects and thermo-circulation cannot simultaneously represent those operative in real buildings[27,28]. This seriously undermines the value of the data from these cells. In larger cells, which are greater than about one-fifth the scale of real buildings, such problems are avoided[27]. Even in these cells, however, the relative magnitude of the various heat flow paths may not resemble those in houses of traditional design. Typically, the thermal behaviour of test cells is dominated by solar gain and conductive heat loss through the glazing and they often have a large surface-area-to-volume ratio; these features are more likely to be exhibited by newer, passive solar designs.

5. CATEGORY 2 : EXPERIMENTAL ROOMS

The 14 experimental rooms (Table 6) are individual, unoccupied, monitored zones which are an integral part of, or attached to, an existing larger building (Fig 3). Their major attraction for research is, of course, that it is much cheaper and quicker to monitor part of an existing building than it is to construct a new full-size experimental facility. There is also the added convenience of being able to safely locate monitoring equipment in the adjoining building.

A variety of experiments, at locations with very different climatic conditions, have been conducted in experimental rooms. An existing multi-zoned building in Urbino, Italy was converted to enable double-storey Trombe walls to be tested and attached sunspaces were monitored in Albuquerque and Santa Fe in New Mexico (Table 6).

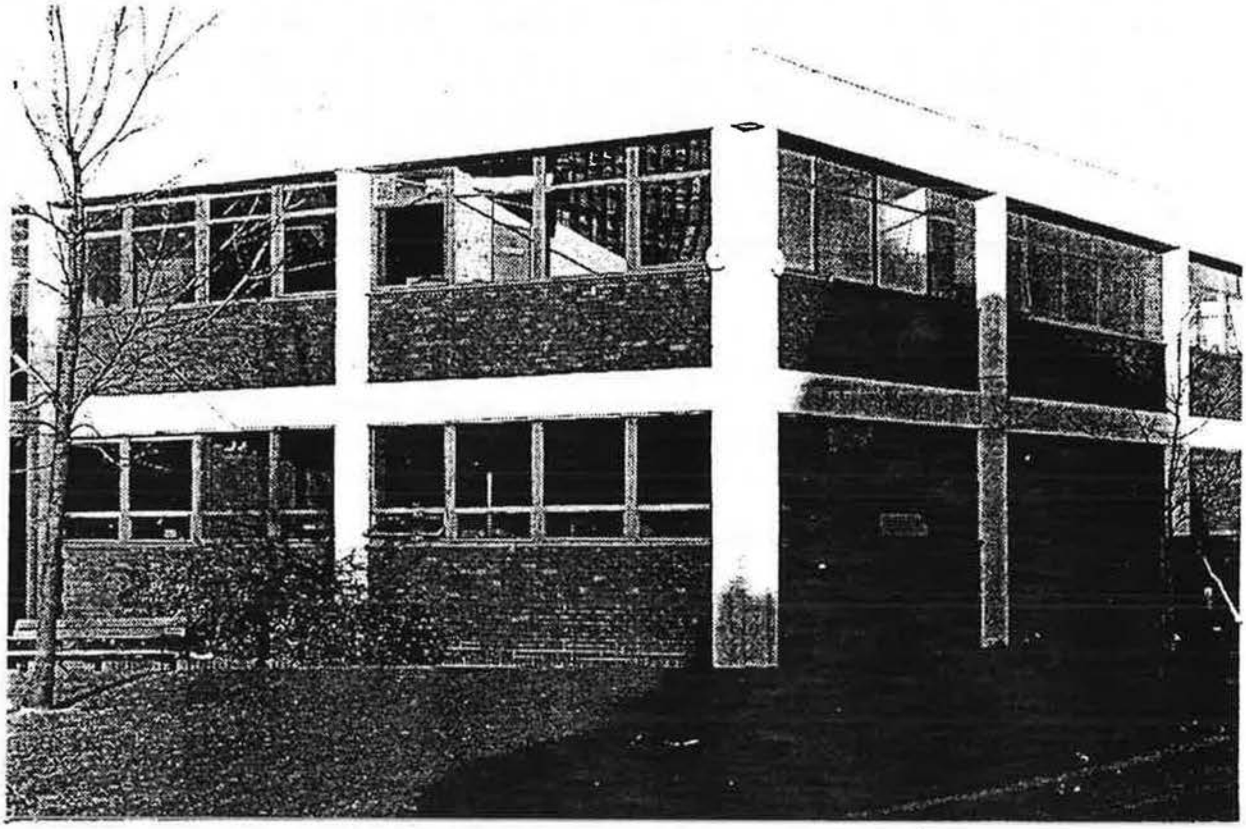


FIG 3 Experimental rooms:
First floor corner room at Lanchester Polytechnic, Coventry, UK, (Room 3).

General Information			Building Description		Monitoring				
Monitoring Institution (Location of Room)	Code & Test		Features	Plant and Schedule	Period	Building	Environment	Data Media	Reference/ Subject
National Bureau of Standards (Houston, TX)	1[1]	a	OL	VPc F	2-4:9:77	Ta Fo A	Ta Ih Wsd	?	88 Mod
		b		VMct F	2-4-8:77				
Politecnico de Torino (Turin, Italy)	2[2]		DH	F	<79	Tao Fo Oi	Ta Inhv Wsd	D/C	94 Smod
Lanchester Polytechnic (Lanchester, UK)	3[1]	a,b	DH	Hdpt F	<79	Toa Ad	Ta Iv Ws?	C?	36 Smod
		c		Cct					
		d		F					
Inst. Univ. de Arch. di Venezia (Urbino, Italy)	4,5[2]		TV	Ht F	80>	Tiagow Ov Eh	Ta Ihv Wsd Oh	D	250 Bres
	6-9[2]			F					
Wessling Consulting (Albuquerque, NM)	10[1]		DH AS	F	13-23:2:78	Tai	Ta I	D	153 Ci 117 Bres
	11[1]								
	12[1]					Ta			
	13[1]					Taoi	Ta Ia		114 Smod
New Mexico Solar Energy Assoc. (Santa Fe, NM)	14[1]		WW AS	F	-4:78-3:79	Taoi	Ta Ih W?	C	85 Bres

[1]Acceptable Data Sets which pass Phase 1 but fail Phase 3
[2]Useful Data Sets which pass Phase 3 but fail Phase 4 criteria.
[3]High quality Data Sets which pass Phase 4 criteria.

TABLE 6 Experimental rooms

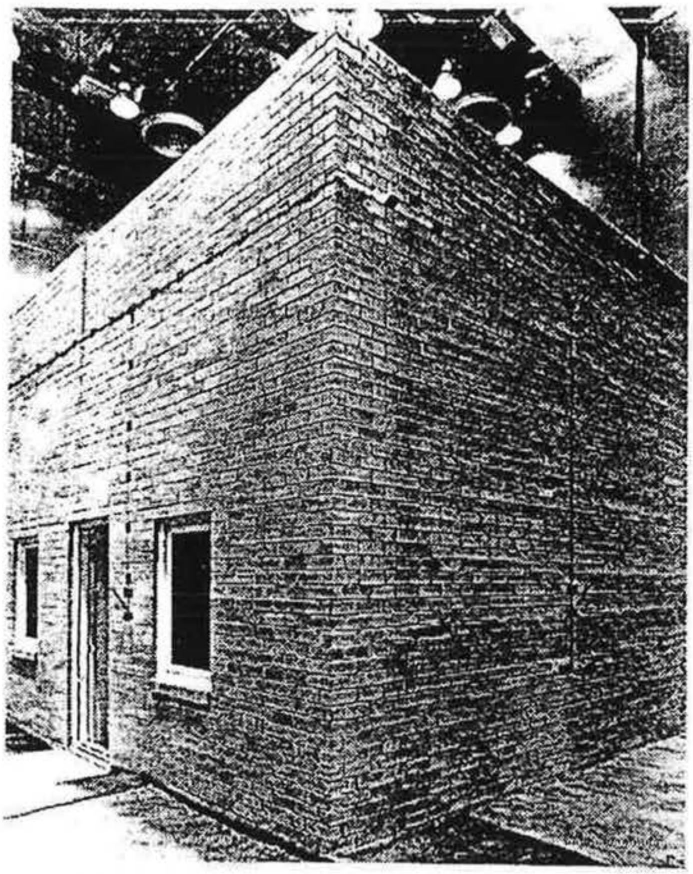


FIG 4 Indoor structures:
Experimental masonry building at the US National Bureau of Standards, Gaithersburg, MD, USA (Structure 3).

General Information			Building Description			Monitoring				
Monitoring Institution (Building Location)	Code and	Test	Type, No. Zones, Construction, Approx. Size	Plant and Schedule	Occupancy	Environmental Temperature Regime	Period	Building	Data Media	Reference/Subject
National Bureau of Standards		a,b		F	U			Taoi Fo		138 Smod
(Gaithersburg, MD)		b-e	Cell, 1, Concrete		M	DC(38 4)		Ad		115 Mod 179,99 NBSLD
	1[2]	f	blocks,		U		<73		P	11 Ci
		g-i	6x6x3m high.	HFct	M			Taoi Fo		36 Mod
		j				DC(21 -12)				
		a,b			F Spa	DC(3 -17)				
		c			F					
		d			F Spa	DC(18 -3)				
		e	Residence, 9,	HDct		DC(18 -7)		Tag Fo		11 Ci
	2[1]	f	Timber framed,		F	DC(21 -8)	<75	Eh/c Ad	D	116-96 NBSLD
		g	Two storey.			CT(-2)				
		h				SC(25 1)				
		i		Cct	F Spa	DC(54 22)				
		j				DC(47 3)				
		a	Cell, 1, Brick	F	Sp	DC(7 -8)				30-107-71 Mod
	3[2]	b	& concrete,	Cp		DC(58 24)	<79	Taoi Fo	D, C	249 NBSLD 11 Ci
		c	6.5x5.3x4.1m high.	Cpt				Ec Ad Oi		114 Mod 101 DOE 90-40 BLAST
		d		VPp		DC(49 28)				71 Mod
	4[2]	a-d	House, 2, Stud & ply.	Hct	U	CT(-12/-5)	<84	Tao Fo	D	120 Mod
		e	2x3x2.5m high.			DC(7 -12)		Ad		
National Institute of Applied Science		a	Residence, 11,	F	U	CT(-4.5?)	<83	Tago Fo	D	75 Mod
	5[1]	b	Concrete,			SC(0 18)		Oi		
(Lyon, France)		c	86m² x2.5m high.	HDj		CT(?)				
Manchester Univ. Inst. of Science & Technology	6[2]	a	Cell, 1, Concrete.	HFs		CT(?)		Ta A		177 Mod
(Manchester, UK)		b	1.7x1.7x1.4m high.	HFs VMc	U		<82		?	
	7[2]	a	Room, 1. Multiple.	HRs/j		?		Ta		97 Mod
		b	5x3x3.5m high.	HFs/j						

[1] Acceptable Data Sets which pass Phase 1 but fail Phase 3 criteria.
[2] Useful Data Sets which pass Phase 3 but fail Phase 4 criteria.
[3] High Quality Data Sets which pass Phase 4 criteria.

TABLE 7 Indoor structures

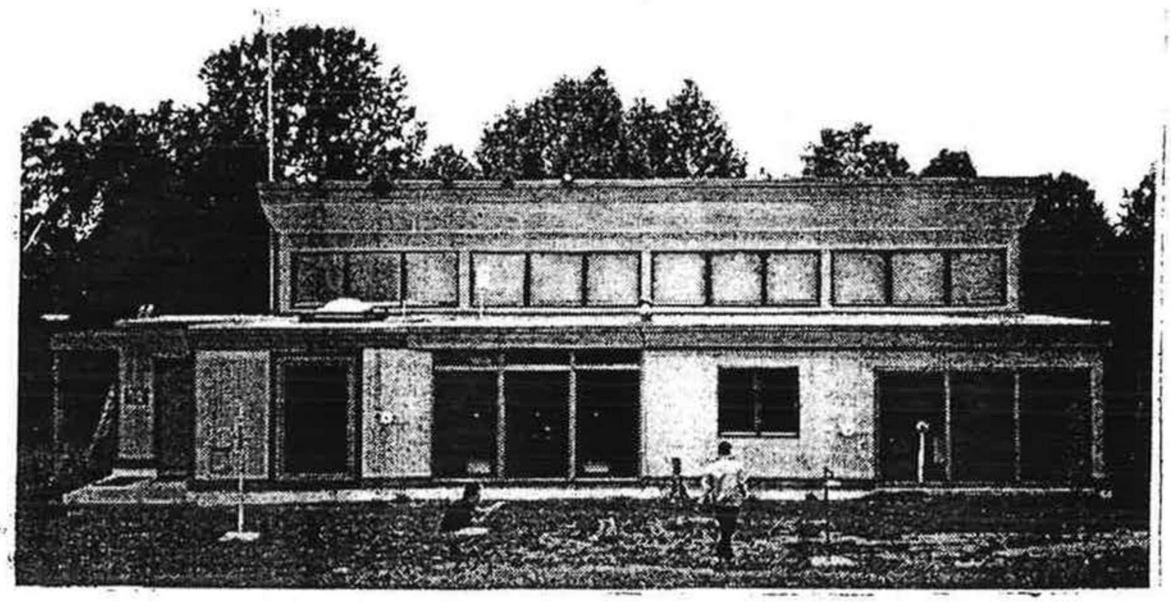


FIG 5 Experimental buildings - zoned:
Passive Solar Test Facility, at the US National Bureau of Standards, Gaithersburg, Md, USA (Building 7).

The rooms at the Polytechnic of Turin, Lanchester Polytechnic, and the attic space in the residence in Houston, Texas, were all monitored to provide data for model validation, however, there are a number of disadvantages to using data from experimental rooms for this purpose. In particular, the room will invariably be less sensitive to ambient conditions than a similar, completely exposed, room and doubt will always exist as to the exact thickness and juxtaposition of the materials within opaque multi-layered constructions. Hidden heat bridges and other complex multi-dimensional heat flow mechanisms may also exist which could be a significant source of error, particularly if the partition walls between the experimental room and the rest of the building are not well insulated.

6. CATEGORY 3 : INDOOR STRUCTURES

This is the smallest category containing just seven structures. These were all unoccupied and tested inside a larger, temperature controlled, enclosure (Table 7). Four of the structures were tested inside the large environmental chamber at the US National Bureau of Standards (Fig 3). Two of these were massive single zoned test cells with a volume of about $120m^3$ (Fig 3), a third was a two storey, timber framed residence, complete with simulated occupants, and a fourth was a small twin-zoned wooden hut used to examine moisture transfer. A complete eleven room apartment was monitored by the National Institute of Applied Science (NIAS) in Lyon, France.

In most of these experiments, the exterior temperature was cycled with a daily frequency, although constant temperature and step change temperature tests were conducted by the NBS and the NIAS. In contrast, in a series of experiments at the University of Wales Institute of Science and Technology, the temperatures on the inside, rather than on the outside, of a $4m^3$ box and a $50m^3$ room were cycled. Except for the NBS experiments on a massive concrete test cell, in which solar radiation was simulated using infra-red lamps and the NIAS experiments in which differential wind pressure was simulated, wind and solar effects were not mimicked in the experiments.

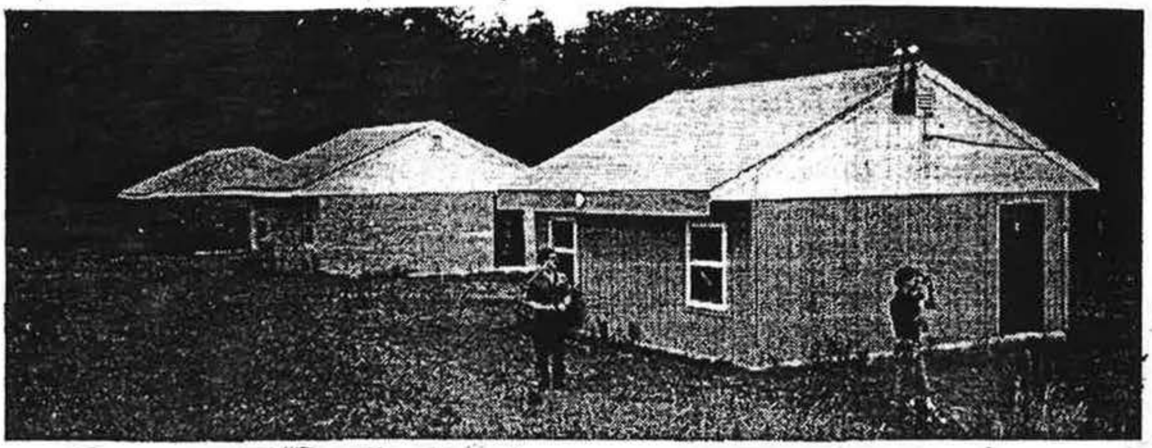
The advantages of data from indoor structures is that the uncertainty associated with measuring real weather patterns is avoided and data from all seven structures have been used for model validation. The obvious disadvantage is that the imposed boundary conditions are a gross simplification of the weather conditions to which buildings are normally exposed. In particular, wind and solar effects are generally absent, so the data is only able to assess the accuracy of a small part of a thermal model, for example, internal long wave exchange and conduction algorithms. This application is likely to be limited, since these algorithms can be examined more quickly and with greater precision using simple analytical tests which are devoid of experimental uncertainty[29].

Other problems, generic to structures in this category, are ground coupling and long wave radiation exchange between the test structure and the surfaces of the test chamber. Estimates by the NBS have indicated that, in their chamber, this long wave exchange is equivalent to a decrease in sol-air temperature of about 1.3°C. For the massive cell being tested, this had a negligible influence on inside temperature[30], however, this may not be so for lighter structures.

General Information			Building Description				Monitoring				
Monitoring Institution (Location of Building) Test Facility Name	**Code Zone and Test**		**Zone Name**	**Features**	**No. of Rooms**	**Plant and Schedule**	**Test Period**	**Building**	**Environ.**	**Data Media**	**Reference/Subject**
Denmark Technical Univ.	1	A[1]	Room A	TU	1	HRct F	25:2-1:5:83	Taiow	Ta Iva	D	80 Bres
(Lyngby, Denmark)		B[1]	Room B					Eh Fo			
Test House											
Tohoku University	2	A[2]	Room A	DH CW	1ac	F	2:81-3:83	Tao Ap	Ta Ih Og	D?	133 Mod
(Japan)		B[2]	Room B	DH/CW/NI/ DL/TV/TW		F/VMp					
Twin-Type Test House											
National Research		A[3]	Unit 1		2						193 Bres 125 Mod
Council of Canada	3	B[3]	Unit R1		ab						218 SERI
(Ottawa, Canada)		C[3]	Unit R2		1						9 Ci
Passive Solar Test		A[3]	Unit R3	DL		HBct	80-81	Ta Ehv	Ta Ihvn	D	125 Bres; 136-124 Bres
Facility	4	B[3]	Unit R4		ab	VMct	81-82		Wsd		195 Bres
		C[3]	Unit 2								193 Bres; 212,33 SERI
	5	A[3]	Unit 3		2 ab						38 ESP 88 Modx10; 212,33 Mod
		B[2]	Unit 4	TV/NI							194 Bres
Centre Exp. du Bat. et		A[2]	Cell 1			HRct VPc		Taoiw	Ta Idvn		
des Travaux Publics	6	B[2]	Cell 2	DH	1ac	F	10:82>	Eh Fo	Wsd	D	126 Des
(Paris, France)		C[2]	Cell 3			HRt		Af Oh	Ohpwag		
Experimental Building		D[2]	Cell 4	OH							
National Bureau of		A[2] b	Cell 2	TU		HDct F		Tgi			178 Bres
Standards		c	Trombe Wall	TU CW				Tw			
(Gaithersburg, MD)		d				F					
Passive Solar Test		B[3] b	Cell 3	DL	1	HDct F	a)20-26:10:81	Tao	Ta Ihvn		159 Db
Facility	7	c	Control			F	b)16:1-13:2:84	Eh	Wsd	D	9 Ci
		d					c)17:2-12:3:84	Ac	Oagl		52-130 Des
		C[3] a	Cell 4	DH		F	d)21:12-2:1:85	C			128,175,171
		b	Direct Gain			HDct F		Tgi			159,263 DOE; Bres
		c		DH CW				Fo			170 Bres
		d				F		I			178 Bres

[1] Acceptable Data Sets which pass Phase 1 but fail Phase 3 criteria.
[2] Useful Data Sets which pass Phase 3 but fail Phase 4 criteria.
[3] High quality Data Sets which pass Phase 4 criteria.

TABLE 8 Experimental Buildings - zoned



Experimental buildings - thermally integrated:

FIG 6 Thermal mass buildings at the National Bureau of Standards, Gaithersburg, MD, USA (Building 16 in foreground).

7. CATEGORY 4 : EXPERIMENTAL BUILDINGS

The 60 experimental buildings in this category were all unoccupied and built entirely for research purposes. They have been divided into two groups and have been tabulated, within each group, in approximately the order of increasing complexity.

Group (a) Buildings in this group contain a number of zones which are essentially thermally isolated (Fig 5, Table 8). As in test cells, each individual zone may provide data suitable for model validation. There are nineteen zones within the seven buildings in this group.

Group (b) The buildings in this group are thermally integrated units and cover a wide range of complexities (Fig 6, Table 9). Except for the REPEAT facility in Fort Collins, Colorado, all the buildings are essentially single storey (although some have attics and basements, etc.).

A number of the facilities have been designed in such a way that their interiors can be reconfigured in order to increase the range of experiments which can be performed. Such buildings include the REPEAT facility, the Passive Solar Test Facility at the NBS, the rooms at the National Research Council of Canada (NRCC) and, more recently, a building built at the Centre Experimental du Batiment et des Travau Publics near Paris.

