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and

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Report 101

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Energy Analysis Tests for Commercial Buildings (Commercial Benchmarks)

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ABSTRACT

A simple module was created for verification of energy analysis programs in the calculation of a commercial building. The module consists of two similar office rooms and a corridor between them and is situated in the middle of a large building. Six separate test cases were created using the module. The results presented were calculated using the weather data of Denver (Colorado, USA).

Six energy analysis programs, BLAST, ESP, SERI-RES, S3PAS, TASE and TRNSYS, participated in this study. The output parameters predicted were annual heating and cooling energies, hourly integrated peak heating and cooling loads, extremes of room air temperatures and heat losses for windows, exterior walls and ventilation.

For the annual heating energies and peak heating loads of the whole module ESP gave approximately 20% smaller and S3PAS 20% greater values than the mean value of all programs. For the annual cooling energies BLAST and SERI-RES gave about 10-15% greater and S3PAS and TASE about 10% smaller values than the mean value of all programs. The greatest relative difference in the peak cooling loads of two separate programs was in the east-facing room, for which SERI-RES gave a 60% greater cooling load than TASE. There were obviously some problems in the calculation of shading in TASE and TRNSYS, because the results of shaded cases were clearly different than those of the other programs.

The heat losses through exterior walls calculated by three of the programs varied considerably. It looks as if the results of TASE are erroneous, because for the south-facing room without shading TASE gave a heat loss which is 60% smaller than that of S3PAS. Even if a window is a more complicated detail in a thermal simulation than an exterior wall, the differences between the heat losses of windows are smaller than between those of the exterior walls when calculated by these programs. The heat losses of ventilation calculated by the various programs differed only a few per cent; these small differences are due to differences in interior air temperatures.

For the interior air temperature of a summer day the programs gave quite different values when the cooling was ended. SERI-RES gave an approximately 1 ^{o}C increase in interior air temperature but ESP approximately 4 ^{o}C. The situation was the same when the heating was ended on a winter day. One reason for the great difference in the air temperatures was in the definition of "air temperature", which for SERI-RES includes also the effects of surface temperatures.

With a comparative study of energy analysis programs like this it cannot be concluded which program is the best or whose results are the most correct. When interpreting the results, it should also be remembered that not only the program itself, but also its user affects the results. In the present study there were several users, which may partly explain the variation of the results.

PREFACE

The International Energy Agency

The International Energy Agency (IEA), headquartered in Paris, was formed in November 1974 as an autonomous body within the framework of the Organization for Economic Cooperation and Development to establish cooperation in the area of energy policy. Twenty-one countries are presently members, with the Commission of the European Communities participating under a special arrangement.

Collaboration in the research, development, and demonstration of new energy technologies has been an important part of the agency's programme. The IEA R&D activities are headed by the Committee on Research and Technology (CERT), which is supported by a small secretariat staff. In addition, four Working Parties (in Conservation, Fossil Fuels, Renewable Energy, and Fusion) are charged with monitoring the various collaborative energy agreements, identifying new areas for cooperation, and advising the CERT on policy matters.

The work reported here resulted from a cooperative effort between the IEA Solar Heating and Cooling Programme and the IEA Energy Conservation in Buildings and Community Systems Programme.

Solar Heating and Cooling Programme

Initiated in 1977, the Solar Heating and Cooling Programme was one of the first IEA R&D agreements. Its objective is to conduct joint projects to advance solar technologies for buildings. The twenty members of the programme are

Australia	France	Spain
Austria	Germany	Sweden
Belgium	Italy	Switzerland
Canada	Japan	Turkey
Denmark	The Netherlands	United Kingdom
European Community	New Zealand	United States
Finland	Norway	

A total of 18 projects or "tasks" have been undertaken since the beginning of the programme. The overall programme is managed by an Executive Committee composed of one representative from each of the member countries, while the leadership and management of the individual tasks is the responsibility of operating agents. These tasks and their respective operating agents are

* Task 1:	Investigation of the Performance of Solar Heating and Cooling Systems - Denmark
* Task 2:	Coordination of Research and Development on Solar Heating and Cooling - Japan
* Task 3:	Performance Testing of Solar Collectors - United Kingdom
* Task 4:	Development of an Insulation Handbook and Instrument Package - United States
* Task 5:	Use of Existing Meteorological Information for Solar Energy Application - Sweden
* Task 6:	Solar Heating, Cooling, and Hot Water System Using Evacuated Collectors - United States
* Task 7:	Central Solar Heating Plants with Seasonal Storage - Sweden
* Task 8:	Passive and Hybrid Solar Low Energy Buildings - United States
* Task 9:	Solar Radiation and Pyranometry Studies - Germany
* Task 10:	Material Research and Testing - Japan
* Task 11:	Passive and Hybrid Solar Commercial Buildings - Switzerland
Task 12:	Building Energy Analysis and Design Tools for Solar Applications - United States

Task 13: Advanced Solar Low Energy Buildings - Norway
Task 14: Advanced Active Solar Systems - Canada
Task 15: Advanced Central Solar Heating Plants
Task 16: Photovoltaics in Buildings - Germany
Task 17: Measuring and Modeling Spectral Radiation - Germany
Task 18: Advanced Glazing Materials - United Kingdom
Task 19: Solar Air Systems - Sweden
Task 20: Solar Retrofit Systems - Sweden

* Completed task # Task in planning stage

Energy Conservation in Buildings and Community Systems Programme

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 the comparison of existing computer programs, building monitoring, the comparison of calculation methods, and studies of occupancy and air quality. Seventeen countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering colaborative research in this area. The designation by governments of a number of private organizations, as well as universities and government laboratories, as contracting parties has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation were restricted to governments. The importance of associating industry with government-sponsored energy research and development is recognized in the IEA, and every effort is made to encourage this trend.

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

Annex 1: Load energy determination of buildings*
Annex 2: Ekistics and advanced community energy systems*
Annex 3: Energy conservation in residential buildings*
Annex 4: Glasgow commercial building monitoring*
Annex 5: Air infiltration and ventilation center
Annex 6: Energy systems and design of communities*
Annex 7: Local government energy planning*
Annex 8: Inhabitants' behavior with regard to ventilation*
Annex 9: Minimum ventilation rates*
Annex 10: Building heating, ventilating, and air conditioning (HVAC) system simulation*
Annex 11: Energy auditing*
Annex 12: Windows and fenestration*
Annex 13: Energy management in hospitals*
Annex 14: Condensation and energy*
Annex 15: Energy efficiency of schools*
Annex 16: BEMS 1 - User interfaces and system integration
Annex 17: BEMS 2 - Evaluation and emulation techniques
Annex 18: Demand controlled ventilating systems
Annex 19: Low slope roofs systems
Annex 20: Air flow patterns within buildings
Annex 21: Calculation of energy and environmental performance of buildings

Annex 22: Energy efficient communities
Annex 23: Multizone air flow modelling
Annex 24: Heat, air, and moisture transport in new and retrofitted insulated envelope parts
Annex 25: Real time simulation of HVAC systems and fault detection
Annex 26: Energy-efficient ventilation of large enclosures
Annex 27: Evaluation and demonstration of domestic ventilation systems
Annex 28: Low-energy cooling systems

* Completed task

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

The scope of task 12 includes: (1) selecting and developing appropriate algorithms for modelling the interaction of solar energy-related materials, components, and systems with the building in which these solar elements are integrated; (2) selecting analysis and design tools, and evaluating the algorithms as to their ability to model the dynamic performance of the solar elements in respect to accuracy and ease of use; and (3) improving the usability of the analysis and design tools, by preparing common formats and procedures and by standardizing specifications for input/output, default values, and other user-related factors.

The subtasks of this project are

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

The participants in this task are: Denmark, Finland, Germany, Norway, Spain, Sweden, Switzerland, and the United States. However, for Subtask B, the following countries participate as a collaborative research activity of Annex 21 of the IEA Energy Conservation in Building and Community Systems Programme: Belgium, France, Italy, and the United Kingdom.

Architectural Energy Corporation serves on behalf of the U.S. Department of Energy as Operating Agent of Task 12.

Annex 21: Calculation of Energy and Environmental Performance of Buildings

The objectives of Annex 21 are to

1. Develop quality assurance procedures for calculating the energy and environmental performance of buildings by producing guidance on

   - Program and modeling assumptions
   - The appropriate use of calculation methods for a range of design applications
   - The evaluation of calculation methods

2. Establish requirements and market needs for calculation procedures in building and environmental services design

3. Propose policy and strategic direction for the development of calculation procedures

4. Propose means to effect the technology transfer of calculation procedures into the building and environmental services design profession.

The subtasks of this project are

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

The participants in this annex are Belgium, France, Germany, Italy, the Netherlands, Switzerland, and the United Kingdom. Canada, Finland and Sweden also participated in the early part of the annex. For Subtask C, the following countries participate an the collaborative research activity of Task 12 of the IEA Solar Heating and Cooling Programme: Finland, Spain, Sweden, and the United States.

This report documents work on intermodel comparisons carried out by the Model Evaluation and Improvement Group from Solar Task 12 and Annex 21. Other work on model evaluation performed by this group is published in separate documents.

ACKNOWLEDGEMENTS

This report forms a part of collaboration between Solar Task 12, Subtask B, and Buildings and Community Systems Annex 21, Subtask C, of the International Energy Agency. Those participating from **Solar Task 12** were

- Timo Kalema, Tapio Haapala and Simo Kataja from Tampere University of Technology, **Finland**,
- Servando Alvarez and Eduardo Rodriguez from Escuela Superior de Ingenieros Industriales, Seville, **Spain**

and from **Buildings and Community Systems Annex 21**

- Rik van de Perre and Peter Verstraete from Vrije Universiteit Brussel, **Belgium**,
- Augusto Mazza and Vittorio Bocchio from Politecnico di Torino, **Italy**,
- Dave Bloomfield, Shirley Hammond and Foroutan Parand from the Building Research Establishment, Watford, **United Kingdom** and
- Kevin Lomas, Herbert Eppel and John Patronis from De Montfort University, Leicester, **United Kingdom**.

The leader of this project was Associate Professor Timo Kalema from Tampere University of Technology, **Finland**.

The simulations were performed by Vittorio Bocchio (BLAST), Herbert Eppel and John Patronis (ESP), Shirley Hammond (SERI-RES), Eduardo Rodriguez (S3PAS), Tapio Haapala and Simo Kataja (TASE) and Foroutan Parand and Peter Verstraete (TRNSYS).

The TRNSYS results presented here are only for TRNSYS (UK), because Vrije Universiteit Brussel and the Building Research Establishment had the same version 13.1 of the TRNSYS and they co-operated to obtain a common set of results for TRNSYS.

We wish to express our gratitude to Mr. Pekka Tenkilä, M.Sc., for his carefully correction of english.

CONTENTS

APPENDICES

1. INTRODUCTION

In the BESTEST benchmark study /1/, which was created as part of the collaboration between Task 12 and Annex 21, test modules for small houses has been created. For commercial buildings a different module is needed, since they have a smaller area of external surfaces, greater heat gains and ventilation rates than small houses. In addition, office buildings have mechanical cooling and temperature setback, which are normally not present in small houses.

This report contains an exact description of the test module for the commercial buildings used to evaluate energy analysis programs for buildings. Six separate test cases were created using this module and several results were calculated using the energy analysis programs BLAST, ESP, SERI-RES, S3PAS, TASE and TRNSYS.

This report also includes four appendices contributed by the users of ESP, SERI-RES, TASE and TRNSYS, describing the individual modelling strategies of the test cases on the calculations performed with comments.

It should be noted that each program in this study used the most detailed level in the calculations. For example, if a program can calculate heat transfer coefficients of walls internally, these were used instead of the constant values suggested in the specification.

2. DESCRIPTION OF THE TEST CASES

2.1 The dimensions of the module

The module consists of two similar office rooms and a corridor between them, Figure 1. The module is situated in the middle of a commercial building, so that it is surrounded by identical modules on the left, right, above and below, Figure 2.

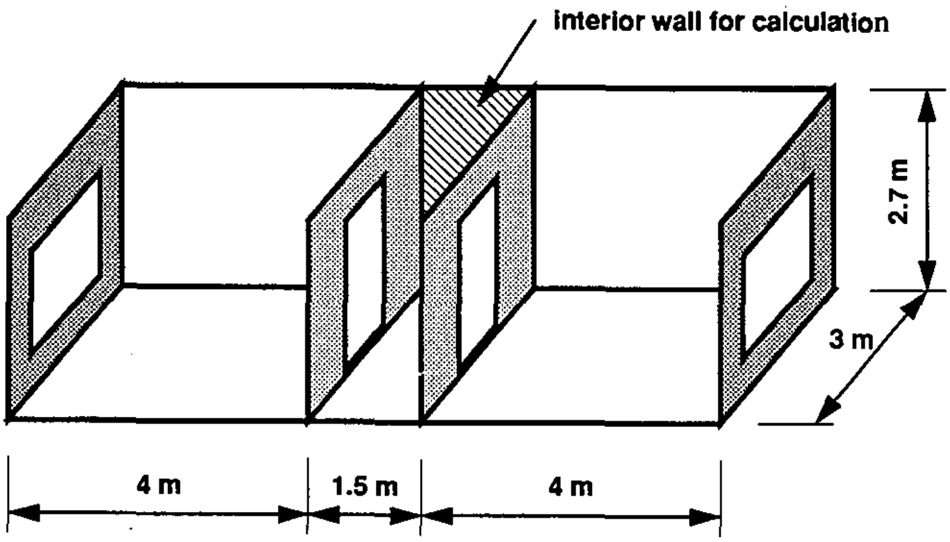


Figure 1. The module of the commercial building.

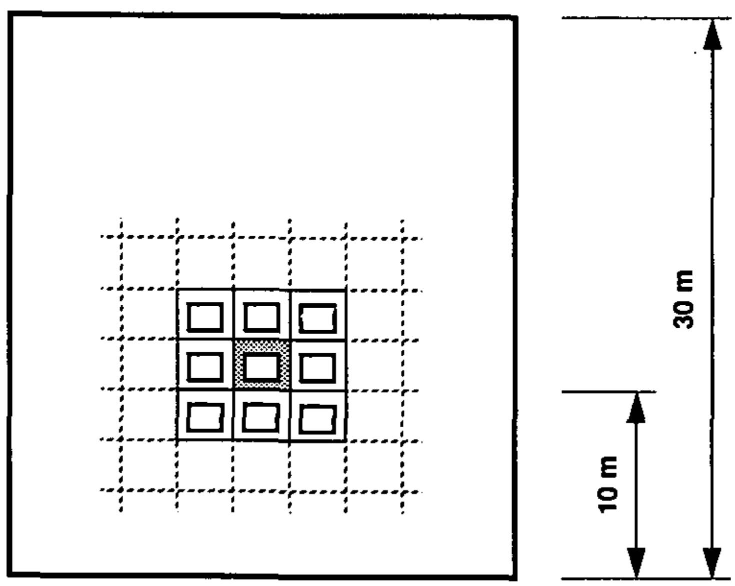


Figure 2. Placing of the module in the commercial building.

The corridor and the rooms are separated by an internal wall with a door, Figure 3. There is a window in the external wall of both the rooms, Figure 4. In a real building, the corridor is a uniform space throughout the whole floor of the building, but in the module it is cut out to simplify the calculations. The cut-out area is treated as internal walls, shadowed areas in Figure 1.

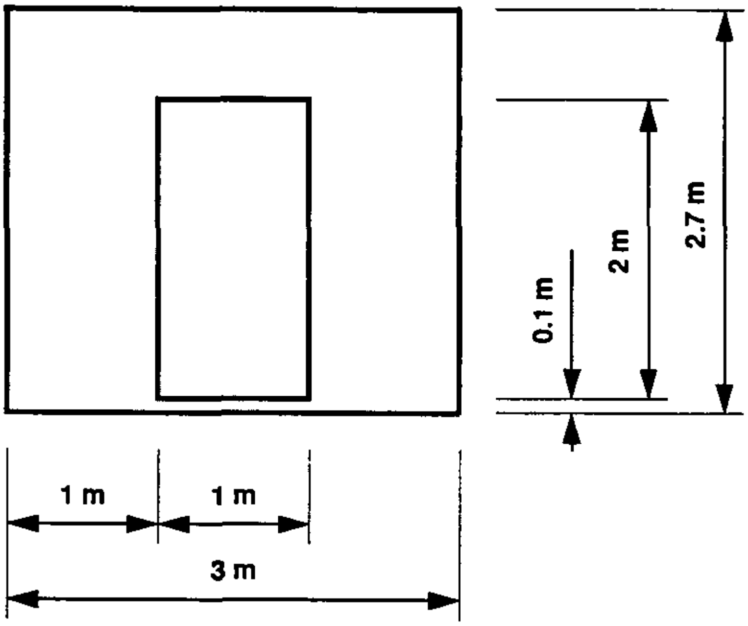


Figure 3. Dimensions of internal wall with door.

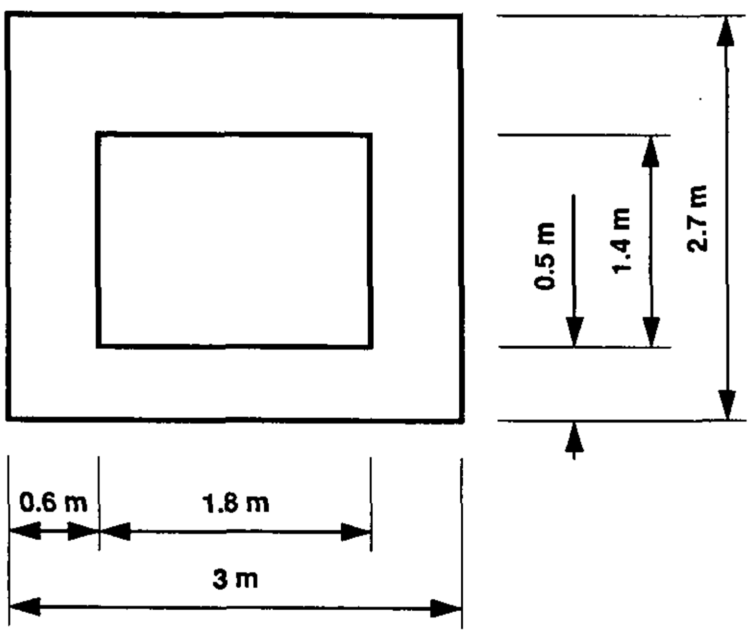


Figure 4. Dimensions of external wall with window.

2.2 Site, environment and weather data

Three test cases were created using the module. In case 1 the external walls with windows are south and north facing. The south-facing room is called room 1 and the north-facing one room 2. Case 2 was generated by turning case 1 90^{0} in a clockwise direction. In cases 1 and 2 the corridor between the rooms is heated. Case 3 has the same orientation as case 1 but the corridor is unheated. The orientation of the test cases is shown in Figure 5.

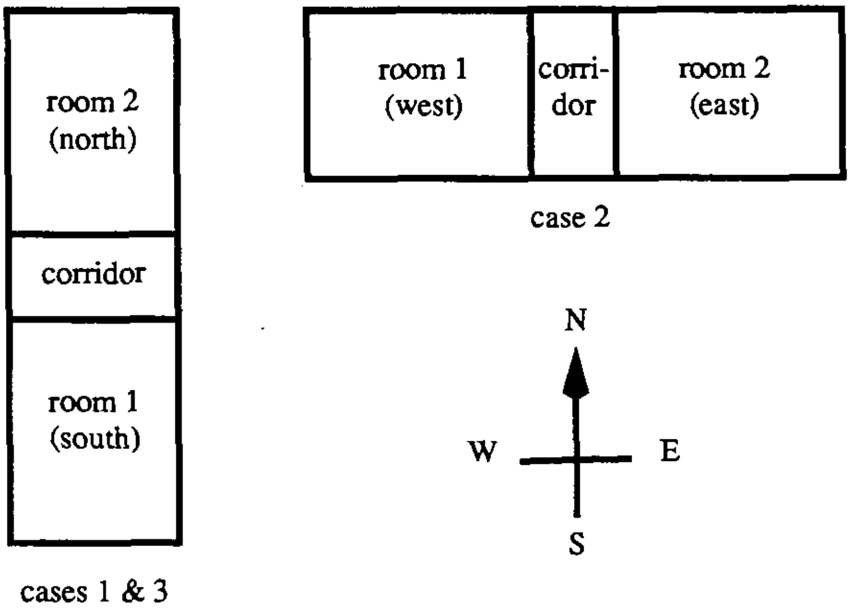


Figure 5. Orientation of the cases.

