International Energy Agency

Calculation of Energy and Environmental Performance of Buildings

Technical Synthesis Report
- IEA ECBCS Annex 21 / IEA SHC Task 12B

Energy Conservation in Buildings and Community Systems Programme

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Calculation of Energy and Environmental Performance of Buildings

Translated from
Energiberäkningsmodeller - Validering och parameterstudier
(Energy Calculation Programs - Validation and parameter studies)

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A Summary of IEA projects:

Annex 21 Calculation of Energy and Environmental
Performance of Buildings
within the Energy Conservation in Buildings and
Community Systems Programme

and

Task 12 Subtask B Building Energy Analysis
and Design Tools for Solar Applications
within the Solar Heating and Cooling Programme

(Duration 1988 – 1993)

Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems (ECBCS)

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following have been initiated by the Executive Committee (completed projects are identified by *):

1 Load Energy Determination of Buildings *
2 Ekistics and Advanced Community Energy Systems *
3 Energy Conservation in Residential Buildings *
4 Glasgow Commercial Building Monitoring *
5 Air Infiltration and Ventilation Centre
6 Energy Systems and Design of Communities *
7 Local Government Energy Planning *
8 Inhabitant Behaviour with Regard to Ventilation *
9 Minimum Ventilation Rates *
10 Building HVAC Systems Simulation *
11 Energy Auditing *
12 Windows and Fenestration *
13 Energy Management in Hospitals *
14 Condensation *
15 Energy Efficiency in Schools *
16 BEMS - 1: Energy Management Procedures *
17 BEMS - 2: Evaluation and Emulation Techniques *
18 Demand Controlled Ventilating Systems *
19 Low Slope Roof Systems *
20 Air Flow Patterns within Buildings *
21 Calculation of Energy and Environmental Performance of Buildings *

22 Energy Efficient Communities *
23 Multizone Air Flow Modelling (COMIS) *
24 Heat Air and Moisture Transfer in Envelopes *
25 Real Time HEVAC Simulation *
26 Energy Efficient Ventilation of Large Enclosures *
27 Evaluation and Demonstration of Domestic Ventilation Systems
28 Low Energy Cooling Systems
29 Daylight in Buildings
30 Bringing Simulation to Application
31 Energy Related Environmental Impact of Buildings
32 Integral Building Envelope Performance Assessment
33 Advanced Local Energy Planning
34 Computer-aided Evaluation of HVAC System Performance
35 Design of Energy Efficient Hybrid Ventilation (HYBVENT)

Annex 21 Calculation of Energy and Environmental Performance of Buildings

Annex 21 was established within the ECBCS Implementing Agreement. The objective of Annex 21 was to carry out an in-depth study of advanced thermal calculation programs in order to examine the deviations produced by different computer models. Furthermore, the projects aimed to validate these deviations against actual measured values. The participants from the various countries taking part in each project are jointly responsible for the findings. The projects' 8 reports, totalling nearly 1500 pages, are available via the IEA information centre AIVC (Air Infiltration and Ventilation Centre).

Participating countries of Annex 21 are Australia, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain, Sweden, Switzerland, United Kingdom and USA.

Scope

This report contains a summary of the work of Annex 21, the duration of which was from 1988 to 1993. The material included reflects developments reached by the end of the working phase of the Annex. This summary provides an introduction for building services practitioners and designers in assessing the capacity and deviations of different thermal calculation programs. The full project reports, as listed in Appendix 2, give more in-depth information.

Acknowledgement

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Contents

1. Introduction

1.1 Background

Developments in IT have lead to greater opportunities to study thermal processes in buildings dynamically. The developments started with the first mainframe computers and really took off during the 1980s when PCs made it possible for researchers, and principally consultants, to use thermal simulation programs. These programs use highly advanced computer models to carry out parameter studies and design calculations of thermal processes in buildings or parts of buildings. Throughout the years that the models have been in use, people have been faced with the problem of 'checking' the simulation program's results against measured values - validating. One problem is that the measured values are also impaired by inaccuracies and disturbances. One method sometimes resorted to in such tests is to compare the programs with each other. Comparisons of various kinds produce differences between the results of different programs. There may also be differences between different versions of the same original program.

Projects aiming to compare results from different models were initiated as early as the 1970s, when the IEA was founded. The differences were sometimes surprisingly large. On examining the reason for the differences, it could be seen that the deviations were due to different interpretations of the input data, simplification of physical relationships, programming errors etc. There was a marked improvement during the 1980s - the programs were improved considerably and it became possible to compare results of simulation calculations with measurements in the field. In some countries, comparisons have also been made between different users of the same version of the software. However, the deviations have still sometimes showed unacceptable levels.

Today there are a large number of programs which are of adequate complexity. It is therefore not possible to include all of the programs, in a comparative survey of results. Special emphasis should thus be placed on developing universal methods. This, however, necessitates carrying out the tests in several different ways in order to reveal both the strengths and the weaknesses. The two IEA projects (Annex 21 and Task 12) which have been summarised, have been organised in this way.

1.2 Objectives

The objective of both of the projects has been to develop processes to carry out a quality review of simulation programs which calculate energy, power and temperatures. A universal basis for assessing all programs can be created by stipulating criteria. Tests are performed for different tests. Developing a focus on quality creates opportunities to examine the programs more closely so that buildings and premises are neither overrated nor cause the user problems with comfort. The aim is also to develop checklists for what the software should contain in order to make it user-friendly. This means that the user should be able to rely on the fact that all aspects have been incorporated in the input data files. The projects have been split into subtasks, shown in Table 1.1. Subtask C in Annex 21 and Subtask B in Task 12 have been carried out jointly.

Table 1.1 Subtasks in Annex 21 and Task 12

Annex 21		Task 12	
Subtask	**Responsibility**	**Subtask**	**Responsibility**
A. Documentation	Great Britain	A. Development of models	
B. Suitability for purpose	Great Britain	B. Evaluation, improvement	USA
C. Evaluation methods			
C1 Validation	Great Britain	C. Application of models	
C2 Office buildings	Finland		
C3 Single-family houses	USA		
D. User interface	Germany		

2. Application of Programs

One of the prime concerns within the project has been to develop a technique for documenting models and programs - an aid for structuring, storing, compiling and analysing the information. The system is menu-driven and contains options to make it more user-friendly and enable the user to work actively with advanced programs. The system works using a structure under which different models of software are stored. These can then be accessed by different users, as the menus lead directly to the programs that the user may need. In this way, the structure also serves as a kind of checklist to ensure that all aspects have been noted.

If several different programs can be applied for a particular function or part of a building, these can be tested against each other to determine which model is the most appropriate in the chosen situation.
The system will be able to provide answers to questions such as:

- How does program A model function X?
- Which program contains detailed models of function Y?
- How do the criteria for program A differentiate from the criteria for program B?

The software developed within the project gives guidance on how models and programs should be documented. It also provides examples of the contents in a library of building components, physical processes and heating, ventilation, cooling and air conditioning systems. The collection of examples contains software from 4 countries. Here, you can analyse the consequences of different assumptions and see which limitations occur in different countries' programs.

With regard to the link between calculation models and computer-aided project management in the form of graphics software, it is worth briefly describing the software currently being developed or already on the market. The prime objective of

Subtask D has been to inform the software developers of the necessary factors which must be included in computer-aided project management. This is especially important when the intention is to link up calculation programs with graphics software. Table 2.1 shows in summary form the current state of developments, in which stage of the building process the programs can be used and the discipline within which they can be used. The report by Hertkorn also describes the programs' function with respect to support for multi-user systems and support for different calculation programs such as TRNSYS, ESP etc.

CH-IES has been judged to best meet the objectives. This software uses an object-centred organisation of the building model as against the graphics based organisation of the S.A.M. software. BESA is considered to be a pragmatic and user-oriented program. A number of programs are still in the development stage, for example COMBINE, which has been granted support from the EU for its development.

3. Structure of Programs

Comparisons were made between program simulations and measured results in well-defined test-houses. In addition, parameter studies were carried out. Deviations between programs were obtained as a result. In order to analyse the deviations, detailed information was compiled for the different programs. Table 3.1 shows a selection of these details. In some cases, different versions of the same software were used. Consequently, the deviations can be explained by means of a detailed analysis. Comparisons of simulations and measured results were made for a total of 24 different versions of 17 basic models.

A further 3 programs and 4 versions were included in the comparisons, but only in parameter studies - see Table 3.2. This table also shows the different organisations in the countries which participated in the comparison of programs. Included in those who took part were 4 consulting firms, 2 of which are planning and design consultants.

4. Comparison Between Programs and Measured Building - Validation

In the first phase, the 24 different calculation groups were given a set of criteria against which the simulations were to be performed. On presentation of the results, the measured values were obtained. During the second phase, the groups were given the opportunity to look through the programs in order to search for errors. This resulted in the presentation of a new set of results from TSI3, TAS, HTB2 v 1.2, BLAST USA, SUN and SERI-RES. All of the programs, with the exception of SERI-RES, were able to present several results within the margin of error. As the changes which were made often resulted in permanent adjustments to the programs, the results accounted for in this summary refer to the values obtained during the second phase.