Since all the experimental buildings have been built specifically for experimental purposes, undesirable thermal mechanisms have been largely suppressed, as in the test cells. The buildings do however display a much wider range in geometrical configurations, construction types and temperature control strategies than test cells. The features embraced by the structures include earth bermed walls, clerestory windows, attached sun spaces and rock bin thermal storage. Structures with intermittent heating and cooling strategies are also included. The majority are of similar size to inhabited buildings and therefore the relative magnitudes of the heat flow paths are realistic.

Virtually all the data from the experimental buildings have been collected since 1980 with the primary aim of evaluating various energy saving techniques. This use is exemplified by the NBS thermal mass buildings and the work at the New Mexico Research and Development Institute, the University of Alberta and the Solar Energy Analysis Laboratory. At each of these sites groups of five to eight buildings with differing wall construction or collector type were used to conduct side-by-side comparisons of energy use. A variety of heating and/or cooling strategies have also been tested in each of the buildings at the NBS and University of Alberta sites, so numerous acceptable data sets have been generated (Table 9).

Although model validation was not the primary reason that most of the experimental buildings were monitored, data from all but five of the monitoring institutions have been used for this purpose. Site handbooks, which are supposed to describe the building and instrumentation in sufficient detail that a third party can use the data to validate thermal models, have been obtained by Leicester Polytechnic for three of the buildings: the NBS Passive Solar Test Facility and the Validation Test House and Validation Test Cell at the SERI. Of all the acceptable data sets revealed by the literature search, these are the only ones for which such handbooks appear to be available. The SERI buildings are also unique in that they were monitored specifically to generate data for validating dynamic thermal models. The Validation Test Cell was extremely heavily

General Information		Building Description				Monitoring				Reference/Subject
Monitoring Institution (Location of Building) Test Facility Name	Code and Test	Building Name	Features	No. of Rooms	Plant and Schedule	Test Period	Bldng.	Envir.	Data Media	
Waseda University (Japan)	1[1] 2[1]	Scale Models	DH CW CL CW	1a	F	16-17:12:83	Ta	Ta I	D?	134 Mod
Washington State Univ. (Pullman, WA)	3[1] 4[1]	Mobile Research Buildings	DL WW DL	2	HBct F	1-6:77	Ta/Tai Ta	Ta	O	153 Ci 127 Bres
Solar Energy Research Institute (Golden, CO)	5[3] a b c d e f	Validation Test Cell	OL DH/DL	2	F HFc F HFct F HFct F	83>	Ad Tago Twi Eh Fow l	Ta Ihnva Wsd Opahlg	D	159 Db 51 Des 53 Des
	6[3] a b	Validation Test House	DH/DL	4ac	HFct F	20-26:4:82 26:2-14:3:83	Ac C			69,109 DOE 69 158 SERI,BLAST 9,202,11 Ci 231 DOE,BLAST,SERI 159 Db 5 DES 54 Des
New Mexico Energy Res. and Dev. Inst. (Tusuque Pueblo, NM) SW Thermal Mass Study	7[3] 8[2] 9[2] 10[2] 11[2] 12[2] 13[2] 14[2]	#2 Adobe 10" #3 Adobe 14" #4 Adobe 24" #5 Adobe 10" #8 Log #6 Unins. Conc. #7 Ins. Wood Fr. #1 Adobe 10"	OH/DH OH OH/DH OL/DL OH/DH	1	HCct F	12:81-12:82 1:81-6:83	Tagoi Eh Fo Ad Oh	Ta Ihnv Wsd Opghl	D	239 Des 240,241,242 Bres 243 DEROB 245 DOE 247 BLAST 45 BLAST,DEROB,DOE 244 DEROB
National Bureau of Standards (Gaithersburg, MD) Thermal Mass Buildings	15[1] d-h 16[1] 17[1] 18[1] 19[1] 20[1]	1. Ins. Wood Fr. 2. Unins. Wood Fr. 3. Conc. Ins. Out. 4. Conc. Unins. 5. Log 6. Conc. Ins. In.	DL DH	1a	HDct HDct F Cct F Cct Cct F Cct F Cpt VMp HDpt F	a4:1-11:4:82 b12:4-2:5:82 c6:7-21:9:81 d8-25:7:82 e13:9-3:10:82 f26:7-17:8:82 g18:8-8:9:82 h24:1-2:5:83	Ta Eh Ad Fo Ohi C	Ta Ihv Wsd Ohg	O	122 Bres 84-119 Bres 213 TARP [redacted] 121 Bres 9 Ci 123 Bres
Solar Energy Analysis Laboratory (San Diego, CA) SEA-LAB or PALA Passive Solar Project	21[2] 22[2] 23[1] 24[2] 25[2] 26[2] 27[2] 28[1]	Conventional High Mass Roof Pond Clerestory Green House Direct Gain Trombe Wall Water Wall	DL DH DL RP DH CW DH AS/RS DH RS TU/TV/RS D WW	2 3 2	F/HDct/Ct	81>	Tag	Ta Ihnv Wsd	D	202 Ci 172 Des 103 Bres
University of Alberta (Edmonton, Canada) Heating Research Facility	29[1] a-e 30[2] a b c-e 31[2] a b c-e 32[2] e 33[2] e	#2 Stdd. Pre '75 #3 Conservation #4 Passive Solar #1 Masonry #5 Stdd. Post '75	DL DL O/DL NI DH NI DL O/DL NI DL NI DH DL	1ab	HDct	a11:79-4:80 b11:80-4:81 c11:81-3:82 d9:82-5:83 e10:83-5:84	Eh Ta Fo Adc I Eh Eh Ap	Ta Ta Ihdv Wsd Og	D	48 Des 234 Mod 235 Mod 236 Mod 237-238 Smod 37 BLAST
National Research Council of Canada (Ottawa, Canada) Pass. Sol. Test Fac.	34[2] 35[2]	Direct Gain Sun Space	DL DL AS	3ab 4ab	HBct VMct	11:10:82- 1:5:83	Ta Ad Ehv Tagoi Ehv Ad	Ta Ihnva Wsd	D	9 Ci 86 Bres 197 Des'
Los Alamos National Laboratory (Los Alamos, NM)	36[2] a b 37[2] a b 38[1] 39[2]	Cell 3 Cell 4 Cells 3 & 4 Cells 7 & 8	DH AS WW DH AS WW DH AS/WW/NI DH AS	2 3	HLct F VMct	11:79-3:80 1-3:82 11:79-3:80 1-3:82 12:80-3:81	Tagoi Eh	Ta Ihva Wsd Od	D	70 Bres 187 Mod 186,162 Bres 70 Bres 187 Mod 186,162 Bres 67 SERI 98 Bres
Colorado State Univ. (Fort Collins, CO)	40[1]	REPEAT Facility	DH AS CW EB	3	F/H	6:83>	Tagowi Fo Ap/c Eh IOh	Ta Wsd Ivhd Ohgp	D	159 Db 9 Ci 165 Des 132,232 Bres 131,192 Smod
Univ. of Sheffield (Sheffield, UK)	41[1]	SHED	DL AS TU WW RS	4	Ht F	9:78>	Ta Eh	Ta Ih	D	65 Smod

[1] Acceptable Data Sets which pass Phase 1 but fail Phase 3 criteria.
[2] Useful Data Sets which pass Phase 3 but fail Phase 4 criteria.
[3] High quality Data Sets which pass Phase 4 criteria.

TABLE 9 Experimental buildings - thermally integrated

FIG 7 Residences - conventional:
Gardener's Cottage at the Cement and Concrete Association, Slough, UK (Residence 30)

General Information		Building Description						Monitoring					Reference/Subject
Monitoring Institution (Location of Residence)	Code	Residence Name	Type & Sto -reys	Plan Area (m^2)	Feat.	Occ.	Plant & Schedule	Period	No. Sen-sors	Building	Environ.	Data Media	
Elec. Counc. Res. Centre (Chester, England)	1 [2]	House no. 8	S2ab	42	DL/DH	U	HRT/HFtt	74>	170	Tawoi Eh Adp Oi	Taw Ih Wsd Owc	T/C	180 Des 95.224 Bres 110 Mod
	2 [2]	House no. 12					HO						
	3 [2]	House no. 16					HD						
	4 [2]	House no. 10			DH								
	5 [2]	House no. 14					HP/HE/HFt						
	6 [2]	House no. 18					HFt						
Ohio State Univ. (Columbus, OH)	7 [1]	KTSC	D2abc	110	DL	O F	HBct F	28:1-4:2:75	35	Ta Ehc Oh Ac	Ta Idh Odwg Wsd	D?	74 Mod 25 DOE Mod; 25 Ci 11 Ci 160 Des
	8 [1]	CTSE				M	HDct F	2-31:12:79	30				
Nat. Bureau of Standards (Houston, TX)	9-10 [1]	House 1 and 2	Dla	136	DL	Sp F	CEt/VMt	7-10:77	?	Tao Fo Ec Oh Ac	Ta Ih Oh Wsd	T	200 Db 25 Ci 155 Bres 101 DOE
	11 [1]	House 3											77 NBSLD, DOE, BLAST
Univ. of Strathclyde (Livingstone, Scotland)	12 [1]	House no. 73	T2ac	52	DH	U	F	15-27:6:78	24	Tao Ad	Ta	C	32 ESP
	13 [1]	House no. 74				O F	HD						
Owens Corning Fibreglas (Little Rock, AK)	14-23 [1]	Mobile Homes	Dlac	98	DL	U	HPct CPct	1:5:77-15:3:78	20	Ta Ehc Ap	Ta Ihd	T	25 Ci 72 Bres
Australian Housing Research Council (Various - see name)	24 [2]	Melbourne	Dla	65	DL	U	Hp F	1-22:11:78	=60	Taw Fo Ad	Taw Ihd Ws Og	T	46 Mod
	25 [2]	Townsville	Dla	70			F	31:3-4:4:79					
	26 [2]	Rockhampton	Dlac	80				13-17:4:79					
	27 [2]	Brisbane	Dlac	93		S		1-13:12:78					
	28 [2]	Longreach	Slac	49		S F		5-18:1:79					
	29 [2]	Canberra	Dlac	106		U	HFp F	8-24-9:79					
Cement & Concrete Assoc. (Slough, England)	30 [2]	Gardener's Cottage	D2a	27	OH	U	HFpt F	2:80-4:81	300	Tao Fo Ad Eh	Tas Og	D	228 Bres 145 Smod
Swiss Fed. Lab. for Mat. Test. and Res. (Maugwil, Switzerland)	31 [1]	Project Maugwil	D2ab	75	DL EB	U	HRct	13:10:80-16:4:81	60	Ta Adp Ohi C	Ta Ihd Ogh Wsd	D	143 Bres 144 DOE
Open University (Milton Keynes, England)	32-38 [1]	Houses 33-36, & 38-40	D2a	55	DH	O F	HRpt F	81-82 82-83	30	Tao Eh W Fo Ap	Ta Ivhd Wsd Oh	D	150 Bres
	39 [2]	House 37				U	HFct F			Ta Eh Fo Apdc			
Univ. of Illinois (Champaign, IL)	40 [1]	Lo-Cal House 4001	Dlac	172	DL	O F	HDt Ct	3-81>	100+	Tao Ehc Od Fo Ac	Ta Ihd Wsd Odgp	D	9 Ci 159 Db 229,227 Des
	41 [2]	Lo-Cal House 4003		192		U	HFct F	31:1-6:2:82 2:9-3:9:82					109 DOE 159 DOE 246 BLAST
Building Research Establishment (Oxfordshire, England) (Cambs., England)	42-43 [1]	No.2 & No.4	S2a	56	DH	Spa	HRct	78-81	20	Ad Tg Eh Ap	Ta Iv Wsd	D	60,61 Bres 59 Des
	44-45 [1]	No.95 & No.97		42				82-85					
	46-47 [1]	No.99 & No.101											
	48-49 [1]	No.89 & No.91	T2a										

[1] Acceptable Data Sets which pass Phase 1 but fail Phase 3 criteria.
[2] Useful Data Sets which pass Phase 3 but fail Phase 4 criteria.

TABLE 10 Residences - conventional

monitored and six experiments were completed in which additional heat flow mechanisms were gradually introduced.

It appears that experimental buildings, along with test cells, will produce the most valuable data for model validation.

8. CATEGORY 5 : RESIDENCES

These are single family dwellings which, even if used for experimental purposes, have not been substantially altered. They are typical of buildings which thermal models may be called upon to simulate when they are used in practice. In addition to the 73 residences listed individually, this category also includes about 313 residences which can be evaluated on the basis of their common group characteristics (Section 3). This category therefore contains more structures than any of the others.

The residences can be further divided into two sub-categories:

Group (a) Conventional residences which differ little in appearance from traditional houses of the area (Fig 7, Table 10).

Group (b) Passive and hybrid solar residences which are innovative and incorporate overt passive (and hybrid) solar features (Fig 8, Table 11).

The majority of the houses are in the USA and all of them are detached. Exceptions include four terraced houses monitored by the University of Strathclyde in Scotland and six semi-detached houses in England monitored by the Electricity Council Research Centre. These six were monitored in the early 1970s in some of the earliest monitoring and validating work revealed by the literature search.

In addition to occupied and unoccupied residences, a number had simulated occupants. The movements of people, and the heat they emit, was usually simulated by periodically switching heat sources, such as light bulbs, on and off. Pulleys, valves, switches and fans were linked to a central timer to establish schedules of blind and curtain opening and closing, hot water run off, appliance usage, and door opening and closing. This approach was exemplified in the houses being monitored by the BRE and has the advantage of introducing an element of realism whilst eradicating the wild and random influences of real people. This approach is particularly useful when the data is to be used for validating thermal models.

Residences in both groups were monitored primarily to determine their basic energy usage. Alternatively, various energy saving schemes were assessed. In the conventional houses (group a) these took the form of either modifications to the building fabric or changes to the mode of heating or cooling. The schemes examined in the passive solar and hybrid residences (group b) were frequently more exotic and included: attached sunspaces, rock stores, tubular water walls, Trombe walls, convective loops, clerestory windows and earth berms. Innovative passive solar cooling techniques have also been investigated, for example at the University of Arizona and New Mexico State University (Table 11).

Data from the majority of the residences has been compared with the predictions of thermal models, however, only three of the residences were monitored specifically for this purpose. These were the two residences monitored by the Ohio State University and the Gardener's Cottage monitored

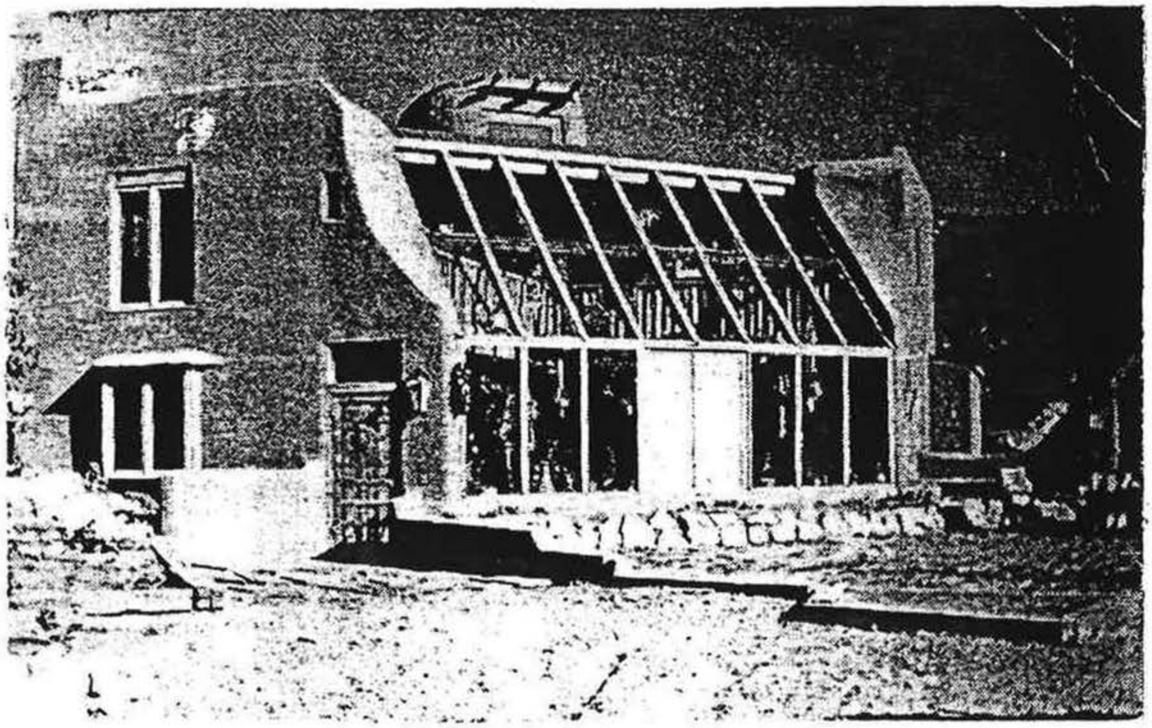


FIG 8 Residences - passive solar and hybrid: Balcomb Residence in First Village near Santa Fe, NM, USA (Residence 20)

General Information		Building Description					Monitoring						Reference/ Subject
Monitoring Institution (Location of Residence)	Code	Residence Name	Type and Storeys	Plan Area (m^2)	Feat.	Occ.	Plant and Schedule	Period	No. Sensors	Building	Environ.	Data Media	
Los Alamos Scientific Laboratory (Albuquerque, NM)	1[2]	Control	D1a	54	DH	U	F	2-8:2:78	40	Taoi	Tag	C/D	202,153 Ci
	2[2]	Trombe Wall			TV								181 Des
	3[2]	Direct-gain			DH								140 Bres
	4[1]	Greenhouse			AS EB			23-26:12:77		Tagi			81 Mod 188 Ci
Technical University of Denmark (Hjortekoer, Denmark)	5[1]	House A	D1a	125	DL	Spa	HC	16-21:8:79 15-20:11:79	50	Ta Eh Ovh Adp	Ta Ws Oh Iv	D	146,147 Des 148,149 Bre
	6[1]	House B	D1ac	140			HR						
	7[1]	House C		121			HB						
	8[1]	House D	D1a	139	DH		HD RS						
	9[1]	House E		130	DL RS								
	10[1]	House F	D2b	88	DH		HB						
Various (Concord, NH)	11[1]	Warren Burns House	D1abc	107	DL AS CL EB	O F	F HOp	17-20:12:79	40	Tago	Ta I	D	137 Smod
Brookhaven Nat. Lab. (Middletown, RI)	12[1]	Ekose & House	D3a	94	AS CL EB	?	HFct	17-30:1:80	* 30	Tai I Ad Oh	Ta I Ohg	D	9 Ci 138 Bres
Los Alamos Sci. Lab. (Santa Fe, NM)	13[1]	Williamson House	D1	120	DH CW	O F	HOp F F?	26:12-1:1:79 18-22:1:80	40	Tgoi	Ta Ih	D?	35,43 DEROB 101 DOE 22 Db
Tennessee Valley Auth. (Union City, TN)	14[1]	Design No.2	D2a	94	TU AS EB	U	HPct	29:2-3:3:80 20:3-23:3:80	60	Tai Fo Oh	Taw Ihv Wad	D	136 Bres
Brookhaven Nat. Lab. (Upton, NY)	15[1]	Brookhaven House	D2ab	186	DH TU AS	U	Dct F	9:80>	72	Taio Eh Oh	Ta Ih Wsd Oh	D	135 Des 139 Bres
Earth Integral Inc. (Davis, CA)	16[1]	Suncatcher House	D1	149	DL WW CW NI	O F	F	5:79-6:81	30	Tagwo I	Ta Ws Og	T	22 Des 209 Ci 93,142 Mod
Ecole Polytechnique Federale de Lausanne (Begnins, Switzerland)	17[1]	Begnins	D3	?	DH EB NI	O F	HO HD	?	65	Ta Eh Ofw	Tag Ihv Wad Ohv	D	225 Des
University of Delaware (Newark, DE)	18[2]	Solar One	D1ab	121	DL AS	U	HDct F	11:77-2:78	?	Ta Eh	Ta Iv	C?	157 Bres
New Mexico St. Univ. (Las Cruces, NM)	19[1]	Skytherm	D1	?	DH NI RP	U/O F	F/VPp/CEp	81-82	91	Tai Fo	Ta I Ws Oh	D	159 Db 164 Bres
Univ. of Texas, Austin (Santa Fe, NM)	20[1]	Balcomb Residence	D2	230	AS EB RS	O F	HBct F	11-14:2:78	36	Taoi	Ta Ih Wd	D	22 DB 9,153 Ci 166 Des 188 Ci 35,233 DEROB
Los Alamos Sci. Lab. (Los Alamos, NM)	21[1]	Bruce Hunn Residence	D2	214	DH TV	O F	HDpt F	27:12-2.1.79	440	Taoi	Ta Ih Wsd	P?	22 Db 9,153 Ci 35,41 DEROB
Univ. of Arizona (Tucson, AZ)	22[1]	Structure 1	D1	?	DH AS	U/O F	CEp F	82>	?	Tawgoi Ov Apd I EC	Taw Ihvd Wsd Og	D	41 Db 9 Ci 168 Bres 223 Des
	23[2]	Structure 2	D2b		DH DL		Cct F?						
	24[1]	Structure 3	D1ac		DL RS TV W CW		Cpt F						

[1]Acceptable Data Sets which pass Phase 1 but fail Phase 3 criteria.
[2]Useful Data Sets which pass Phase 3 but fail Phase 4 criteria.

Table 11 Residences - passive and hybrid solar

criteria, although many had been gathered for validation purposes. Monitoring experiments need to be carefully conceived and executed if the data is to be of value for validating dynamic thermal models.

5. The limitations imposed on experimental designs by the requirements for validating dynamic thermal models are, in general, far more stringent than those imposed by any other monitoring objectives. Therefore, if data sets are to be used for model validation the constraints imposed by this objective should be given the highest priority. Any other approach is likely to produce data which will not fulfil this objective.