There are two kinds of environments for these three cases. The 'a-case' assumes the module is situated on an unshaded, flat site. The 'b-case' assumes the module is situated between two similar buildings with a length of 40 m, Figure 6. In each case the module is situated in the middle of the building with relation to its length. The difference in height between the centre of the windows and the ground is 11.2 m.

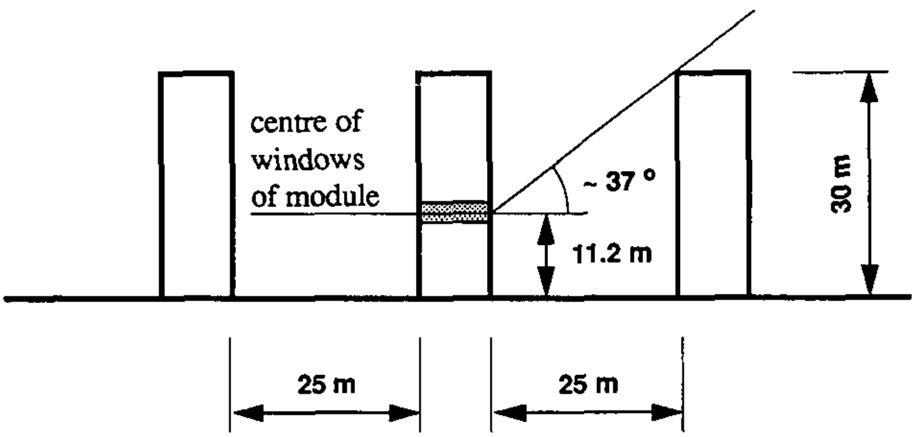


Figure 6. Environment of the commercial building for b-cases.

By combining these two sites (a and b) with the three cases presented previously (1, 2 and 3) we have six separate test cases (1a, 1b, 2a, 2b, 3a and 3b), which will be used in the calculations in this study. A summary of the differences between the cases is presented in Table 1.

Table 1. Summary of the differences between the test cases.

test case	orientation	site	corridor [i)]
1a	north-south	unshaded	heated
1b	north-south	shaded	heated
2a	east-west	unshaded	heated
2b	east-west	shaded	heated
3a	north-south	unshaded	unheated
3b	north-south	shaded	unheated

i. Heating and cooling strategies are presented in Chapter 2.8.

All the test cases are situated at the exact location of the weather station in Denver (Colorado, USA), which has a latitude of 39.8^{o} north of the equator, longitude 104.9^{o} west of Greenwich and altitude 1610 m above sea-level. The reflectivity of the ground is a constant 0.2 throughout the year. The weather data are the same (DRY-COLD.TMY) as those used in the BESTEST benchmark study /1/.

2.3 Wall structures

The thermal properties of the floor, ceiling, walls and door are presented in Table 2. The layers are presented from the outside to the inside. The surface resistances are presented in the form of heat transfer coefficients in Chapter 2.5. All internal walls are symmetric and have a lightweight structure. The thermal properties of the windows in the external wall are presented in Chapter 2.4.

Table 2. Wall structures from outside to inside.

	layer thickness	thermal conduc-tivity	density	specific heat capacity	thermal resistance
	m	W/(Km)	kg/m^3	J/(kgK)	m^2K/W
Floor					
Concrete Slab	0.160	1.130	1400	1000	-
Carpet	0.004	0.300	1600	1380	-
Ceiling					
Carpet	0.004	0.300	1600	1380	-
Concrete Slab	0.160	1.130	1400	1000	-
Heavyweight External Wall					
Brick	0.102	0.950	1920	920	-
Foam Insulation	0.061	0.040	10	1400	-
Concrete Block	0.100	0.510	1400	1000	-
Lightweight Internal Wall					
Plasterboard	0.010	0.160	950	840	-
Cavity	0.050	-	-	-	0.180
Plasterboard	0.010	0.160	950	840	-
Door					
Chipboard	0.012	0.130	600	1380	-
Air Gap	0.020	-	-	-	0.160
Chipboard	0.012	0.130	600	1380	-

2.4 Window structure

The windows are double-glazed and it is assumed that they do not have any frames. Shadings caused by exterior walls are also disregarded. The thermal and optical properties of the windows are presented in Table 3 and the transmittances of beam radiation as a function of the angle of incidence in Table 4. The surface resistances are presented in the form of heat transfer coefficients in Chapter 2.5.

Table 3. Thermal and optical properties of windows.

Number of panes	2
Pane thickness	3.175 mm
Air gap thickness	13 mm
Thermal resistance of panes	0.005 m^2K/W
Thermal resistance of air gap	0.155 m^2K/W
U-value of the whole window (air to air)	3.0 $W/(Km^2)$
Extinction coefficient	0:0196 1/mm
Index of refraction	1.526

Table 4. Beam transmittance.

Angle of incidence	Transmittance
o	-
0	0.747
10	0.746
20	0.745
30	0.740
40	0.730
50	0.707
60	0.652
70	0.517
80	0.263
90	0

2.5 Surface properties

If the program used does not calculate the exterior or interior convective and radiative heat transfer coefficients internally, the values given in Table 5 should be used for heat transfer coefficients. The radiative portion of these combined coefficients may be taken as 5.0 W/(Km^2). Emissivities for all the surfaces are 0.9. Absorptivities for interior surfaces are 0.3 and for exterior surfaces 0.7.

Table 5. Combined constant heat transfer coefficients.

Surface	Heat transfer coefficient
	W/(Km^2)
Exterior	
Walls	29
Windows	21
Interior	
Walls	8.3
Windows	8.3
Floor	6.1
Ceiling	9.3
Door	8.3

2.6 Ventilation

The ventilation is wholly mechanical, and the proportion of exterior air is 100 %, i.e. there is no internal air circulation. Neither is there infiltration to any of the rooms. The two rooms and the corridor always have the same air change rates. There is no air change between the rooms and the corridor. The operating schedules (in solar time) for the ventilation are presented in Table 6. For air density at sealevel use the value 1.201 kg/m^3.

Table 6. The operating schedules for the ventilation.

Time interval	Room 1	Room 2	Corridor
h	1/h	1/h	1/h
0700 ... 1700	3.0	3.0	3.0
1700 ... 0700	0.5	0.5	0.5

If the program used does not use barometric pressure from the weather data or otherwise automatically correct for the change in air density due to altitude, adjust the ventilation rates to yield equivalent mass flow. For density of air at the altitude of 1610 m use the value 0.987 kg/m^3 and multiply the given ventilation rates in Table 6 by 0.987/1.201. Then the rate 3.0 1/h becomes 2.465 1/h and the rate 0.5 1/h becomes 0.411 1/h.

2.7 Internal heat loads

The operating schedules for the internal heat loads are given in Table 7. Of the loads 50% is convection into the room air and 50% long-wave radiation which falls evenly on all interior surfaces. Thus the heat flux density due to this radiation is the same on all surfaces.

Table 7. The operating schedules for the internal heat loads.

Time interval	Room 1	Room 2	Corridor
h	W	W	W
0800 ... 1600	500	500	0
1600 ... 0800	0	0	0

2.8 Heating and cooling

Both the heating and the cooling is performed using supply air with an air sensing thermostat. There is available a maximum power of 1 MW for heating in both rooms and in the corridor and a maximum power of 1 MW for cooling in both rooms, but not in the corridor. In case 3, there is no heating in the corridor. The set point temperatures and their schedules for heating and cooling are presented in Tables 8 and 9. The values 100 °C and -100 °C in the Tables mean that the heating or cooling plants are shut off, because the air temperature never reaches these values. The heat generation efficiency of heating and cooling is assumed to be 100 %.

Table 8. The operating schedules and the set point temperatures for heating and cooling for cases 1 and 2.

Time interval	Rooms 1 and 2		Corridor
	heating	cooling	heating
h	°C	°C	°C
0700 ... 1700	20	25	20
1700 ... 0700	18	100	18

Table 9. The operating schedules and the set point temperatures for heating and cooling for case 3.

Time interval	Rooms 1 and 2		Corridor
	heating	cooling	heating
h	°C	°C	°C
0700 ... 1700	20	25	-100
1700 ... 0700	18	100	-100

3. OUTPUTS

Using the six test cases presented, the participants calculated the following outputs using six energy analysis programs.

1. Annual heating and cooling energies for the whole module and separately for both rooms and the corridor for all the cases. The energies are presented in MWh.

2. Annual hourly integrated peak heating and cooling loads for the whole module and separately for both rooms and the corridor for the a-cases (1a, 2a and 3a). The peak loads are presented in kW.

3. Annual minimum and maximum values of hourly room air temperatures for both rooms and the corridor for cases 3a and 3b. The temperatures are presented in ^{o}C.

4. Annual heat losses for the exterior walls, windows and ventilation of the whole module and the same heat losses separately for both rooms in each case. The heat loss of the window does not include the solar radiation transmitted through the window, but does include the radiation absorbed by the glazing.

5. Hourly room air temperatures for January 4th and July 27th for both rooms and the corridor for cases 3a and 3b (hourly temperature variations during the day).

4. RESULTS

4.1 Presentation

The results of the calculations are presented in Chapters 4.2 - 4.11. Each chapter includes a brief summary, conclusions and a table in which the calculation results of individual programs are compared with the arithmetic mean value of all programs. Only for the daily interior air temperature (Chapter 4.11) has this table not been made.

The figures are numbered so that the subnumber shows the test case. For example, Figure 7.1a contains the results from case 1a.

The module comprised three separate spaces. Therefore every figure in Chapters 4.2 - 4.10 consists of four subfigures which represent the results of each individual space and of the whole module. The order of the subfigures and the shading style of the bars are the same in all the figures. The upper-left subfigure shows the results of room 1, the upper-right those of room 2, the lower-left those of the corridor and the lower-right those of the whole module. In some cases, e.g. the minimum room air temperature with heating (Figure 12), the results are not shown and the corresponding subfigures are missing because the results are obvious (e.g. input values).

4.2 Annual heating energies

The annual heating energies for the whole module were approximately 20% smaller for ESP than the mean value of all programs (Table 10). S3PAS gave values which were 15 - 25% greater than the mean value of all programs. For the annual energy consumption of the whole module the other programs gave values which were quite close (1 - 9%) to the mean value.

For the energy consumption of the corridor all programs calculated a value which was very close to the mean value of all programs (Figure 7.1). The greatest relative difference between the annual energy values of a space calculated by the various programs was in the unshaded south-facing room (Figure 7.1a), in which the maximum ratio was 2.7 (the ratio of annual energy consumptions calculated by S3PAS and ESP). The greatest absolute difference between the annual energy values of a space was in the north-facing room, in which the difference between the values of S3PAS and ESP was 0.38 MWh, approximately 45% of the mean value of all programs.

Table 10. Annual heating energies of the whole module. The mean value of all programs and the relative differences between the results of individual programs and the mean value.

Program	Case					
	1a	1b	2a	2b	3a	3b
	Mean Value $\overline{Q}_h$, MWh					
All	**1.27**	**1.67**	**1.40**	**1.65**	**1.18**	**1.58**
	Relative difference $(Q_{hi}-\overline{Q}_h)/\overline{Q}_h$, %					
BLAST	-1	-4	-2	-5	-3	-6
ESP	-25	-21	-17	-16	-28	-23
SERI-RES	+8	-4	+1	+3	+9	-4
S3PAS	+22	+14	+22	+14	+28	+18
TASE	0	+9	+2	+8	-2	+7
TRNSYS	-4	+6	-5	-4	-4	+7

$\overline{Q}_h$ mean value of annual heating energy
Q_{hi} annual heating energy calculated by an individual program

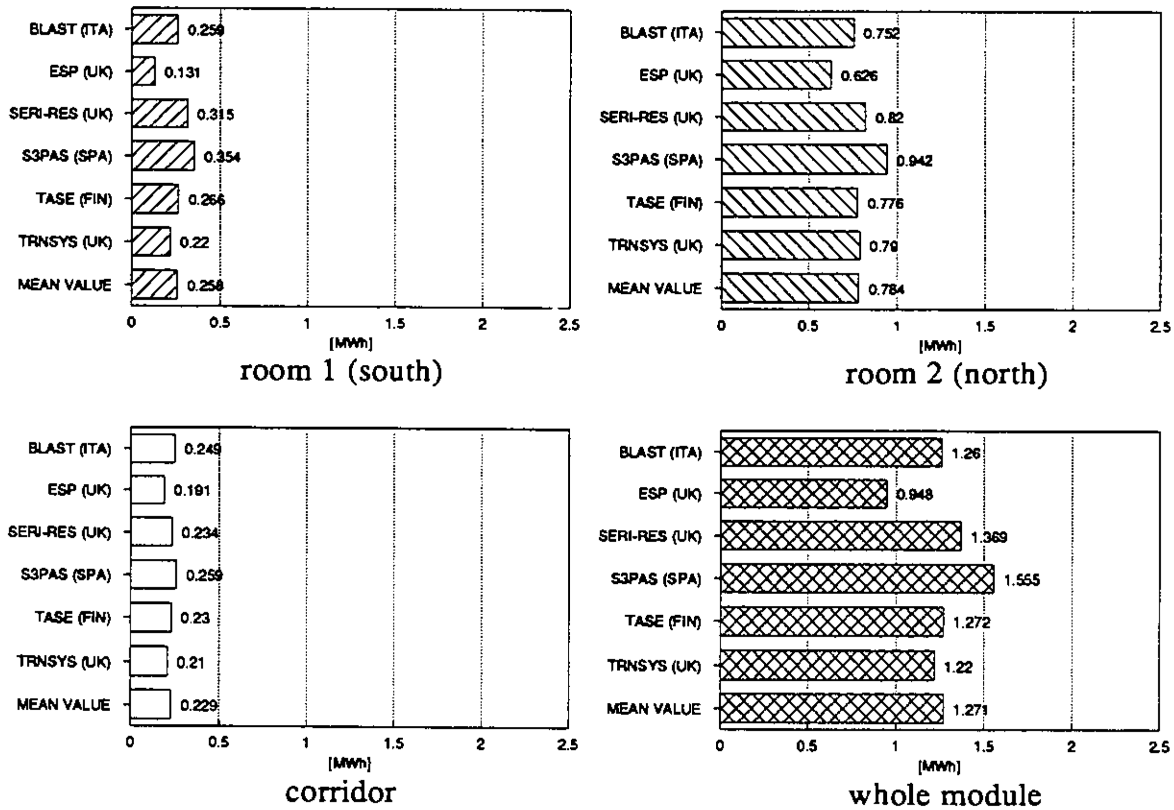


Figure 7.1a Annual heating energies in case 1a.

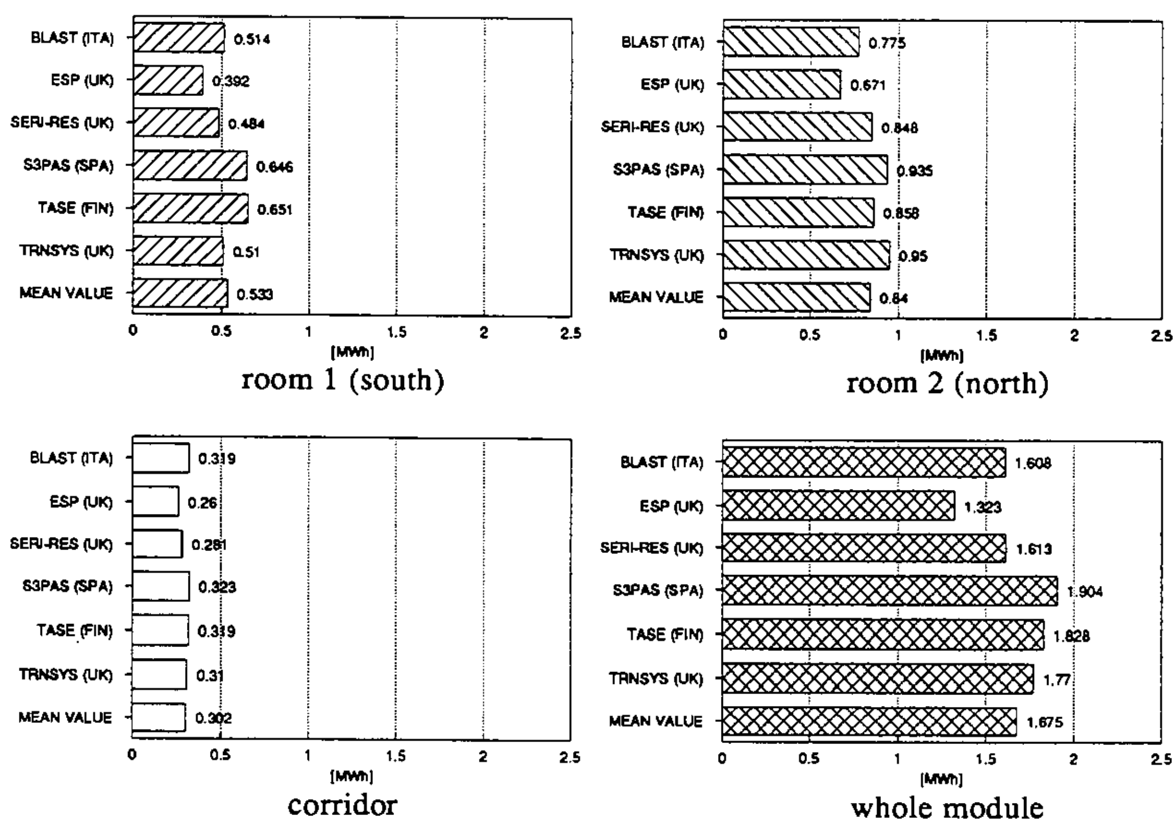


Figure 7.1b Annual heating energies in case 1b.

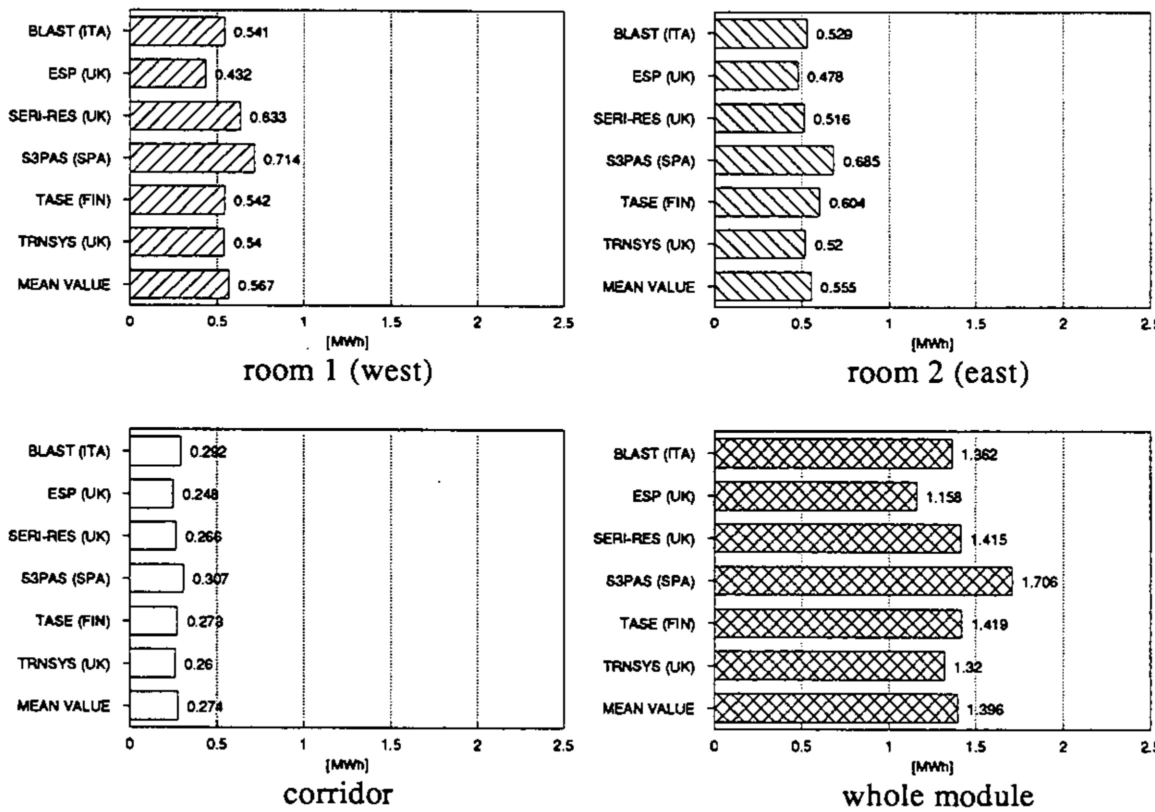


Figure 7.2a Annual heating energies in case 2a.