Table 2.1 Programs linking calculations and designs

	AEDOT	BESA	INTE-GRIS	IBP-DES	IBIPS	RETEX			BEANS	FACET	IDEFIX	IFE	INTER-GRAPH	S.A.M.	A+	A4
							EBERT	Logo-CAD								
Country	USA	CAN	CH	UK	B	D	D	D	UK	UK	B	UK	USA/UK	CH	D	D
Company, Institute	PNL LBL CalPol	PWC Candapla Scanada	PSI Byron	BRE COMB-INE	VUB ESRU TNO CONPA-HOEBUS	IFIB ROM EBERT	EBERT	Logotech ROM	Ove Arup	Facet Auto-CAD m.fl	Univ. Luxemb. Arlon	Ruther-ford Lab. ESRU	Inter-graph	Suter + Suter	IFIB	IFIB
Commercial *Res./develop.* *Operating syst.*	- ⊗ AIX, UNIX	• - DOS	⊗ • HP-UX	- O DOS, UNIX	- O UNIX	- ⊗ UNIX	- ⊗ DOS	• - WIN-DOWS SUN OS	• - DOS, UNIX	• - DOS, UNIX	- • DOS	- O UNIX	• - UNIX	• - VMS, UNIX	Δ • UNIX	- • NextStep
Pilot studies *Building docs.* *Design* *Inspection* *Operation*	⊗ Δ Δ Δ Δ	• • ? ? ?	• ⊗ - - -	O O - Δ -	O Δ - - -	O O Δ Δ Δ	O • ? ⊗ Δ	⊗ • - O -	• • - ⊗ O	- • - - -	- • - - -	O - - - -	⊗ • ? ? •	O • ? ⊗ ?	• ⊗ - - -	⊗ ⊗ Δ Δ Δ
Architects *HVAC* *Instal'tn* *Control syst.* *Bld mgt admin.*	⊗ O O Δ	• • • ?	• • ⊗ ?	Δ ⊗ ? -	O ? ? -	O O O Δ	- O ⊗ Δ	• • • O	• • ? ?	- • • -	• O - -	O O O O	• • ? •	• ⊗ ? ?	• • ⊗ -	⊗ ⊗ ⊗ Δ

• Exists; ⊗ Partially exists; O Planned; Δ Long-term objective; - Not planned; ? No information

PNL	Pacific Northwest Lab, Wa, USA	BRE	Building Research Establishment, GB
LBL	Lawrence Berkeley Lab, USA	VUB	Vrije University, Brussels, Belgium
CalPol	California Polytechnic State Univ, USA	ESRU	ESRU Strathclyde Univ, GB
PWC	Public Works Canada	IFIB	Institute für Industrielle Bauprod, Univ Karlsruhe, Germany
PSI	Paul Scherrer Institute, Switzerland	ROM	Rudolf Otto Meyer, Hamburg, Germany

Table 3.1 Structure of the programs

		TSBI3 V 2.0	DOE 2.1 E	TAS v 7.54	ENERGY 2 v 1.0	CHEETAH v 15.2	3 TC v 1.0	APACHE v 6.5.2	HTB2v 1.10	HTB2 v 1.2	CLIM2000 v 1.1	DEROB v lth	S3PAS v 2.0	BLAST v. lvl 143	BLAST v 3.0	TASE v 3.0	TRNSYS v 13.1	TRNSYS v 12	SUNCODE v 5.7	SERI-RES v 1.2	ESP+ v 2.1	ESP-R v 7.7A **	ESP v 6.18a
Availability	Public		X						X	X		X		X*	X*					X			
	Commercial	X		X	X	X		X						X*	X*		X	X	X		X		
	Research			X			X				X	X	X			X						X	X
Method of solution	Finite difference	X			X			X	X	X		X	(X)						X	X	X	X	X
	Response factor		X	X									(X)	X	X		X	X					
	Other					X	X				X		X			X	X	X					
Climatic data - to be transformed	None	X									X	X		X	X		X	X					
	Cloudiness		X		X	X			X	X						X							
	Hour centring			X		X	X	X												X	X	X	X
	Other												X						X				
Model of radiator	Solely convective		X		X	X						X					X	X	X				
	Fixed convection/ radiation																			X			
	Detailed	X		X			X	X	X	X	X		X	X	X	X					X	X	X
Control	Perfect	X		X	X	X	X		X	X		X	X			X	X	X	X	X	X	X	X
	Thermostat																						
	on/off				X		X	X	X	X	X			X	X						X	X	X
	+ dead band			X	X		X	X	X	X				X	X				X	X	X	X	X
	Proportional	X	X	X	X		X	X	X	X	X			X	X	X*					X	X	X
Long-wave heat transmission in zones	Constant	X	X*		X	X					X						X	X	X	X			
	Linear		X*									X		X	X						X	X	X
	Non linear								X	X	X												
	Emissive			X			X	X				X				X					X	X	X
	Other												X	X*	X*								
Windows	Fixed U-value	X		X	X	X	X	X			X	X	X				X	X	X	X			
	Variable U-value		X						X	X				X	X						X	X	X
	Other															X							
Distribution of solar radiation	Floor					X					X										X		X
	All surfaces	X	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X		X	

* various data ** also ESP-r v.8

The measured values were obtained from test rooms set up at an airport in England. The side of the test rooms with the replaceable window section faced south and had a wall area of 1.5×2.28 m^2 and a window area of 1.00×1.50 m^2 (breadth x height). The floor area of the rooms was 3.54 m^2 and the volume was 8.07 m^3. The rooms were heated by means of an oil-immersed electric room heater. The rooms were 100% tight and did not have any ventilation.

In order to determine errors in measurement, in addition to the normal error analysis of measuring instruments, some of the test rooms were dismantled and any errors which were built into the construction were noted. Together with the error analysis of the measuring apparatus, an interval could then be obtained within which the measured results had to fall. The interval for the error in measurement, or the margin or error, is shown in the figures as horizontal bands with the following notations: 'upper' = upper limit of error in measurement, 'mean' = measured mean, 'lower' = lower limit in error in measurement.

Table 3.2 Survey of the various comparisons produced by the different programs

Program	Type of comparison			
	Actual measured values	Between the programs, parameter studies		
	Section 4	Offices Section 5	Lightweight buildings Section 6.2	Single-family dwellings BESTEST Section 7
TSBI3 v 2.0 - SBI, DK	X			
DOE 2.1E - LBL, USA	X			X
TAS-le v 7.54 - de Montford Univ, UK	X		X	
TAS-bre - BRE, UK			X	
ENERGY2 v 1.0 - Arup, UK	X		X	
CHEETAH v 15.2 CSIRO, AUS	X			
3TCV v 1.0 Facet, UK	X			
APACHE v 6.5.2 Facet, UK	X			
HTB2 v 1.10 - Univ Cardiff, UK	X			
HTB2 v 1.2 - FHT, Stuttgart, D	X			
CLIM2000 v 1.1 - EDF, F	X			
DEROB v lth - LTH, S	X			X
S3PAS v 2.0 - Univ Seville, E	X	X		X
BLAST v 1 vl 143 - Colorado U, USA	X			
BLAST v 3.0 - Pol. Torino, I	X	X		X
BLAST- ROM, D			X	
TASE, v 3.0 - Tampere, SF	X	X		X
TRANSYS v 13.1 - Univ Wisconsin, USA	X			
TRANSYS v 13.1 - Vrije Univ, B, CH[1]	X	X	X, X	X
TRANSYS v 13 - BRE, UK	X		X	
TRANSYS v 12 - BRE, UK	X			
SERI-RES/SUNCODE v 5.7 - Ecotope, USA	X			X
SERI-RES v 1.2 - BRE, UK	X	X	X	X
SERI-RES -n - Newcastle Univ, UK			X	
ESP+ v 2.1 - de Montford Univ, UK	X		X[2]	
ESP-R v 7.7a - Strathclyde Univ, UK	X			
ESP v 6.18a - de Montford Univ, UK	X		X[3]	
ESP-r v 8 – BRE / de Montford Univ, UK; Vrije Univ, B		X	X, X	X
BREADMIT - BRE, UK			X	
VA114 - TNO, NL			X	
Probability - BRE, UK / China			X	

Bold type denotes the programs in figures
[1] Both Belgium (B) and Switzerland (CH) have used this version
[2] Used ESP-t version
[3] Used ESP-u version

The measurements of the different cases are shown in Table 4.1. The following three variants of window were tested: sealed double glazed window, single glazed window (compare glass-enclosed veranda) and with the window hole sealed (fully insulated) in the same way as the wall. The measurements were carried out during one week in October and during one week at the end of May. The minimum temperatures were obtained by turning off the electric room heater for the October measurements. In May the heating was turned off completely.