6. Data from only eight sites appeared to be of sufficiently high quality to enable an accurate evaluation of the predictive ability of all three models being used by the SERC/BRE validation group, namely, ESP, SERIRES and HTB2. Data from the Polytechnic of Central London Test Cells, the US National Bureau of Standards Passive Solar Test Facility, and the Energy Monitoring Company Rooms are valuable 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 models. In particular, there appear to be no such data from multi-zoned structures located in Western Europe.

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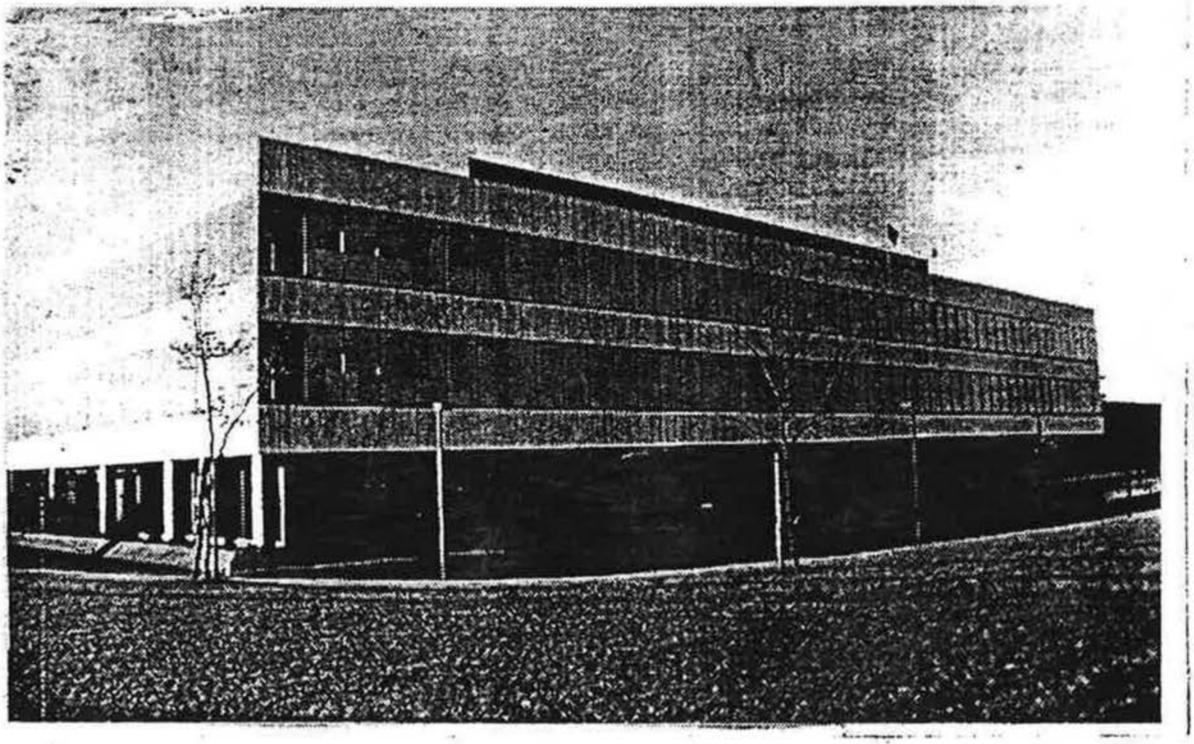

FIG 9 Commercial buildings:
Collins Publishers Building in Glasgow, Scotland, UK (Building 4)

by the UK Cement and Concrete Association, which was used to evaluate a ground conduction model. The Passive Cooling Facility monitored by the University of Arizona and the University of Illinois Lo-Cal house are, however, part of the US DOE Class A monitoring project (Table 1) which has, as one of its priorities, the generation of data for model validation.

Residences have a number of inherent disadvantages for detailed model validation. Firstly, they are highly likely to incorporate complex heat flow mechanisms such as infiltration, advection, thermal bridging and ground coupling, which frequently remain ill-defined by the level of monitoring adopted by the researchers. Secondly, many of them contain interior features, such as stair wells, bathroom and kitchen fittings, in-built partitions and other furnishings, which existing models cannot deal with explicitly. Thirdly, the heating systems which are frequently used (eg. domestic hot water radiators, ducted air systems, gas or solid fuel fires, etc.) cannot be modelled explicitly by most load calculating programs. Finally, occupants could introduce a further source of significant but unquantifiable, external error.

9. CATEGORY 6 : COMMERCIAL BUILDINGS

Seven commercial buildings have been tabulated. They are all multi-zoned and occupied and contain complex HVAC systems. They vary in size from a single storey US Army dental clinic to a seven storey office block. A further 55 commercial buildings were revealed by the literature search but not tabulated because they can be evaluated as a group based on their common characteristics (Section 3).

Data from all seven individually tabulated buildings have been used to validate dynamic thermal models. In most of these studies, the validation was conducted by the institution which conducted the monitoring. However, the largest studies, involving many different models, were conducted by the International Energy Agency. The Annex 1 work in 1973, in which the South Wales Electricity Board monitored the Avonbank building, represents one of the earliest empirical validation exercises. More recently, in Annex IV, the Collins Building (Fig 9) was monitored by the University of Glasgow and the data compared with predictions made by ten modellers. This was probably the most adventurous, and the most expensive, validation exercise ever undertaken.

Numerous difficulties were encountered in all these validation exercises. This was because commercial buildings tend to be dominated by internal gains, due to occupants, lights and other heat sources and these ill-defined heat sources cannot be described in sufficient detail by the currently available thermal models. The heating, ventilating and, in some case, air conditioning systems, also posed severe modelling difficulties for the load calculating models. Commercial buildings are also structurally very complex, incorporating all the geometrical and constructional uncertainties of residences. In the Annex IV study, these problems were such that one participant concluded: "The measurements and computation results should be used neither for 'validating' the existing models, nor for establishing any classification of their respective performance"[31].

10. PHASE 3 : IDENTIFYING USEFUL DATA SETS

10.1 Selection Criteria

General Information		Building Description				Monitoring				
Monitoring Institution (Location of Building)	Code	Building Name	Storeys	Plan Area (m²) Glazed Area (%)	Occ.	Period	Bldg.	Environ.	Data Media	Reference/ Subject
Los Alamos Scientific Laboratory (Pecos, NM)	1[1]	Dove Publications Building	1?	700 ?	O F	10-15:2:80	Ta	?	?	101 DOE
National Bureau of Standards (Manchester, NH)	2[1]	Norris Cotton Federal Building	7b	1600 6	O F	9:79-9:80	Ta Eh Fo	Ta	D?	185 Bres 62-63 Mod 173 Smod
South Wales Electricity Board (Bristol, UK)	3[1]	Avonbank Office Building	3b	1538 12	O F	6-19:1:73 14-27:7:73	Tagio Ehc	Ta	D	33,68,34 Mod
University of Glasgow (Glasgow, UK)	4[1]	Collins Publishers	4b	4000 90	O F	23-31:7:82 12-18:9:82	Tao Eh	Ta	D	[redacted]
US Army Construction Engineering Research Laboratory (Fort Hood, TX) (Fort Carson, CO)	5[1]	Dental Clinic	1	872 9	O F	1:6-6:7:78	Ta Eh Oh	Ta I Wsd Odp	D	11 Ci 44 BLAST
	6[1]	Battalion HQ and Classroom	1b	1757 11	O F	1:8-6:9:78				
Univ. of Naples (Naples, Italy)	7[1]	Appartment Block	7b	107 13	O F	12-17:2:81	Ta	Ta Ih Ws	D	66 Mod

[1] Acceptable Data Sets which pass Phase 1 but fail Phase 3 criteria.

TABLE 12 Commercial Buildings

The purpose of the criteria derived in this phase was to identify data sets which appeared to have deficiencies rendering them unsuitable for validating **any** dynamic thermal model. (The criteria were not therefore specific to any particular dynamic thermal model or group of such models.) The data sets which pass these criteria were termed 'Useful Data Sets'.

Clearly, it was impossible to work with each data set and the complete range of dynamic thermal models currently available in order to determine exactly what the consequences of the errors in each data set would be. An alternative, and feasible, approach was to exploit the experiences of others who have attempted to use monitored data to validate thermal models.

In the course of compiling the information about acceptable data sets, the details of over 130 exercises involving comparisons between measured data and values predicted by thermal models, 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 model being used and the type of structure from which the data had been collected. They were:

(a) missing temperature, wind, and/or solar radiation data during the period for which the comparisons were made[32,33,34,35,36,37];

(b) the inability to separate out the direct and diffuse components of the solar radiation[38,39,40];

(c) the inability to accurately model the influences of real occupants[35,41,42,43,44];

(d) the use of data from a building containing features which were beyond the explicit modelling capabilities of the particular program(s) being used[34,35,41,42].

(e) Difficulty in modelling central plant and distribution systems and in measuring the amount of energy input to, or extracted from, the individual zones of the building[33,34,43,45]; and

(f) missing air infiltration and/or advection measurements[33,34,38,40,41,44,46,47,48].

References are given here to a few validation exercises in which these external errors are stated to have caused major problems. The reasons for the problems and the level of uncertainty introduced has been discussed elsewhere[5].

To be of value in validating any dynamic thermal model, it seems clear that data sets containing the above sources of external error should be avoided. Therefore, the following criteria were developed to screen out such data sets.

Criterion 1: All three major elements of the weather, namely air temperature, wind speed and the direct and diffuse components of solar radiation, must be measured at the site of the building and be available for the whole comparison period.

Criterion 2: The structure must be unoccupied, it must not contain passive solar features which cannot be explicitly modelled and each zone in

Phase Number	Criterion Number	Relevant Table Location		Codes Necessary to Pass Criterion[1]	Codes Causing Failure of Criterion[1]
		Section	Column		
3	1	Monitoring	Environment	Ta and Ws and Ig and In or Id	All other code combinations
	2a	Building Description	Occupancy	All others	O and/or F
	2b		Features	All others	CL or RP or WW or EB
	2c		Plant and Schedules	All others	HD or HO or HP or HR or CE
	3	Monitoring	Building	A	-
4	1a	Building Description	Features	Any others	PCM or TV or TU or RS
			Plant and Schedules	Any others	C or CE
	2	General Information	Location of Building	Any others	Japan or Australia
		Monitoring	Data Media	Any others	C or P or T
	3	Reference/ Subject	-	Smod or Mod or BLAST or DEROB or DOE or ESP or NBSLD or SUNCAT or SUNCODE or SERIRES or TARP	Any other codes

[1] Extra subscripts to codes listed do not influence pass or failure criteria.

TABLE 13 Tabulated codes relevant to assessment against each criterion the building must have independent heating and/or cooling plant and controls.

Criterion 3: Measured infiltration and, where appropriate, inter-zonal air flow rates, must be available for the whole comparison period.

It was relatively easy to apply Criteria 1 and 3, however, care had to be exercised when applying Criterion 2, particularly when trying to decide whether certain passive solar features or heating systems could, or could not, be modelled explicitly by any dynamic thermal model.

In this phase, buildings were deemed to fail Criterion 2 if they were earth bermed or contained either a convective loop system, evaporative roof ponds or tubular water walls. None of these features can be modelled by any of the well-known simulation programs.

Other buildings, such as those with Trombe walls or direct gain systems, can be modelled by at least some programs, such as SERIRES.

To assess heating systems by Criterion 2, it is important to note that most building load calculation models predict, on a zone-by-zone basis, the energy input to, or extracted from, each zone, for particular thermostat set points and on/off strategies. To evaluate such predictions, monitored energy use data must be available on the same zone-by-zone basis. This can be achieved relatively easily when electrical ceiling heaters, base-board heaters, or a fan plus heating or cooling coils are used. It is much more difficult to gather such data for domestic hot air systems, heat pumps, open fires, hot water radiator systems, evaporative roof cooling sprays or large HVAC systems. With such systems it may even be difficult to determine the gross energy use of the central plant, particularly where the primary fuel is not electricity and where, as in many domestic hot water systems, the energy for space heating and hot water systems is supplied by the same central boiler. Buildings with such systems were therefore deemed to fail Criterion 2.

Steps are being taken to integrate air flow algorithms into dynamic thermal models, however, it is difficult to generate an algorithm which is accurate and versatile and yet is also sufficiently compact to nestle within the framework of the existing thermal models. Until this problem is fully resolved measured ventilation rates will be needed to ensure accurate model predictions. Criterion 3 seeks to eliminate data sets which are deficient in this regard.

10.2 Results of Applying the Criteria

The three criteria were applied successively to all the structures listed in Tables 4 to 12 by searching for the appropriate codes which indicate either a pass or a fail by each criterion (Table 13). An indication is given in Tables 4 to 12 of the result of this assessment.

Care was exercised, particularly when applying Criteria 1 and 3, because a missing code could mean either that the parameter had not been measured, that no details were available in the source references or, in the case of Criterion 3, that the structure was well sealed and thus infiltration measurements were irrelevant. At this stage, only those data sets which definitely failed one of the criteria were rejected.

The criteria were also applied to the 368 data sets which were not tabulated

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	48	16	9
- Custom-Designed	22	10	5
2. Experimental Rooms	14	7	0
3. Indoor Structures	7	5	0
4. Experimental Buildings			
- Zoned [1]	19	17	9
- Thermally Integrated	41	25	4
5. Residences - 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 14 Number of structures remaining after each phase of the evaluation process individually (Section 3). Except for 20 residences listed in the IEA Task VIII report and 13 listed by Jones and Associates (Table 2), all these data sets failed one or more of the criteria. In total, of the 589 individual structures evaluated only 123 were not rejected; the numbers remaining in each structural category are given in Table 14. 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.

The literature search was extremely rigorous, and 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 therefore, that the data sets examined are representative 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 models, only about 20% would, due to the existence of external errors, be of value for this purpose. This is disturbing, since 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 model validation.

The main reason for the high failure rate stems from a conflict between 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 on the geometry, construction and operation of the building and on the number, type and location of the sensors (and hence on the data acquisition and storage system) are, in general, far more stringent than those imposed by other objectives, eg. building or component, energy use, energy saving, or thermal comfort assessment. Therefore, if data sets are to be used for model 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.

11. PHASE 4 : IDENTIFYING HIGH QUALITY DATA SETS

11.1 Selection Criteria

In Phase 4, the aim was to select from the useful data sets those which were most appropriate as the basis for the validation tools. For these tools to be of greatest value, they should be usable with as many models as possible. The emphasis therefore shifted from (in Phase 3) identifying data sets which could be useful for validating any one of the many dynamic thermal models which exist, to identifying those which can be used to validate the widest possible range of models. The models 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 models are likely to be of use for validating many other (simpler) models as well.

Criteria were devised and applied to the data sets which passed the Phase 3 criteria. Data sets which passed these new criteria, and were thus suitable as the basis for widely applicable validation tools, were termed `High Quality Data Sets'.

The criteria were:

Criterion 1: The structures must not contain design features, or environmental control systems, which cannot be modelled explicitly by ESP, HTB2 or SERIRES.

Criterion 2: The data medium must be of a type which is readily usable, and close liaison with the monitoring institution must be possible.

Criterion 3: Data from sites which have never produced data for model validation work or data which, due to external errors, has introduced uncertainty into previous validation work, must not be included.

The only passive solar features which all the models being used by the SERC/BRE group could model explicitly were simple direct gain and sun-space systems with their associated interior thermal storage, clerestory windows, night insulation shutters and blinds. These can also be modelled by many other programs[49,50,51]. Features which could not be modelled explicitly by a large number of programs, including ESP and HTB2, are Trombe walls, phase-change materials or rock thermal storage systems. Data sets containing these features fail Criterion 1.

Systems which mechanically cool the interior of zones could not be modelled by HTB2, so data sets which contain such systems also failed Criterion 1. Furthermore, it would also be impossible for the three models to simulate the cycled internal temperature regime within the indoor structures monitored by Manchester University Institute of Science and Technology (Table 7).

Criterion 2 addresses the practical problems associated with acquiring the data, using it, and liaising with the monitoring institution to elecit any necessary support. Such support would almost certainly be necessary when using large amounts of complex data. These considerations mitigate against use of data from geographically remote locations, and data on any media which cannot be fed easily into a computer.

Criterion 3 avoids the problem of unforeseen external errors which could exist in recently acquired and untested data. Such errors could include improperly calibrated sensors, misplaced sensors, broken sensors, missing or incorrectly labelled data, and documentation which does not describe the structure accurately or in sufficient detail for validation purposes. This criterion also eliminates data sets which, in previous validation work, have been shown to contain significant sources of external error.

11.2 Results of Applying the Criteria

Having applied the above criteria to the tabulated data sets, five data sets remained for which the information available was insufficient to resolve whether or not they definitely passed the Phase 3 and Phase 4 criteria. (As explained above in Section 10.2 only data sets which definitely failed the Phase 3 criteria were rejected as that stage.) In this phase, these too were rejected.

The remaining 33 Residences in either the IEA report or the Jones and Associates compilation (Section 10.2) were also rejected at this stage, as were Residences 39 and 41 (Table 10). All these appeared to be much too complex for validation purposes, particularly validation at the mechanism level. This perception was confirmed by a visit to Residence 39, the Lo-Cal house. Although it had been monitored at the highest level as part of the US-DOE Class A performance evaluation programme (Table 1), it contained numerous geometrical and contructional complexities which existing computer models could not describe accurately.

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:

* 2, Polytechnic of Central London Cells, Codes 37, 38 and 41 (Table 4)
* 7, Energy Monitoring Company Rooms, Codes 42 to 48 (Table 4)
* 2, EMPA Dubendorf Cells, Codes 14 and 15 (Table 5)
* 1, Ecole Polytechnique Federal Cell, Code 16 (Table 5)
* 2, University of Strathclyde Cells, Codes 21 and 22 (Table 5)
* 2, National Bureau of Standards Cells, Codes 7B and 7C (Table 8)
* 7, National Research Council of Canada Rooms, Codes 3, 4 and 5A (Table 8)
* 1, Solar Energy Research Institute Cell, Code 5 (Table 9)
* 1, Solar Energy Research Institute House, Code 6 (Table 9)
* 2, National Research Council of Canada Buildings, Codes 34, 35 (Table 9)

These twenty seven structures were therefore deemed to have produced data sets which were of sufficiently high quality that they were suitable as the basis for widely applicable validation tools. These twenty seven structures represent just 4.5% of the total number examined (Table 14), however, because a number of different experiments have been conducted in some of the structures, the data cover a reasonably wide range of weather conditions, modes of heating system operation and glazing areas and types.

12. AVAILABILITY OF DATA SETS FOR MODEL VALIDATION

Since twenty four of the structures which provided high quality data were located on just three sites in North America and three sites in England, visits were made to glean further information to assist in making a final accurate evaluation. This exercise could be viewed as a fifth phase in the selection process.

Unfortunately, these visits revealed that, due to time and fiscal limits, neither the data from the SERI validation test house and the validation cell, nor data from the NRCC passive solar test facility, could be made available for use within the SERC/BRE project. A similar problem existed with regard to the data from the cell monitored by the EPFL.

Therefore, the data sets which are available as the basis for whole model validation tools are from:

Monitoring Institution [Location of Structure] Contact (and Number) [Major References]	'Name' and Code Number	STRUCTURE: Volume (m³)	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)
Polytechnic Central		10.4			*		*			*				2:84	9	60
London	Test Cell 1	10.4			*		*	*		*				4:84	9	60
[Peterborough UK] Kevin Lomas (0533-551551)																
		10.4			*		*			*				2:84	9	60
[A1-A5]	Test Cell 2	10.4			*		*			*				4:84	9	60
Energy Monitoring Co.	British Gas									*[3]			*[3]	:85	16	3/20[2]
[Cranfield UK]	Test Cell	9.7	*				*						*	:85	35[4]	3/20[2]
R. Hitchin (071-736-1212)												*		:85	21[5]	3/20[2]
										*[3]		*[3]		:85	16	3/20[2]
														12:88	21	5
														1:89	9	5
		9.7	*				*				*			2:89	9	5
														2:89	1	5
														3:89	20	5
		9.7	*				*					*		2:90	13.5	5
														8:87a	10	60
	Room 0	7.9				*	*					*		8:87b	10	60
	Room 1	7.9				*	*						*	10:87a	10	60
	Room 2	7.9	*				*					*		10:87b	10	60
	Room 3	7.9	*				*						*	1:88	10	60
	Room 4	7.9				*	*					*		2:88	10	60
	Room 5	7.9				*	*						*	3:90	48	60
														5:90	48	60
National Bureau	Control	87.1				*					*			1:84	21	60
Standards	Room 3													2:84	25	60
[Washington DC USA]	Direct Gain	87.1				*					*			1:84	21	60
Kevin Lomas (0533-55155)	Room 4													2:84	25	60
Univ. of Strathclyde	Cell 1	31.3		*			*			*				2:89	32	60
[Glasgow, Scotland]	Cell 2			*			*					*	*[8]	2:89	32	60
P Strachan (41-552-4400)																

'Name' and Code Number	Start Date	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	Globe	Opaque Surface	Window Surface	Intra-fabric	Below Floor	Above Ceiling	Ventilation: Continuous Flow Meter	Continuous Gas Decay	Others: Auxiliary Heating Power	Surface Heat Flux	Interior Insolation	Interior Longwave	Some thermo-physical Props.
	2:84																									
Test Cell 1	4:84																									
		*					*		*			10	*				*									*
	2:84																									
Test Cell 2	4:84																									
British Gas	:85	*[3]		*[3]																						
Test Cell	:85			*																						
	:85			*			*				*	26	*		*					*		*	*			
	:85	*[3]		*[3]																						
	12:88	*[6]	*[6]	*[6]																						
	1:89	*[6]	*[6]	*[6]																						
	2:89	*[6]	*[6]	*[6]			*				*	54	*		*		*			*		*	*		*	
	2:89		*																							
	3:89					*																				
	2:90	*[7]	*[7]	*[7]			*				*	59	*		*		*			*		*	*		*	
	8:87a		*																							
Room 0	8:87b			*																						
Room 1	10:87a		*				*		*			20	*	*	*			*	*			*	*			
Room 2	10:87b			*																						
Room 3	1:88		*				*				*	20	*	*	*			*	*	*		*	*			
Room 4	2:88		*				*		*			20	*	*	*			*	*			*	*			
Room 5	3:90		*				*		*			20	*	*	*			*	*			*	*			
	5:90	*					*		*			20	*	*	*			*	*				*			
Control	1:84			*				*		*																
Room 3	2:84			*				*		*		26	*		*			*			*	*				
Direct Gain	1:84			*				*		*		226	*	*	*	*	*	*			*	*	*	*		*
Room 4	2:84			*				*		*																
Cell 1	2:89	*			*		*			*		2	*									*				*
Cell 2	2:89	*			*		*					2	*													

'Name' and Code Number	Start Date	WEATHER MONITORING: Sensors	Temperature: Air, Dry Bulb	Air, Wet Bulb	Ground	Radiation: Global Horizontal	Direct Normal	Diffuse Horizontal	Vertical Glazing Plane	Ground Reflected	Net Longwave	Wind: Speed	Direction	VALIDATION Data: High Quality Datasets	Site Handbook Available	Comparisons: ESP	HTB2	SERIRES	DOE-2
	2:84																		
Test Cell 1	4:84																		
		6	*			*		*	*			*	*	4	*	*	*	*	
	2:84																		
Test Cell 2	4:84																		
British Gas	:85																		
Test Cell	:85																		
	:85	6	*			*		*			*	*	*	10					
	:85																		
	12:88																		
	1:89																		
	2:89	6	*			*		*				*	*	5					
	2:89																		
	3:89																		
	2:90	6	*			*		*				*	*	1					
	8:87a																		
Room 0	8:87b													12	*		*	*	
Room 1	10:87a																		
Room 2	10:87b	10	*			*		*				*	*						
Room 3	1:88													24	*		*	*	
Room 4	2:88																		
Room 5	3:90																		
	5:90	13	*	*		*		*	*		*	*	*	12	*				
Control	1:84																		
Room 3	2:84	26	*		*	*	*		*	*	*	*	*	4	*	*	*	*	*
Direct Gain	1:84																		
Room 4	2:84																		
Cell 1	2:89	6	*	*		*		*				*	*	2		*			
Cell 2	2:89																		

[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

TABLE 15 Compiled information about high quality data sets in the U.K.