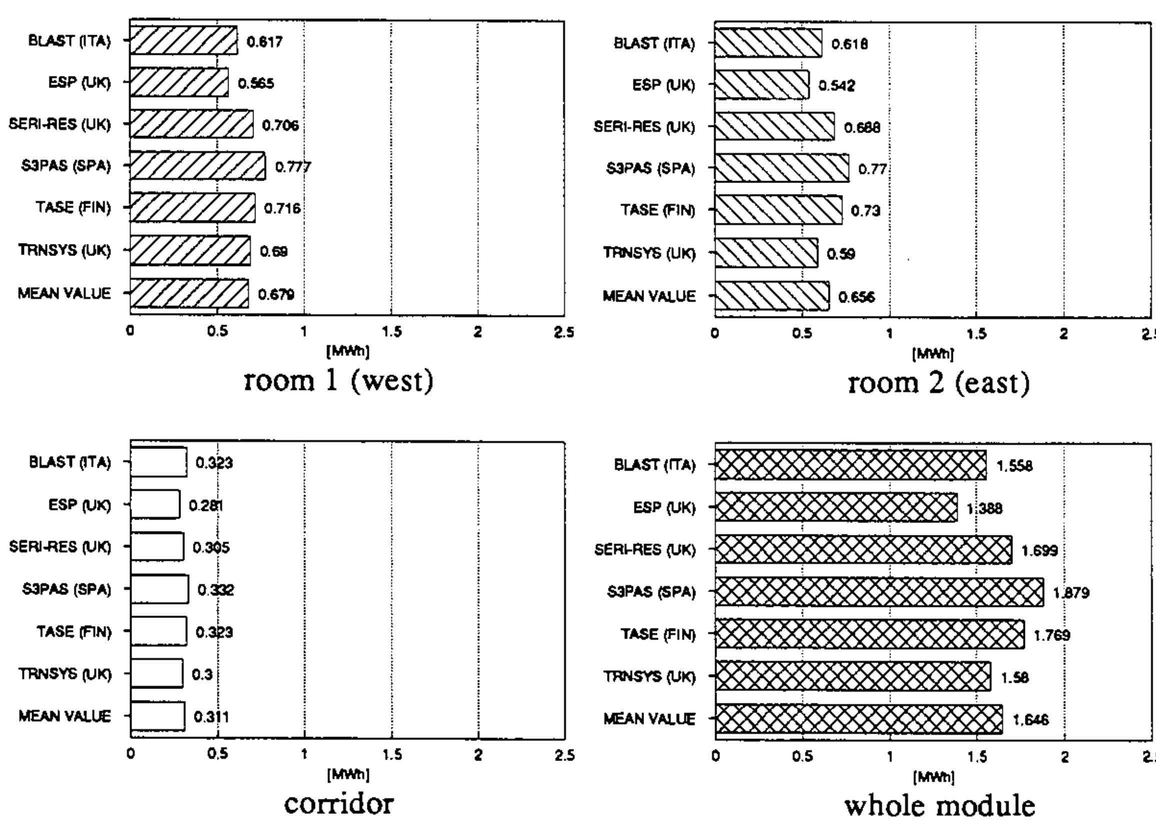


Figure 7.2b Annual heating energies in case 2b.

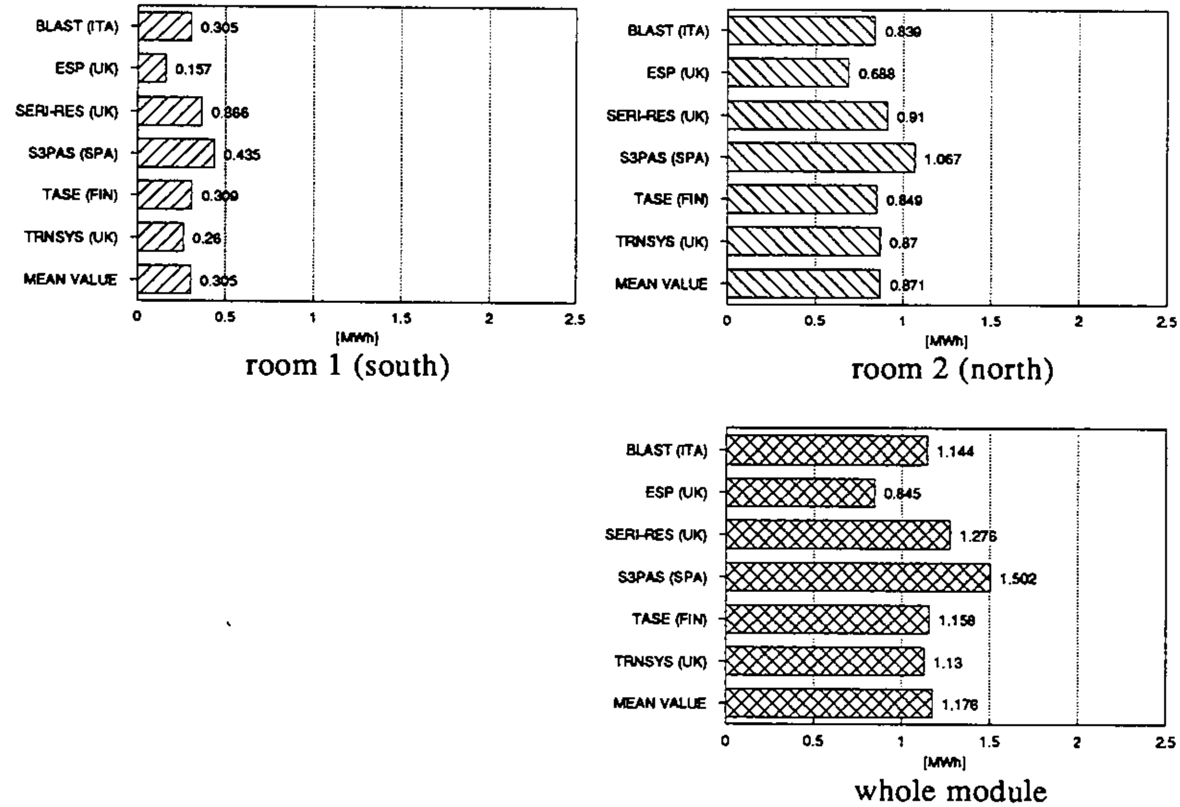


Figure 7.3a Annual heating energies in case 3a.

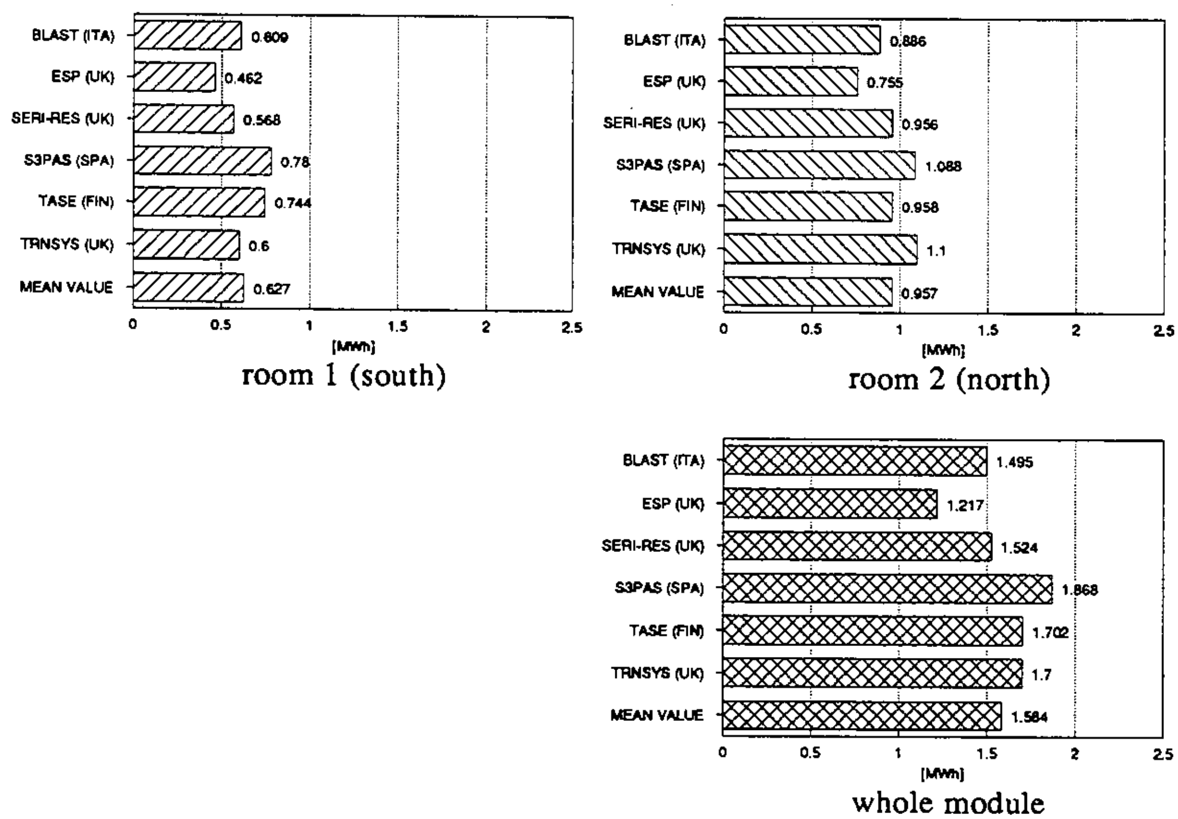


Figure 7.3b Annual heating energies in case 3b.

4.3 Annual cooling energies

BLAST and SERI-RES calculated for all cases of the annual cooling energy of the whole module values which were approximately 10 - 15% greater than the mean value of all programs (Table 11.). On the other hand, S3PAS and TASE gave for the annual cooling energy of the whole module for all cases values which were approximately 5 - 15% smaller than the mean value of all programs. ESP gave for all cases and TRNSYS for the unshaded cases (a-cases) results which were very close to the mean value of all programs.

There are obviously some problems in the calculation of the effects of shading in TRNSYS, because its results for shaded cases (b-cases) differ so great from the mean value.

The greatest differences between the values of annual cooling energy of a space calculated by the various programs are in the south and east-facing rooms. The maximum difference between the results of two programs is approximately 0.4 MWh, which is 35% of the mean value of all programs (Figure 8).

Table 11. Annual cooling energies of the whole module. The mean value of all programs and the relative differences between the results of individual programs and the mean value.

Program	Case					
	1a	1b	2a	2b	3a	3b
	Mean Value $\overline{Q}_c$, MWh					
All	**1.73**	**1.52**	**2.17**	**1.57**	**1.71**	**1.51**
	Relative difference $(Q_{ci}-\overline{Q}_c)/\overline{Q}_c$, %					
BLAST	+13	+17	+9	+15	+13	+17
ESP	-6	+1	-6	-7	-7	+1
SERI-RES	+16	+19	+12	+3	+15	+18
S3PAS	-13	-3	-10	-5	-13	-3
TASE	-8	-10	-7	-17	-8	-10
TRNSYS	-1	-24	+2	+11	0	-24

$\overline{Q}_c$ mean value of annual cooling energy
Q_{ci} annual cooling energy calculated by an individual program

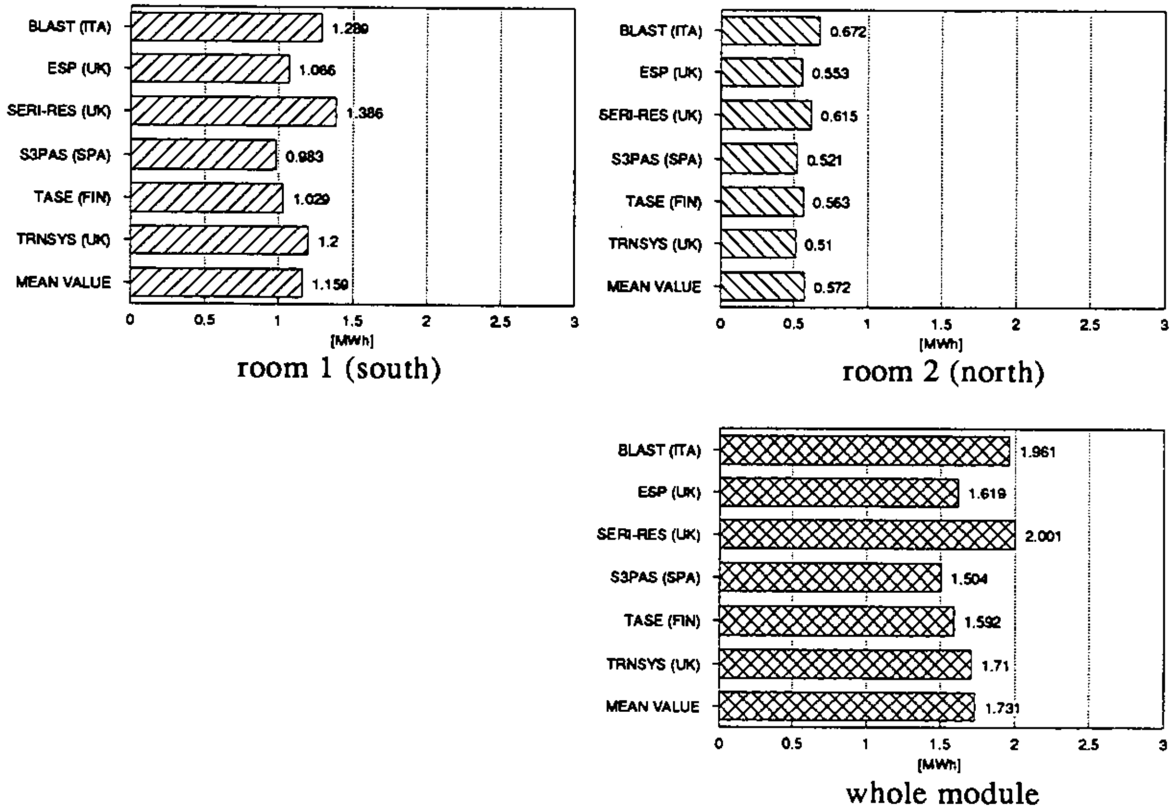


Figure 8.1a Annual cooling energies in case 1a.

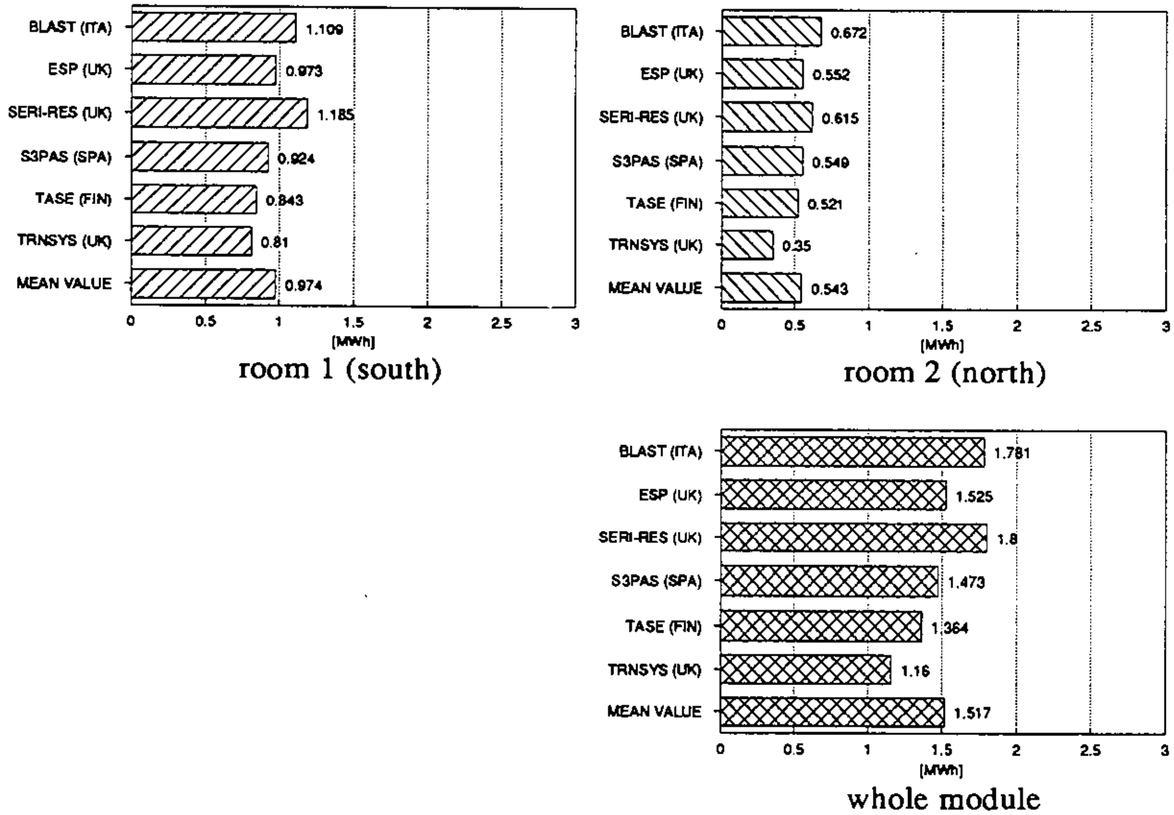


Figure 8.1b Annual cooling energies in case 1b.

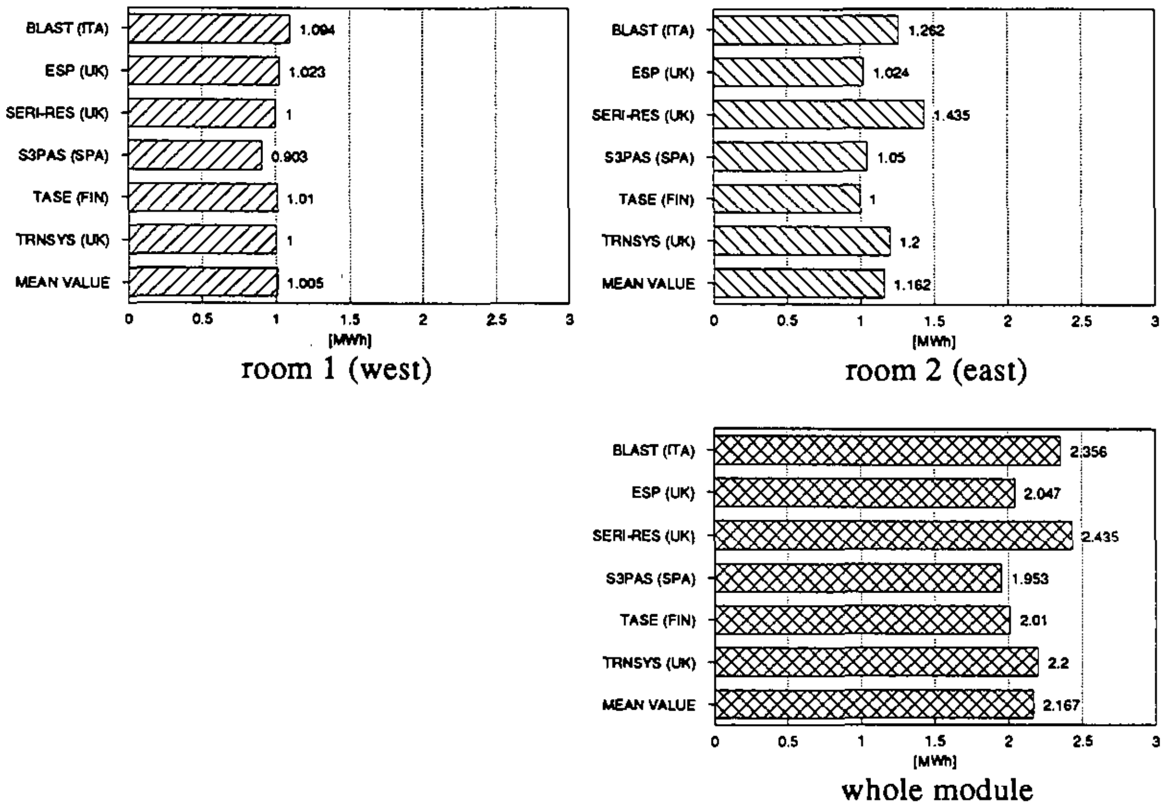


Figure 8.2a Annual cooling energies in case 2a.