Table 4.1 Measured wall combinations and values

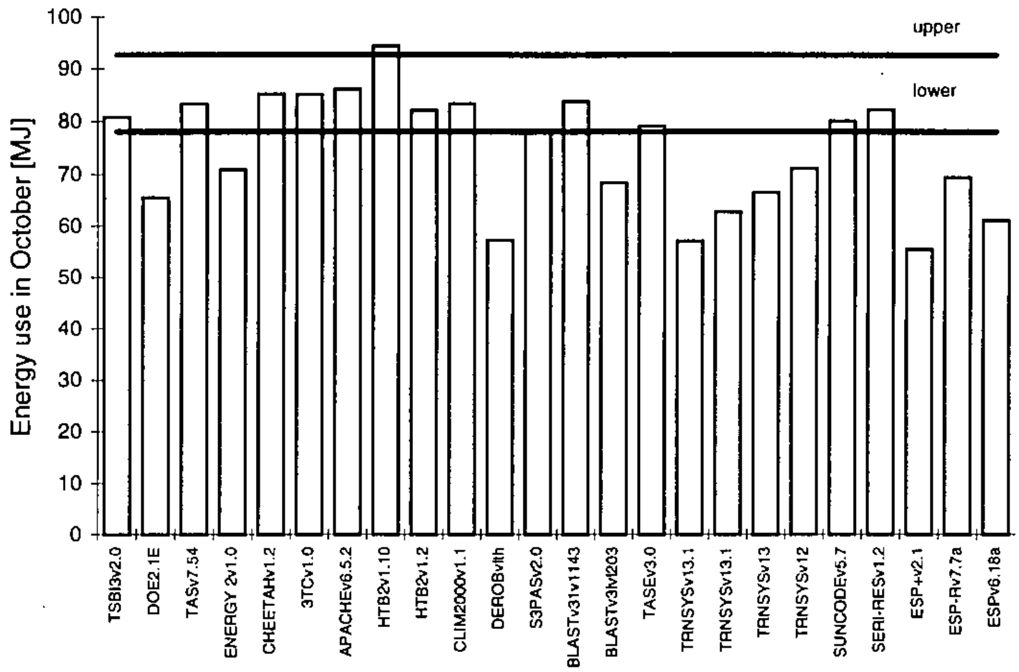
Simulated and measured values	**Unit**	Design of south facing wall				
		Double glazed		Single glazed	Fully insulated	
		October	May	May	October	May
Heating requirement	MJ	X			X	
Max. temperature, T ↑	°C	X	X	X	X	X
Min. temperature, T ↓	°C	X	X	X	X	X
Insolation	MJ	X	X			

4.1 The heating case - October

For double-glazed windows, energy use varied from 94.4 MJ (HTB2 v 1.10) to 55.5 MJ (ESP+ v 2.1) and 12 programs produced results within the margin of error - see Figure 4.1. In the case of the fully insulated wall, results varied from 123.4 MJ (BLAST, USA) to 82.6 MJ (DEROB) and 8 programs produced results within the margin of error. If the two cases are compared, it can be seen that only 6 programs meet the requirements of being within the margin of error for both cases. DEROB and all ESP and TRNSYS versions consistently show energy use values which are too low. The simulation values above the upper limit of error in measurement are slightly too high whilst the values below the lower limit of error in measurement are well below or 22% for fully insulated walls and 29% for double glazed windows.

The results vary considerably in terms of the programs' capacity to calculate minimum and maximum temperatures in the room. For maximum values, there is a difference of 10.5 °C between the highest and the lowest calculated values for rooms with double glazed windows. For minimum values, the difference is 4.7 °C. This is also reflected in the fact that only 8 programs managed to produce values within the margin of error for maximum temperatures whilst 11 managed to show minimum temperatures within the margin or error.

In the case using the fully insulated wall without 'compromising' insolation through windows, the programs showed better results. All of the programs managed to show maximum temperatures within the interval for error in measurement. However, only 6 programs managed to show minimum temperatures within the margin of error in measurement and all of them showed low values, the lowest being 3.4 °C below the lower limit of error in measurement.



Comparison between measured and calculated values with different programs.
Upper and lower limits in error of measurement are also shown.

Figure 4.1 Energy use in October for rooms with double glazed windows.

The TSBI3 program was the only software which managed to produce all values within the margin of error for the case using heating, both for the rooms with double glazed windows and for the rooms with the fully insulated wall. In order to accomplish this, however, modifications had to be made between the first and the second set of calculations. No other programs succeeded in producing heating and maximum temperature values within the margin of error for both cases, even though a couple of programs came close.

4.2 The summertime case - May

For double glazed windows. the programs' results with respect to maximum temperatures vary from 35.0 °C (DEROB) to 26.4 °C (HTB2 v 1.10). All of the programs, with the exception of DEROB, show values within the margin of error (6 programs) or too low. The results for minimum temperatures were far more in concordance with the measured values, with only 3 programs failing to produce results within the margin of error and showing temperatures which were too low. The results for the single glazed windows displayed a very low level of concordance with measured values. The majority of programs showed temperatures which were consistently lower than measured values. 5 programs managed to produce maximum values within the margin or error and only 2 programs managed to produce minimum values within the margin of error.

In the case using the fully insulated south-facing wall, the majority of programs managed to calculate temperatures within the margin of error. However, there were still 4 programs which did not manage to produce either maximum temperatures or minimum temperatures within the margin or error.

4.3 Explanation of the deviations

The measurements carried out in the test rooms were reviewed with regard to errors in measurement in the measuring devices. Structural deviations in the rooms also widen margins of error. The thickness of the insulation and the dimensions of the studs etc. were measured afterwards. Errors in measurement and structural deviations give an interval, a margin of error, within which the simulation results should fall. No measured values were specified for air humidity. Both the ESP and TASE programs take air humidity into account in their calculations. All of the programs presuppose that the room temperature is constant throughout the entire volume. One of the most important explanations of the occurrence of deviations is the fact that the DOE2, DEROB, TRNSYS (all versions), CHEETAH and ENERGY programs simulate only convective heat output from the radiator and take no account of the radiation. The ESP-r v 7.7a and ESP+ v 2.1 programs use higher coefficient of surface conductance values (7 $W/m^2{\cdot}K$) than the other programs (approx. 3 $W/m^2{\cdot}K$) - this explains the deviations. The insolation is simulated in somewhat different ways and varies for October between 84.1 MJ and 67 MJ. Only 9 programs, however, manage to produce results within the margin of error. For May, the results vary from 84.7 MJ to 77.5 MJ. All of the programs, with the exception of BLAST, I, managed to produce results within the margin of error.

Table 4.2 shows which programs produced results within the margin of error given by accurate measuring. These programs are screened in black in the table. It is evident that the TSBI3 program has the most results within the margins of error but its results for maximum temperatures for the summertime case in rooms with windows are too low. With respect to maximum temperatures for both summer and autumn cases for double glazed windows, only the TASE program was able to produce results within the margins of error. CLIM2000 v 1.1 was the only program which could give energy use for both of the autumn cases and also maximum temperatures within the margin of error for double glazed windows. It thus appears as though one program is needed to study the case using heating and another to study the case using unheated rooms.

5. Parameter Studies of Offices

Parameter studies have been carried out for an office module. Six different programs took part in these studies. The module consisted of two rooms with a corridor between them. The height of the rooms was 2.7 m and the floor area was 12 m^2, giving a volume of 32.4 m^3. The breadth of the corridor was 1.5 m. The facade was 3 m in length with a double-glazed window of 1.8 m × 1.4 m (breadth × height) and 0.5 m of wall below the window. The building was studied both in a densely built-up