(a) the 2 Polytechnic of Central London test cells;

(b) the 7 Energy Monitoring Company test cells;

(c) the 2 National Bureau of Standards passive solar test cells (B and C) for periods b, c and d; and

(d) the 2 PASSYS cells at the University of Strathclyde.

Synoptic details about these buildings, the monitoring undertaken and the uses which have been made of the data are given in Table 15. It can be seen that data from all of them has been used as the benchmark against which model predictions were compared. Although the EMC test room data has not been used for rigerous hourly comparisons with an analysis of errors, the comparisons of daily energy use predictions which were made were undertaken 'blind' (i.e. the modellers did not have access to the measured results) this is thought to be only the second time that blind comparisons have been undertaken.

The PCL data was developed as the basis of an empirical validation tool within the BRE/SERC validation project. Detailed site handbooks are available for the PCL , NBS and EMC cells, although good descriptions and access to the actual cells is possible for all the buildings. The data for the PCL and NBS cells can be obtained from the author of this note. The data for the others can be obtained via this route or by directly contacting the Energy Monitoring Company in Milton Keynes, or British Gas (Table 15 gives relevant telephone numbers).

13. CONCLUSIONS

1. A four phase methodology has been devised which provides a valuable and workable framework for the classification and evaluation of data which describe the thermal performance of buildings. Whilst the primary thrust was to identify data sets suitable for validating dynamic thermal models, the classification procedure will be useful to those who seek hourly on-site weather and building performance data for many other purposes.

2. An extensive literature search revealed around 600 structures which have been monitored in such a way that the data could be valuable for validating dynamic thermal models. These structures, located throughout the world, covered a wide variety of forms and modes of operation and were all monitored in the last twenty five years. The structures were divided into six distinct categories and 231 of them have been described in detail. It is thought to be the largest compilation of this type every assembled.

3. Reference material, describing over 160 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 identify data sets which contain external errors which would prevent them being useful for validating <u>any</u> dynamic thermal model. Only about 20% of the data sets passed these

References

1. Bloomfield, D. B., Appraisal techniques for methods of calculating the thermal performance of buildings. Building Serv. Eng. Res. & Tech., Vol. 6, No. 1, pp13-20 (1985).

2. Clarke, J. A., ESP documentation set. Arch. and Bldg. Aids Computer Unit Strathclyde, Univ. of Strathclyde, 17 sections (1982).

3. Palmiter, L. and Wheeling, T., Solar Energy Research Institute residential energy simulator version 1.0. Solar Energy Research Institute, Golden, CO, USA, 356-pp (1983).

4. Alexander, D., HTB2 fix/upgrade notes: r1 to r12; dates 5/3/86 to 27/9/86. Univ. of Wales Inst. of Sci. and Techn. (Private communication) (1986).

5. Bowman, N. T. and Lomas, K. J., Empirical validation of dynamic thermal computer models of buildings. Building Services Eng. Res. & Tech., Vol. 6, No. 4, pp153-162 (1985).

6. Lomas, K. J. and Bowman, N. T., An investigation into analytical and empirical validation techniques for dynamic thermal models of buildings. A SERC/BRE Collaborative Research Project, Vol. 4, Leicester Polytechnic, School of Architecture, 331-pp (1987).

7. Leslie Jones and Associates Inc., Evaluation of passive solar design tools, testing methodology. Rep. for Solar Energy Project, Nat. Research Council of Canada, Ottawa, Ontario (1985).

8. Burch, J., Data requirements for validation of building energy mechanism level simulation. Draft Report, Solar Energy Research Institute, Golden, CO, USA, 452-pp (1984).

9. IEA, Performance data sources, IEA Task VIII passive and hybrid solar low energy buildings. Draft Rep., 223-pp (1985).

10. Hamilton, B. L. and Scofield, P. M., National passive/hybrid performance evaluation program for systems development. Proc. 5th Nat. Passive Solar Conf., Amherst, MS, USA, pp342-345 (1980).

11. Wagner, B. S., Comparisons of predicted and measured energy use in occupied buildings. Pre-print ASHRAE Trans. Vol. 90, Pt. 2, 21-pp (1984).

12. Burch, J. D., A methodology for testing of mechanism level simulation of the commercial building thermal problem. Final Report for US, DOE Commercial Buildings Class A Task, Solar Energy Research Institute, Golden, CO, USA, 109-pp (Private communication) (1985).

13. Diamond, S. C. and Hunn, B. D., Comparison of DOE-2 computer program simulation to metered data for seven commercial buildings. ASHRAE Trans., Vol. 87, Pt. 1, pp1222-1231 (1981).

14. Diamond, S. C. et al, DOE-2 vertification project, phase 1, interim report. Los Alamos Scientific Laboratory, Report LA-8295-MS, 77-pp (1981).

15. Mahajan, S., et al, Class C survey data versus computer predictions - a comparison between field data and simulations. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp311-316 (1983).

16. Gordon, H. T. and Fisher, W. J., The DOE passive solar commercial building program: performance evaluation. Proc. Passive and Hybrid Solar Update, Washington, DC, USA, pp131-136 (1982).

17. Sachs, B., Class C passive solar performance evaluation: summary of national analysis and regional comparisons. Proc. 7th Nat. Passive Solar Conf. Knoxville, TN, USA, pp751-754 (1982).

18. Baird, G. and Pool, F., Energy end-use monitoring of commercial sector buildings, School of Architecture, Victoria University, Wellington, New Zealand, Draft Final Rep. for New Zealand Energy Res. and Dev. Committee, Contract 3177, 236-pp (1984).

19. Rosenfeld, A. H. et al, Building energy use compilation and analysis (BECA): An international comparison and critical review: Part A: New residential buildings. Energy and Buildings, Vol. 3, pp315-332 (1981).

20. Ross, H. and Whalen, S., Building energy use compilation and analysis (BECA) Part C: Conservation progress in retrofitted commercial buildings. Energy and Buildings, Vol. 5, pp161-196 (1983).

21. CEC, Directory of energy data bases. Prep. by Commission of the European Communities, Commission for Inf. & Doc. on Sci. and Tech. (CIDST), Working Grp. 'Information on Energy', Luxembourg, Rep. No. EUR9097:EN-Information Management, 142-pp (1984).

22. Busch, R. D., The new SERI data base for validating passive system computer models. Proc. Systems Simulation & Economic Analysis Conference, San Diego, CA, USA, pp349-353 (1980).

23. Trim, M. J. B., Monitored domestic energy use archive, for Housing Field Trials Workshop, July 1985, 16-pp (Private communication) (1985).

24. Trim, M. J. B., Further details of better insulated housing and energy improvement kit projects. 9-pp (Private communication) (1985).

25. Merriam, R. L. and Rancatore, R. J., Evaluation of existing programs for simulation of residential building energy use. Arthur D. Littler Inc., Cambridge, MA, USA, Final Report for Elec. Power Res. Inst., EPRI EA-2575, Proj. 1775-1 and Gas Res. Inst., Res. Cont. 5014-341-0289, 256-pp (1982).

26. Balcomb, J. D., McFarland, R. D. and Moore, S. W., Simulation analysis of passive solar heated buildings - comparison with test room results. Proc. 2nd An. Meet. AS/ISES, pp11-5 to 11-9 (1977).

27. Littler, J. and Watson, M., Passive solar design, scale models and component tests. Rep. to UK-DOE via D. Bartholomew, Environmental Technology Support Unit, 254-pp (1981).

28. Grimmer, D. P., Theoretical considerations in the use of small passive solar test boxes to model the thermal performance of passively solar heated building designs. Solar Energy, Vol. 22, pp343-350 (1979).

29. Various, An investigation into analytical and empirical validation techniques for dynamic thermal models of buildings. A BRE/SERC Collaborative Research Project, Vol. 2, Published by BRE, 770-pp (1988).

30. Gujral, P. S., Clark, R. J. and Burch, D. M., An evaluation of thermal energy conservation schemes for an experimental masonry building. NBS Building Science Series 137, 38-pp (1982).

31. Building Research Establishment, Glasgow commercial building monitoring project: Final report. Int. Energy Agency, Energy Conservation in Buildings and Community Systems Programme: Annex IV, 163-pp (1984).

32. Clarke, J. A. and Forrest, I., Validation of the ESP thermal simulation program. ABACUS Occ. Pap. No. 61, 74-pp (1978).

33. Anon, Results and analyses of Avonbank building simulation. Rep. by Oscar Faber & Part. for IEA Exec. Comm. on Energy Conservation in Bldgs. and Community Systems, Annex 1, 65-pp (1980).

34. Cockroft, J. P., Validation of buildings and systems energy prediction using real measurements. Computer Aided Design, Vol. 14, No. 1, pp39-43 (1982).

35. Arumi-Noe, F. and Wysocki, M., DEROB: A system for simulating the dynamic energy performance of passive solar structures. ASME Pap. n80-HT-21 for pres. at Joint ASME/AICHE Nat. Heat Transfer Conf., Orlando, FL, USA, 11-pp (27-30 July 1980).

36. Waters, J. R., The experimental verification of a computerised thermal model for building. Building Services Engineering Research & Technology, Vol. 1, No. 2, pp76-82 (1980).

37. Yuill, G. K. and Assoc. Ltd., Verification of the BLAST computer program for houses. A research report, Prep. for Saskatchewan Res. Council, Building Energy Technology Transfer Prog., Pub. No. 83.05, 63-pp (1983).

38. Gough, M., ESP simulation of Canadian direct gain test cell, Report on IEA Task VIII, sub-task B Validation Exercise, 17-pp (unpublished) (1981).

39. Arumi-Noe, F. and Burch, D. M., DEROB simulation of the NBS thermal mass test buildings. ASHRAE Trans., Vol. 90, Pt. 2, 20-pp (1984).

40. Bauman, F. et al, Verification of BLAST by comparison with measurement of a solar dominated test cell and a thermally massive building. Trans. of ASME, Jnl. of Solar Energy Eng., Vol. 105, pp207-216 (1983).

41. Northrup, D. O. and Arumi, F. N., The Bruce Hunn residence as simulated by the DEROB system. Pres. at Ann. Meet. of ASHRAE, Denver, CO, ASHRAE Trans., Vol. 86, Pt. 2, pp873-887 (1980).

42. Wysocki, M. D. et al, The Williamson house as simulated by the DEROB system: a field validation. Proc. of the Ann. Meet. of US-ISES, Phoenix, AZ, Vol. 3.2, pp794-798 (1980).

43. Yuill, G. K. and Phillips, E. G., Comparisons of BLAST program predictions with energy consumptions of two buildings. ASHRAE Trans., Vol. 87, Pt. 1, pp1200-1206 (1981).

44. Herron, D. et al, Comparison of building loads analysis and system thermodynamics (BLAST) computer program simulations and measured energy use for army buildings. Const. Eng. Res. Lab., Interim Rep. E-161, 41-pp (1980).

45. Robertson, D. K. and Christian, J. E., Comparison of four computer models with experimental data from test buildings in Northern New Mexico. Pre-print for ASHRAE Trans., Vol. 91, Pt. 2 (1985).

46. Australian Housing Research Council, An evaluation of thermal performance computer programs. Final Rep., Australian Res. Counc., Dept. of Housing and Const., AHRC Proj. 89, 147-pp (1984).

47. Palmiter, L. et al., Summary of passive test unit performance. Proc. 4th Nat. Passive Solar Conf., Kansas City, MO, USA, pp698-699 (1979).

48. Gilpin, R. R. et al, Construction of the Alberta home heating research facility and results for the 1979-1980 heating season. Dept. of Mech. Eng., Univ. of Alberta, Edmonton, Canada, Dept. Rep. No. 23, Prep. for Alberta/Canada Energy Resources Res. Fund (ERRF), 90-pp (1980).

49. Littler, J. G. F., Overview of some available models for passive solar design. Computer Aided Design, Vol. 14, No. 1, pp15-18 (1982).

50. Littler, J. G. F., Comparison of design tools: carried out by member countries of the EEC. Proc. 8th National Passive Solar Conference, Santa Fe, NM, USA, pp895-898 (1983).

51. Judkoff, R. et al, A methodology for validating building energy analysis simulations. SERI Draft Report, TR-254-1508, 204-pp (1983).

52. Mahajan, B. M., Short duration winter-time performances of different passive solar systems. Prep. for US/DOE, Rep. No. NBSIR 84-2930, 52-pp (1984).

53. Burch, J., Solar Energy Research Institute validation test cell site handbook. SERI Rep. 254/9-2-7, 42-pp, (Private communication J. Burch) (1985).

54. Burch, J. et al, Solar Energy Research Institute validation test house set handbook. SERI Rep., Rough Draft, 43-pp, (Private communication R. Judkoff) (1985).

55. Judkoff, R., A comparative validation study of the BLAST-3.0, SERI-RES-1.0, and DOE-2.1A computer programs using the Canadian direct gain test building. Solar Energy Res. Inst., Draft Rep., 86-pp (1985).

56. Watson, D. M. J., Working drawings for the PCL test cells. (Private communication) (1985).

57. Martin, C., Ruyssevelt, P. and Watson, M., Various private communications, Energy Monitoring Company, formerly Polytechnic of Central London (1984-1987).

58. Littler, J. G. F. et al, No-fines versus concrete blocks for passive solar thermal storage. Research In Building, Rep. RIB/84/958/1, Polytechnic of Central London for the DOE via ETSU, 87-pp (1984).

59. Fisk, D., Control of domestic heating. Energy Research, Re-print of BRE News 46, Winter, pp4-5 (1978).

60. Rayment, R., Comparing energy-saving measures in houses. BRE News 55, Winter, pp4-5 (1981).

61. Kahwaji, G., Burn S. P. and Winn, C. B., Convection studies in the sunspace of the REPEAT facility. Dept. of Mech. Eng., Colorado State Univ., Fort Collins, CO, USA, 47-pp (1985).

62. May, B. W. and Speilvogel, L. G., Analysis of computer simulated thermal performance - the Norris Cotton Federal Office Building. ASHRAE Jnl., Vol. 23, No. 7, pp45-50 (1981).

63. May, B. W. and Speilvogel, L. G., Analysis of computer-simulated thermal performance of the Norris Cotton Federal Office Building. ASHRAE Trans., Vol. 87, Pt. 1, pp1207-1220 (1981).

64. Arumi-Noe, F., The continued development and physical validation of computer program DEROB. Pres. at US DOE Passive and Hybrid Solar Energy Prog. Up-date Conf., Washing DC, USA, pp2.69-2.72 (1980).

65. Green, C. and Riley, P., Evaluation and modelling of thermal storage in a passive hybrid experimental prototype building. Sun at Work in Britain, No. 16, Passive Issue, UK-ISES, pp45-57 (1983).

66. Bloisi, F. et al, Field validation of the AMBRA program simulation. App. Energy, Vol. 87, Pt. 1, pp1200-1206 (1984).

67. Dalrymple, G. J. and James, R., A report on the IEA task VIII test cell simulation LASL Cell 3 and 4 - period February 14th-26th 1981, Prep. for D. Bartholomew, Energy Tech. Support Unit UK DOE, by CAP Scientific, Rep. Ref. 4406/IEA/R1, 9-pp (unpublished) (1983).

68. Irving, S. J., Energy program validation: conclusions of IEA Annex 1. Computer Aided Design, Vol. 14, No. 1, pp 33-38 (1982).

69. Judkoff, R. et al, Empirical validation using data from the SERI Class A validation house. Report No. SERI/TF-234-1923, prep. under Task No. 1953.20, WFA No. 304-32, for U.S. DOE, Contract No. E8-77-8-01-4042, Pre-print for Proc. Ann. Meet. of the US/ISES, Minneapolis, MN, USA, Vol. 6, pp705-710 (1983)

70. Hyde, J. C., Passive test cell experiments during the winter of 1979-80. Los Alamos National Laboratory, Rep. LA-9048-MS, 40-pp (1981).

71. Gujral, P. S., Transient thermal behaviour of an externally insulated massive building. ASHRAE Trans., Vol. 86, pp521-532 (1980).

72. McBride, M. F., Field validation of energy conservation specifications on ten test homes through a metering program. ASHRAE Trans., Vol. 85, Pt. 2, pp563-584 (1979).

73. Hyde, J. C., Performance of night insulation and selective absorbent coatings in LASL test cells. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp277-281 (1980).

74. Blancett, R. S. et al, Residential thermal load analysis and validation. ASHRAE Trans, Vol. 85, Pt. 1, pp678-683 (1979).

75. Brau, J. et al, Comparison of different thermal models for buildings with experiments in artificial climatic conditions. ASHRAE Trans., Vol. 89, Pt. 1A, pp23-34 (1983).

76. Howard, B. D., Measured performance of a direct gain passive system compared to F-chart/SLR 2.1 results. Progress in Solar Energy, Vol. 6, Proc. Ann. Meet. AS/ISES, Minneapolis, MN, USA, pp687-692 (1983).

77. Kusuda, T. et al, Comparison of calculated hourly cooling load and attic temperatures with measured data for a Houston test house. ASHRAE Trans., Vol. 87, Pt. 1, pp1185-1198 (1981).

78. Arumi-Noe, F., Field validation of the DEROB/PASOLE system. Proc. 3rd Nat. Passive Solar Conf., San Jose, CA, USA, pp152-158 (1979).

79. Heikhaus, H. and Lebrun, J., Thermal monitoring of a dozen of reduced scale models of houses. Proc. CEC Int. Colloqu. on Comparative Experimentation of Low Energy Houses, Liege, Belgium, 17-pp (1981).

80. Olsen, L. and Paludan-Mu!H"ller, C., Transparent insulation for thermal storage walls. Meddelelse NR. 142, Final Report CEC Contract no. ESA-PS-146DK(G), 111-pp (1983).

81. Jones, R. W. and McFarland, R. D., Simulation of the ghost ranch greenhouse residence. Proc. 3rd Nat. Passive Solar Conf., San Jose, CA, USA, pp35-40 (1979).

82. Palmiter, L., Results from heated direct gain and selective surface Trombe wall test units. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp273-276 (1980).

83. Wheeling, T., Wadsworth, B. and Palmiter, L., Performance of passive test units during the 1978-79 heating season. Proc. of Int. Solar Energy Soc. Silver Jubilee Congress, Atlanta, GA, USA, p1589-1593 (1979).

84. Burch, D. M., Effect of wall mass on energy consumption. Building Research and Practice, Vol. 11, No. 5, pp282-286 (1983).

85. Stickney, B. L. and Cicero, A., Thermal performance of an attached solar greenhouse. Proc. 4th Nat. Passive Solar Conf., Kansas City, MO, USA, p715-718 (1981).

86. Ruberg, K., NRCC's sunspace and direct gain test facility: thermal performance during 1982-83 heating season. Appx. A of Status Rep.: =2 for IEA Task VIII - Passive and Hybrid Solar Low Energy Buildings, pp1-9 (1984).

87. Palmiter, L. et al, Preliminary results from direct gain and selective surface Trombe wall test units. Proc. Ann. Meet. of AS/ISES, Phoenix, AZ, USA, Vol. 3.2, pp803-807 (1980).

88. Peavy, B. A., A model for predicting the thermal performance of ventilated attics. US Nat. Bureau of Standards, Spec. Pub. 548, pp119-137 (1979).