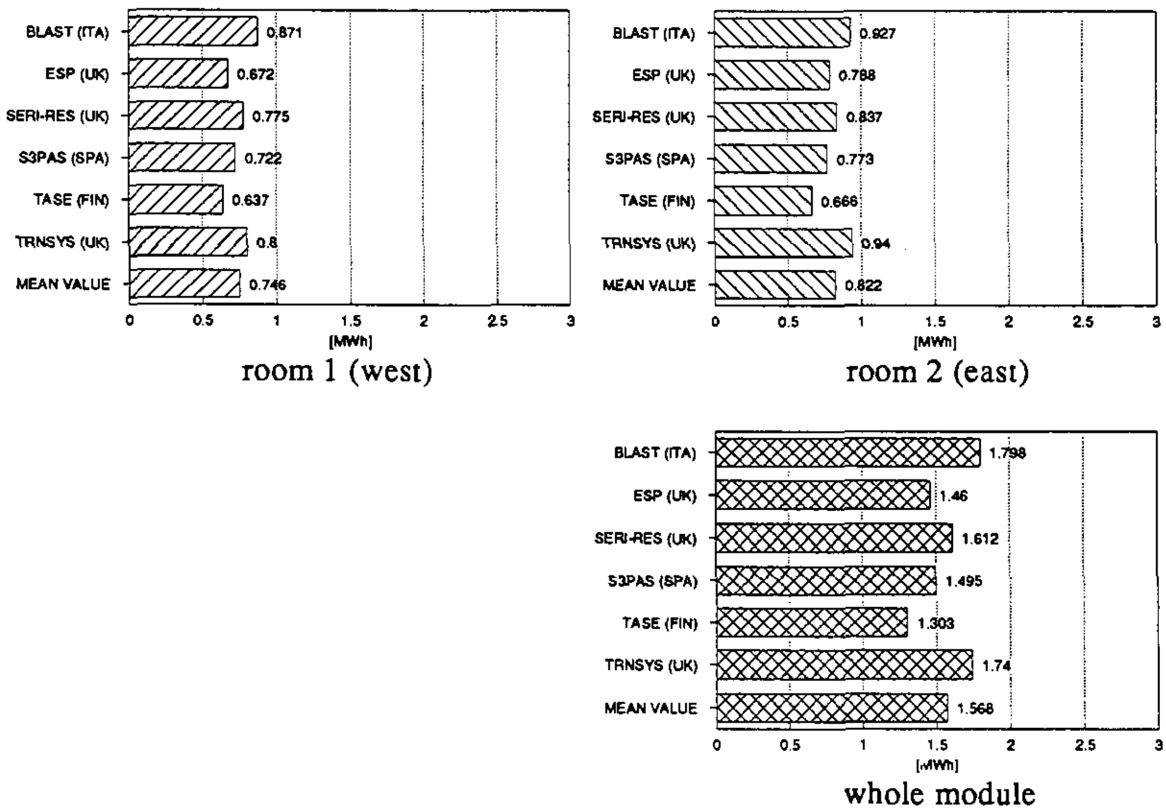


Figure 8.2b Annual cooling energies in case 2b.

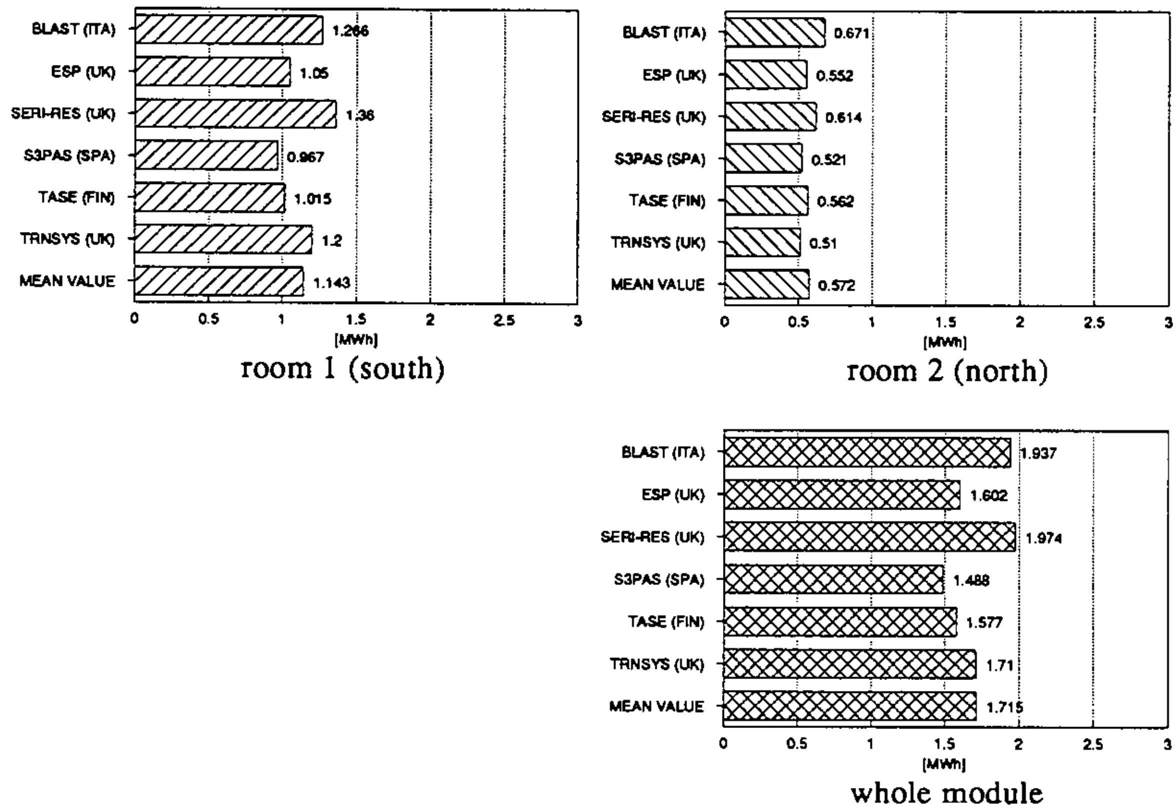


Figure 8.3a Annual cooling energies in case 3a.

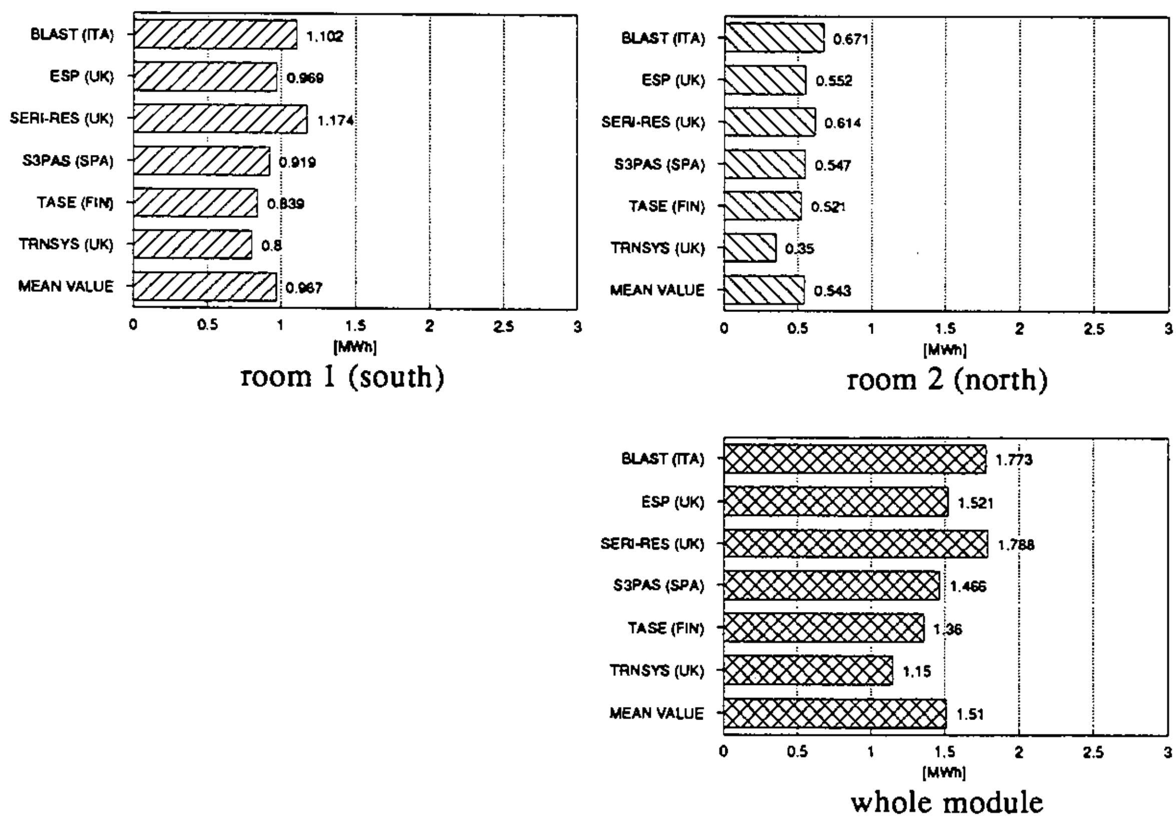


Figure 8.3b Annual cooling energies in case 3b.

4.4 Annual peak heating loads

The peak heating loads were calculated only for the unshaded cases (a-cases), because the shading does not affect these loads. For total load of the whole module ESP calculated values which were 20 - 25% smaller and SERI-RES and S3PAS values which were 10 - 15% greater than the mean value of all programs (Table 12). The other three programs calculated for the total peak load of the whole module values which were quite close (difference 0 - 5%) to the mean value of all programs.

The relative differences between the results of the various programs for the annual peak heating loads of separate spaces were approximately similar in all rooms and slightly smaller in the corridor. The maximum ratio between the calculated peak loads of two programs was approximately 1.65 (Figure 9).

Table 12. Annual peak heating loads of the whole module. The mean value of all programs and the relative differences between the results of individual programs and the mean value.

Program	Case		
	1a	**2a**	**3a**
	Mean Value $\overline{P}_{hu}$, kW		
All	**4.15**	**4.19**	**3.72**
	Relative difference $(P_{hui}-\overline{P}_{hu})/\overline{P}_{hu}$, %		
BLAST	+3	+2	+3
ESP	-24	-20	-26
SERI-RES	+16	+14	+16
S3PAS	+10	+9	+14
TASE	-4	-6	-5
TRNSYS	-1	0	-1

$\overline{P}_{hu}$ mean value of maximum peak heating load
P_{hui} maximum peak heating load calculated by an individual program

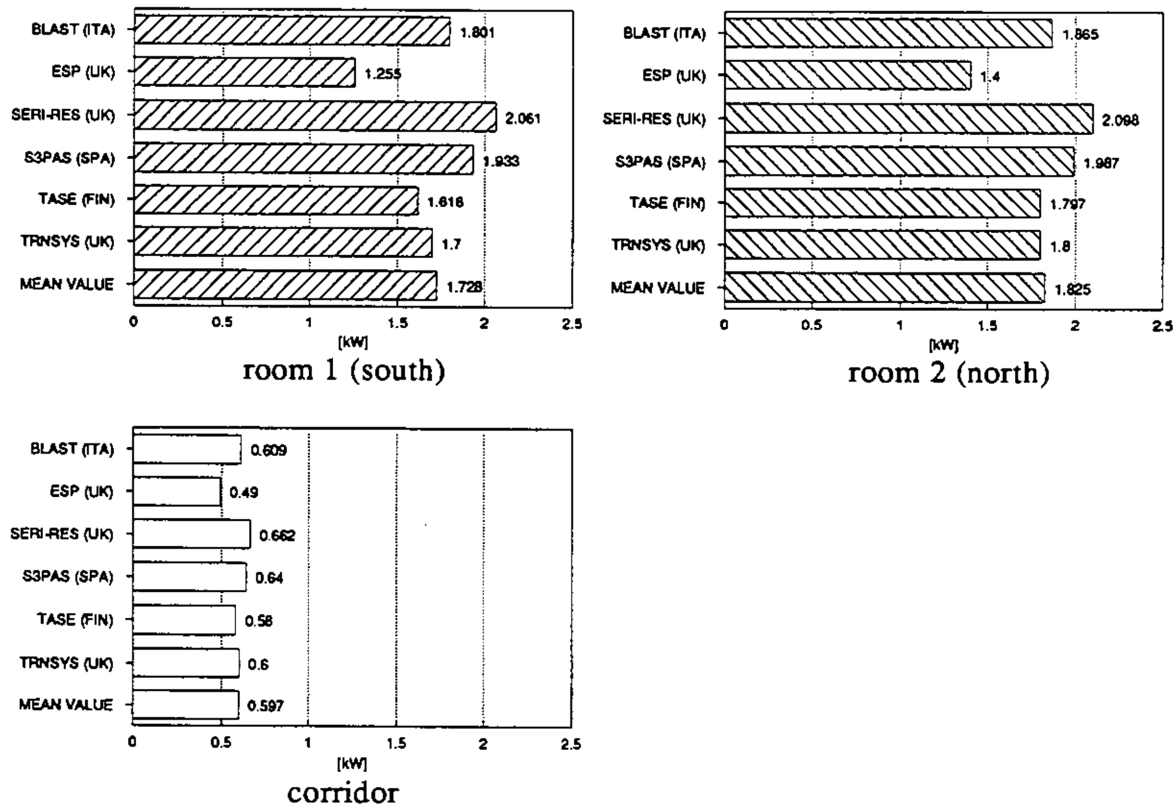


Figure 9.1a Annual peak heating loads in case 1a.

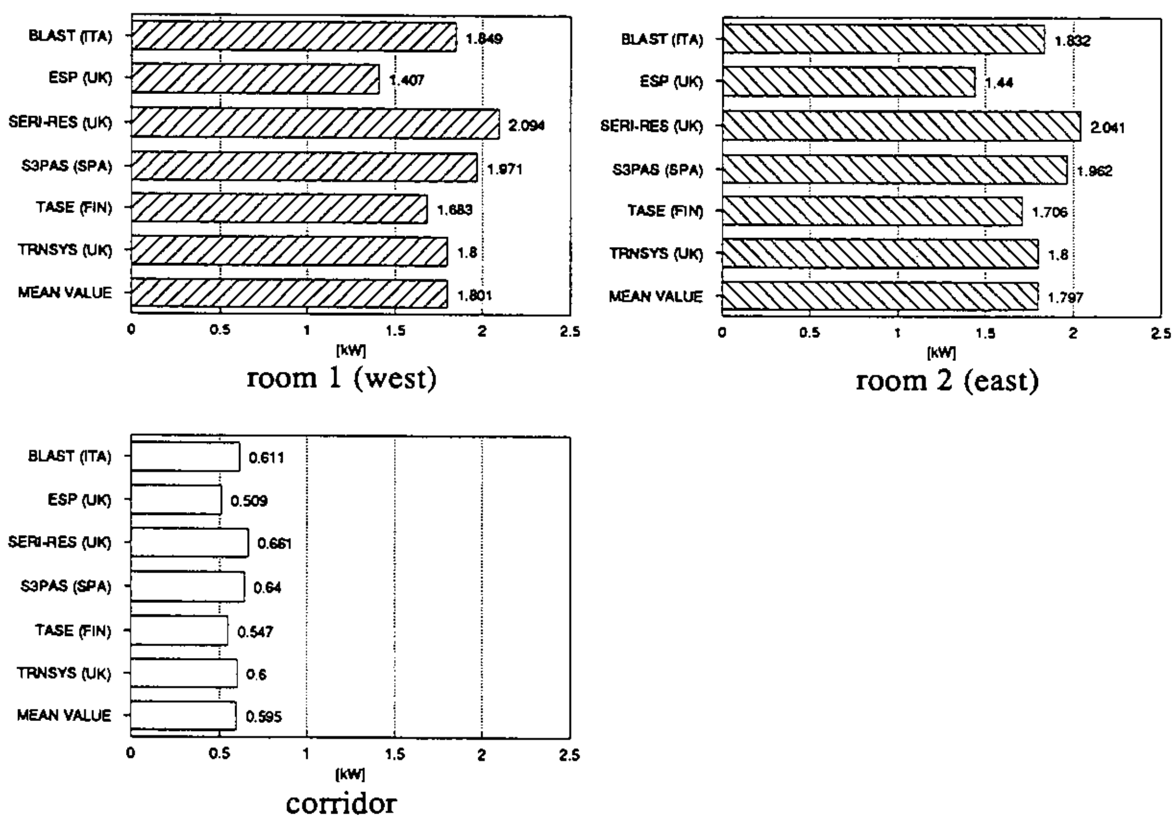
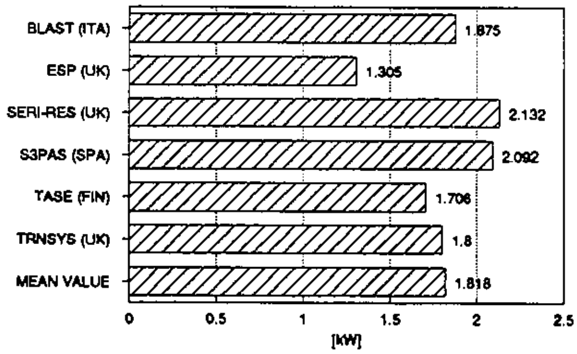
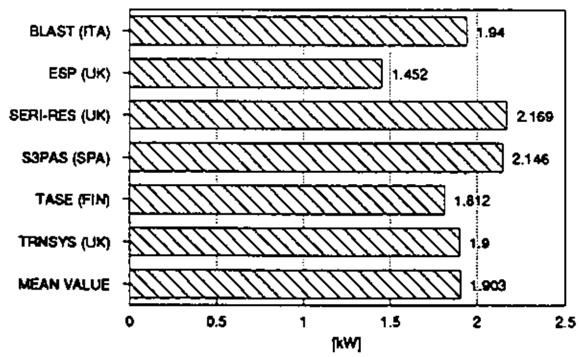


Figure 9.2a Annual peak heating loads in case 2a.



room 1 (south)



room 2 (north)

Figure 9.3a Annual peak heating loads in case 3a.

4.5 Annual peak cooling loads

The peak cooling loads are calculated only for the unshaded cases (a-case) even if the shading affects these loads.

BLAST, S3PAS and TASE calculate for the peak cooling load of the whole module values which differ less than 10% from the mean value of all programs. SERI-RES gives for the peak cooling load of the east-west facing module, and TRNSYS for that of the south-north-facing module, a peak cooling load which differs more than 20% from the mean value of all programs (Table 13).

The greatest relative difference in the peak cooling loads calculated by individual programs is in the east-facing room, in which SERI-RES gives a 60% greater cooling load than TASE (Figure 10).

Table 13. Annual peak cooling loads of the whole module. The mean value of all programs and the relative differences between the results of individual programs and the mean value.