Table 4.2 Programs giving results within the margin of error for measurement

Program	Heated rooms - October						Summertime case - May						Insol-ation		Number of simulations within the margins of error
	Double glazed			Fully insulated			Double glazed		Single glazed		Fully insul-ated				
	Energy	T↑	T↓	E	T↑	T↓	T↑	T↓	T↑	T↓	T↑	T↓	October	May	
TSBI3	▨	▨	▨	▨	▨	▨		▨			▨	▨	▨	▨	11
DOE 2.1E			▨		▨		▨		▨		▨		▨	▨	7
TAS	▨	▨		▨	▨			▨			▨			▨	7
ENERGY2		▨			▨			▨			▨	▨	▨	▨	7
CHEETAH	▨				▨			▨			▨	▨		▨	6
3TCV	▨		▨	▨	▨	▨		▨			▨	▨		▨	9
APACHE	▨		▨	▨	▨	▨		▨			▨	▨		▨	9
HTB2 v 1.10				▨	▨									▨	3
HTB2 v 1.2	▨				▨			▨				▨		▨	5
CLIM2000	▨			▨	▨		▨	▨						▨	6
DEROB					▨			▨	▨		▨	▨		▨	6
S3PAS		▨	▨	▨	▨			▨			▨	▨	▨	▨	9
BLAST, USA	▨				▨						▨	▨		▨	5
BLAST, I			▨		▨	▨	▨	▨	▨		▨	▨			8
TASE	▨	▨			▨		▨	▨			▨	▨		▨	8
TRANSYS v13.1, USA			▨		▨			▨			▨	▨	▨	▨	7
TRANSYS v13.1, B, CH		▨	▨		▨			▨			▨	▨	▨	▨	8
TRANSYS v 13			▨		▨			▨			▨	▨	▨	▨	7
TRANSYS v 12					▨			▨			▨	▨		▨	5
SUN	▨			▨	▨			▨			▨	▨		▨	7
SERI-RES	▨	▨			▨			▨			▨	▨		▨	7
ESP+ v 2.1			▨		▨	▨	▨	▨	▨	▨			▨	▨	9
ESP-R v 7.7a		▨	▨					▨					▨	▨	5
ESP v 6.18a					▨	▨	▨	▨	▨	▨	▨			▨	8

location with its facade shaded by buildings of an equal height located at a distance of 25 m, and in an open location. The module was positioned in both a north-south direction and in an east-west direction. Studies were carried out for the climate in Denver, Colorado, USA. After adjustments had been made on account of the town's location at 1610 m above sea level, the air throughput was 2.5 air changes per hour during the daytime from 07.00 to 17.00 and 0.4 air changes per hour during all other hours. The rooms were considered to be 100% tight and thus with no aboveflow between the rooms and the corridor. The internal load was 500 W during the daytime.

Table 5.1 shows the different cases which were studied and the participating programs are given in Table 5.2. The results are shown in the figures for power and annual energy requirement for heating and cooling, maximum and minimum temperatures and energy losses through external walls and windows.

Table 5.1 Office module calculations

Case no.:	Direction	Location	Corridor
1a	North-south	Free	Heated
1b	North-south	Shaded	Heated
2a	East-west	Free	Heated
2b	East-west	Shaded	Heated
3a	North-south	Free	Unheated
3b	North-south	Shaded	Unheated

Table 5.2 Participating programs

Program	Country	Organisation
BLAST, I	Italy	Polytecnico, Turin
ESP v8	Great Britain	BRE
SERI-RES	Great Britain	BRE
S3PAS v2.0	Spain	Esc Sup Ing Ind, Seville
TASE v3.0	Finland	Technical University in Tampere
TRNSYS v13.1	Great Britain and Belgium	BRE and Vrije University, Brussels

The six programs which took part in the tests are the same as those described in section 4, with the exception of a new version 8 that had been compiled for ESP. Examples of results with respect to annual energy requirements for heating are shown in Figure 5.1. Figure 5.2 shows results with respect to the power requirement for cooling. All of the results of the different programs are shown here and the means of the six programs have been added.

The results show considerable differences between the programs with respect to the different cases. It can be seen that the results can vary from -50% to +43% deviation from the mean with respect to the annual energy requirement for an individual room. The calculated power requirement for heating shows a deviation of up to 20%.

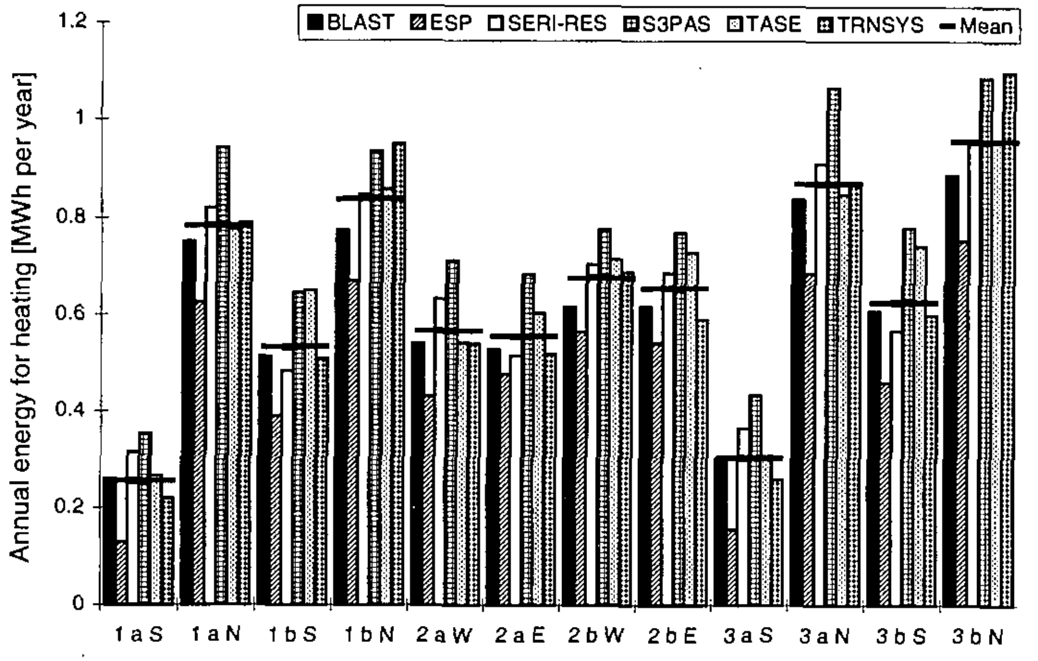


Figure 5.1 Annual energy requirement for heating

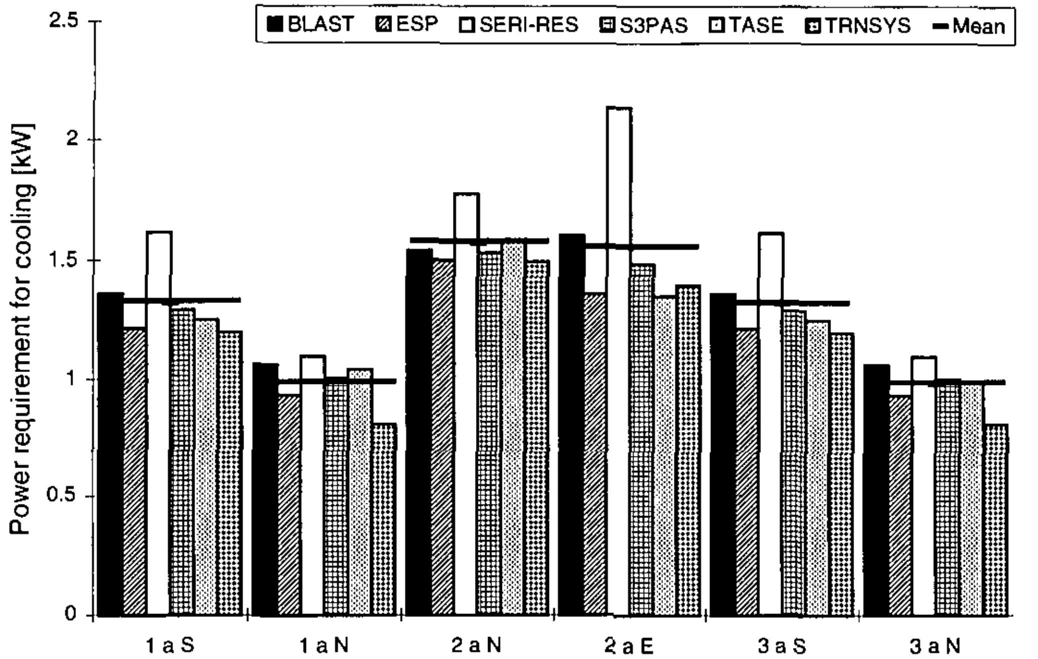


Figure 5.2 Power requirement for cooling

For the annual energy requirement for cooling, the values deviate from the mean by between +24% and -36%. With respect to the power requirement for cooling, the values deviate from +37% to -18%.