89. Lowe, R. et al, The Pennyland project. Executive summary ERG/054 ETSU-S-1046(S), Open University, for Milton Keynes Development Corporation, under contract to Energy Technology Support Unit, 57-pp (1985).

90. Bauman, F. et al, Verification of BLAST by comparison with measurements of a solar-dominated test cell and a thermally massive building. Solar Engineering - 1981, Proc. of the ASME Solar Energy Division 3rd Ann. Conf. on Systems Simulation, Economic Analysis/Solar Heating & Cooling Operational Results, Reno, NV, USA, pp299-308 (1981).

91. Trim, M. J. B., The better insulated house programme 1974-1982. Data Build Ltd., Birmingham, UK, 1984, Crown Copyright 1985, 13-pp (Private communication) (1985).

92. Arumi, F. et al, Field validation of the DEROB system: The Bruce Hunn residence. Proc. Systems Sim. and Economic Analysis Conf., San Diego, CA, USA, pp81-83 (1980).

93. Maeda, B. T. and Grant, P. W., Comparison of simulation and measured performance of the Suncatcher house design using SOLSIM and SOLEST. Proc. Systems Sim. and Economic Analysis Conf., San Diego, CA, USA, pp323-329 (1980).

94. Cali, M. et al, Experimental analysis of a test room's unsteady state thermal behaviour. Proc. 2nd CIB Symp. on Energy Cons. in the Built Environment, Session 4, Design for low energy consumption, Copenhagen, Denmark, pp241-252 (1979).

95. Siviour, J. B., Experimental thermal calibration of houses. Proc. of Comm. of the European Communities Int. Colloquium on Comparative Experimentation of Low-Energy Housing, Liege, Belgium, ppV1-V15 (1981).

96. Burch, D. M. et al, Comparison between measured computer-predicted hourly heating and cooling energy requirements for an instrumented, wood-framed town house subject to laboratory tests. ASHRAE Trans., Vol. 81, No. 2, Paper No. 2363, pp70-87 (1975).

97. Letherman, K. M. and Palin, C. J., Experiments on the dynamic thermal response of rooms. Bldng. and Environment, Vol. 17, No. 3, p235-241 (1982).

98. McFarland, R. D., Passive test cell data for the solar laboratory winter 1980-81. Los Alamos National Laboratory Rep. LA-9300-MS, 82pp (1982).

99. Anon, Environmental testing of full size buildings. Building Systems Design, Vol. 70, No. 3, p-107 (1973).

100. Rey, Y. et al, Measurements and modelisation of a Trombe wall. Int. Solar Energy Society, Solar World Forum, Brighton, UK, Vol. 3, pp1865-72 (1981).

101. Kerrisk, J. F. et al, Passive solar design calculations with the DOE-2 computer program. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp116-120 (1980).

102. Hull et al, Solar heating performance for a transwall test prototype system. Proc. Ann. Meet. of AS/ISES, Phoenix, AZ, USA, Vol. 3.2, pp923-927 (1980).

103. Clinton, J. R., Results from the Pala Passive Solar Project. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, p15-20 (1983).

104. Kneubuhl, F. K. et al, Energy saving by reduction of the thermal radiation from building envelopes. Proc. of Int. Congress on Building Energy Management, Conventional and Solar Approaches, Povoa de Varzim, Portugal, pp153-172 (1980).

105. Dupagne, A. et al, Practical method to evaluate the effect of building characteristics in the energy needs for heating. Proc. of Int. Congress on Building Energy Management, Conventional and Solar Approaches, Povoa de Varzim, Portugal, pp127-141 (1980).

106. Gay, J. B. and Faist, A., Dynamic heat balance of windows. Proc. of Int. Congress on Building Energy Management, Conventional and Solar Approaches, Povoa de Varzim, Portugal, pp259-264 (1980).

107. Gujral, P. S., Clarke, R. J. and Burch, D. M., Transient thermal response of an intermittently cooled massive building. Proc. ASHRAE/DOE-ORNL Conf. on Thermal Performance of the Exterior Envelopes of Building, Kissimmee, FL, USA, pp751-756 (1979).

108. Duncan, J. P. and Prowler, D., Testing and simulation of passive solar systems. Proc. 2nd Nat. Passive Solar Conf., Philadelphia, PN, USA, pp581-587 (1978).

109. Hunn, B. D., Analysis of validation data sets in the Class A performance evaluation program. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp9-14 (1983).

110. Basnett, P., Modelling the effects of weather, heating and occupancy on the thermal environment inside houses. Mathematical Models for Environmental Problems; Proc. Int. Conf., Univ. of Southampton, UK, Pentech Press, London, pp353-365 (1975).

111. Palmiter et al, Performance of passive test units in Butte, Montana. Proc. 2nd Nat. Passive Solar Conf., Philadelphia, PN, USA, pp591-595 (1978).

112. Burns, P. J. et al, Thermal radiation calculations for a vertical cylindrical water wall. Proc. 4th Nat. Passive Solar Conf., Kansas City, MI, USA, pp168-172 (1979).

113. Hull, J. R. et al, Effect of design parameter changes on the thermal performance of a transwall passive solar heating system. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp394-398 (1980).

114. Wessling, F. C., Passive solar thermal simulations - three models. Passive Systems '78, AS/ISES, pp40-44 (1978).

115. Penman, J. M., (Private communication) (1984).

116. Peavy, B. A. et al, Comparison of measured and computer predicted thermal performance of a four bedroom, wood-framed town house. NBS Building Science Series 57, 56-pp (1975).

117. Wessling, F. C., Solar retrofit test modules. Proc. 2nd Nat. Passive Solar Conf., Philadelphia, PN, USA, pp445-451 (1978).

118. Hunn, B. D. et al, Applications of DOE-1 to passive solar heating of commercial buildings: preliminary results. Proc. 3rd Nat. Passive Solar Conf., San Jose, CA, USA, pp159-163 (1979).

119. Burch, D. M. et al, A field study of the effect of wall mass on the heating and cooling loads of residential buildings. Proc. of Building Thermal Mass Seminar, Oak Ridge National Laboratory, Knoxville, TN, USA, pp265-311 (1982).

120. Burch, D. M. et al, Experimental validation of an attic condensation model. Pre-print ASHRAE Trans., Vol. 90, Pt. 2, 19-pp (1984).

121. Burch, D. M. et al, The effect of wall mass on the summer space cooling of six test buildings. Pre-print ASHRAE Trans., Vol. 90, Pt. 2, 16-pp (1984).

122. Burch, D. M., The effect of wall mass on winter heating loads and indoor comfort - an experimental study. Pre-print ASHRAE Trans., Vol. 90, Pt. 1, 28-pp (1984).

123. Burch, D. M., The effect of thermal mass on night temperature set back savings. Pre-print ASHRAE Trans., Vol.90, Pt. 2, 22-pp (1984).

124. Barakat, S. A., NRCC Passive Solar Test Facility description and data reduction. Div. of Bldg. Res., Nat. Res. Council of Canada, Bldg. Res. Note No. 214, 30-pp (1984).

125. Barakat, S. A., NRCC Passive Solar Test Facility performance of direct gain units. Div. of Bldg. Res., Nat. Res. Council of Canada, Bldg. Res. Note No. 215, 18-pp (1984).

126. Beaudoux, M. and Fauconnier, R., Thermal research in in-situ test cells. Rep. by Centre Experimental du Batiment et des Travaux Publics, for Federation Nationale du Batiment, 15-pp (1984).

127. Allen, R. B., Controlled experiments using passive solar techniques in the Pacific Northwest. Proc. 2nd Nat. Passive Solar Conf., Philadelphia, PN, USA, pp431-434 (1978).

128. Mahajan, B. M., Short duration winter-time performances of different passive solar systems. Prep. for US/DOE, Rep. No. NBSIR 84-2930, 52-pp (1984).

129. Spears, J. W. and Sersen, S. J., Comparison of actual vs. predicted performance of a passive system using TI-59 programs. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp56-80 (1980).

130. Solar Energy Group, National Bureau of Standards direct gain test cell site handbook. Los Alamos Nat. Lab., NM, Rep. No. LA-9786-MS, 41-pp (1983).

131. Burns, P. J. et al, Passive Solar/gas-fired heating system characterization and development. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, pp3-8 (1983).

132. Armstrong, P. et al, Passive solar/gas technology character¦ization and development. Mech. Eng. Dept., Colorado State Univ., 7th Quarterly Rep., Prep. for Gas Research Inst., 46-pp (1984).

133. Hasegawa, F., Performance evaluation of passive solar systems using a twin-type test house and computer simulation. Reps. on Proj. Res. on Energy under Grant Aid of Sci. Res. of Min. of Ed. Sci. and Culture, Japan, Res. on Nat. Energy, Vol. 8, pp17-27 (1984).

134. Kimura, K., Studies on the architectural planning with complex use of natural energy. Reps. of Spec. Proj. Res. on Energy under Grant Aid of Sci. Res. of Min. of Ed. Sci. and Culture, Japan, Res. on Nat. Energy, Vol. 8, pp1-16 (1984).

135. Temple, P. L., Class A monitoring of the Brookhaven House. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp351-355 (1980).

136. Suhs, N. E. and Wessling, F. C., Initial monitoring results of TVA's solar house no. 2. Proc. 5th Nat. Passive Solar Conf., Amherst, MS, USA, pp356-360 (1980).

137. Saunders, N. B. et al, The double shell house: quantitative thermal analysis with measured verification. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp498-502 (1980).

138. Ghaffari, H. T. et al, Approach to performance evaluation of a double wall convective loop house. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp518-522 (1980).

139. Ghaffari, H. T. and Jones, R. F., Comparative thermal performance of the direct gain, Trombe, and sunspace walls. Proc. 6th Nat. Passive Solar Conf., Portland, OR, USA, pp-93-97 (1981).

140. Wilson, Q. C., Thermal performance of the Ghost Ranch sun-dwellings. Proc. 2nd Nat. Passive Solar Conf., Philadelphia, PN, USA, pp457-461 (1978).

141. Royal, G. C. et al., Archiving of the information from the commercial building program. Proc. 9th Nat. Passive Solar Conf., Columbus, OH, USA, pp168-173 (1984).

142. Maeda, B. T., Suncatcher monitoring project: three years of monitoring. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp931-936 (1983).

143. Hartmann, P. and Mühlebach, J., Messprojekt Maugwil: Messdaten der gebäudekonstruktion und des energieh aush altes. Swiss Fed. Labs. for Mat. Testing and Res., EMPA Rep. No. 41643/1, (in German), 64-pp (1983).

144. Marcus, I. and Gass, J., Messprojekt Maugwil: Verification des rechenprogramms DOE-2 anhand des gemessenen energieh aushaltes. Swiss Fed. Labs. for Mat. Testing and Res., EMPA Rep. No. 41643/2, (in German), 58-pp (1983).

145. Spooner, D. C., Heat loss measurements through an insulated domestic ground floor. Building Serv. Eng. Res. and Tech., Vol. 3, No. 3, pp147-150 (1982).

146. Djurtoft, R. G., Monitoring energy conservation houses. Thermal Ins. Lab., Tech. Univ. of Denmark, Rep. No. 82-28, Pre-print for ENERGEX '82, Regina, Saskatchewan, Canada, 7-pp (1982).

147. Byberg, M. R. et al, Six low-energy houses at Hjortekoer. Thermal Ins. Lab., Tech. Univ. of Denmark, Rep. No. 83, 14-pp (1979).

148. Huusom, J. and Madsen, T. L., The thermal indoor climate in six low-energy houses. Prep. for 7th Int. Congress of Heating and Air Conditioning CLIMA-2000, Budapest, Hungary, 16-pp (1980).

149. Saxhof, B. and Nielsen, A. A., Low-energy houses: insulation and air tightness. Building Res. and Pract., Vol. 11, No. 3, pp142-152 (1983).

150. Everett et al, Performance of passive solar houses at Great Linford, Milton Keynes. Final Rep. by Open Univ. for Milton Keynes Dev. Corp. under ETSU contract No. E/SA/CON/1025/174/020, 430-pp (1984).

151. Eriksson, C. et al., Mathematical modelisation of a direct gain test cell. Int. Solar Energy Society, Solar World Forum, Brighton, UK, Vol. 3, pp1811-1817 (1981).

152. Tichy, J. A., Performance of the RPI passive solar visitors information centre building: Progress report. Proc. Passive and Hybrid Solar Energy Up-date, Washington, DC, USA, pp340-345 (1985).

153. AIA Research Corp., Passive solar design: a survey of monitored buildings. Prep. for U.S. DOE under contract EG-77-C-01-4113, 358-pp (1978).

154. Heidell, J. A., Commercial building end-use energy metering inventory. Battelle Pacific Northwest Laboratory Rep. PNL-5027, UC-95d for US DOE under contract DE-AC06-76RLO 1830, 134-pp (1985).

155. Burch, D. M. and Treado, S. J., Ventilating residences and their attics for energy conservation - an experimental study. NBS Spec. Pub.548, Summer Attic and Whole-House Ventilation, pp73-104 (1979).

156. Howard, B. D. and Pollock, E. O., Insolation versus insulation comparisons of monitored system performance. Proc. 7th Nat. Passive Solar Conf., Knoxville, TN, USA, pp63-68 (1982).

157. Faunce, S. et al, Solar One - active and passive contributions to space heating. Proc. 2nd Nat. Passive Solar Conf., Philadelphia, PN, USA, Vol. 2, pp621-625 (1978).

158. Judkoff, R., Empirical validation of building energy analysis simulation programs: a status report. Proc. Passive and Hybrid Solar Energy Up-date, Washington, DC, USA, pp33-40 (1982).

159. Hunn, B. D. et al, The DOE passive solar Class A performance evaluation program: preliminary results. Proc. Passive and Hybrid Solar Energy Up-date. Washington, DC, USA, pp41-49 (1982).

160. Sepsy, C. et al, Fuel utilization in residences. Ohio State Univ., Final Rep. EPRI-898, for Elec. Power Res. Inst., 252-pp (1978).

161. Balcomb, J. D., McFarland, R. D. and Moore, S. W., Passive testing at Los Alamos. Proc. 2nd Nat. Passive Solar Conf., Philadelphia, PN, USA, pp602-609 (1978).

162. McFarland, R. D. et al, Los Alamos passive test cell results for the 1981-82 winter. Los Alamos National Laboratory Rep. LA-9543-MS, 54-pp (1982).

163. Niles, P. W. B., Graphs for direct gain house performance prediction. Passive Systems '78, AS/ISES, pp76-81 (1978).

164. Mancini, T. R., The New Mexico State University passive solar house. Proc. Passive and Hybrid Solar Energy Up-date, Washington, DC, USA, pp89-92 (1982).

165. Swartz, D. et al, REPEAT facility status report - September 1982. Proc. Passive and Hybrid Solar Energy Up-date, Washington, DC, USA, pp331-338 (1982).

166. Balcomb, S., Living in a passive solar home. Energy and Buildings, Vol. 7, pp309-314 (1984).

167. Gay, J. B., Measurements on a Trombe wall. EPFL, Solar Energy Research Group, EPFL, 18-pp (Private communication) (1985).

168. Kessler, H. J., Passive cooling for hot arid regions. Proc. Passive and Hybrid Solar Energy Up-date, Washington, DC, USA, pp302-310 (1982).

169. Atkinson, B. A. et al, Validation of CALPAS3 computer simulation program. Proc. 6th Nat. Passive Solar Conf., Portland. OR, USA, pp358-361 (1981).

170. Hunn, B. D. et al, Validation of passive solar analysis/design tools using Class A performance evaluation data. Proc. 7th Nat. Passive Solar Conf., Knoxville, TN, USA, 6-pp (1982).

171. Mahajan, B. M. and Liu, S. T., Initial results from the NBS passive solar test facility. Proc. ASME Solar Div., 6th Ann. Tech. Conf., pp109-115 (1983).

172. Clinton, J. R., The SEA-LAB passive test building project. Proc. Systems Simulation and Economic Analysis Conf., San Diego, CA, USA, pp91-94 (1980).

173. May, W. B., Equivalent thermal parameters from measured data. Building Research and Practice, Nov.-Dec., pp348-360 (1982).

174. Lofchie, H. et al, The Massachusetts multi-family passive solar program: a comparison of monitoring data to a design tool predictions. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp229-234 (1983).

175. Mahajan, B. M. and Liu, S. T., Experimental research at the NBS passive solar test facility. Conf. Paper, 6-pp (Private communication) (1985).

176. Palmiter, L. et al, Measured and modelled passive performance in Montana. Passive Systems '78, AS/ISES, pp76-81 (1978).

177. Letherman, K. M. et al, The thermal frequency response of rooms. Building and Environment, Vol. 17 No. 1, pp5-10 (1982).

178. Mahajan, B. M. and Liu, S. T., Results from the NBS passive solar test building, a status report. Conf. Paper, 8-pp (Private communication) (1985).

179. Peavy, B. A. et al, Dynamic Thermal performance of an experimental masonry building. U.S. Nat. Bureau of Standards, Bldng. Sci. Ser. 45. 98-pp (1973).

180. Siviour, J. B., Construction instrumentation and heat loss data of the SERC experimental houses. Elec. Counc. Res. Cent., Job No. 461, ECRC/N840 (unpublished) (1975).

181. Ghost Ranch Conference Centre, Sun dwellings demonstration centre. Pamphlet Ghost Ranch Conf. Centre, Abiguiu, NM, USA, 4-pp.

182. Swisher, J. N. and Duffy, J. J., Measured performance of 50 passive solar residences in the United States. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp223-227 (1983).

183. Tsongas, G., Measured versus SLR-predicted performance of a monitored direct gain home. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp321-326 (1983).

184. Howard, B. D., Measured total performance of a solar home using concrete masonary. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp283-288 (1983).

185. Richtmyer, T. E. et al, Thermal performance of the Norris Cotton Federal building in Manchester, New Hampshire. Proc. ASHRAE/DOE-ORNL Conf. on Thermal Performance of Exterior Envelopes of Buildings, Kissimmee, FL, USA, pp781-797 (1979).

186. McFarland, R. D. and Balcomb, J. D., Los Alamos test room results. Los Alamos Nat. Lab. Rep. LA-UR-82-1836, Pres. 7th Nat Passive Solar Conf., Knoxville, TN, USA (1982).

187. McFarland, R. D., Jones, R. W. and Lazarus, G. S., Annual thermal performance of sunspace-type passive solar collectors for residence heating - attached and semi-enclosed geometries. Los Alamos National Laboratory Rep. LA-9424-MS, 79pp (1982).

188. Jones, R. W., Monitored passive solar buildings. Los Alamos National Laboratory Rep. LA-9098-MS, 70-pp (1982).

189. Swisher, J. N., Performance results from passive solar residences in Denver, Colorado. Proc. 7th Nat. Passive Solar Conf., Knoxville, TN, USA, pp783-788 (1982).

190. Duffy, J. J., Class B passive solar monitoring results for the Northeast: I. Proc. 7th Nat. Passive Solar Conf., Knoxville, TN, USA, pp789-794 (1982).

191. Swisher, J. N. and Frey, D. J., Performance monitoring of passive solar residences at the Class B level. Proc. 7th Nat. Passive Solar Conf., Knoxville, TN, USA, pp1107-1117 (1982).

192. Burns, P. et al, Summer-time test results from the REPEAT facility. Paper, pp411-416, (Private Communication P. Burns) (1985).

193. Barakat, S. A., Performance of passive solar systems in a cold climate. Rep. Div. of Building Res., Nat. Res. Council of Canada, Intersol '85, Congress of Int. Solar Energy Soc., Montreal, 6pp (1985).

194. Barakat, S. A., NRCC passive solar test facility performance of a mass-wall unit. Div. of Building Res., Nat. Res. Council of Canada, Rep. No. 216, 11-pp (1984).

195. Barakat, S. A., NRCC Passive solar test facility, performance summary. Rep. Div. of Building Res., Nat. Res. Council of Canada, For pres. at Int. Solar Arch. Conf., Cannes, France, 6-pp (1982).

196. Wray, W. O. et al, Sensitivity of direct gain performance to detailed characteristics of the living space. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp92-95 (1980).

197. Ruberg, K., Sensor placements in NRCC sunspace units. Private communication (1985).

198. Rubini, F. and Mazza, A., Experimental evaluation of some calculation codes for predicting the thermal behaviour of buildings in transient conditions. Proc. of the CEC Int. Colloqu., Comparative Experimentation of Low Energy Houses, Liege, Belgium, 28-pp (1981).

199. Howard, B. D., Comparing NSDN passive solar buildings with selected super-insulated houses. Proc. 7th Nat. Passive Solar Conf., Knoxville, TN. USA, pp1085-1096 (1982).

200. Barnett, J. P., Selected measured data from residential housing for use in testing and verification of building energy analysis programs. Nat. Bureau of Standards, Washington, DC, USA, NBSIR-81-2456, 65-pp (1982).

201. Watson, M. and Littler, J., External test rooms. Final SERC Report on GR/B/26626, PCL, 24-pp (1983).

202. Moore, E. F. and McFarland, R. D., Passive solar test modules. Los Alamos Nat. Laboatory Report LA-9421-MS, 78-pp (1982).

203. Schnurr, N. M. et al., Applications of DOE-2 to direct gain passive solar systems: Implementation of a weighting-factor calculation technique. Proc. of the 4th Nat. Passive Solar Conf., Kansas City, MO, USA, pp182-186 (1979).

204. Kolar, W. A., A guide to using the Class B passive solar performance data. Solar Energy Research Institute, Rep. SERI/SP-254-2248 (1984).

205. Mahajan, S. et al, Performance of passive solar and energy conserving houses in California - Class B monitoring. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp235-240 (1983).

206. Shea, M., et al, Documentation of data processing procedures and extension of Class B data analysis. Solar Energy and Acoustics Consultants, Sacramento, CA, USA, Final Sub. Cont. Rep., SERI/STR 254-2085, 169-pp (1983).