Program	Case		
	1a	2a	3a
	Mean Value $\overline{P}_{cl}$, kW		
All	2.48	3.13	2.48
	Relative difference $(P_{cli}-\overline{P}_{cl})/\overline{P}_{cl}$, %		
BLAST	-2	0	-2
ESP	-13	-8	-13
SERI-RES	+9	+25	+10
S3PAS	-7	-4	-7
TASE	-7	-6	-9
TRNSYS	+21	-7	+21

$\overline{P}_{cl}$ mean value of maximum peak cooling load
P_{cli} maximum peak cooling load calculated by an individual program

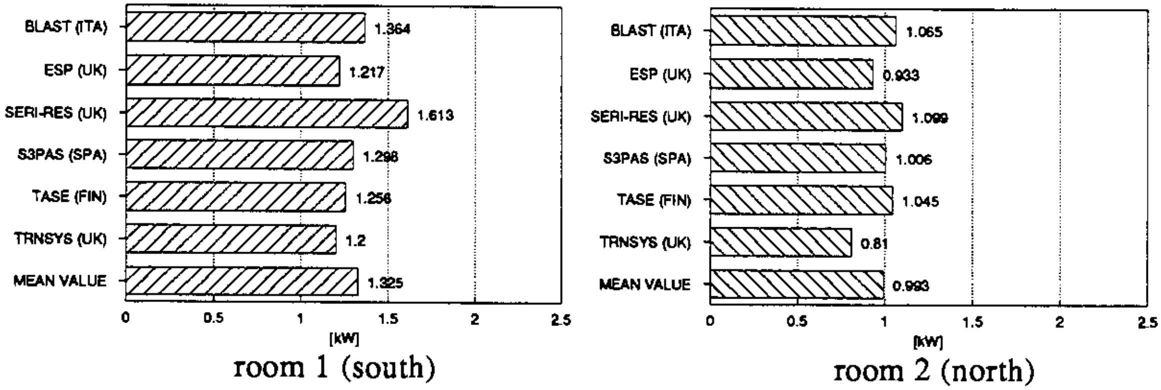


Figure 10.1a Annual peak cooling loads for both rooms in case 1a.

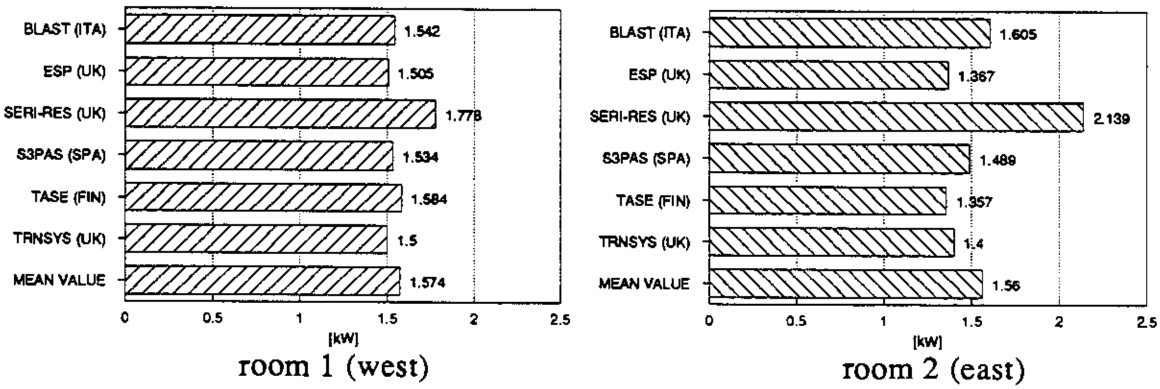


Figure 10.2a Annual peak cooling loads for both rooms in case 2a.

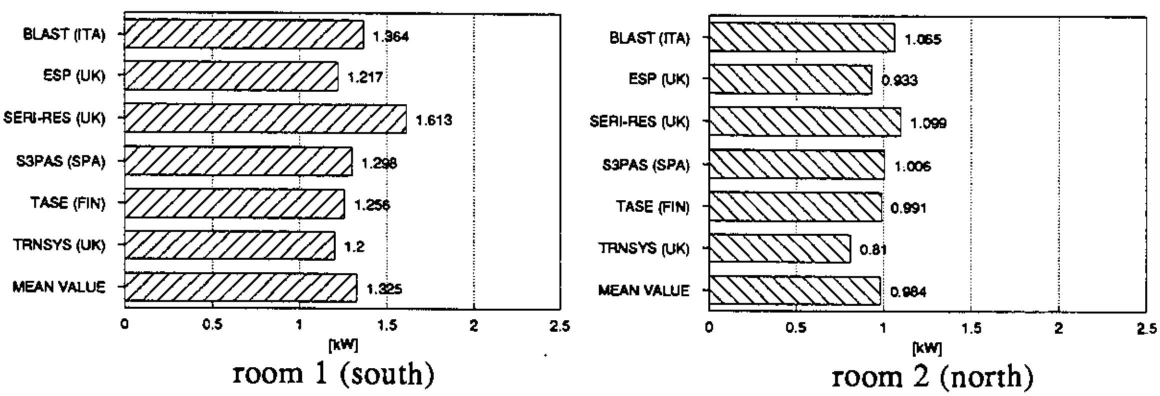


Figure 10.3a Annual peak cooling loads for both rooms in case 3a.

4.6 Maximum annual room air temperatures

The annual maximum room air temperature presented for the whole module (Table 14) is a weighted average of all the spaces (the two rooms and the corridor). The air volumes of the spaces are the weights. The results are calculated only for case 3, in which the corridor was unheated.

The weighted maximum air temperature of the whole module calculated by the various programs differs less than -2.3 ... +2 °C from the mean value of all programs, which was approximately 28.5 °C (Table 14).

The greatest difference between the results of two programs for a single space is between the temperatures of TASE and SERI-RES. TASE gives approximately 4.5 °C greater maximum temperatures for the south-facing room than SERI-RES.

One reason for the difference in the maximum air temperatures calculated by SERI-RES and TASE is in the definition of "air temperature". For TASE the air temperature is simply the average room air temperature, but for SERI-RES it is a weighted temperature in which the effects of surface temperatures are also taken into account. Also for ESP, which gives high maximum temperatures, the air temperature is a simple air temperature. It is natural that the maximum temperature is lower if the values of surface temperatures are included.

Table 14. Inside volume weighted mean value of the maximum annual room air temperature of the whole module. The mean value of all programs and the absolute differences between the results of individual programs and the mean value.

Program	Case	
	3a	3b
	Mean Value $\overline{T}_{au}$, °C	
All	28.6	28.5
	Absolute difference (T_{aui}-$\overline{T}_{au}$), °C	
BLAST	-0.6	-0.5
ESP	+1.4	+1.5
SERI-RES	-2.3	-2.2
S3PAS	-0.5	-0.3
TASE	+2.0	+1.9
TRNSYS	-0.1	-0.5

$\overline{T}_{au}$ mean value of maximum weighted air temperature
T_{aui} maximum weighted air temperature calculated by an individual program

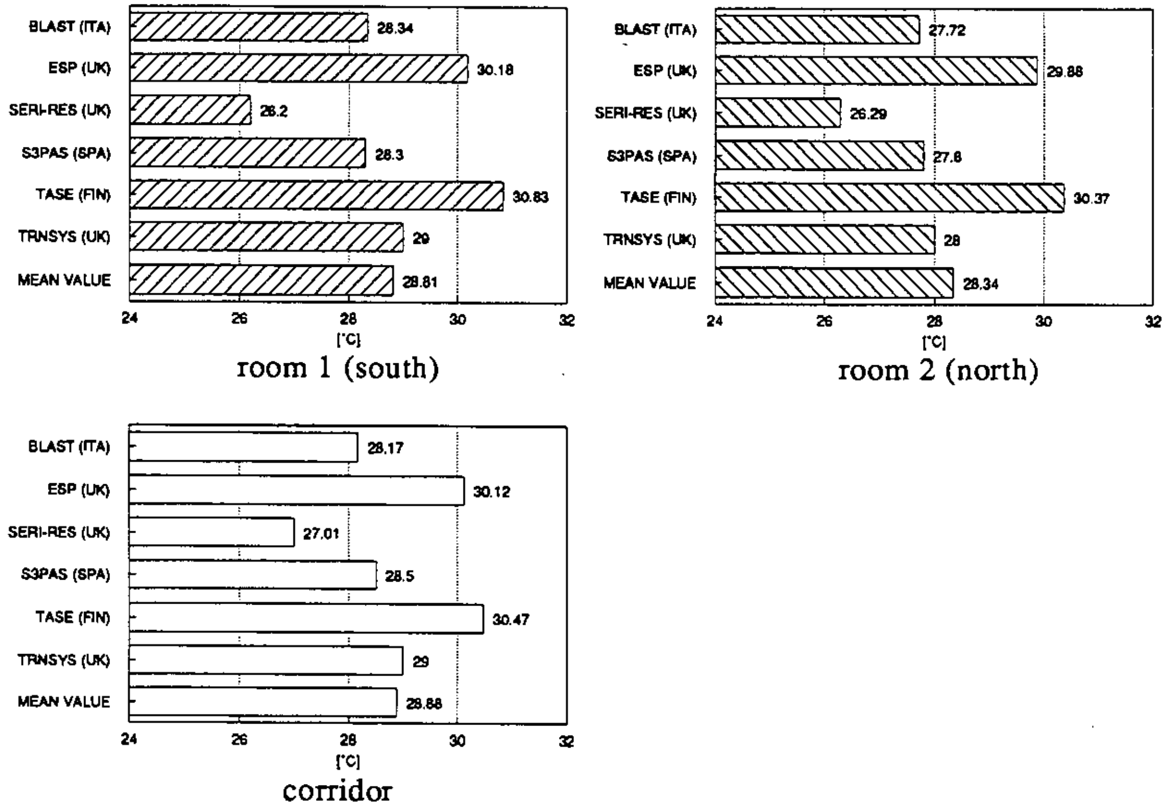


Figure 11.3a **Maximum annual air temperatures for each space in case 3a.**

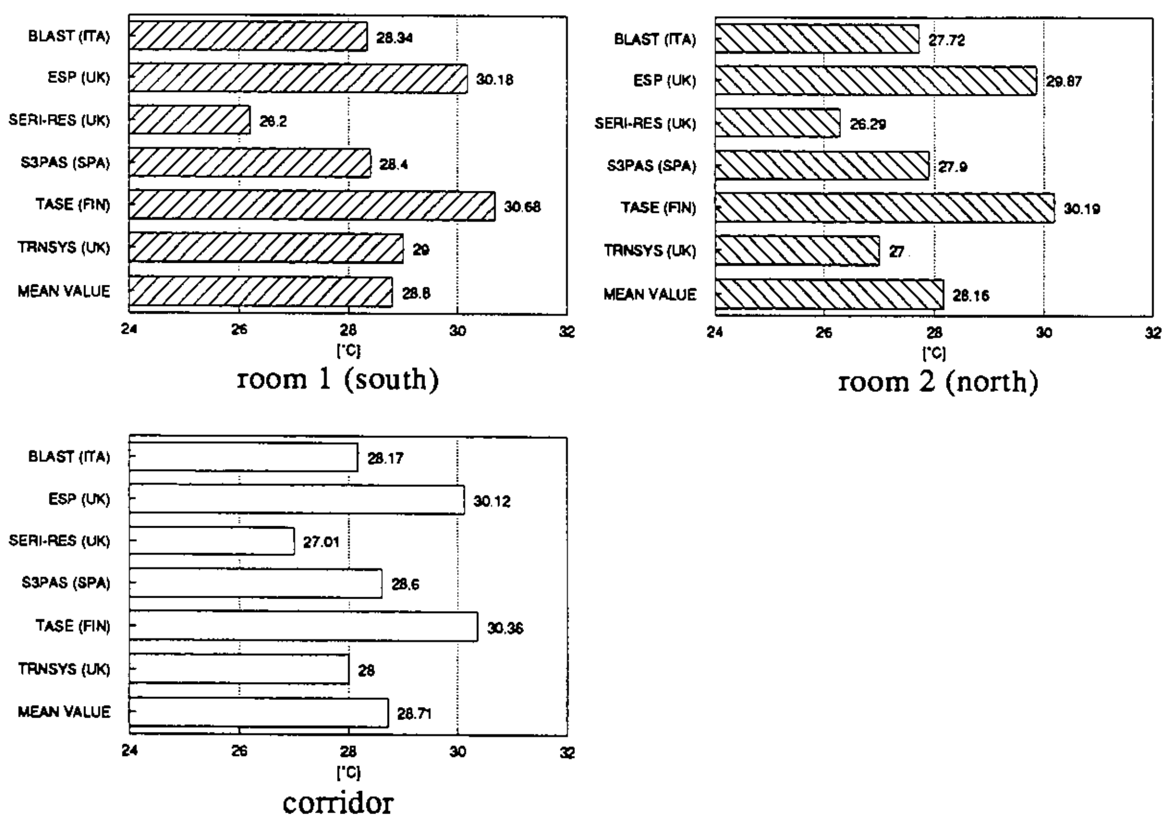


Figure 11.3b **Maximum annual air temperatures for each space in case 3b.**

4.7 Minimum annual room air temperatures

The two rooms of the module were heated in all cases. Thus their minimum air temperature was the set-point temperature. For case 3 the corridor was unheated and therefore the minimum air temperatures presented are those of the corridor for that case.

The minimum temperatures of the corridor calculated by the various programs differ less than -2 ... +2.6 °C from the mean value of all programs. For reasons mentioned in Chapter 4.6, SERI-RES gives the highest air temperatures and TASE the lowest (Table 15, Figure 12).

Table 15. Annual minimum room air temperature of the corridor. The mean value of all programs and the absolute differences between the results of individual programs and the mean value.

Program	Case	
	3a	**3b**
	Mean Value $\overline{T}_{al}$, °C	
All	**9.27**	**8.84**
	Absolute difference (T_{ali}-$\overline{T}_{al}$), °C	
BLAST	-0.5	-0.6
ESP	-0.1	-0.5
SERI-RES	+2.4	+2.6
S3PAS	-0.3	-0.2
TASE	-2.0	-2.0
TRNSYS	+0.5	+0.8

$\overline{T}_{al}$ mean value of minimum weighted air temperature
T_{ali} minimum weighted air temperature calculated by an individual program

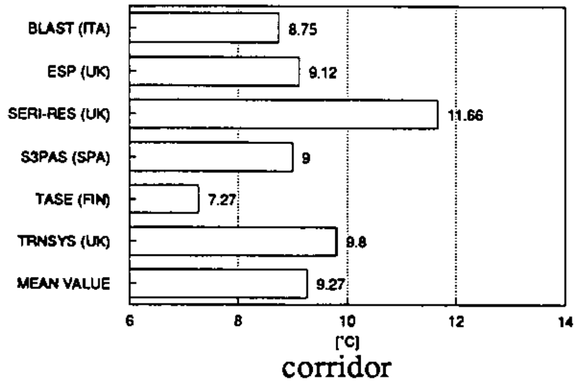


Figure 12.3a Minimum annual air temperature for corridor in case 3a.

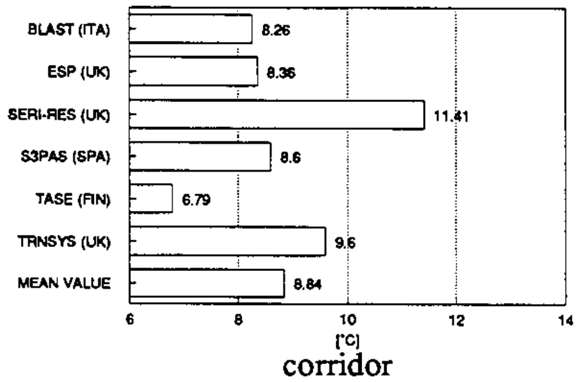


Figure 12.3b Minimum annual air temperature for corridor in case 3b.

4.8 Annual heat losses through exterior walls

The heat losses through exterior walls are calculated only for ESP, S3PAS and TASE (Table 16). All programs give quite accurately the same results for the north-facing room in case 1. In the south-facing room without shading and whit unheated corridor TASE gives a heat loss which is 60% smaller than that of S3PAS (Figure 13). In general the differences between the heat losses through exterior walls calculated by these three programs vary from 3 to 60%.

It would be worth further study to determine why there are such great differences in the heat losses through exterior walls. It looks as if the results of TASE are erroneous.

Table 16. Annual heat losses through exterior walls of the whole module. The mean value of all programs and the relative differences between the results of individual programs and the mean value.

Program	Case					
	1a	1b	2a	2b	3a	3b
	Mean Value $\overline{Q}_w$, kWh					
All	743	697	742	687	803	773
	Relative difference $(Q_{wi}-\overline{Q}_w)/\overline{Q}_w$, %					
BLAST						
ESP	+11	+13	+15	+11	+2	+1
SERI-RES						
S3PAS	+16	+9	+13	+8	+32	+29
TASE	-27	-21	-27	-20	-33	-30
TRNSYS						

$\overline{Q}_w$ mean value of heat loss of exterior walls
Q_{wi} heat loss of exterior walls calculated by a separate program

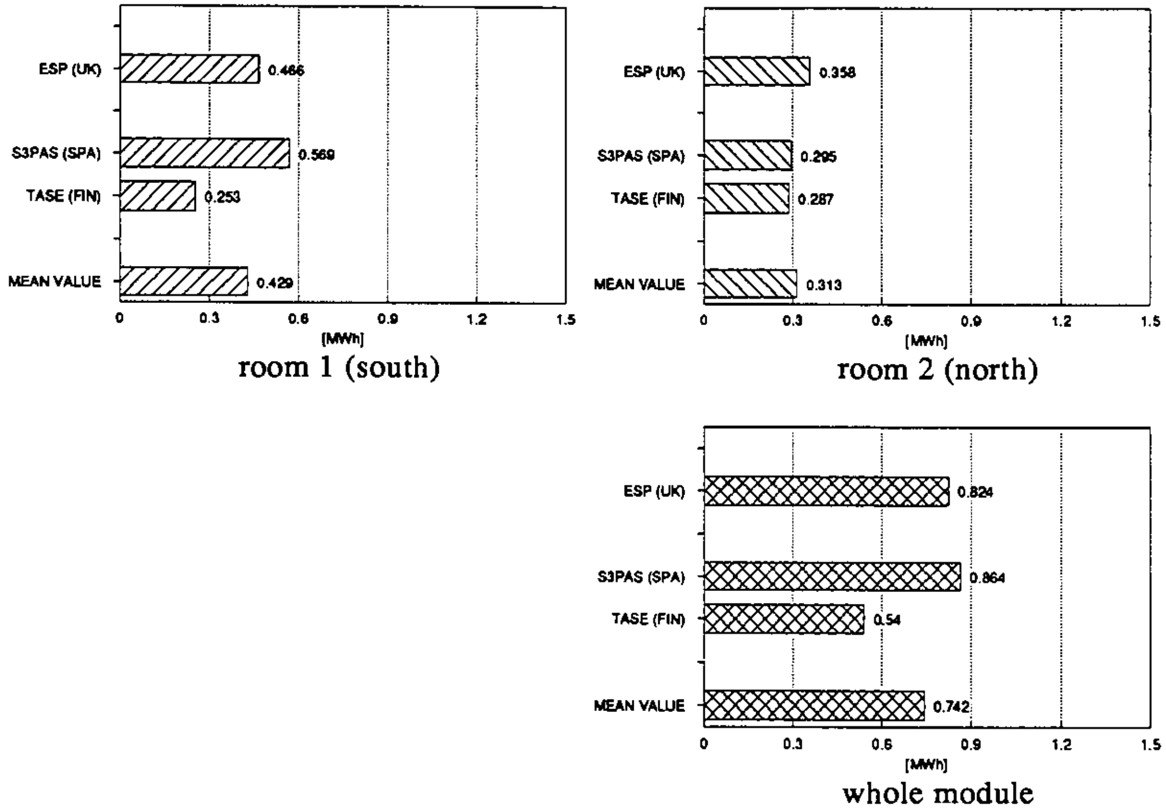


Figure 13.1a Annual heat losses through exterior walls in case 1a.