Table 5.3 outlines the overall performance of the different programs. The table uses a scale of seven to give a qualitative valuation. Values above or below the mean are denoted by the following:

---	greatly below; deviate more than 35 %
--	below; deviate 15 - 35 %
-	slightly below; deviate 10 - 15 %
0	approx. mean
+	slightly above; deviate 10 - 15 %
++	above; deviate 15 - 35 %
+++	greatly above; deviate more than 35%

Table 5.3 Values above and below the mean - qualitative valuation

		Case	Program					
			BLAST	ESP	SERI-RES	S3PAS	TASE	TRNSYS
Heating	Annual energy	1aS	0	---	+	+++	0	--
		1aN	0	--	0	++	0	0
		1bS	0	--	-	+	++	0
		1bN	0	--	0	+	0	+
		2aW	0	--	+	++	0	0
		2aE	0	-	0	++	0	0
		2bW	0	-	0	+	0	0
		2bE	0	-	0	+	+	-
		3aS	0	---	++	+++	0	-
		3aN	0	--	0	++	0	0
		3bS	0	--	-	++	++	0
		3bN	0	--	0	+	0	+
	Power requirement	1aS	0	--	++	+	0	0
		1aN	0	--	+	0	0	0
		2aW	0	--	++	+	0	0
		2aE	0	--	+	+	0	0
		3aS	0	--	++	+	0	0
		3aN	0	--	+	+	0	0
Cooling	Annual energy	1aS	+	0	++	-	-	0
		1aN	+	0	0	0	0	-
		1bS	+	0	++	0	-	--
		1bN	++	0	+	0	0	---
		2aW	0	0	0	-	0	0
		2aE	0	-	++	0	-	0
		2bW	+	-	0	0	-	0
		2bE	+	0	0	0	--	+
		3aS	+	0	++	-	-	0
		3aN	++	0	0	0	0	-
		3bS	+	0	++	0	-	--
		3bN	++	0	+	0	0	--
	Power requirement	1aS	0	0	++	0	0	-
		1aN	0	0	+	0	0	--
		2aW	0	0	+	0	0	0
		2aE	0	-	+++	0	-	-
		3aS	0	0	++	0	0	0
		3aN	0	0	+	0	0	--

-- below; - slightly below; 0 approx. mean; + slightly above; ++ above; +++ greatly above

To sum up, the following characteristics can be outlined for the programs:

BLAST Values close to the mean except for values for annual energy requirement for cooling, which were above the mean.
ESP Deviates consistently giving lower values for heating. Values around the mean or just below for cooling.

SERI-RES Heating gives values which are too high or around the mean. The cooling case gives values above the mean and which deviate substantially with respect to the power requirement.

S3PAS Values for heating greatly above the mean. Values for cooling cases similar to the mean.

TASE Values for heating around the mean and several cases above the mean whilst cooling values are around the mean and sometimes below.

TRNSYS Gives somewhat inconsistent results with heating values around the mean, but also both above and below. For cooling, results were either around the mean or below but also occasional values above. The results showed no pattern - e.g. the values for rooms facing north were above the mean except in one case. The same applied to rooms facing other directions. It appears, however, that an unshaded facade is likely to give greater deviations from the mean.

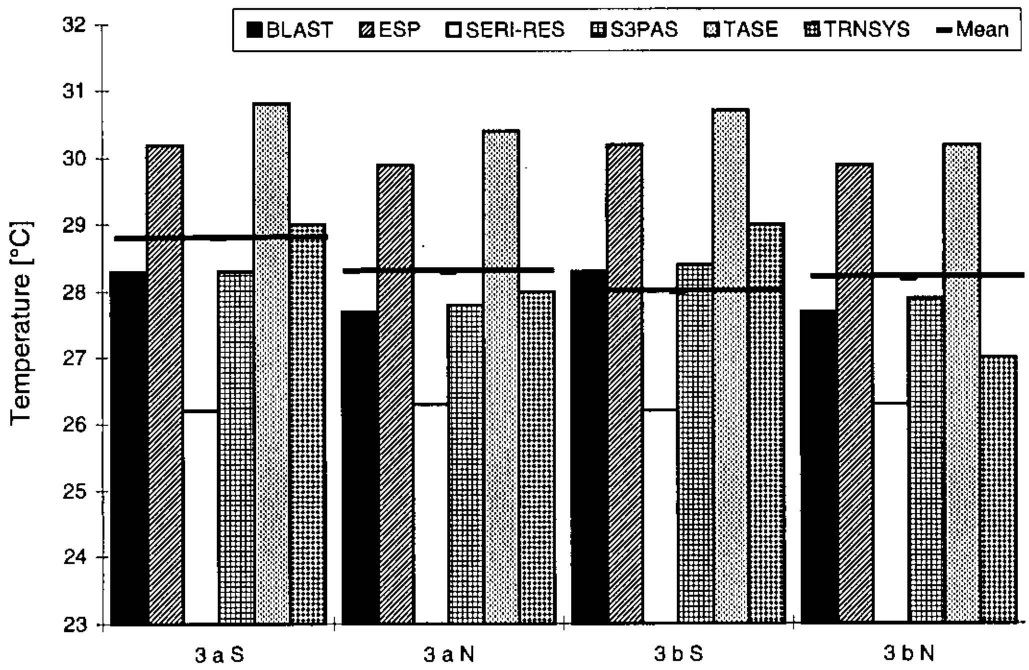
Maximum temperatures were studied for cases 3a and 3b, in which the office module was unheated. It can be seen from Figure 5.3 that the temperatures for the six programs varied from 2.3 °C below the mean temperature to 2.0 °C above. Studies of a single summer day show a similar difference when the office is not being used. During office hours the airflow enables the temperature to be maintained at 25 °C.

Annual energy loss through windows and external walls was calculated by three of the programs. For windows the values were consistently within the interval -5 % to +9% deviation from the mean. The values for the external walls varied to a considerably greater degree. The values produced by TASE are between 20% and 30% below the mean whilst the ESP values are up to 15% higher than the mean and S3PAS results vary greatly with values from +9 % to +29 %.

Due to the small number of programs, the figures must be treated with caution. However, the programs do show variations of up to almost 30 % for a single case.

6. User Variations

Subtask B of the Annex addresses the problem of user variations by providing a guide on how to use the programs correctly. Several examples illustrate how the results can vary depending on the different ways that the program may be interpreted



Facades facing south (S) and north (N)

Figure 5.3 Temperature variations for offices in an open location (3a) and shaded offices (3b)

by the user. The examples illustrate how the choice of program for an intended situation can affect the results, how different users can interpret and select input data and also how they can add various new assumptions to the approximations previously given.

Tests were carried out as early as 1979 on a number of users of the same program. The result of one comparison between 21 users showed a variation in a ratio of 4:1. A spread of such size is clearly unacceptable. A standardisation of input and output files would allow them to function as a checklist to ensure that all aspects have been noted. A large number of sources of error could be eliminated in this way.

Again, the following demands on a computer program for all types of calculation must be maintained:

- The programs must be technically and scientifically correct
- The applications must be correct
- Users must be able to obtain probable and accurate results
- The use of the program must be economically viable
- Different users must be able to obtain the same results
- It must be possible to use the program for buildings of different designs

6.1 Division into zones

The significance of the user is shown in the example to identify which room results in the maximum temperature. Comparisons were made between 17 different users. The users divided up a 5 storey office building into zones. The office building had 16 rooms on each floor where the corner rooms were larger than the other rooms. All of the centre rooms had one window whilst the corner rooms had a window in each direction (denoted as SE, SW, NE, NW).

Thorough and detailed calculations have shown that the middle room facing east on the middle floor - the second floor - has the highest temperature. Only 5 users identified this. The users divided the building into between 2 and 15 zones. Two distinct groups of users can be identified - those who divided the office building into few zones, from 2 to 6 zones, and those who divided it into 11 or more zones. None of the users who divided it into few zones were able to find the room with the maximum temperature but neither were two of the users with the greater number of zones. Figure 6.1 shows the distribution between the different rooms calculated by the users' simulations to be the room with the maximum temperature. All of the users used the SERI-RES program. It is evident from Figure 6.1 that most users (13) judged that rooms facing south on the second floor would give the highest temperature, followed by rooms facing west.

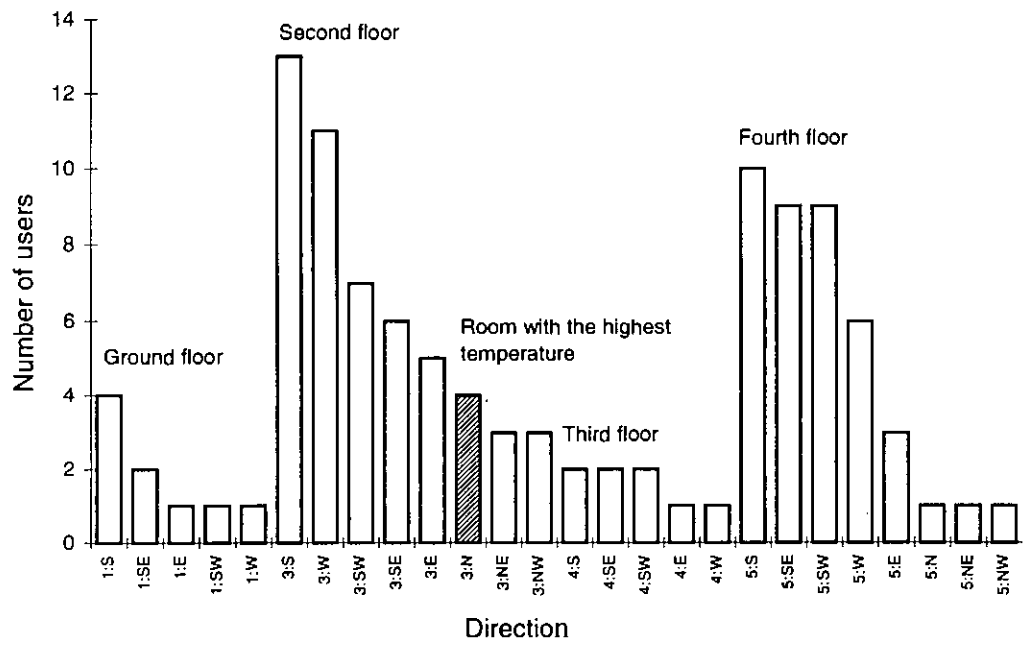


Figure 6.1 How the 17 users selected rooms when dividing the building up into zones in order to identify the room giving the highest temperature

6.2 Lightweight buildings - comparisons between various programs

A building with low thermal mass was designed in order to demonstrate that the programs produce results which differ amongst themselves. The original intention of the study - to show that results can differ more greatly between different users of the same program than between different programs - has not been confirmed. This is due partly to the fact that the study incorporated an inadequate number of users and also uncertainty as to whether the version of the programs used were exactly the same. Table 3.2 shows the 16 programs and participants which carried out the comparison.