207. Mahajan, S. et al, Performance of passive solar and energy conserving houses in California. Physics Dept., Calif. St. Univ., Sacramento, CA, USA, Final Sub. Cont. Rep., SERI/STR-254-2017, 326-pp (1983).

208. Mahajan, S. et al, One-time measurement of the infiltration rate and conductive loss coefficient for houses in California - Class B sites. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp241-246 (1983).

209. McKinstry, M. et al, Heating season results from the Bonneville power administration Class B passive solar monitoring program. Proc. 8th Nat. Passive Solar Conf., Santa Fe, NM, USA, pp211-216, (1983).

210. Spears, J. W., Performance analysis methodology for passive heating systems in the NSDN. Proc. 6th Nat. Passive Solar Conf., Portland, OR, USA, PP8-12 (1981).

211. Pollock, E. O., NSDN passive program. Proc. Passive and Hybrid Solar Energy Update, Washington, DC, USA, pp207-212 (1982).

212. Doak, L. G. and Waterman, R. E., Applicability of data from the National Solar Data Network for simulation studies. Proc. Systems Sim. & Economic Analysis Conf., San Diego, CA USA, pp389-395 (1980).

213. Burch, D. M. et al, The effect of wall mass on annual heating and cooling loads of single family residences for five selected climates. Symp. on Thermal Insulation Materials and Systems, Dallas, TX, USA, 33-pp (1984).

214. Howard, B. D., Measured performance of a direct gain passive system compared to F-Chart/SLR 2.1 results. Proc. Ann. Meet. of AS/ISES, Minneapolis, MN, USA, pp687-692 (1983).

215. Colley, M. D., NRC/Solar energy program intermediate level passive solar monitoring work. Appx. B of status Rep: Canada 2 for IEA Task VIII Passive and Hybrid Solar Low Energy Buildings, pp187-191 (1984).

216. Goldstein, D. B., Modelling passive solar buildings with hand calculators. Proc. 3rd Nat. Passive Solar Conf., San Jose, CA, USA (1979).

217. Moore, E. F., Passive solar test modules: A survey summary. Proc. 7th Nat. Passive Solar Conf., Knoxville, TN, USA, pp1055-1060 (1982).

218. Leslie Jones & Associates Inc., Solar radiation sensitivity study. (Private communication Leslie Jones), 11-pp (1984).

219. Frank, T. and Grob, P., Meteorological data, Maugwil monthly, daily and hourly averages. EMPA Rep. Sept. 1981, for Swiss National Science Foundation, Project No.: 4.089-0.76.04, 123pp (in German).

220. Frank, T., Passive solar heat gain of opaque building structures. Paper pres. at CIB Conf., Stockholm, Sweden (Private communication), 11-pp (1983).

221. Frank, T. and Grob, P., Measurement at the Maugwil test cells. Validation of simulation model HELIOS through field experiments in two test cells. EMPA Rep. Nov. 1982, for Swiss Nat. Science Foundation: Project Nr.: 4.089-0.76.04 (in German), 109-pp (1982).

222. Zurcher, C. et al, The influence of thermal and solar radiation on the energy consumption of buildings. Infra-red Physics, Vol. 22, pp227-291 (1982).

223. Peck, J. F. and Kessler, H. J., A passive cooling experimental facility for a hot/arid climate. Proc. Int. Passive and Hybrid Cooling Conf., Miami Beach, FL, USA, pp436-441 (1981).

224. Siviour, J. B., Solar heating in unoccupied houses. Elec. Council Res. Centre, ECRC/N840 (unpublished) (1975).

225. Perrin, G. R. et al., Case study of passive solar houses under Swiss climate. ISES, Solar World Forum, Brighton, UK, Aug. 23-28, Vol. 3, pp1798-1802 (1979).

226. Richtmyer, T. E. and Liu, S. T., Test facilities for passive solar systems integrated with buildings, Proc. 7th Nat. Passive Solar Conf., Knoxville, TN, USA, pp1049-1054 (1982).

227. McCulley et al., The University of Illinois Lo-Cal house: computer simulation, monitoring equipment installation, data acquisition methods and data analysis. Proc. of Comm. of the European Communities Int. Colloqu. on Comparative Experimentation of Low Energy Houses, Liege, Belgium, 18-pp (1981).

228. Spooner, D. C., Heat losses from an unoccupied house. Cement and Conc. Assoc., Tech. Rep. 549, 23-pp (1982).

229. Nicol, J. L., Evaluation of energy conservation components in a Lo-Cal house. M.Sc. Thesis, Univ. of Illinois, 108-pp (1982).

230. Russell, K., Comparison of UK test cell data and SERI-RES simulations. Draft Rep., Polytechnic of Central London, 79-pp (Private communication J. Littler) (1985).

231. Judkoff, R., and Wortman, D. N., Validation of building energy analysis simulations using 1983 data from the SERI Class A test house. Solar Energy Research Institute, Draft Rep. 254/3-4-8, 80-pp (1984).

232. Gough, M., Report on a visit to the reconfigurable passive solar test facility at Colorado State University, Fort Collins, CO, 10th January 1984. 2-pp (unpublished) (1984).

233. Arumi-Noe, F. and Northrup, D. O., A field validation of the thermal performance of a passively heated building as simulated by the DEROB system. Energy and Buildings, Vol. 2, No. 1, p65-75 (1979).

234. Gilpin, R. R. et al., Second annual report on the Alberta home heating research facility: Results for the 1980-81 Heating Season. Dept., of Mech. Eng., Univ. of Alberta, Edmonton, Canada, Dept. Rep. No. 24, Prep for Alberta/Canada Energy Resources Res., Fund (ERRF) and Dept. of En., Mines & Resources, (Canada), 82-pp (1981).

235. Ackerman, M. Y. et al., Final report on the Alberta home heating research facility: Results of the 1981-82 heating season and part of the 1982-83 heating season to January. Dept. of Mech. Eng., Univ. of Alberta, Edmonton, Canada, Dept. Rep. No. 34, Prep. for Alberta/Canada Energy Resources Res. Find (ERRF) and Dept. of En., Mines and Resources (Canada), 139-pp (1983).

236. Ackerman, M. Y. et al., Fourth annual report on the Alberta home heating research facility: Results of the 1982-83 heating season. Dept. of Mech. Eng., Univ. of Alberta, Edmonton, Canada, Dept. Rep. No. 41, 79-pp (1984).

237. Kostiuk, L. W., Thermal performance of an insulated masonry structure: Results of the 1983-84 heating season. Dept. of Mech. Eng., Univ. of Alberta, Edmonton, Canada, Dept. Rep. No. 44, 66-pp (1984).

238. Ackerman, M. Y., Fifth annual report on the Alberta home heating research facility: Results of the 1983-84 heating season. Dept. of Mech. Eng., Univ. of Alberta, Edmonton, Canada, Dept. Rep. No. 48, 69pp (1984).

239. Gustinis, J. and Robertson, D. K., Southwest thermal mass study Tesuque Pueblo, New Mexico, Construction and Instrumentation Phase. New Mex. En. Res. and Dev. Inst., Univ. of New Mexico, 38-pp (1981).

240. Gustinis, J. and Robertson, D. K., Southwest thermal mass study Tesuque Pueblo, New Mexico, The effect of envelope thermal mass on the heating energy use of eight test buildings in a high desert climate. Research Phase 1 (September 1981 through December 1982), New Mexico En. Res. and Dev. Inst., Univ. of New Mexico, Prep for Oak Ridge Nat. Lab. 117-pp (1984).

241. Robertson, D. K., Southwest thermal mass study Tesuque Pueblo, New Mexico, Observation and prediction of the heating season thermal mass effect for eight test buildings with and without windows. Research phase II, (January 1983 through June 1983). New Mexico En. Res. and Dev. Inst., Univ. of New Mexico, Prep. for Oak Ridge Nat. Lab., (1984).

242. Arumi-Noe, F., Data consistency study, Analysis of the interior air temperatures of the New Mexico test cells (SWTMS). Rep. for En. Div., Oak Ridge Nat. Lab., 33-pp (1984).

243. Arumi-Noe, F., Data consistency study of the New Mexico test cells (SWTMS), DEROB simulation of the air temperature and heating load analysis. Rep. for En. Div., Oak Ridge Nat. Lab., 46-pp (1984).

244. Arumi-Noe, F., Data consistency study of the New Mexico test cells (SWTMS) DEROB simulation of the north wall heat flux of test cell 1 during the weather test period from Jan. 5 through Jan. 8 1982. Rep. for En. Div., Oak Ridge Nat. Lab., 34-pp (1985).

245. McLain, H. A., Simulation of the SWTMS test cells using the DOE-2.1A model. Draft Rep., Oak Ridge Nat. Lab., 120-pp (Private communication) 1985).

246. Bauman, F., Preliminary verification of BLAST by comparison with Lo-Cal house data. Small Homes Council, Building Res. Council, Technical Note 31, 10-pp (1982).

247. Carroll, W. L. et al, Thermal mass: A comparison of measured and BLAST predictions for six test cells in two climates. Passive Research & Development Group, Lawrence Berkeley Lab., Draft. Rep. LBL-18020, 119-pp (1985).

248. Emergy, A. F. et al., The simulation of building heat transfer or passive solar systems. Energy & Buildings, Vol. 3, pp287-294 (1981).

249. Kusuda, T. and Bean, J. W., Comparison of calculated hourly cooling load and indoor temperature with measured data for a high mass building tested in an environmental chamber. ASHRAE Trans., Vol. 87, Pt. 1, pp1232-1240 (1981).

250. Fanchiotti, A., Two-storey Trombe wall test cells. Proc. 5th Nat. Passive Solar Conf., Amherst, MA, USA, pp376-380 (1980).

251. Barakat, S. A., Passive solar heating studies at the Division of Building Research. Div. of Bldg. Res., Nat. Res. Council of Canada, Bldg. Res. Note No. 188, 10-pp (1983).

252. Watson, M. and Martin, C., British Gas heating experiments December 1984 - March 1985, Research in Buildings Unit, Polytechnic of Central London, 48-pp (1985).

253. Anon, Intermittent heating experiments in a thermally massive test room, Technical Report, Energy Monitoring Company, 31-pp (1986)

254. Martin, C. and Watson, M., Experiments in a highly instrumented test room - 1988/89, Technical Report, Energy Monitoring Company, 31-pp (1989).

255. Martin, C., Stochastic heating trial in the British Gas test room, Technical Report, Energy Monitoring Company, 14-pp (1989).

256. Martin, C. and Watson, M., (1990) Further experiments in a highly instrumented test room - 1990, Technical Report, Energy Monitoring Company, 27-pp (1990).

257. Martin, C., Description of the EMC test room facility 1987-88, Contractor Report from Energy Monitoring Company to U.K. Department of Energy, via ETSU, ETSU S 1197-P4, 68-pp (1990).

258. Martin, C., An investigation of the influence of heater type and thermostat response on passive solar buildings performance: model/data comparison study, Contractor Report from Energy Monitoring Company to U.K. Department of Energy, via ETSU, ETSU S 1197-P5, 110-pp (1990).

259. Martin, C., An experimental investigation of the influence of thermostat type on passive solar building performance, Contractor Report from Energy Monitoring Company to U.K. Department of Energy, via ETSU, ETSU S 1197-P3, 54-pp (1990).

260. Martin, C., An experimental investigation of the influence of heater type on passive solar building performance, Contractor Report from Energy Monitoring Company to U.K. Department of Energy, via ETSU, ETSU S 1197-P2, 64-pp (1990).

261. Anon, Detailed model comparisons: An empirical validation exercise using SERIRES, Contractor Interim Report from Energy Monitoring Company to U.K. Department of Energy, via ETSU, ETSU S 1197-G, 128-pp (1990).

262. Anon, (1990), The PASSYS Test Cells, A Common European Outdoor Test Facility for Thermal and Solar Building Research, Commission of the European Communities, Directorate-General XII for Science, Research and Development, PASSYS Project Phase I 1986-1989, Sub-group Instrumentation Final Report Part 1, Doc. No. 114-89-PASSYS-INS-033 EUR 12882 EN, Ed. Wouters, P. and Vandaele, L., Belgian Building Research Institute, Brussels, 64-pp.

263. Pinney, A. A. and Strachan, P. (1990), Whole Model Validation, Chapter 15 of the PASSYS Project Phase 1, Sub-group Model Validaation and Development, Final Report, 1986-1989, Ed. Jensen, S. O., Thermal Insulation Lab. Tech. Univ. of Denmark, Ref. 033-89-PASSYS-MVD-FP-017.

264. Martin, C. and Watson, D. M. J., A low frequency stochastic heating experiment in the British Gas Test Room (1991).

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Appendix 1: DESCRIPTION OF DATA SETS

A1. INTRODUCTION

A detailed description of the attributes of each data set is given in the main text in Tables 4 to 12. Additional descriptive information about each individual structure, which could not be presented within the tabular format, is given below. This information was extracted from the references listed in the tables for each structure. The code numbers of the structures, as given in the tables, are used for identification purposes in these descriptions. The variation in the amount of information about each structure, reflects the differing levels of documentation available to the authors, the interest value of the structure, for a UK reader in particular, and previous experience when using the data sets for model validation.

A2. TEST CELLS

A2.1 Los Alamos Type

Cells 1 to 11: The original Los Alamos cells, Cells 1 and 2, were built in 1976. They were constructed as a pair and were approximately 1.5 m wide by 2.7 m high by 2.5 m deep and each had about 4m^2 of south facing glazing. Twelve additional cells were constructed in 1977 based on this original design. The walls and floor were constructed of plywood on a stud frame with insulation between the framing members. There was also an inner layer of rigid insulation. The ceilings and party walls of the cells were also well insulated. Each pair of cells had been largely de-coupled from the ground by raising them up on the ground beams. This enabled the free circulation of air below the floor.

Experiments to compare the performance of alternative passive solar heat storage components were conducted in Cells 1 to 11. The air temperature was uncontrolled and ventilation was by natural infiltration.

Data from Cell 11 has probably been more widely used for validation than any other structure in this report. A sensitivity analysis clearly demonstrated, however, that the predictions of the model BLAST were extremely sensitive to the air infiltration rate and the split between diffuse and direct radiation. Neither of these parameters were measured in Cells 1 to 11.

Cells 12 to 23: Cells 12 to 23 were 12 of the 14 LANL cells for which experiments during the three winters between November 1979 and March 1982 have been reported. (The other two cells had a sunspace attached to the front so, as defined in this report, this represented an experimental building; it is described in the section 5.2.) The cells were modified versions of Cells 1 to 11. The modifications, made in 1979, included the addition of an auxiliary, thermostatically controlled, heating system and a mechanical ventilation system. A nominal forced ventilation rate of three air changes per hour was used during the three winter periods. The glazing used on all the cells varied from winter to winter. In 1979/80 this was acrylic sheet double glazing but some single glazing tests were conducted in Cells 12 to 15. For the latter winters, the area of glazing was reduced in all the cells and the acrylic was replaced by glass. Single glazing tests were also conducted in Cells 12 to 14 and more advanced glazing systems were tested in Cells 16 and 17 during the 1981/82 winter. (In 1980/81 these two cells were also configured as experimental buildings.) Modifications were made to the method of temperature control and energy use monitoring before each winter, however, some problems were still experienced during each experimental period. No documented comparisons with model predictions were revealed for these winters. Difficulties however, lie in the uncertainty in the air change rate, due to the rather crude control system used, and in the inability to accurately separate the diffuse and direct components of the solar radiation.

Cells 24 and 25: Cells 24 and 25 were operated with model validation in mind and data from them was incorporated in the SERI data base, however, the air infiltration rate is uncertain.

Cell 26: Cell 26 is only described briefly but appears to have been monitored with few sensors using a chart recorder to log the data.

Cells 27 and 28: It appears that no diffuse radiation measurements were made in conjunction with the monitoring of Cells 27 and 28. There is also no indication that wind parameters or air infiltration rates were recorded. Cell 27 contained a standard masonry Trombe wall whereas the wall in Cell 28 was transparent, consisting of water filled plastic blocks.

Cells 29 to 36: Cells 29 to 36, whilst not monitored specifically for the purpose of model validation, may as a secondary use "provide data directly useful for code validation".

Cells 37 to 40: Data from Cells 37 to 40 was gathered partly for the purpose of model validation, and has already been compared with the predictions of SERIRES.

Cell 41: The cell was the same as cells 37 to 40, but a single layer of bricks was placed inside the walls to add thermal mass. The large area of glazing was shaded by a screen placed 700mm away from the outer surface of the glass. Tests a and c, consisted of an unheated period (2 or 4 days) followed by a period of continuous heating. The other test b, consisted of six experiments with no gaps between them. In these, the room was intermittently heated, but the heating schedule, set-point and plant capacity were varied.

Cell 42: Data from this cell was collected for British Gas. It was completely opaque, with controlled and monitored ventilation. It was lined with bricks to add thermal mass. The tests, using various heating schedules and very detailed monitoring, were intended to examine the interaction between heating systems and the building fabric. They cover a period of 6 years with tests being undertaken during the winter time. The level of instrumentation and the control of the mechanical ventilation system was gradually enhanced over this period. Of particular interest is the use of flux meters and a Meyer Ladder to extract surface convection coefficients. The use of pseudo-random heating sequences and 28 hour heating/free-float cycles are a unique feature of the winters D and E respectively.

In winter A, tests a and j consisted of 7 days free floating operation, 7 days continuous heating and then 2 more days free floating operation. In tests b to i, intermittent heating was used but the 'on-period' and the heating set point varied from one test to the next. In tests g to j, the oil-filled panel radiator was covered with a polished metal cover to reduce the radiant component of the heat output.

In winter C, a fan convector heater was used. This had precise (proportional, integral and derivative) control rather than simple on/off switching to hold the set-point more precisely. The level of monitoring in the cell was significantly increased over previous winters. Experiments a, b and c consisted of a period of continuous heating, followed by a period of intermittent heating and then finally a free floating period. Experiment e is interesting as it consists of a 20 day period of pseudo-random heating at 5-minutely switching intervals. The aim was to use statistical techniques based on covariance analysis to extract the underlying relationships between the heat input and the building response.

In winter D, a natural- (rather than a fan-) convector heater was used. The series consisted of 3 days continuous heating followed by a 12 hour free floating period, then 7 days of intermittent heating on a 28 day cycle (6 hours on, 2 hours off, 6 hours on, 14 hours off), and finally 3 days of free floating operation. The aim was to separate the heating on/off periods from climatic influences to ensure no spurious correlations occured at the data analysis stage.

In winter E, a fan convector was used to heat the cell in a pseudo-random manner, where the switching interval was half-hourly.

Cells 43 to 48: Each of these six cells was monitored for eight different 8 to 10 day periods, thereby producing a total of 48 data sets. For all 8 periods, Cells 43 and 44 were double glazed (1.5m^2 glass), Cells 45 and 46 were opaque and Cells 47 and 48 had either 0.75m^2 of double glazing (tests a to d) or 0.75m^2 single glazing (test e to h). Cells 43, 45 and 47 were heated by a natural convector heater, the other three by an oil-filled radiator producing a significant radiant portion of heat output. Heating set points, heating schedule and thermostat type were varied as, in test e, was the ventilation rate. A detailed site hand book is available. Simulations have been undertaken with ESP, HTB2, Tas and SERIRES and compared with the 10-day energy consumption totals, and the trends in consumption as glazing type and area changed. Far more detailed simulation and analysis has been undertaken for the period where pseudo-random heating was employed (g) although this centred on using SERIRES.

A2.2. Custom Designed

Cells 1 to 12: Cells 1 to 12 were small, 1 m-sided cubes of wooden construction supported 1 m above the ground on metal legs. Each cell had a single, usually south facing, double glazed window and two air pipes in each of the south and north facing walls to induce natural 'infiltration'. These pipes were calibrated in a wind tunnel to determine the relationship between infiltration and wind speed, direction and temperature. Cells 1 to 4 differed in their level of insulation and internal heat capacity and one of them faced east rather than south. Cell 5 had no window and in Cell 6 the air pipes had been closed off. Cells 7 to 12 were identical to Cells 1 to 6 except that they were heated to a set point of either 21 or 25°C. For Cells 1 to 5, and their heated counterparts, the experimenters judge that the estimation errors on the air infiltration induced by the calibrated air pipes remain the most important limitation. One pair of Cells, 3 and 9, had the added disadvantage that the internal panels, added to increase the thermal inertia, could not be explicitly modelled by the models to be used in the SERC/BRE programme of work. Data was recorded for two years and the cells have figured in work undertaken by the European Passive Solar Modelling Sub-Group sponsored by the Commission of the European Communities.

Cell 13: Limited information was available about Cell 13. It was 2.4 m cubed but it is unclear whether it was de-coupled from the ground.

Cells 14 and 15: Cells 14 and 15 were part of a study to measure the thermal performance of structures with different surface longwave radiation properties and to compare their measured performance with the predictions of the model HELIOS. The two cells had a metal frame construction with a lightweight cladding. They were supported on pillars to minimise ground coupling and, although they were well sealed, the infiltration rate was not recorded. The long wave emissivity of the external aluminium roof cladding was 0.92 for Cell 14 and 0.07 for Cell 15; both had the same short wave absorptivity. In all, eight side-by-side tests were undertaken lasting between 6 and 31 days. In each of these the interior air temperature control was the same in both cells; tests d to g included a night set back. In tests a and b, both cells were opaque, in tests c to h, the cells had differing south facing facades. An additional ninth test was undertaken in Cell 14.

Cells 16 to 19: Cells 16 to 18 had a 2.4 m cubed, well insulated, double-glazed shell supported on ground beams. Cell 17 had been selected to provide data for the IEA Task VIII validation effort, and data in a number of operating modes had been gathered. Cell 19 was a very heavy, 2.6 m cubical cell. The south facing wall contained two separate features. The top part was simply 2.45 m of double glazing whereas the bottom part housed a 0.4 m thick rectangular water wall behind a 1.25 m double-glazed window. From the available information it is not clear whether air infiltration measurements were made in any of the cells and the climatic data appears to be very limited.