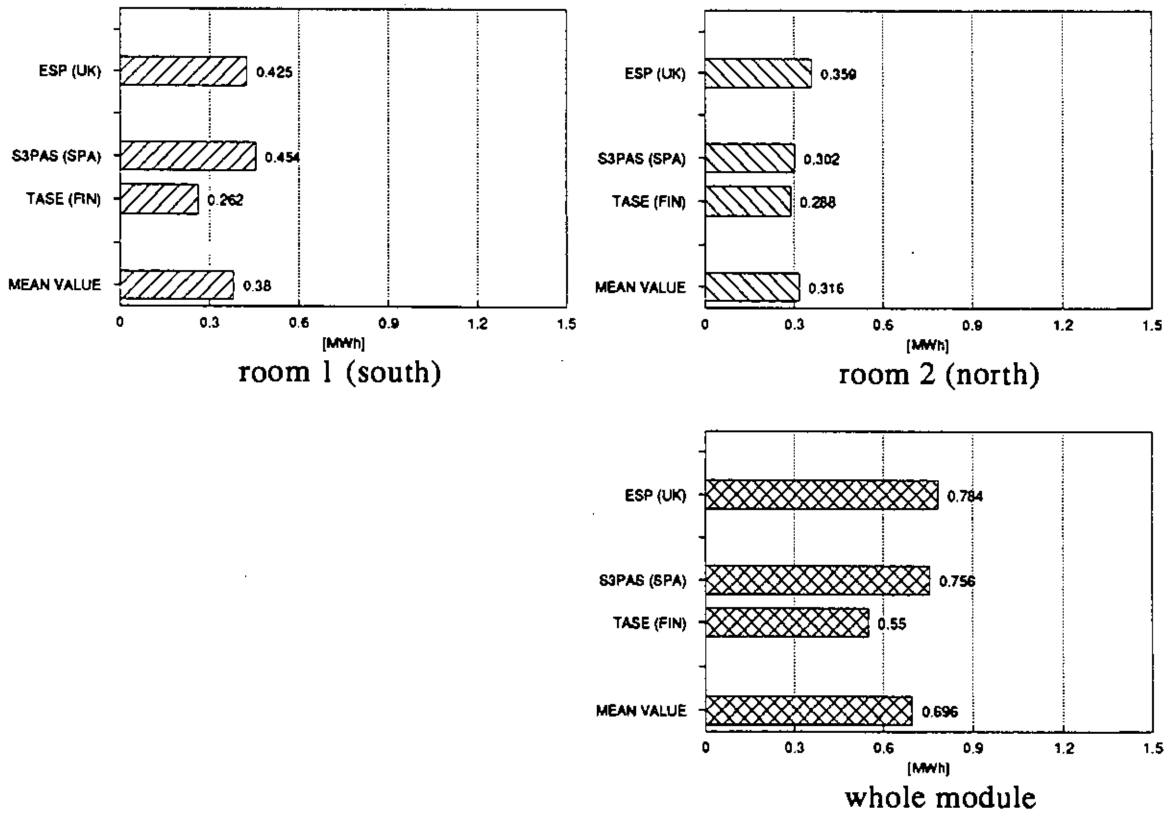


Figure 13.1b Annual heat losses through exterior walls in case 1b.

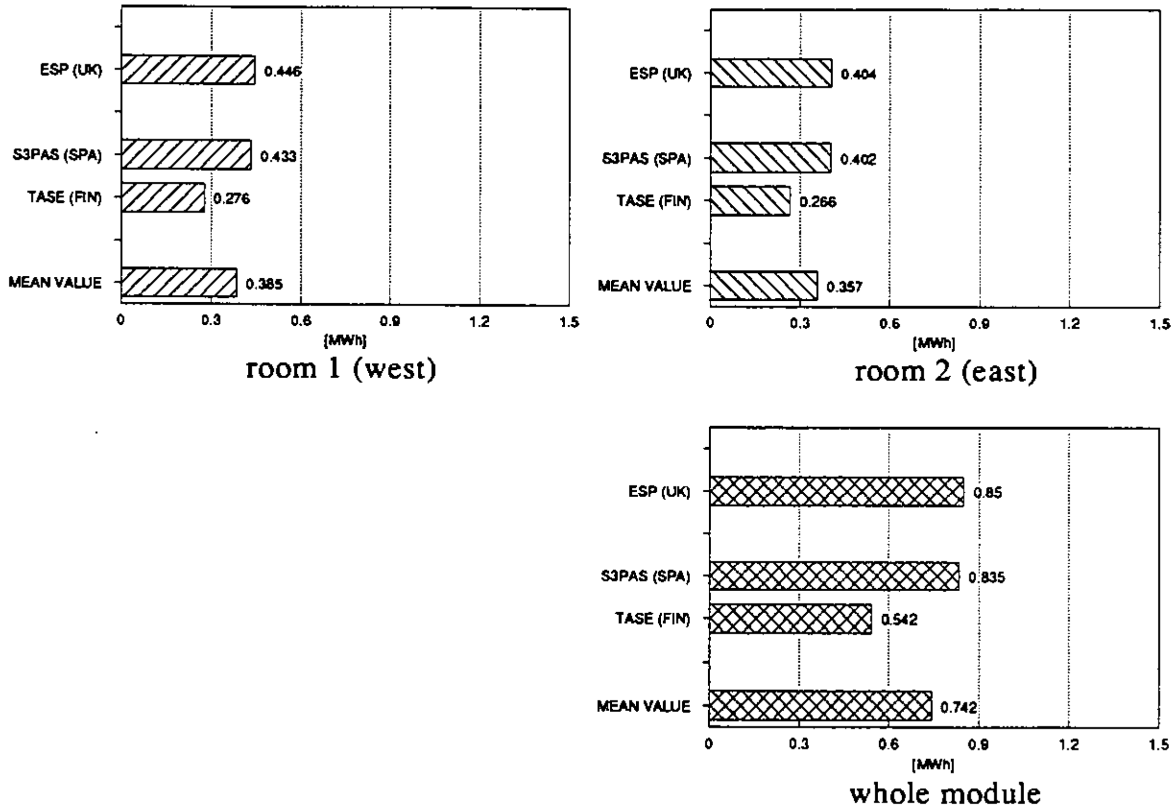


Figure 13.2a Annual heat losses through exterior walls in case 2a.

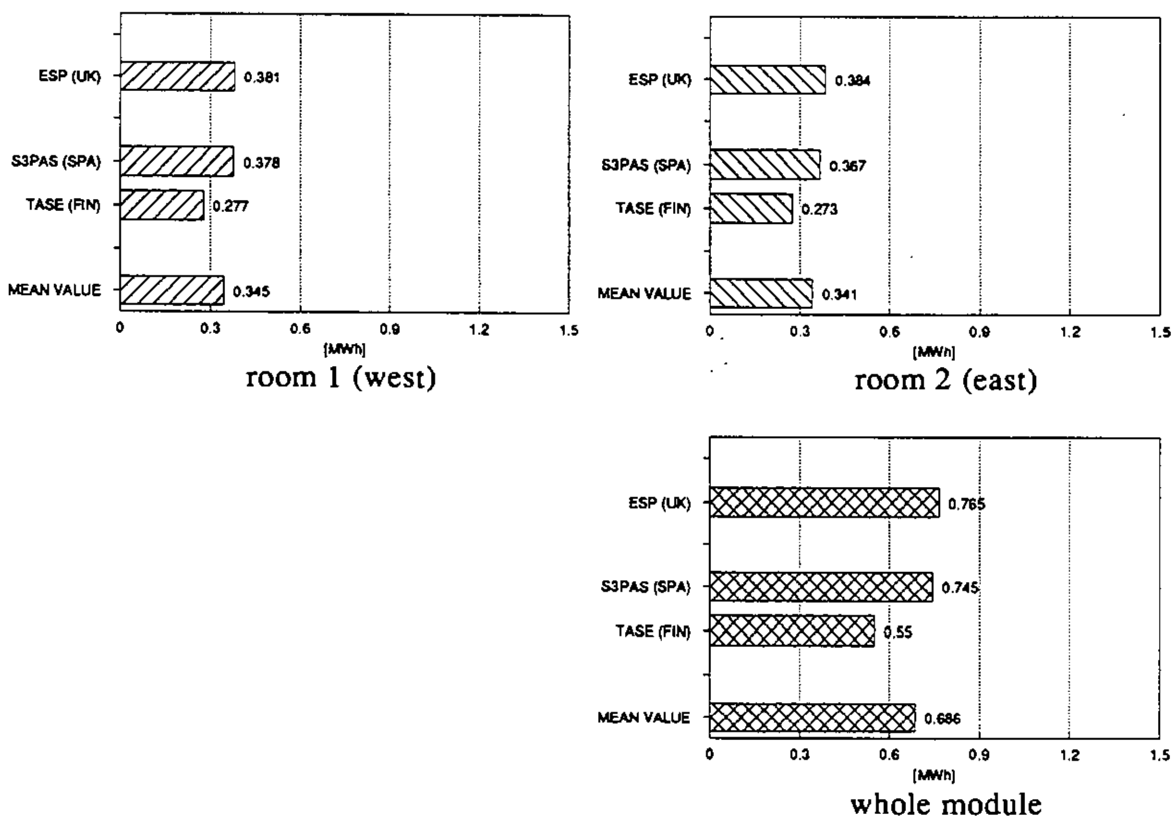


Figure 13.2b Annual heat losses through exterior walls in case 2b.

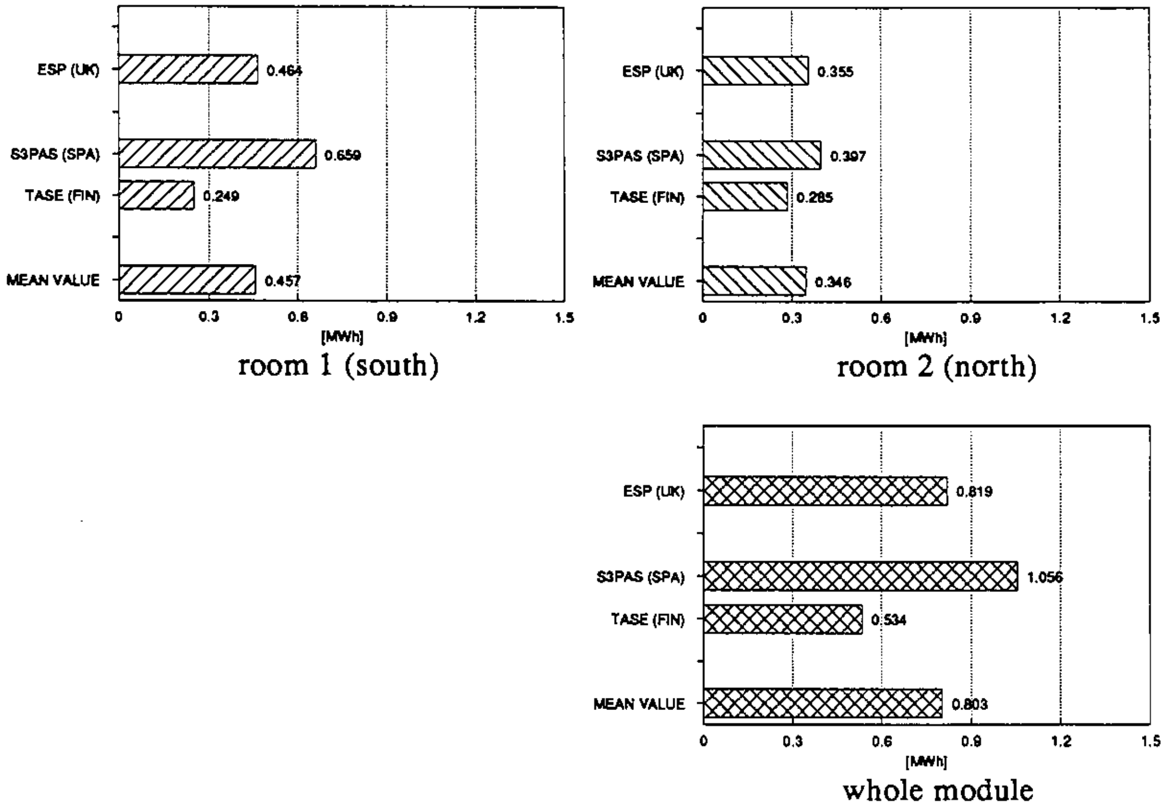


Figure 13.3a Annual heat losses through exterior walls in case 3a.

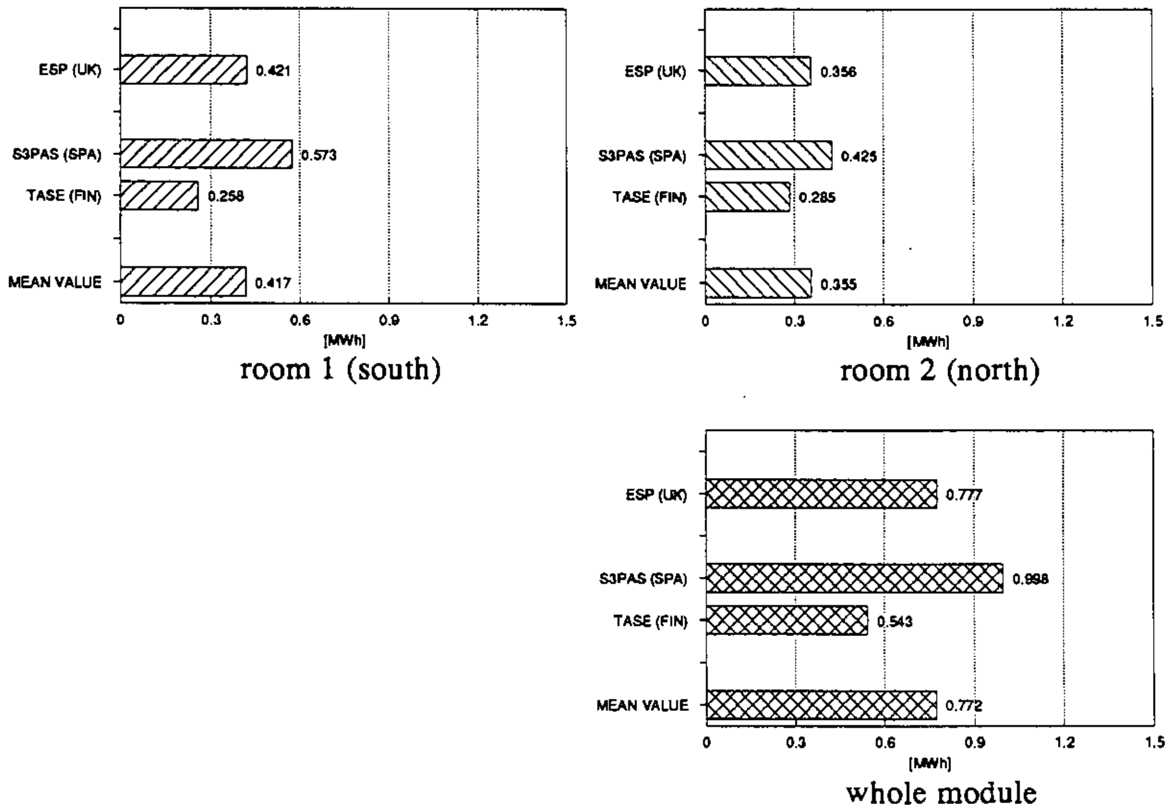


Figure 13.3b Annual heat losses through exterior walls in case 3b.

4.9 Annual heat losses through windows

The heat losses through the windows are the heat losses through the glazing. The frame was not taken into account. The results for the same three programs, ESP, S3PAS and TASE, as in the case of the heat losses through exterior walls, are presented. The differences between the results of these three programs are not great, approximately 0 - 20% (Table 17, Figure 14). Thus, even if a window is a more complicated detail in a thermal simulation than an exterior wall, the differences between the heat losses of windows are smaller than those of the exterior walls when calculated by these programs.

Table 17. Annual heat losses through windows of the whole module. The mean value of all programs and the relative differences between the results of individual programs and the mean value.

Program	Case					
	1a	1b	2a	2b	3a	3b
	Mean Value $\overline{Q}_g$, MWh					
All	1.80	1.70	1.83	1.70	1.78	1.69
	Relative difference $(Q_{gi}-\overline{Q}_g)/\overline{Q}_g$, %					
BLAST						
ESP	-6	-2	-3	0	-6	-2
SERI-RES						
S3PAS	+9	+4	+8	+4	+9	+4
TASE	-4	-2	-4	-3	-4	-2
TRNSYS						

$\overline{Q}_g$ mean value of annual heat losses through windows (glazing)
Q_{gi} annual heat losses through windows calculated by an individual program

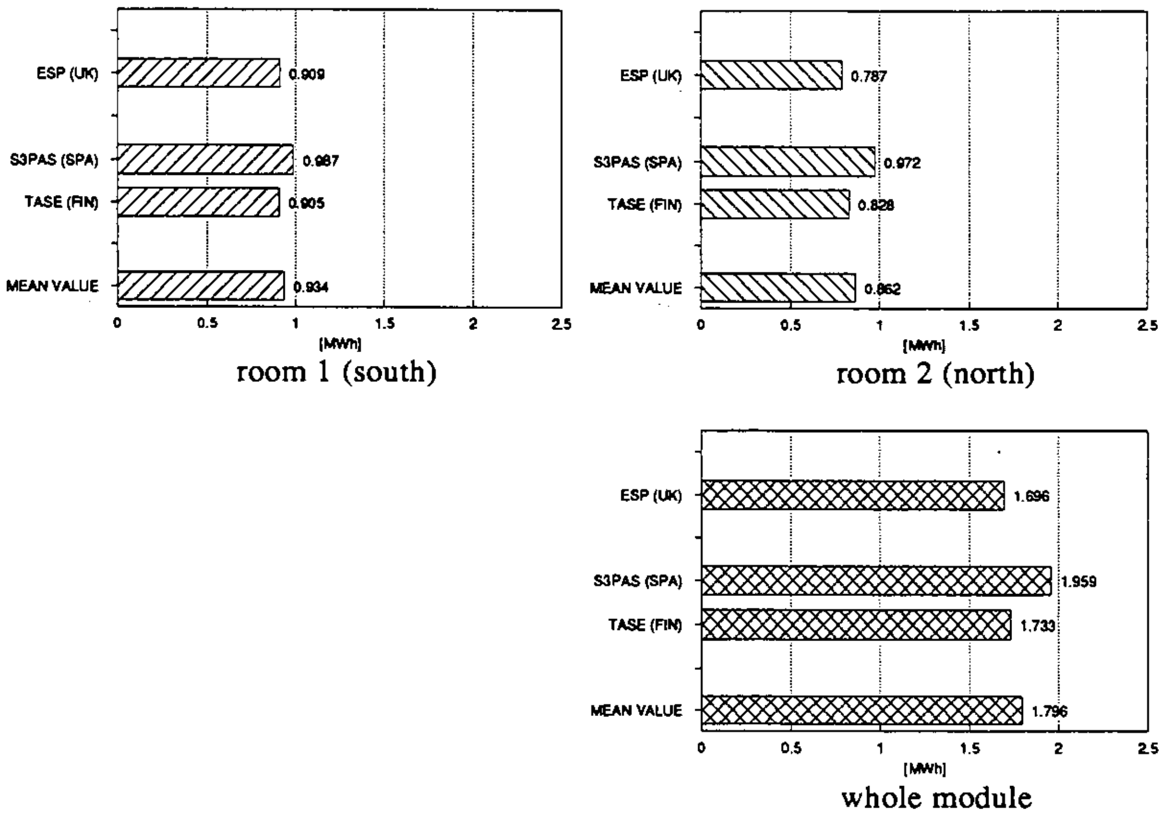


Figure 14.1a Annual heat losses through windows in case 1a.