When maximum temperatures for a single day (30 May) are studied, temperatures from 26.7 °C and 37.5 °C are obtained, see Figure 6.2. This can hardly be viewed as satisfactory. One explanation may be that the highest insolation value is 1.35 times higher than the lowest. If the frequency of the number of hours above 25 °C is studied, it can be seen that this varies from 100 h to 180 h per annum. The results with respect to annual energy use for heating and cooling - see Figure 6.3 - show a spread between 8000 kWh and 9800 kWh for heating and from 1000 kWh to 1300 kWh for cooling.

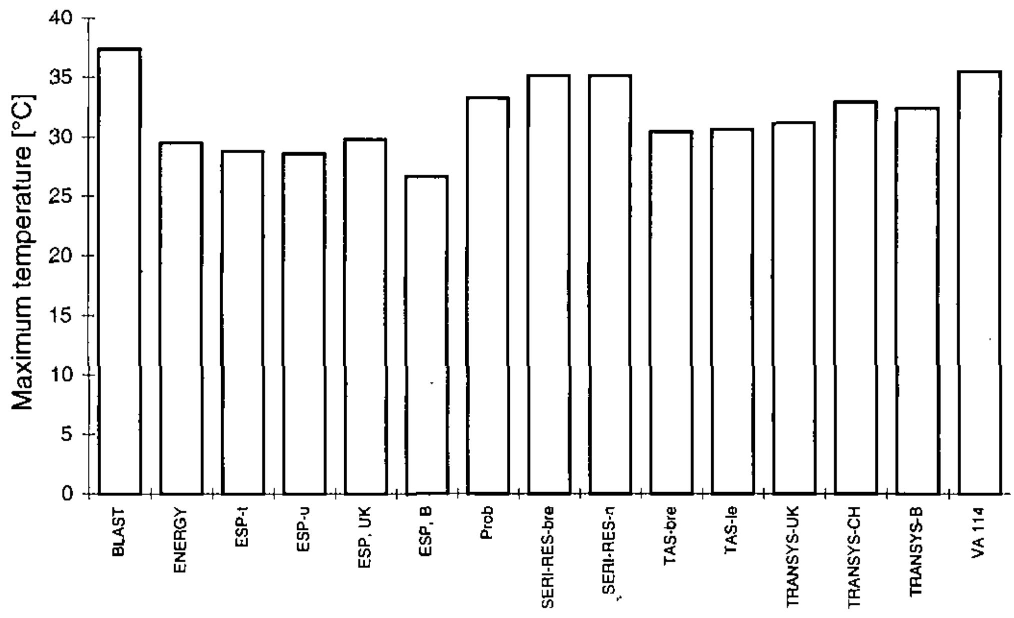


Figure 6.2 Maximum temperature for a summer day. Comparison between different programs calculated for a lightweight building.

6.3 Windows

User variations with respect to windows were carried out in order to study the effect of selecting different input data. The same program, VA114, was used in the parameter studies. The variations performed used the insolation factor, the convection factor and the U-value for the glass part of the window, the window frame and the window casement. Generally, the selection of parameters has the greatest effect if temperatures above 28 °C are accepted in the room. If the maximum temperature is set to this value, then the choice of parameter has no effect on the results. The higher the temperature that can be accepted, the greater the

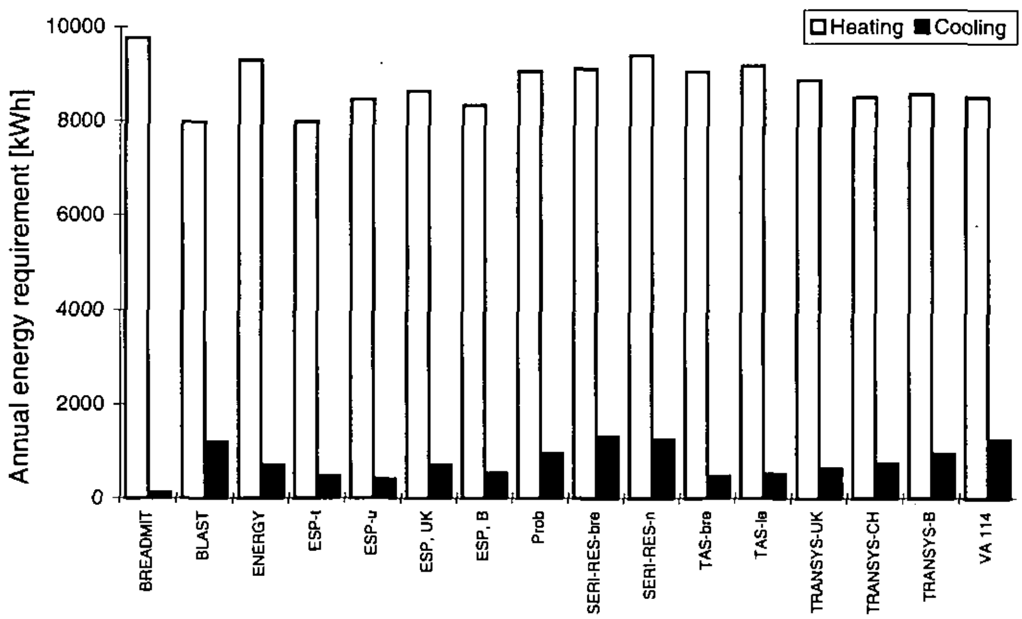


Figure 6.3 Annual energy requirement for heating and cooling. Comparison between different programs calculated for a lightweight building.

differences between the different variations in solar protection. For example, for temperatures above 34 °C in the room, the time varied from 400 h to 900 h.

Table 6.1 shows the number of hours above a given temperature (28 °C and 34 °C respectively) with two different window positions in the external wall and two different positions of venetian blinds.

Table 6.1 Number of hours above 28 °C and 34 °C respectively for different means of solar protection.

T [°C]	Window in facade rib	Blinds		Window 0.12 m in from facade rib
		Middle	Inside	
28	1100 h	900 h	1100 h	1100 h
34	400 – 900 h			100 h

7. Parameter Studies of Single-Family Houses - (BESTEST)

'Diagnostic tests' were designed to be carried out on the programs which had undergone qualifying tests. The diagnostic tests are made up of 40 different cases varying from simple to complex. The qualifying tests examine programs' capacity to simulate window positioning, shading, dead bands in thermostats, night-time ventilation for cooling, glass-enclosed verandas and ground insulation. The diagnostic tests work by varying one parameter at a time in order to study the effect that this has on each algorithm in the program. In this respect, the diagnostics tests are performed according to the conventional school of thought on parameter studies - i.e. the parameters are not varied simultaneously. If the statistical method of selecting combinations was used, a greater area could be covered, allowing a better study of the effects of different combinations of parameters.

The internal dimensions of the house on which the simulations were performed were $6 \times 8 \times 2.7 = 129.6$ m^3. The selection of materials, the area of the windows, the thickness of the insulation etc. were varied correspondingly. 9 programs took part in the comparisons. Of these 9, DEROB did not perform all of the combinations performed by the other programs. The participating programs can be seen in Table 3.2. Different tests can be performed with respect to climatic data, available on a disc accompanying the BESTEST report. All of the simulations were performed for the climate in Golden, Colorado, with 3636 degree-days for heating and 481 degree days for cooling. Table 7.1 shows a survey of the different parameters and values used in the parameter studies. It is evident that some of these values are unrealistic.

Table 7.1 Parameters

Parameter	Values
Reference values, temp	20/20; 20/27 °C; Night-time fall in temp.
Thermal mass	Lightweight, heavy
Internal load	0; 200 W
Infiltration	0; 0.5; 1 h^{-1}
Window; area of glass (Direction)	0 (S); 6+6 (E + W); 12 (S) m^2
Shade	None; 1 m hor.; 1 m hor. + 1 m vert.
Radiation, infra-red	0.1; 0.9
Absorption, short wave	0.1; 0.6; 0.9

Figure 7.1 shows the annual heating requirement for houses fitted with windows in different directions, when the house is lightweight or heavy and equipped with different shading devices. Figure 7.2 also shows the power requirement for cooling in the same case. These cases should be seen only as examples of the combinations included. A trend can be seen for the individual programs in the different scenarios. With respect to maximum temperatures - see Figure 7.3 - it should again be noted that the tests were performed in a location that is considerably further south than any location in Sweden. Golden is located on approximately the same latitude as Madrid. The values presented in the figures are typical for a continental climate.