Cell 20: Cell 20 was 4.1m x 4.1m x 3.4m high and built of 15cm thick prefabricated reinforced concrete slabs. It had a double-glazed, south facing window, was well sealed and, although measurements are not reported, the air infiltration rate was considered by the experimenters to be quite negligible. To de-couple the cell from the ground the edges of the heavily insulated floor were supported on a rubber-topped foundation wall. The chart-recorded data may introduce a further external source of error into any analysis.

Cells 21 and 22: These cells are part of the pan-European PASSYS project. The cells are 2.5m x 2.5m high to 5m deep well sealed and insulated, but there are significant heat bridges and edge/corner effects. The cells had the opaque calibration wall installed during the earaly period (of 32 days) which yielded data useful for model validation. One cell (21) was left free floating whilst the other (22) was heated. The schedule consisted of two short periods of heat injection and one period of continuous heating to 30°C, these were interspersed with free floating periods. The data collected was compared with the predictions of ESP.

A3. EXPERIMENTAL ROOMS

Room 1: Room 1 is the earliest experimental room reported in this report. It was the windowless attic space of House no. 2 in Houston, Texas (Residence 10). The primary purpose of the monitoring was to validate an attic ventilation model. In test a, air entered the attic passively through the soffit vents. The flow rate at any time was calculated from an empirical equation derived from some air infiltration tests. The type of measurements used to derive this equation are not reported. A thermostatically controlled fan vented the attic in test b. Diffuse solar radiation measurements are not reported to have been made and the ducts for the house heating system which passed through the loft released heat, the amount of which was imprecisely known.

Room 2: Room 2 was located on the corner of the first floor of existing buildings. The uninsulated external concrete walls of Room 2 faced south-east and south-west. A single window occupied about one third of the south-west facing wall. To minimise heat exchange with adjoining unmonitored zones the inside surface of the concrete party walls were insulated. The structure was intensively monitored and the data collected for a three-month winter period enabled heat transfer coefficients and heat fluxes to be compared with the values predicted by a simple model. The room was well sealed, although air infiltration measurements were not made. The air temperature sensors were well shielded and aspirated.

Room 3: Room 3 was also located on the corner of the first floor of an existing building. The external walls of Room 3 faced south and west and consisted of about 50% single glazing and 50% brick with cavity walling. Below the roof decking was a suspended ceiling which concealed the ducting for the air conditioning system. For modelling purposes, this roof space was treated as a dummy zone. The predicted internal air temperatures during one day heating periods (tests 3a and 3b) and a three-day unconditioned period (test 3d) were compared with measured values. The predicted and measured cooling loads during a sunny three day period were also compared (test 3c). A major limitation of the environmental data is that no diffuse solar radiation measurements were made and values could not be derived for the period 12 noon to 6.00 pm. No attempt appears to have been made to insulate the room from the adjoining spaces which were not monitored.

Rooms 4 to 9: Rooms 4 to 9 were adjacent rectangular cells in an existing brick and stone, two-storey building. Each cell had a detachable double-glazed wall size 3 m x 3 m. Behind this glazing was a vented Trombe wall built of either brick, brick and stone, or concrete block. Three of the cells were on the ground floor and three vertically above on the first floor. Temperatures in the adjacent, non-experimental rooms were also recorded. No air infiltration measurements or diffuse solar radiation measurements are reported. It was noted that the data generated will provide a valuable insight into the performance of 'twin-storey' Trombe Walls and will also be used by the experimenters to validate a dynamic thermal network model.

The remaining rooms were all highly solar driven conservatories attached to existing buildings but with differing thermal storage elements. They were monitored primarily to determine the thermal performance of such structures.

Rooms 10 to 13: Rooms 10 to 13 were all attached to the same stucco-framed residence. In the experiments reported, all four rooms were unheated and thermally insulated from the residence. The conservatories varied in size. Their thermal storage elements were: Room 10, pumice block wall immediately behind the glazing with perforations to allow some direct gain; Room 11, direct gain with an iron oxide thermal storage wall; Room 12, direct gain (the hybrid fan and rock storage unit was inoperative); and Room 13, simple direct gain with brick floor thermal storage. Although the rooms were highly solar driven the solar measurements may not enable the separation of the direct and diffuse components. No air infiltration or wind measurements are reported to have been made.

Room 14: Room 14 was monitored to provide a data base for assessing the costs and benefits of attached greenhouses. It had a sloping double glazed frontage and contained a water wall and concrete planters to provide thermal storage. Vents released excessive summer heat and supplied warm air to the house in winter.

A4. INDOOR STRUCTURES

Structure 1: The first series of experiments in the NBS chamber represents one of the earliest attempts to gather data for model validation that is described in this report. The heavy cell (Structure 1) was supported on insulated concrete footings with a floor slab resting on a layer of insulation placed on the ground. In the ten experiments, the effect on inside temperature and heating energy consumption of the glazing type, the location of insulation (inside or outside) and the amount of internal mass (concrete blocks) was investigated. Although the simplicity of the structure may make it acceptable for validating models, a number of possible problems are foreseen.

(a) The one-time air infiltration measurements were made at the time of greatest temperature difference between the inside and the outside. The value recorded especially for the windowless cell (0.38 Ach^{-1}) may not be applicable at other times.

(b) The concrete footings, despite being insulated, may well induce multi-dimensional heat flows.

(c) In all but two tests, cylindrical concrete cylinders were installed to provide internal mass and these would be difficult to model explicitly.

(d) The original punched card data, collected in 1973, if still available, would be extremely cumbersome to handle.

The published data has enabled some validation to be undertaken, however, problems were encountered because the measured internal air temperature seemed to be inconsistant with the stated driving temperatures. In particular, the mean measured inside air temperature was 19.7°C. In a free floating regime such as this it should be equal to the mean driving temperatures (although the magnitude of the swing will vary). The weighted mean of the average outside and ground temperatures was in fact 20.4°C, which is inconsistent with the physical expectations. Interestingly, PASOLE predicted a mean inside temperature of 20.4°C; which is very close to the value expected but 0.5°C higher than the recorded value. Waters, using a finite difference model, predicted an internal temperature 0.5°C higher than the recorded ones. The evidence points to an experimental error and a number of possible reasons for a low recorded air temperature exist:

(a) The air temperature in the chamber was not the steady-periodic cycle stated.

(b) The four-day equilibrium time between tests was insufficient.

(c) The mortar bonding the blocks was still shedding moisture.

(d) The shielded air temperature probes were not recording true air temperature (i.e. they were inadequately shielded).

(e) The external longwave effects may have been significant.

Structure 2: The prefabricated residence, Structure 2, was operated as if it were occupied by a single six person family. It was fully equipped with both soft furnishings and domestic appliances. The occupancy effects simulated included the movements of the people, doors opening and closing, and the use of lights and domestic appliances, etc. In some of the heating tests the ducted air was heated by electrical resistance wires and in others by a gas boiler. In either case, the energy consumed was measured; as was the energy used for cooling the building and for operating domestic appliances.

Structure 3: The second experimental masonry building, Structure 3, was a proto-type dormitory for the University of Makkah, Saudi Arabia. In the first test (3a), passive solar gain was simulated by using infra-red lamps to mimic the sun in a clear sky at latitude 40°N. The sol-air temperature was based on the January extremes for Chicago, Il. These artificial experimental conditions would be difficult, if not impossible, to model explicitly with the programs to be used in the SERC/BRE project. In experiments 3b to 3d sol-air temperature cycles typical of those experienced in summer in Saudia Arabia were imposed.

In test 3b, the ceiling mounted cooler operated continuously for nine hours during the night. In test 3c the cooler was on for twelve hours under thermostatic control. In test 3d the cell was naturally vented with air when the external temperature dropped below that inside the cell.

In the two mechanical cooling tests, 3b and 3c, two significant sources of error exist in the measured data. Firstly, the recently built cell released large amounts of moisture into the air. During the warm, daytime, periods the relative humidity in the cell was about 80%, however, during the night the value dropped to 45% as moisture condensed out on the chiller coils. The effect of this would, presumably, be to reduce daytime air temperatures and to increase the cooling loads; particularly at the beginning of the night-time cooling period. Discrepancies between the measured internal air temperatures and those predictions by NBSLD and DOE and the measured cooling loads and those predictions of NBSLD, DOE and BLAST are consistent with this error source. The moisture in the fabric would also pose problems when trying to select appropriate thermophysical properties. A second possible source of error arose because the cold air from the cooling valance descended past one of the walls of the cell. Although infra-red thermography revealed only a small vertical temperature gradient, the increase in the inside surface convection coefficient could change the heat transfer between the room and the thermal mass by as much as 30%.

Structure 4: Structure 4 resembled a shed with a pitched, ventilated roof. Experiments were undertaken to investigate the build-up of moisture transferred between the room and the attic space above. In four of the tests, the room and test chamber temperatures and humidities were held steady and various attic ventilation rates were imposed. In two of the tests, the ceiling between the room and the attic was punctured to enhance the rate of air flow between the zones and in a fifth test, cyclic environmental temperature was imposed. The measured and predicted roof sheathing and attic air dew point temperatures were compared. The experiments were designed to investigate the transfer and storage of water vapour and the data does not appear to have been used to validate any of the better known dynamic models.

Structure 5: Structure 5 was a full sized concrete apartment (called OBITAT) typical of those built in 1966 near Lyon, France. It had an 86m^2 floor area and a 2.4 m ceiling height. The inside consisted of eleven rooms which were heated by a ducted air system. To simulate the conditions which would prevail in the field, two opposing faces of the apartment were controlled to simulate external temperatures and an air pressure difference was applied between them. The remaining four faces were subject to temperatures representing those in the adjoining apartments. The steady state behaviour was examined (5a) as well as the thermal response to step changes in external temperature (5b) and a step change in heating power input (5c). The measured internal air and resultant temperatures were compared with the predictions of three models. Although the pressure difference applied across the building induced air flow, no measured internal air flow rates are reported; the flow volumes and directions were assumed for the purposes of the simulations. The internal complexity of the structure, and the modes of testing, would pose serious problems for the models to be used in the SERC/BRE project.

Structures 6 and 7: In Structures 6 and 7, the variations of internal temperature in response to changes in the rate of internal heat supply were recorded. Structure 6 had concrete block walls built on a solid concrete floor with a polystyrene roof. This small cell was situated in a temperature controlled laboratory, and heated by a small fan heater. In the first series of experiments (5a), the fan heater was controlled to produce a sinusoidal power output with a frequency ranging from about 1 minute to 1 day. The internal temperature response, in particular the phase lag, was recorded. In a second series of similar experiments, additional internal insulation was provided and fans were used to control the air infiltration rate. Structure 7, a rectangular storage room, was the subject of a similar set of experiments although the temperature outside the structure was not controlled. The heat input was provided either by radiators (for low frequencies) or by fan heaters (for higher frequencies). These conditions differ fundamentally from those normally experienced by buildings since internal, rather than external, cyclic variations in temperature were imposed. These heating regimes would be very difficult to simulate with the models to be used in the SERC/BRE project.

A5. EXPERIMENTAL BUILDINGS

A5.1 Zoned

Building 1: Building 1 contained two south facing experimental rooms with an equipment storage room between them. In the experiments reported, the performance of a conventional Trombe wall was compared with the performance of a similar wall in which convection between the glass and wall was inhibited by a transparent honeycombed polycarbonate insert. Both walls had selective absorber coatings. The list of parameters measured does not include wind data, or air infiltration measurements and the diffuse, and global solar measurements are for the vertical collector surface only.

Building 2: Rooms A and B of Building 2 were located to the west and east of a central access corridor. A ceiling hatch enabled solar radiation entering the clerestory windows to penetrate the rooms. In the experiments reported, the configuration of Room A was fixed whilst 14 different passive solar winter heating, and 4 summer cooling, configurations were evaluated in Room B. The fan pressurisation tests revealed that the rooms had similar air change rates; about 0.5 ach^{-1}. No wind or diffuse solar measurements are reported.

Buildings 3 to 5: Buildings 3 to 5 were of similar size and construction and were reconfigurable. The superstructure was of lightweight wood frame construction and was built over a concrete basement. The interiors were divided essentially into four rectangular zones of equal size, one at each corner with an access corridor between them. These zones had a common attic space above them. The naturally ventilated attic was monitored, as was the basement which was used for ground heat loss experiments. Thermostatically controlled fans vented the zones with outside air to prevent overheating during sunny periods. Two internal zone configurations were used in this series of tests.

In Mode 1, the four zones were isolated from each other (Units R1 to R4). Each zone had a single window and the four windows faced each of the four cardinal points of the compass.

In Mode 2, the door between the north and adjoining south zone was open and air was mechanically circulated between the two zones (Units 1 to 4). Units 1 to 3 had different internal thermal mass and Unit 4 had a Trombe wall.

The data has been used within IEA Task VIII and it was as part of this work that comparisons were made with the predictions of SERIRES, ESP and eight other models, including DOE and BLAST. Sensitivity studies using SERIRES demonstrated that the model is sensitive to using direct solar radiation derived from measured values of total solar radiation, as opposed to using measured values for both total and direct radiation. SERIRES also predicted energy consumption of the lightweight direct gain unit more accurately using the measured rather than the derived solar data.

In later experiments, the buildings were operated as thermally integrated units, these experiments are therefore described in Section 5.2.

Building 6: Building 6 was also reconfigurable. It had fixed concrete walls on the north and east side and fixed concrete partition walls which formed four cells. Hence, Cells 2 to 4 had interchangeable southern facades whilst Cell 1 had interchangeable southern and western facades. In each cell, ventilation tubes passed through the floor from the crawl space below and through the ceiling into the attic space above. The flow rate and the temperature of the air as it passed through these tubes could be continually recorded. In the experimental plans reported, the tubes were blanked off in Cells 3 and 4. A major reason for gathering the data is to validate models, however, no comparisons between these data and model predictions were revealed by the literature search.

Building 7: Building 7 was a lightweight single storey construction with clerestory windows. The reconfigurable interior walls were positioned to produce three experimental cells, each with a differing southern facade. A fourth cell housed the data acquisition system. In the experiments for which detailed information is available, the interior temperature had either been controlled to a heating set point or free floating and, in Cells 2 and 4, tests both with and without the clerestory window shutters open were conducted. The monitoring is of a high quality, the data is part of the DOE Class A data base, and a site handbook has been produced. Destratification of the air in the cells in some experiments, continuous air infiltration measurements, and ground temperature records, enhance the value of this data set; particularly for assessing the accuracy of model predictions in buildings with clerestory windows.

A5.2 Thermally Integrated

Buildings 1 to 6 had a lightweight, wooden exterior although extra internal mass was added during specific experiments.

Buildings 1 and 2: Limited information is available about Buildings 1 and 2 which were quarter scale models of Rooms A and B of the Twin-Type Test House monitored by the Tohoku University (Building 2, Table 5). They had a large south facing window in the main room and a clerestory window in the attic roof.

Buildings 3 and 4: Buildings 3 and 4 were simple shed-like constructions built on wheels, the experiments were part of an early low budget undergraduate exercise to examine the viability of passive solar design principles in the north-west of the USA. Their performance at different orientations, as well as with and without a water wall, was examined.

Buildings 5 and 6: Buildings 5 and 6 appeared to be unique in that, of all the structures in all the categories, they were the only ones operated and instrumented purely to produce data for model validation. They were built and operated so that they could be precisely modelled and they were heavily instrumented, at the mechanism level, using around 200 sensors in each structure. The climatic data was also extensive. Both buildings were well caulked to suppress both inter-zonal advection and infiltration and the air within each zone was de-stratified. Data from both buildings was to be incorporated in the DOE computer data base and draft site handbooks have been produced for both buildings.

Building 5 looked similar to Los Alamos type test cells but inter-zonal conduction was deliberately encouraged in some of the experiments. In all, six experiments have been completed. These gradually increased in complexity as additional heat flow mechanisms were introduced by progressively modifying the building. Initially, it consisted of two, thermally independent, opaque and lightweight zones, and finally, a thermally integrated, direct gain structure in which one zone was heavyweight and highly solar driven and the other was lightweight with more modest solar gain. In this zone, the temperature was thermostatically controlled to different day and night minimum temperatures. The building thus resembled a sunspace with an adjacent living area.

Building 6 was a single storey ranch house divided into four major zones. In two of these, additional thermal mass was added. The temperature in one heavyweight zone and one lightweight zone was controlled whilst the other zones were free floating. The total measured energy use has been compared with the values predicted by DOE, BLAST and SERIRES. Whilst reasonable agreement was obtained during the 1982 period the model predictions differed markedly from each other, and from the measured values, for the 1983 period. This was attributed to internal errors in the models which, for the 1982 period, were mutually compensating thus producing the satisfactory agreement.

Buildings 7 to 28: Buildings 7 to 28 were part of North American multi-building monitoring projects at four sites. The primary purpose was to examine various energy conservation strategies in residential buildings. In particular, the effects of thermal mass, (Buildings 7 to 14) and passive solar heating and cooling concepts (Buildings 21 to 28), mass, insulation and heating strategies (Buildings 15 to 20). Generating data for model validation was a secondary objective.

Buildings 7 to 14 were constructed to assess the influence of thermal mass on heating energy requirements and thermal comfort. They were, like the NBS, thermal mass buildings (15 to 20), about 6 m square with insulated slab-on-grade floors. Buildings 11, 12 and 13 had a similar wall construction to NBS Buildings 19, 18 and 15. Unlike the NBS buildings however, they had no windows and flat insulated roofs. The model simulations were conducted for a number of 10 day periods during the year to examine the consistency of the measured data. The lateral stratifications in the cells, due to the plenum and fan air circulation system, was a source of difficulties. The four modellers, using DOE-2.1A, DOE-2.1C, BLAST and DEROB, adopted different modelling strategies to try and simulate this. Other problems were: the uncertain thermal capacity of the adobe; the uncertain hourly energy use figures; and the possibility of significant edge effects due to the relatively large wall thickness to floor perimeter ratio. In the 1983 experimental period four windows were added to Buildings 7 and 9 to 13 and eight to Building 14; Building 8 was unchanged. Glazing temperatures, and heat fluxes and interior solar radiation levels were recorded in Building 14. No model simulations have been reported for this period.

Buildings 15 to 20 were 6m square rooms with a ventilated attic space above. Their differing constructions are representative of current construction practice in the USA. All six buildings were subjected to tests a to g but only buildings 15, 17, 19 and 20 were included in test h. The comparisons with DEROB were conducted for three or five day periods within the duration of tests a to c to check the consistency of the data gathered. The TARP comparisons for Buildings 15, 17 and 20 were for one winter heating and one summer cooling period; the exact dates were not specified. During the work with DEROB, problems were encountered disaggregating the direct and diffuse components of the solar radiation. This was because, only vertical solar radiation measurements had been gathered and the horizontal solar measurements gathered at an adjacent site were not always complete. The siting of the outside air temperature sensors was such that there was signficant uncertainty in these values. There were also numerous thermal anomalies in the buildings which could not be modelled accurately.

Each of Buildings 21 to 28 had a similar size and internal, two-zone, configuration. Details are scant but no mention of air infiltration measurements is made in the references listed. A continuous loop of fluid served the cooling units in each building.

Buildings 29 to 33: Buildings 29 to 33 were five of the six structures built to assess energy conserving construction and heating strategies. They all had a wooden frame super-structure over a six foot deep basement with thick concrete walls. They were electrically heated using a ducted air system located in the basement. Free circulation between the basement and the upper room was possible through the open stair-well. During winter periods b to e, both interior and exterior night insulation shutters were tested in Buildings 30 and 31. In Building 33 during period e, gas replaced electricity as the fuel source and intra-construction, surface temperature and infra-red thermography measurements were conducted. Air pressurization and de-pressurization tests were made on all the buildings. Heating energy use was measured continually throughout all the winters; the other building parameters were recorded for shorter periods. Problems encountered when modelling the buildings with BLAST were due to: inadequate ground temperature records which prevented accurate basement modelling - a serious source of error; basing infiltration rates on correlations between (old) measurements and wind speed and temperature difference; and missing, but essential, weather parameters.

Buildings 34 to 41: Buildings 34 to 41 were monitored to assess, amongst other things, the thermal performance of attached sun spaces. They all incorporated south facing sunspaces of various geometries except for Building 34; which was a control used for comparison purposes.

Buildings 34 and 35 had the same shell construction as Buildings 3 to 5 in Table 5. Internally however, they were divided into three zones. Two of these faced north, with an access corridor between them, and the third one faced south and spanned the width of the building. Building 35 had a sunspace with a thermostatically controlled fan to circulate air to the rooms behind. The temperature in the rooms was controlled by heating and venting in the same way as for Buildings 3 to 5 in Table 5. The buildings feature in work undertaken as part of the IEA Task VIII work.

Buildings 36 to 39 were formed by placing double-glazed sun spaces on the front of standard Los Alamos test cells. The exact configuration varied for each winter. During the 1979-80 winter (period a), Buildings 36 and 37 had identical but separate sun spaces. During the 1982 winter (period b), a sun space was built across the face of them both and divided in half by a partition wall. In Building 37, natural circulation between the sun space and the cell occurred through vents in the dividing wall. In Building 36, circulation was induced by a thermostatically controlled fan. Circular water drums and concrete blocks on the floor of the sunspaces provided thermal storage.

During the 1980-81 winter, there was no partition in the sun space and a wall of concrete blocks separated the cells from the sun space. Natural inter-zone circulation was also encouraged by cutting two doorways, one through the partition wall between the cells and one between Cell 3 and the sunspace (Building 38). SERIRES validation work was conducted during this period a part of IEA Task VIII. Building 39 was similar to 38 except that there were no water drums and the sun space was of differing geometry.