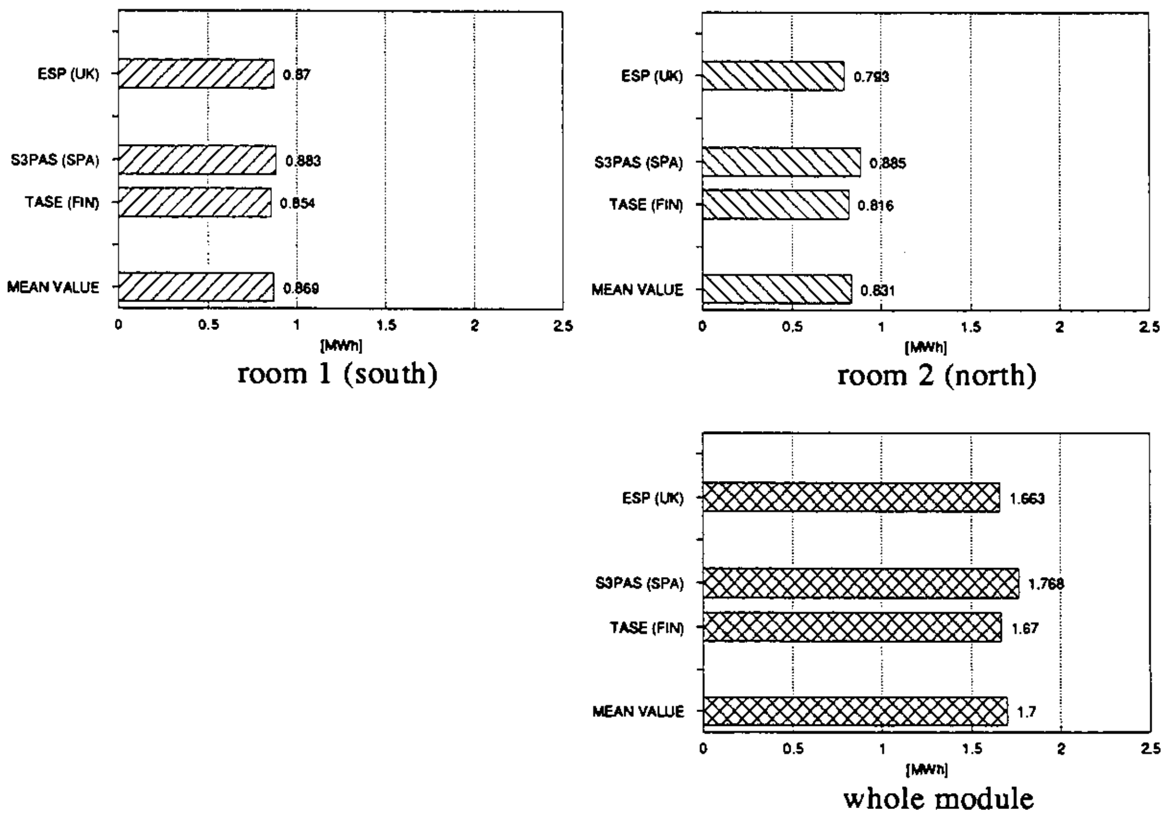


Figure 14.1b Annual heat losses through windows in case 1b.

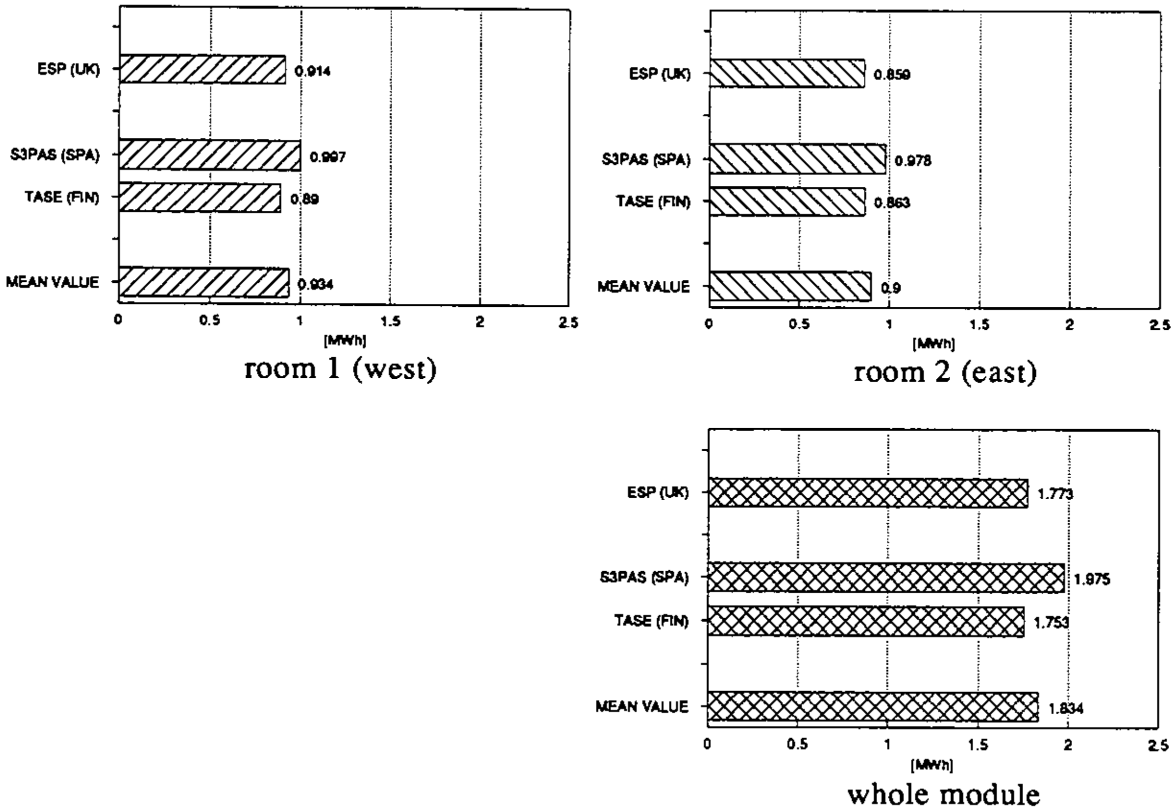


Figure 14.2a Annual heat losses through windows in case 2a.

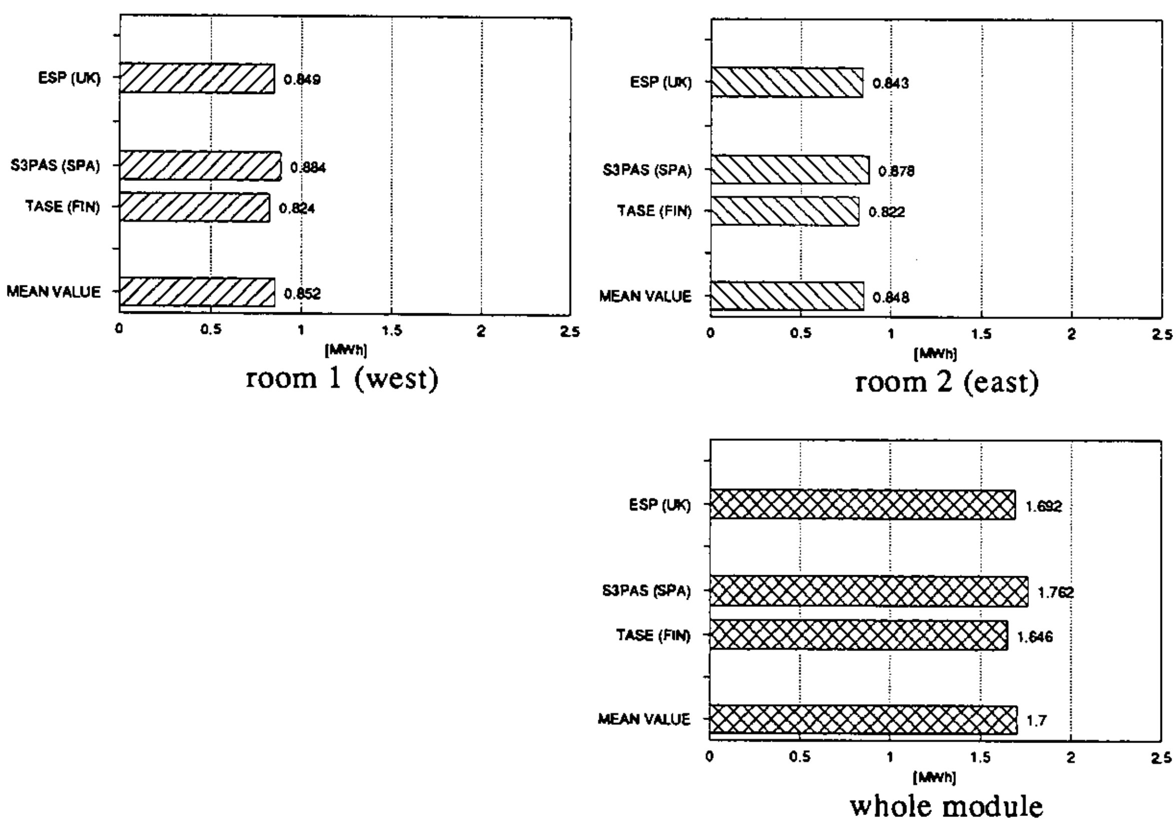


Figure 14.2b Annual heat losses through windows in case 2b.

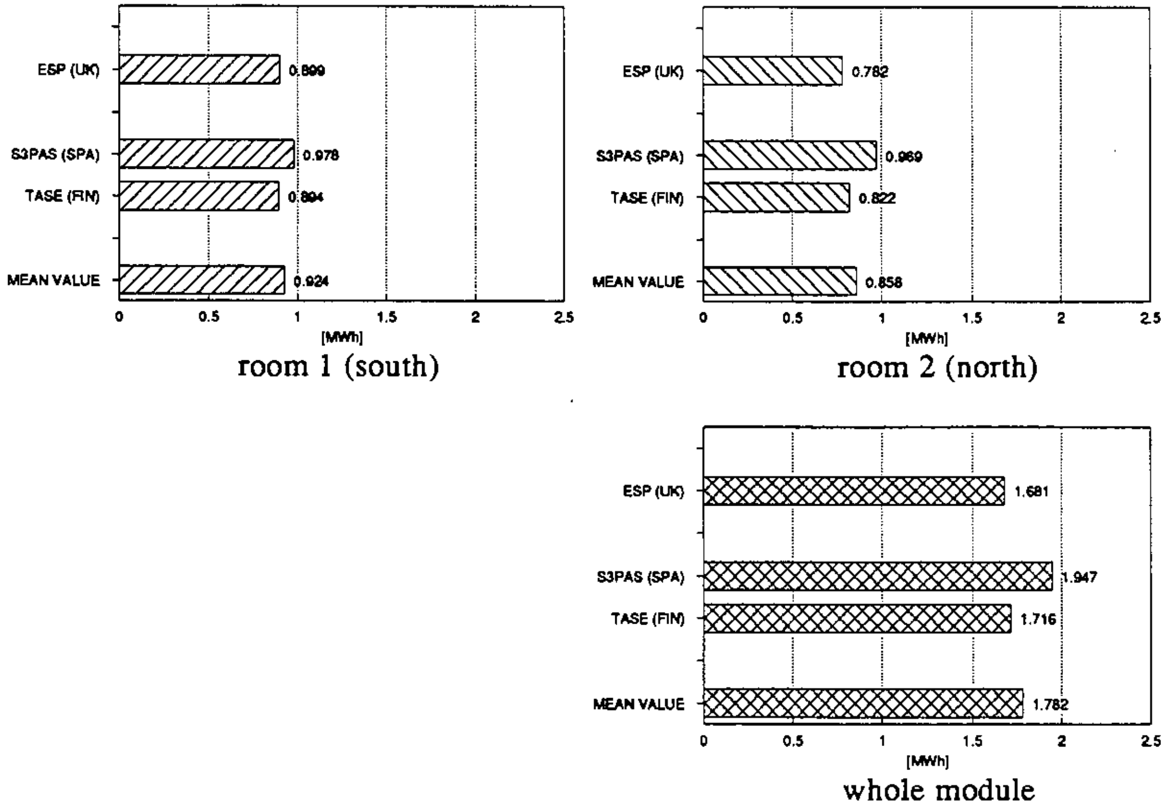


Figure 14.3a Annual heat losses through windows in case 3a.

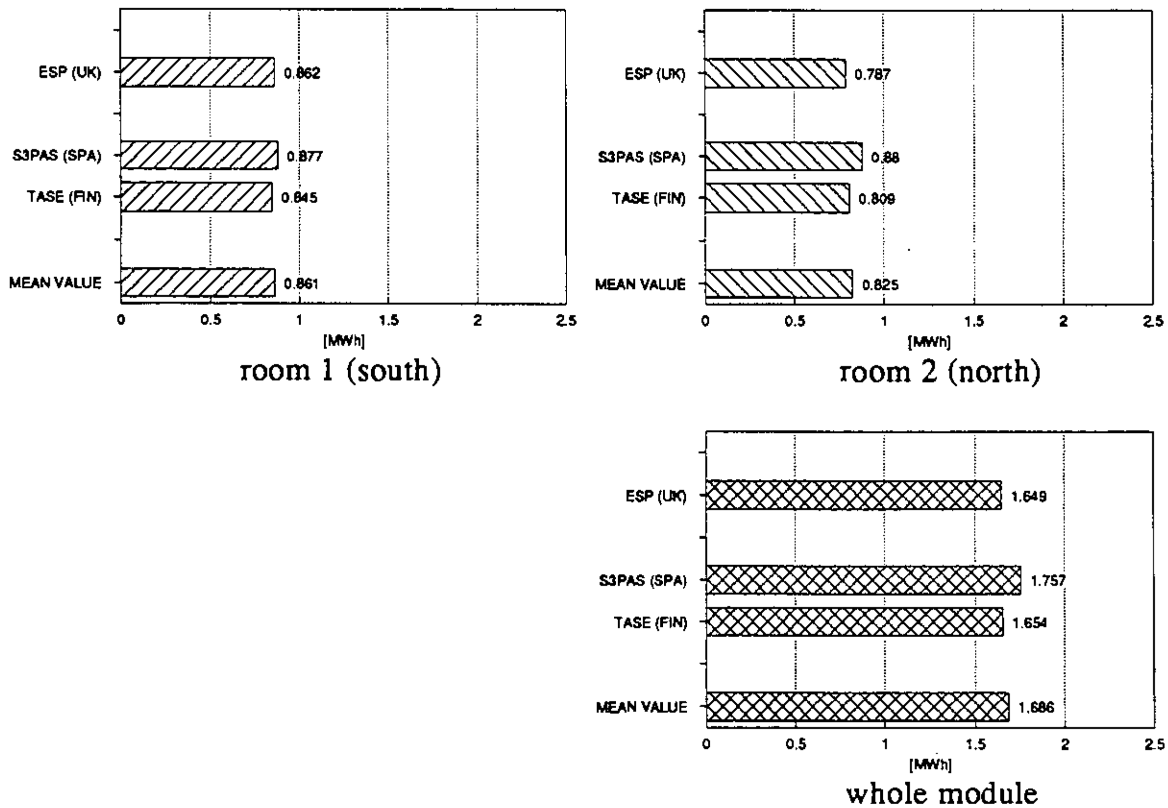


Figure 14.3b Annual heat losses through windows in case 3b.

4.10 Annual heat losses of ventilation

The heat losses of ventilation differed only a few per cent when calculated by ESP, S3PAS, TASE and SERI-RES (Table 18, Figure 15). These small differences are due to the differences in interior air temperatures.

Table 18. Annual heat losses of ventilation for the whole module. The mean value of all programs and the relative differences between the results of individual programs and the mean value.

Program	Case					
	1a	1b	2a	2b	3a	3b
	Mean Value $\overline{Q}_v$, MWh					
All	3.14	3.04	3.16	3.05	3.07	2.95
	Relative difference $(Q_{vi}-\overline{Q}_v)/\overline{Q}_v$, %					
BLAST						
ESP	-1	-1	-1	-2	-1	0
SERI-RES						
S3PAS	+3	+4	+3	+3	+3	+4
TASE	0	-1	0	-2	0	-1
TRNSYS	-2	-3	-2	+1	-1	-2

$\overline{Q}_v$ mean value of annual heat losses of ventilation
Q_{vi} annual heat losses of ventilation calculated by an individual program

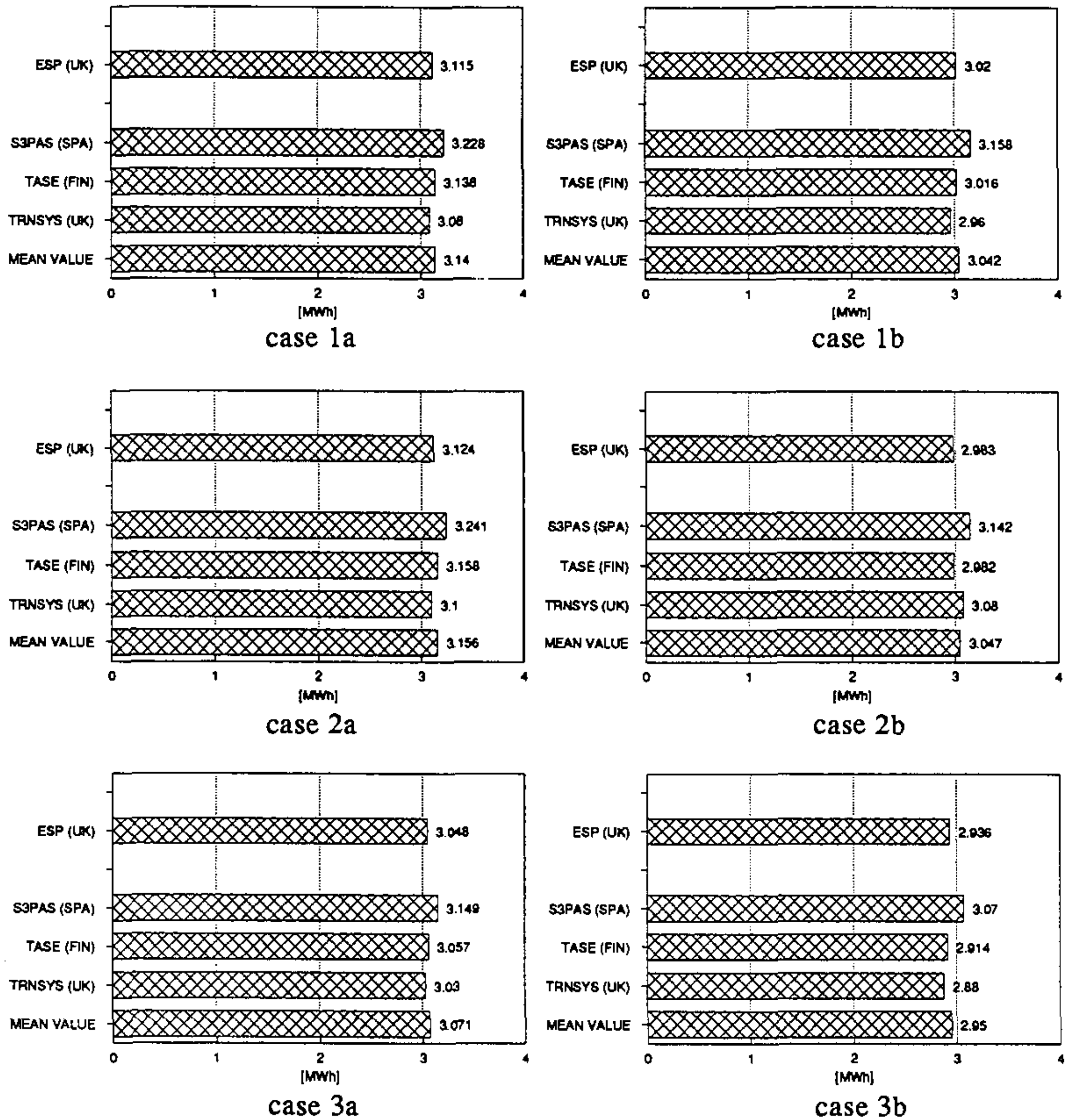


Figure 15. **Annual heat losses of ventilation of the whole module.**

4.11 Daily interior air temperatures

Figures 16 and 17 show hourly interior air temperatures for both rooms and the corridor for a winter day (January 4th) and for a summer day (July 27th).

The calculation results of daily room air temperatures (Chapter 4.11) are presented as curves, in which the results of the various programs are distinguished by means of different line-types (solid, dashed or dashdot) and by the use of character pointers and their respective horizontal positions.

When heating or cooling is used, the air temperatures of both rooms are exactly the same as the set-point values (18 ^{o}C, 20 ^{o}C or 25 ^{o}C). The only exeption is January 4th in the south-facing room, in which SERI-RES gives an unexpected temperature peak between the hours 11 - 17. The reason can be the fact that air temperature of SERI-RES takes into account also the surface temperatures.