Table 7.2 portrays the different scenarios shown in Figures 7.1 - 7.3. Lightweight and heavy buildings sharing the same design features have been presented adjacently in Figures 7.1 and 7.2. It can also be noted that an internal heat load of 200 W and air leakage of 0.5 h^{-1} was assumed. Table 7.3 shows the differences with respect to heating and cooling values for simulations of lightweight and heavy buildings. The percentage deviation is less for power than for annual energy. The annual energy requirement for cooling shows a greater percentage deviation compared to that for heating. Heavy buildings show greater deviations than lightweight buildings.

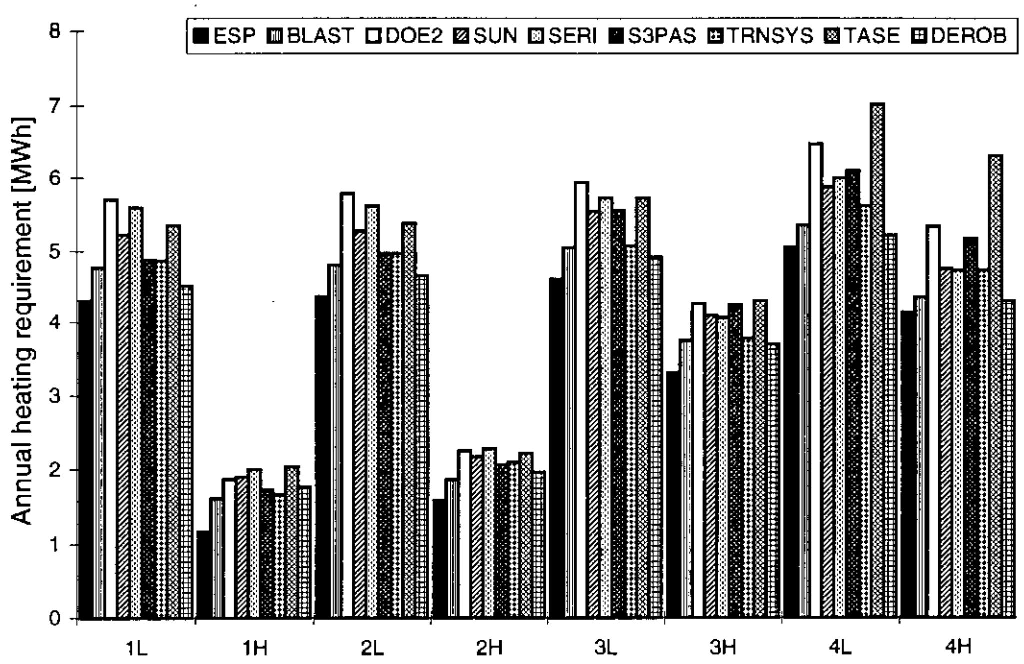


Figure 7.1 Annual heating requirement for lightweight (L) and heavy (H) buildings respectively, as shown in Table 7.4

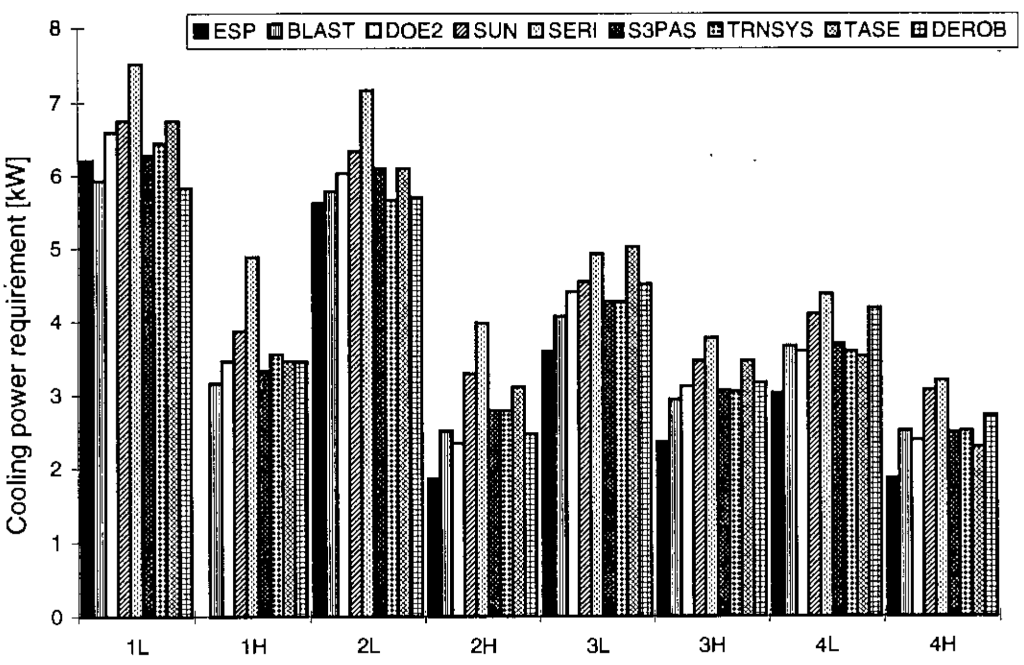


Figure 7.2 Cooling power requirement for lightweight (L) and heavy (H) buildings respectively, as shown in Table 7.4

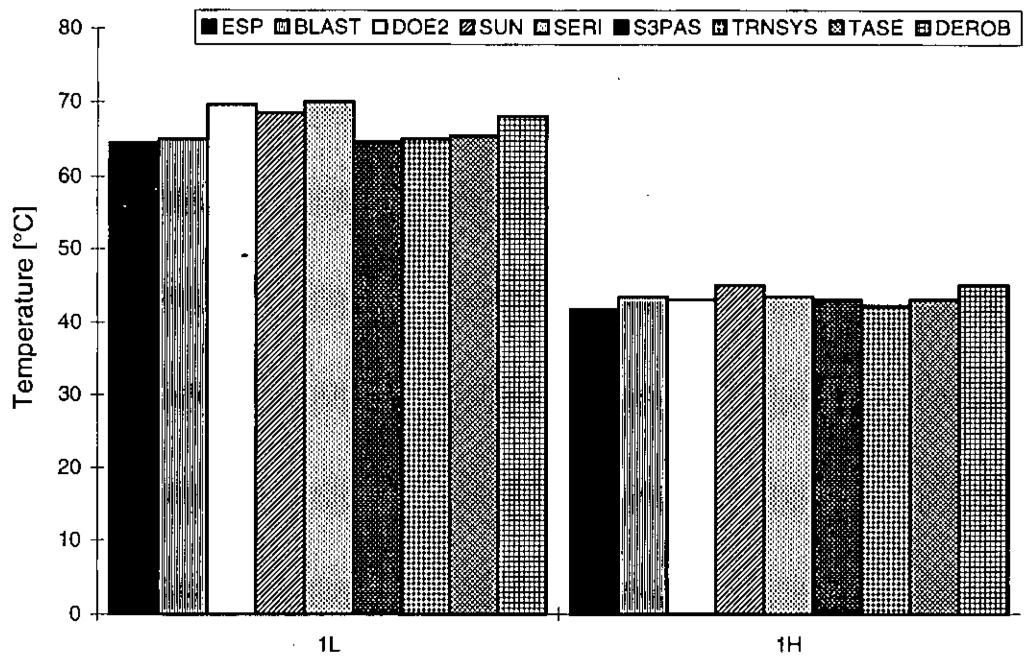


Figure 7.3 Temperatures for lightweight (L) and heavy (H) buildings

Table 7.2 Description of the different scenarios

Parameters	1L	1H	2L	2H	3L	3H	4L	4H
Thermal mass Light	x		x		x		x	
Heavy		x		x		x		x
Window area, m^2	12	12	12	12	6 + 6	6 + 6	6 + 6	6 + 6
Positioning of window, direction	S	S	S	S	E + W	E + W	E + W	E + W
Shading, Horizontal	-	-	1 m	1 m	-	-	1 m	1 m
Vertical	-	-	-	-	-	-	1 m	1 m

Table 7.3 Summary of annual power and energy requirement

Scenario		Difference between highest and lowest value	
Type of building	**Heating/ Cooling**	**Energy/ Power**	**%**
Lightweight	Heating	1.3 MWh	28
Lightweight	Cooling	1.7 MWh	37
Lightweight	Heating power	1.0 kW	23
Lightweight	Cooling power	0.9 kW	17
Heavy	Heating	0.9 MWh	39
Heavy	Cooling	1.0 MWh	66
Heavy	Heating power	1.0 kW	27
Heavy	Cooling power	0.8 kW	35

Analysis of the different results indicates that ESP shows the consistently lowest values. In the cooling scenario, SERI-RES has the highest values, except for in one case. SUN and TASE have the next highest values after SERI-RES. In the heating scenario, DOE2 shows the highest values in the majority of cases, followed by TASE, SERI-RES and SUN. DEROB shows the second lowest values for heating. Table 7.4 shows how the different programs rank both with respect to heating and to the power requirement for cooling. The programs are ranked so that the program with the highest values is given the highest ranking (No. 1)

Table 7.4 Ranking. Highest number represents highest values

Program	Heating	Cooling
ESP	9	9
BLAST	7	8
DOE2	1	7
SUN	4	2
SERI	3	1
S3PAS	4	5
TRNSYS	6	5
TASE	2	3
DEROB	8	4

High values (low numbers in the ranking) can result in over-rating whilst low values (high numbers) can cause problems with comfort.