As arranged, the reconfigurable REPEAT facility, Building 40, represented a two-storey house or small commercial building. The north, east and west walls of the lower room were solid concrete and earth bermed, whereas the upper room was of insulated wooden frame construction. A brick thermal storage wall partitioned the rooms from the two storey conservatory. Air was free to circulate between the three rooms through doorways. The structure was thus very complicated and defining the air flow pattern could be a problem.

Building 41 was prefabricated and erected at low cost to demonstrate, and monitor the performance of, many different passive solar techniques.

A6. RESIDENCES

A6.1 Conventional

Residences 1 to 6: The six Electricity Research Council Houses (1 to 6) are the earliest monitored residences reported. Each house had the same arrangement of internal rooms, although adjacent pairs were a mirror image of each other. The external walls differed, half had brick and masonry walls and the other half had brick and masonry gables and a lightweight south facing wall. Alternative heating systems were to be investigated. The available literature reports whole house conduction and ventilation experiments, experiments to determine the solar gain in three unheated houses and a comparison between measured air temperatures and the predictions of a thermal network simulation model. The houses were intensively instrumented and they were unoccupied, however, the data is now quite old and is stored on various data media. No diffuse radiation measurements were reported as having been made.

Residences 7 and 8: The two Columbus Ohio residences (7 and 8) were a subset of nine residences in the same neighbourhood but of different styles, which were monitored to develop and validate procedures for predicting the hourly thermal loads and energy consumption of residences. The value of the data has been assessed and those from two of the houses listed have been deemed the best for validation purposes. The selection criteria were based on: the complexity of the building; the accuracy with which the heating system efficiency could be defined; and the completeness of the data available. Residence 8 was operated specifically for research purposes; it contained concrete blocks to simulate furnishings. Comparisons between the measured and predicted daily and hourly energy usage of the two houses formed the backbone of the validation efforts.

Residences 9 to 11: The three houses in Houston Texas (9 to 11) were monitored during the summer to investigate the effect of various attic ventilation techniques on the indoor comfort conditions and central air conditioner energy consumption. The cooling energy used and the attic air temperatures in House 11, during a five day period, were compared with the prediction of NBSLD. Artificial, rather than actual, on-site weather data was used in the BLAST and DOE simulations. The data set from House 11 is also contained in the NBS data base although it lacks diffuse solar radiation measurements.

Residences 12 and 13: Residences 12 and 13 are two of only four terraced houses tabulated. In the unoccupied house (12), the first floor bedroom and the ground floor living room were monitored. In the occupied house (13), only the dining room was monitored. Three, out of six intended monitoring tasks, are reported. Measured air and surface temperatures in House 12 were compared with those predicted by ESP.

Surface temperatures predicted by ESP, when the known measured air temperature was used as input, were compared with the values measured in House 13. Sources of error in the validation process were due to: digitizing chart records; inaccuracy in the air infiltration measurements; and recording the solar radiation data at a site two miles from the residence.

Residences 14 to 23: The ten mobile residences (14 to 23) were each formed from two pre-fabricated units which were sited alongside each other to form the complete house. Three of the houses were insulated to minimum standards, three had increased insulation, and four had additional insulation plus other energy conserving features. The interior temperature was controlled by a ducted air system which incorporated an air to air heat pump which automatically switched from heating to cooling. The monthly energy consumption of the houses was compared but a secondary objective of the monitoring was to investigate their detailed thermal performance. No wind data is reported to have been gathered and the infiltration rates are uncertain.

Residences 24 to 29: The data from the six Australian residences (24 to 29) was gathered with the specific aim of validating four Australian models which are capable of predicting the behaviour of unconditioned buildings. The residences cover a range of Australian housing types and climates. Temperatures were measured in all the rooms plus, where appropriate, the attic and crawl space. The occupancy effects simulated were the periodic opening and closing of the external windows and, for House 27, the external doors. A correlation between air infiltration rate and wind velocity was derived for each house but only with the windows closed. This led to a substantial lack of confidence in the model predictions, especially for Houses 27 and 28. The data was available for periods of 4 to 22 days. The hourly internal air temperatures were compared with the predicted values but, unlike virtually all other validation work, the modellers themselves were unaware of the measured performance. It was concluded that none of the programs accurately predicted the internal conditions in the test houses. The data necessary for modelling the buildings is freely available.

Residence 30: Residence 30 was a mid-nineteenth century dwelling, with solid walls in a mature garden setting. It had been up-graded by removing various extensions and then externally insulating the walls and internally insulating the floor and roof space. Thermo-couples were installed on either side of the insulating boards so that they formed large heat flow meters. This enabled the flux through each board, and hence the overall house heat flux, to be measured. The windows were covered and insulated and the whole house was well sealed to minimise infiltration. Comparison of measured heat input and measured heat loss showed that cold bridges constituted a significant energy drain. Measurements of heat loss from the ground floor slab indicated that presently available techniques for calculating such losses from houses may be significantly in error. From the published information it is unclear whether a complete set of hourly weather data was collected.

Residence 31: Residence 31 was a one-family residence typical of central Switzerland. It has been monitored (and the results compared with DOE-2 predictions) as part of IEA Annex III. The upper two storeys were of insulated wood constructions and the uppermost one was within the V-shaped roof space. The lower basement area, which was also divided into rooms, was of heavyweight concrete construction and, except for the south-east corner, was below ground. The thermal conductivity of one window and one wall element were measured. The air leakage though each door and window was measured along with the whole house infiltration rate. This varied with the time of year due to shrinkage of the timbers. Advection between floors via the open stair-wells is a signficant factor. Measurements of thermal performance were made for two three-month periods, one of continuous heating and one with night setback. The hourly energy use of the oil fired central heating system and the internal temperatures were compared with the predictions of DOE-2.

Residences 32 to 39: The eight low-energy houses (32 to 39) were insulated to Danish regulation standards. They had the majority of the double glazing located on the south side and heavyweight interior walls were used for heat storage. Each house had the same construction. One house was unoccupied to act as a control. They were intensively monitored during two heating seasons to determine their thermal performance. A series of experiments was undertaken and the data interpreted to examine: annual energy consumption; heat losses; energy balances; incidental gains, solar gains; and auxiliary heating.

Residences 40 and 41: The Illinois Lo-Cal houses (40 and 41) were built to substantially reduce their energy usage compared with houses of standard Illinois construction. They incorporated: maximum insulation; multiple, mainly south facing, glazings; tight construction; and passive solar orientation. Their design was based on predictions from BLAST. The houses were monitored at the Class A level and the data will form part of the U.S. DOE Class A data base. A series of experiments, with the house in different modes of operation has been undertaken, comparisons have been made between the predictions of DOE and measured data from the unoccupied house, both in the free floating and the controlled temperature mode. Similar comparisons with the predictions of BLAST have also been made.

Residences 42 to 49: Residences 42 to 49 represented four matched pair houses in which the energy consumption in one of the pair was used as a reference against which to assess the effect of alternative heating system controls and design modifications in the adjoining test house. They were typical of UK residences built around the 1960s. All had cavity brick walls and were heated by a gas fired hot water radiator system which also provided domestic hot water. Residences 48 and 49 were in the centre pair of a four-house terrace; the end houses are not used in the matched pair experiments. During all the experiments, complex occupancy schedules were simulated. This included: the use of electrical appliances; hot water run off; light switching; and curtain operation. Virtually all interior doors were left open. The level of monitoring is very low. Specific difficulties for validation are: it may be difficult to separate the energy used for space heating and that used for domestic hot water; it is not possible to determine the heat injected to each zone; apart from energy monitoring, only the globe temperature in each room was recorded hourly; and finally, it does not seem possible, from the information available, to separate out the diffuse and direct components of solar radiation.

A6.2 Passive and Hybrid Solar

Residences 1 to 4: The passive solar residences (1 to 4) in the Sun Dwellings Demonstration Centre at Ghost Ranch, were of similar construction but incorporated differing passive solar features. Native construction materials were used whenever possible. These included, adobe and pumice walls, logs, flagstones, and sawdust insulation. The Centre's aim is the demonstration of, and training in, the aspects of passive solar design, as well as passive solar testing and monitoring. The room globe, sunspace air, and outer wall temperatures were compared with those predicted by PASOLE. A full assessment of the completeness of the data, particularly which climatic parameters and infiltration measurements were made, is not possible from the publications examined.

Residences 5 to 10: The six low energy houses (5 to 10) provided a variety of architecural and technical solutions to minimising heating, ventilating and hot water energy usage. To achieve the energy use target of 5,000 $Kwh.yr^{-1}$, all the houses were extremely well insulated and double or triple glazed. The infiltration rate was carefully controlled to less than $0.12Ach^{-1}$, by using impermeable barriers in the walls and by weather stripping the windows. All the houses included heat recovery systems in the exhausted air stream and some of the houses had shutters to reduce the night heat loss. Houses 7 and 10, were passive solar designs and had solar collectors to supplement the conventional heating systems and in House 6 a heat pump extracted ground heat to reduce the primary heating energy usage. The heat output and occupancy patterns of two adults and two children were simulated, this included their use of household appliances such as the television and refrigerator.

Residences 11 and 12: Houses 11 and 12 were double envelope, or convective loop, designs. The Warren Burns house (11) was constructed to evaluate the performance of the double envelope concept and to compare the measured performance with the predictions of a microcomputer program. In principle, the air from the sunspace passes over and above the ceiling and descends through the hollow, earth bermed, north wall and the crawl space and basement, before re-entering the greenhouse. A similar system is employed in House 12.

Residence 13: The Williamson house (13) had exterior walls of adobe block and interior brick and concrete walls which acted as the primary heat storage elements. The floor to ceiling south facing windows were designed to provide all the heating energy required although an open fire provided auxiliary heating.

Residence 14: The Tennessee Valley Authority built 35 passive solar homes of 11 designs. These were monitored to assess energy usage and comfort levels. Four of the homes had additional instrumentation. The initial results from one of these (Residence 14) have been reported. This house used a two-storey mass storage wall and earth banking around the lower storey on the north and part of the east and west walls. A TRNSYS simulation predicted an energy use only 20% of that measured.

The discrepancy was traced to construction defects. The house thus performed worse than a conventional house.

Residence 15: The superinsulated house (15) was built in the grounds of the Brookhaven National Laboratory. The house was heated by electrical resistance coils in the air supply ducts. Infiltration rates were inferred by subtracting, from the total energy usage, all other heat losses. Although the house was unoccupied it was entered on a number of occasions by the experimenters. The overall goal was to add natural thermal storage to a fairly conventional house in order to save heating fuel without reducing comfort. It was well insulated, included three passive solar heat collection devices, and employed double or triple glazing. The heat demand was about half that of a typical house of the area. The monitoring was designed to evaluate the overall thermal performance of the house.

Residence 16: The Suncatcher House (16) was a complex innovative passive solar house, with clerestory windows, and an internal tubular water wall, to illuminate and heat the north side of the building. A reflective roof aided solar capture by these windows, particularly in winter, and manually operating window shutters reduced winter heat loss. The data was gathered to quantify the performance of the roof. Additionally, the actual hourly performance was compared with that predicted by a large simulation model and two simple calculation methods for a two-day winter period.

Residence 17: Information available about Residence 17 is limited. It was one of three Swiss residences which were instrumented as part of the IEA Task 1; one of the others incorporated an active system, and in the third, monitoring focused on part of the building only. The objectives were to monitor the performance of the houses and to provide data to validate a thermal network simulation program.

Residence 18: House 18, Solar One, was multi-levelled with windows covering the entire southern facade. Overheating was avoided by well positioned internal mass and overhangs.

Residence 19: The Skytherm passive solar house (19) incorporated a roof pond and movable insulation to control the collection and rejection of energy for heating and cooling. The effect on performance of deflated air cells, changed in pond depth, and evaporative cooling, plus insulation panels, were examined. It was made of externally insulated, pre-cast concrete, with double-glazed windows and a well insulated door. Tests, both with and without occupants, and in various operating modes, are planned. The data will contibute to the DOE Class A data base.

Residence 20: The Balcomb residence (20), also known as Unit 1, First Village, was an L-shaped hybrid structure with a two-storey sunspace enclosing the front forecourt. The heated air was circulated from the top of the greenhouse, by fans, through two radiant rock beds. Heat was transferred to the living space by convection through open doors, the adobe walls between the greenhouse and the living area provided thermal storage.

Residence 21: The Bruce Hunn residence (21) was equipped with a two storey Trombe wall from which air would be ducted to a rock storage system. Due to construction defects however, this active part of the hybrid house did not function. Only the radiant heat from the Trombe wall therefore supplemented the auxiliary heating. In addition to the main two-storey block of the house, there was a single storey annexe on the west side. The data from this residence and the Balcomb and Williamson houses were used to validate the model DEROB.

Residences 22 to 24: Residences 22 to 24 were part of the University of Arizona passive cooling experimental facility and will contribute data to the SERI Class A data base. Structure 1 was built of stabilized mud adobe with a corrugated metal roof decking. Structure 2 was of solid concrete construction and the basement has provided data to validate a program designed to predict heat loss from basements. Structure 3 was of lightweight construction and included a rock store and water wall, in addition, numerous active solar collectors have been built in. The structures were built for experimental purposes, however, during appropriate periods it is intended that the buildings will be occupied by the researchers to record their comfort perceptions.

A7 COMMERCIAL BUILDINGS

Building 1: The information about Building 1 is extremely limited, in particular, there is no indication of precisely which parameters were recorded. Meaningful comparisons between the predictions of DOE and the measured data were difficult as the building occupants interfered with the vents in the water wall which separated the warehouse from the office space.

Building 2: Building 2 was designed to demonstrate a number of energy saving concepts. Each floor used different types and arrangements of HVAC equipment and lighting systems. Problems with the automatic temperature control systems resulted in the occupants resorting to manual control. Gas, oil and electricity were used as primary fuel sources. Although over 700 sensors were used, the only climatic data gathered was air temperature so simulations had to be conducted using data from a site some 15 miles away.

Building 3: Building 3 was monitored in 1973, it is thus the earliest combined monitoring and model validation project included in this report; and one of the most ambitious. The work was a distinct sub-task of the IEA Annex 1. The overall aim was, "to evaluate a number of different approaches to modelling the energy requirements of commercial buildings". The buildings was rectangular and of heavyweight construction with the insulation on the inside. Data was not gathered with model validation in mind. Particular problems were the unknown infiltration rates, minimal climatic data and uncertainty in the measured energy use values. Eleven participants each modelled the building with a different thermal model.

Building 4: Building 4 was monitored for the IEA Annex IV to provide details of its thermal performance and hence to enable an in-depth comparison with model predictions to be made. The building was steel framed and extensively glazed and, like Building 3, had an open plan interior design. The monitoring and modelling concentrated on the second floor which was partitioned into an occupied and an unoccupied half. The monitoring was very detailed; over 500 sensors were used. (Information about the weather data is not, however, included in reference 81.) Despite this detail, the size and complexity of the building and organisational difficulties led to the conclusion by one participant that, "the measurements and computation results should be used neither for 'validating' the existing models, nor for establishing any classification of their respective performances". Nine different dynamic thermal models were each used by a different participant in the project.

Buildings 5 and 6: Buildings 5 and 6 were just two out of over 100 different U.S. Army installations for which energy use was recorded. For most of them the energy use of individual, rather than groups of buildings, could not be determined. The 18 chair dental clinic was of brick and block construction with a steel truss roof. Heating was via a central gas fired boiler and cooling was by a reciprocating chiller. The environment in the battalion HQ was controlled by remote, electrically powered, central boiler and chiller units.

Building 7: Building 7 consisted of 14 apartments, two to each storey. These were of brick and block cavity wall construction and were heated by hot water radiators which were supplied from a central gas-oil fired pressurized boiler. Differences between measured interior air temperatures and those predicted by the plant and systems orientated model were attributed to the occupancy effects.

APPENDIX 2 - KEY TO TABLES

0. Introduction

The key is divided into four sections corresponding to the four main parts of Tables 5 to 10. In each section the left hand column contains the headings from the tables and the right hand column, the definition of the entries under each heading.

In all the tables, ? indicates an uncertain entry and / indicates alternative features or modes of operation in successive tests.

1. General Information

Monitoring Institution	Institution responsible for gathering the data.
(Location of 'Structure')	Nearest city and country or, for structures in the USA, the nearest city and the customary abbreviation of the state.
Test Facility Name	Name of the experimental facility of which the buildings are a part.
Code and Test No.	Code adopted to identify each entry in the tables.

2. Building Description

Type, No. Rooms, Approx. Size, Construction	Description of the indoor structure, number of rooms in the main body of the indoor structure, the approximate size of the structure and the building materials used.
Structure or Zone Name	Name given by the monitoring institution to the experimental building or the name given to the individual cells within them.
Residence Name	Name by which the residence is commonly known.
Type	Letter - type of residence: D detached; S semi-detached; T terraced. Digits - number of storeys excluding: a attic space; b basement; c crawl space below the ground floor.
Plan Area m^2/Glazed Area %	Plan area of the residence, in square metres / Percentage of facade glazed.
Features or Feat.	Codes to the solar gain features incorporated in all the structures, except those tested indoors. AS attached sun space with associated thermal storage. CL convective loop or double envelope system. CW south facing clerestory windows. D direct gain structure: H heavyweight construction, masonry floors and/or walls, or added thermal mass; L lightweight, usually timber, construction and no added thermal mass. EB partially earth bermed structure. NI night insulation of windows by shutters or other novel technique. O opaque, windowless structure with descriptors H and L as above. PCM phase change material. RP roof pond system. RS under floor rock thermal storage system. T Trombe wall with or without selective absorption surface: V vented, with or without back-draft dampers; U unvented. WW opaque or semi-transparent water wall, with or without supplementary direct solar gain.

Plant & Schedule	Codes to auxiliary heating and/or cooling plant, if any:- C cooled structure: E evaporative cooling by roof sprays; 'no descriptor' indicates whole structure air conditioning plant. F free floating, no heating, cooling or venting. H heated structure: B electrical baseboard heating; C electrical ceiling heating; D ducted air system from central gas or electric heater; F electrical resistance/ fan heaters; L light bulbs; O open fire; P heat pump (usually air-to-air); R domestic hot water radiators; 'no descriptor' heating mode unknown. V vented with outside air: M mechanically; P passively. Combinations are used e.g. F with H or C indicates free floating when temperature is above or below the set points.
	Codes to the mode of operation and control, if any:- c plant is on continuously. p scheduled 'on' periods, typically twice per day. t thermostatic control during 'on' periods, otherwise no control. j step change or jump in heat input) indoor structures only s sinusoidal heat input rate)
Occupancy or Occ.	Code indicating the occupation of the indoor structure, residence of commercial building. F contains typical domestic or office furnishings. M furnishings simulated by adding masonary blocks etc. O occupied. S simulated occupancy: p simulation of people, usually by electric lamps; a simulation of appliance use, water run-off, light switching, window opening, curtain operation etc.; 'no descriptor' features simulated unknown. U unoccupied.

3. Monitoring

External Temperature Regime	Codes describing the temperature regime in the environmental chamber. DC(V W) daily cyclic temperature fluctuation between maximum temperature V°C and minimum temperature W°C. CT(X) constant temperature of X°C. SC(Y Z) step change in temperature from Y to Z°C.
Period	Period during which the building was monitored or, if known, when experiments were performed. V date of measurements, day:month:year. <W before and/or during the date W. X> during and/or after the date X. Y-Z between the dates Y and Z.

Appendix 2 - 3 continued

Building or Bldg.	Building response parameters which were recorded. T temperatures of: a zone air, shielded or unshielded; g globe, o opaque surfaces; w glazed (window) surfaces; i intra fabric. E energy use for: h heating; c cooling; v mechanical venting. F heat fluxes through: o opaque surfaces; w glazed (window) surfaces. A air infiltration and/or advection by: d tracer gas decay sampling method, results may be correlated with wind direction and/or speed; c continuous (constant concentration) measurements; f flow meter measurements; p fan pressurisation or depressurisation tests; 'no descriptor' unknown method of measurement. I interior solar fluxes. C construction thermophysical properties for some or all building materials or fabricated elements. O others: v velocity of air in Trombe wall spaces or rooms; h interior relative humidity; f thermosyphon flow rate; i infrared thermography survey; w status of window, door or night shutters recorded.
Environment or Environ.	Codes describe the environmental or climatic parameters which were measured for all except structures tested indoors. T air temperatures: a dry bulb; w wet bulb; s sol-air. I solar radiation intensity: h global horizontal; v global vertical; n direct normal; d diffuse horizontal; a global at some other angle; o other, (e.g. diffuse vertical). W wind: s speed; d direction. O others: c cloud cover; p pressure; a ground albedo; d dew point; g ground temperature; h relative humidity; w rain water; l long wave radiation.
Data Media	Codes indicate the media on which the monitored data were recorded. D In digital form on magnetic disc, cassette or tape. T Punched tape. C Continuous chart record. P Punched card. O Other media, e.g. "on paper".

4. Reference/Subject

Reference	Digits - code numbers of reference from which the information was extracted. Separators - comma: references detail different work in the same subject area. dash: alternative references containing similar information.
Subject	Codes describing the subject of the reference. Ci compiled information about data sets (see Table 1a). Db description of existing data base for empirical validation (see Table 1b). The remaining codes have a strict hierarchy ranging from Des to BLAST etc. Only the highest appropriate code in the list is used after the reference number. Des - description of the facility and experimental intensions only. (**bold face** - document is a site handbook) Bres - experimental data reported to demonstrate the response of the building only. They are not compared to model predictions. Smod - results compared with the predictions of simple calculation methods. Mod - results compared to predictions of a dynamic thermal model. BLAST, DEROB, DOE, ESP, SUNCAT, SUNCODE, SERIRES, TARP, NBSLD - results compared to the predictions of these simulation models. (**Bold face** - comparisons made by a different institution from that which collected the data.)

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