8. Conclusions

It has been estimated that 50 % of the errors arising in the construction process originate from the various stages of the planning phase, 40 % originate from the building phase and 10 % are due to flaws in materials. With this in mind, it is obviously important to be able to rely on the calculation programs to be used in the planning phase, either at an early stage or for the rating of heating, ventilation or cooling systems.

When choosing between several different programs, there are a number of different things that a buyer/user needs to know about the programs. Learning to use a program can take a great deal of time and effort. In addition to the main issues such as how user-friendly the program is and how the program is presented, the following questions should be asked:

- Is the correct method used for describing the problem?
- Are the laws of physics described correctly?
- Are the applications correct?
- Are the results plausible?
- Is the use of the program economically viable for the matter in question?
- Do different users obtain the same results?
- Is the program widely used?

Often, there are no ready answers to the above questions and neither have the program designers been able to provide the answers. This project has shown that, in spite of the fact that several of the programs have been in use for many years, it has not been possible to remedy all of the errors. Simplifications have also been made resulting in values which have either been too low or too high. Those involved in the project must be able to demand good results from the program supplier or they risk being sued for faulty project management. For example, a program which shows summertime temperatures which are far too high could lead to the over-rating of a cooling plant. If, on the other hand, the program gives values which are too low, this may result in the plant capacity being too low, which can in turn lead to complaints by the user. It is important that the program buyer has an insight into these kind of problems, since he/she may incur large expenses as a result of under-rating or over-rating.

This project, operating within the framework of IEA, has developed some general methods to carry out a quality rating of different programs. The project uses checklists for software designers and discs containing data that a buyer of a program can use himself to test the reliability of the program. In principle, there are three different ways of evaluating programs, all of which have been used in this project:

1. Empirical validation. The calculated values are compared with the measured values.

2. Analytical verification. Output data, subroutines and algorithms are compared with results from known analytical solutions for clearly defined and easily separable characteristics, e.g. heat transmission. This can be used only for very simple cases.

3. Comparative tests whereby different programs are compared with each other. Attention is paid to how the sub-routines work, whether the algorithms are correct, i.e. physically correct (BESTEST, Commercial Benchmark) or if there are algorithms which can be better validated.

This IEA project provides the largest comparison between different thermal calculation programs carried out to date, even though it has not been possible for the project to evaluate every thermal calculation program. The comparisons show that the programs depict the actual measured values very differently. However, the assumptions made by the user, the data which he inputs and how correctly the building in question is emulated are all factors which are often just as significant as the selection of program. Another important factor is of course how much experience the user has had of similar cases, where he has had the opportunity to perform detailed simulations to familiarise himself with the program's possibilities. In this way the user can gain experience for future projects and also the opportunity to decide when detailed studies need to be carried out. The most common reasons for using computer calculation programs are to monitor building standards, to calculate power requirements for the rating of heating and cooling plants and to inspect temperature levels, moisture content, condensation risks and annual energy requirements. The following are common causes of problems when performing calculations:

- Non-availability of clearly expressed assumptions and simplifications.
- Well-documented and reliable data is difficult to find.
- Lack of guidance on how to transfer the data for an actual building to the simplified form needed for a program.
- Non-availability of rules governing the selection of climatic data and other user data.
- Lack of guidance on the type and form of presentation and the interpretation of results.
- User interface needs to be adapted to users in order to reduce input errors.
- Lack of reliable and accepted methods to ensure that the programs are correct and adequate. This is especially important with respect to the risk of being sued for inaccurate rating.

Unfortunately, it is not possible as a result of all of these comparisons, to select one program as being the best. Different programs are good for different situations. In addition, the comparisons relate only to a limited number of combinations of parameters. The parameters have been varied according to the conventional method so that it has not been possible to combine parameters of ordinary situations with those of extreme situations. This can only be done using statistical methods as it is not feasible to perform all of the possible computational combinations, which can number a great many thousands.

When the comparisons are noted against the measured values, it appears for example as though one program is needed to calculate the energy requirement for heating and another is needed for cooling. The 4 programs TASE, TRNSYS, SERI-RES and ESP took part in all four comparisons. 11 different programs took part in two or three comparisons. Table 8.1 shows the attempt made to compare the outcomes of the programs in relation to each other or compared to measured values. For validation, the programs' results have been compared to measured values. It is evident from the table that it is difficult to get a clear-cut impression of most of the programs. However, ESP distinguishes itself by giving values that are mostly greatly below or above the other programs and measured values, whilst SERI-RES gives values above those of the other programs.

The ventilation model in a thermal program is still very basic in design. The more complex multi-cellular models which have been developed during the last 10 years have not yet been linked to the thermal models. Development work has started and in a couple of years, more complex programs will have been developed in Sweden at KTH (Royal Institute of Technology) Department of Building Services Engineering, in the USA at LBL, Berkeley and in Great Britain at Strathclyde University, Glasgow.

Table 8.1 Estimation of outcomes of different comparisons

Program	Actual measure-ment		Offices		Light-weight buildings		Single family dwellings	
	H	C	H	C	H	C	H	C
DOE2	--	0					++	-
TAS	0	-			++	--		
ENERGY	-	-			++	0		
DEROB	--	+					--	0
S3PAS	0	-	++	0			0	0
BLAST	-	0	0	+	-	++	-	--
TASE	0	0	0	0			++	++
TRNSYS	-	-	0	-	0	0	0	0
SUNCODE	0	-					0	++
SERI-RES	0	-	++	++	+	++	++	++
ESP	--	0	--	0	-	-	--	--

-- below; - slightly below; 0 mean/median; + slightly above; ++ above; H heating; C cooling

Appendix 1 Contributors

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Appendix 2 Publications

1. Lomas K J, Eppel H, Martin C and Bloomfield D, *Empirical validation of thermal building simulation programs using test room data, Volume 1: Final Report*, September 1994.
2. Lomas K J, Eppel H, Martin C and Bloomfield D, *Empirical validation of thermal building simulation programs using test room data, Volume 1: Final Report, Volume 2: Empirical Validation Package*, September 1994. (Diskettes)
3. Lomas K J (Editor), *Empirical validation of thermal building simulation programs using test room data, Volume 3: Working Reports*, September 1994.
4. *Calculation of energy and environmental performance of buildings, Subtask B, Appropriate use of Programs, Volume 1*, May 1994.
5. Calculation of energy and environmental performance of buildings, *Subtask B, Appropriate use of Programs, Volume 2*, May 1994.
6. Hertkorn C (Editor), *Calculation of energy and environmental performance of buildings, Subtask D, Building design support environments*, Universität Karlsruhe, Institut für Industrielle Bauproduktion, D-761 28 Karlsruhe, Germany, November 1994.
7. Judkoff R and Neymark J, *Building Energy Simulation Test (BESTEST) and Diagnostic Method*, NREL, NREL/TP - 472 - 6231 UC Category: 350 DE 94000280, February 1994.
8. Haapala T, Kalema T and Kataya S, *Energy analysis tests for commercial buildings (commercial benchmarks)*, Tampere University.

All of the above reports can also be obtained from the Air Infiltration and Ventilation Centre (AIVC), University of Warwick Science Park, Sovereign Court, Sir William Lyons Road, Coventry CV4 7EZ, United Kingdom.
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34 Computer Aided Fault Detection and Diagnosis

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35 Control Strategies for Hybrid Ventilation in New and Retro-fitted Office Building - HybVent

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The International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems Programme (ECBCS)

The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) in 1974, with the purpose of strengthening co-operation in the vital area of energy policy. As one element of this programme, member countries take part in various energy research, development and demonstration activities. The Energy Conservation in Buildings and Community Systems Programme has sponsored various research annexes associated with energy prediction, monitoring and energy efficiency measures in both new and existing buildings. The results have provided much valuable information about the state of the art of building analysis and have led to further IEA sponsored research.