The six programs give very different changes in air temperatures when heating or cooling is ended. E.g. when cooling is ended at 17 on July 27th, SERI-RES gives an approximately 1 ^{o}C increase in interior air temperature, while ESP gives approximately 4 ^{o}C. The results of other programs are between these two extremes. Also the free-floating temperatures of the corridor in summer differ greatly. The difference between the daily maximum and minimum temperatures is approximately 1.5 ^{o}C when calculated with SERI-RES and 2.5 ^{o}C with ESP.

The decrease in the air temperature of the corridor between the hours 7 - 17 is due to the increase of the ventilation air change rate. Also here the hourly air temperatures calculated with various programs show a very different course. SERI-RES gives the smallest decrease in air temperature (approximately 2.5 ^{o}C) and BLAST the greatest (approximately 2.5 ^{o}C).

Accordingly, the thermal dynamics of these programs, when estimated using the hourly temperatures, differ greatly from each other.

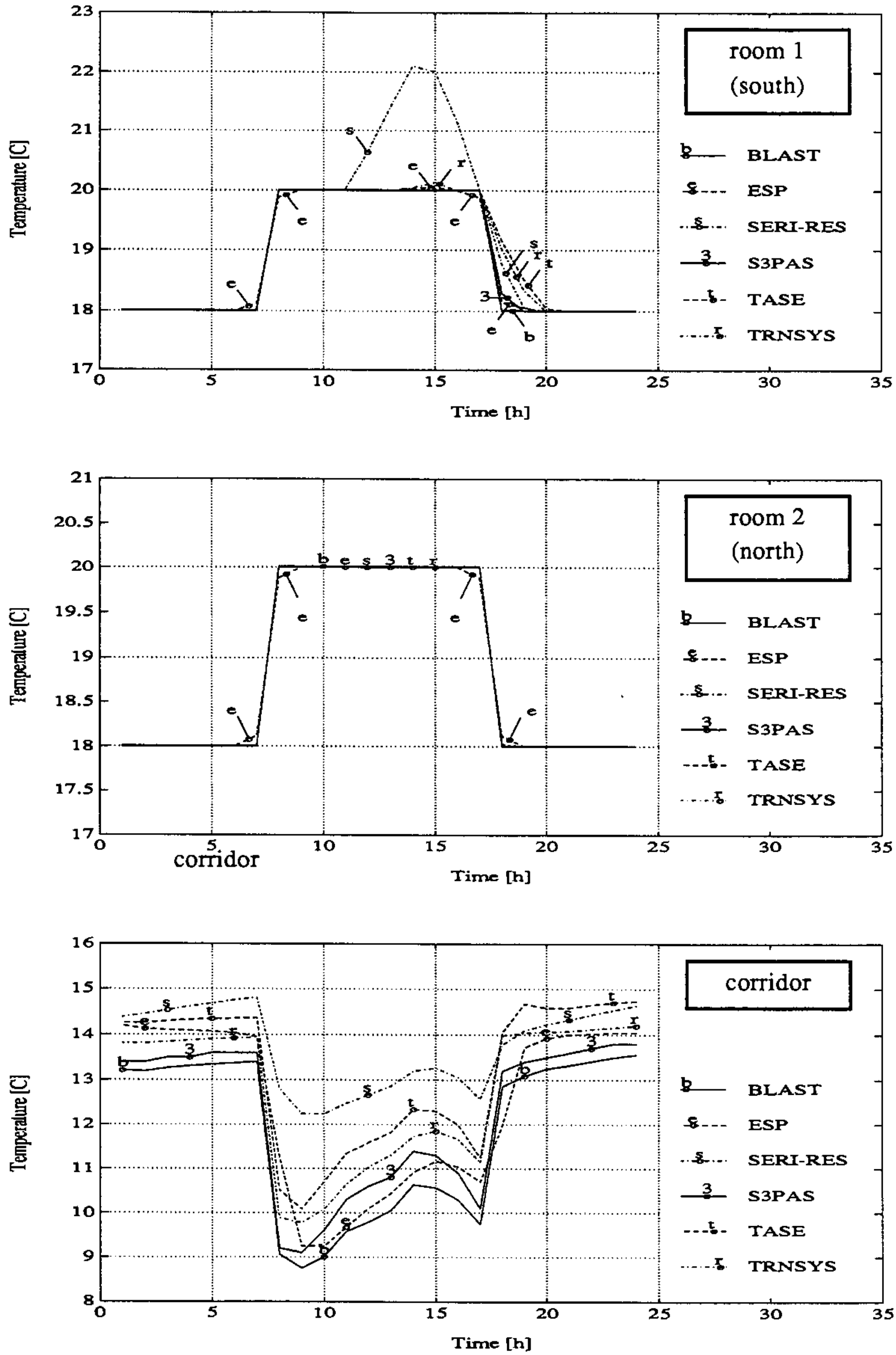


Figure 16.3a Room air temperatures for both rooms and corridor on January 4th in case 3a.

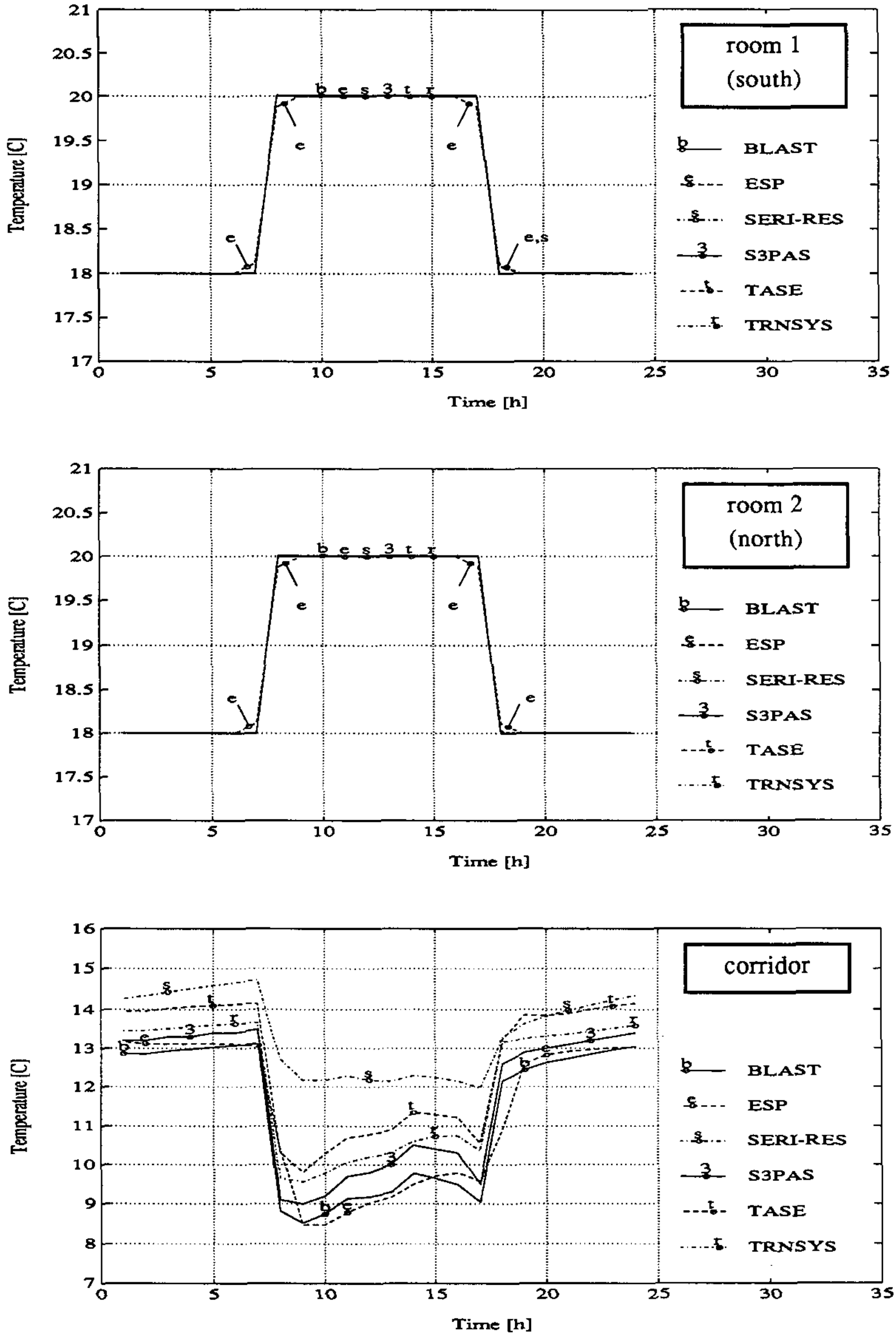


Figure 16.3b Room air temperatures for both rooms and corridor on January 4th in case 3b.

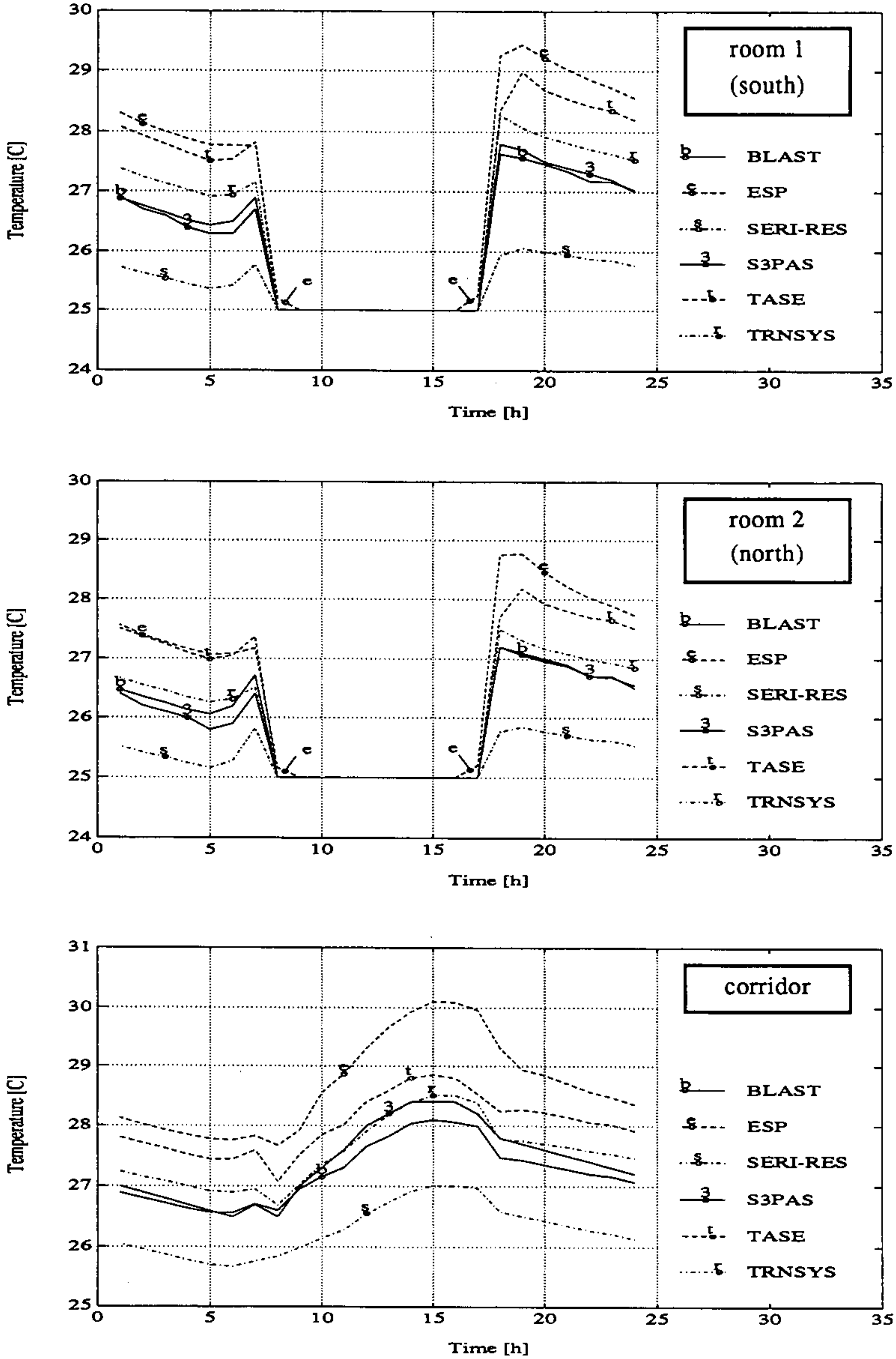


Figure 17.3a Room air temperatures for both rooms and corridor on July 27th in case 3a.

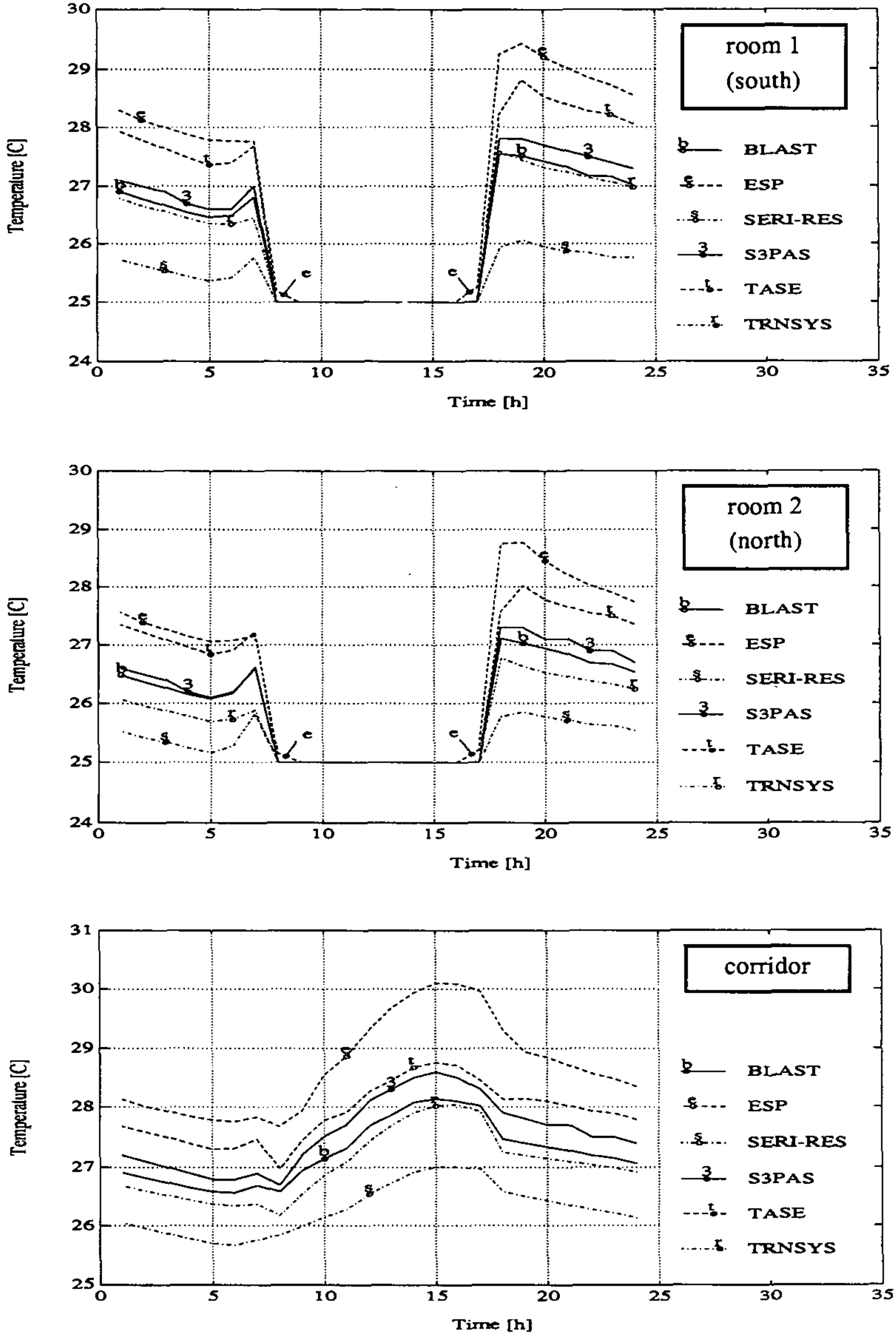


Figure 17.3b Room air temperatures for both rooms and corridor on July 27th in case 3b.

5. CONCLUSIONS

This report contains an exact description of a test module for commercial buildings for evaluation of energy analysis programs. BLAST, ESP, SERI-RES, S3PAS, TASE and TRNSYS have been used for calculating the benchmark results. The module consists of two similar office rooms and a corridor between them. The module is situated in the middle of a large building and its windows face either south and north or east and west. Six separate test cases were created using this module. There are two kinds of environments for these cases. The 'unshaded case' assumes the module is situated on an unshaded, flat site and the 'shaded case' assumes the module is situated between two similar buildings. All the test cases are situated at the exact location of the weather station in Denver (Colorado, USA). The weather data are the same (DRY-COLD.TMY) as those used in the BESTEST benchmark study /1/.

For the annual heating energies of the whole module ESP gave approximately 20% smaller values than the mean value of all programs. S3PAS gave values which were 15 - 25% greater than the mean value of all programs. The other programs gave for the annual heating energy of the whole module values which were quite close (1 - 9%) to the mean value.

For all cases BLAST and SERI-RES calculated for the annual cooling energy of the whole module values which were approximately 10 - 15% greater than the mean value of all programs, while S3PAS and TASE gave values which were approximately 5 - 15% smaller than the mean value of all programs. ESP gave for all cases and TRNSYS for the unshaded cases results which were very close to the mean value of all programs. There are obviously some problems in the calculation of shading in TRNSYS, because its results for shaded cases differ so greatly from the mean value.

For the total peak heating load of the whole module ESP calculated values which were 20 - 25% smaller and SERI-RES and S3PAS values which were 10 - 15% greater than the mean value of all programs. The other three programs calculated for the total peak heating load of the whole module values which were quite close (difference 0 - 5%) to the mean value of all programs.

BLAST, S3PAS and TASE calculate for the peak cooling load of the whole module values which differ less than 10% from the mean value of all programs. SERI-RES gives for the peak cooling load of the east-west facing module and TRNSYS for that of the south-north facing module a peak cooling load which differs more than 20% from the mean value of all programs. The greatest relative difference in the peak cooling loads of individual programs is in the east-facing room, in which SERI-RES gives a 60% greater cooling load than TASE.

The indoor volume weighted maximum air temperature of the whole module calculated by the various programs differs less than -2.3 ... +2 ^{o}C from the mean value of all programs, which was approximately 28.5 ^{o}C. The greatest difference between the results of two programs for a room is between the temperatures of TASE and SERI-

RES. TASE gives approximately a 4.5 °C greater maximum temperature for the south-facing room than SERI-RES. The minimum temperatures of the corridor calculated by the various programs differ less than -2 ... +2.6 °C from the mean value of all programs. SERI-RES gives the highest air temperatures and TASE the lowest.

The heat losses through exterior walls are calculated only for ESP, S3PAS and TASE. In general, the differences between the heat losses through exterior walls calculated by these three programs vary from 3 to 60%. For the north-facing room all programs give the same results quite accurately, but for the south-facing room without shading and when the corridor is unheated TASE gives a heat loss which is 60% smaller than that of S3PAS. It is worth further study to determine whythere are such great differences in the heat losses through exterior walls. It looks as if the results of TASE are erroneous.

The results for the heat losses through windows are calculated for the same three programs, ESP, S3PAS and TASE. The differences between the results of these three programs are not great, approximately 0 - 20%. Even if a window is a more complicated detail in a thermal simulation than an exterior wall, the differences between the heat losses through windows are smaller than between those through the exterior walls when calculated by these programs.

The heat losses of ventilation differed only a few per cent when calculated by ESP, S3PAS, TASE and SERI-RES. These small differences are due to differences in interior air temperatures.

For the change in interior air temperature on a summer day (July 27th) the six programs give quite different results when cooling is ended. SERI-RES gives an approximately 1 °C increase in interior air temperature but ESP approximately 4 °C. The results of the other programs are between these two extremes. The changes in air temperatures in the corridor are similar when heating is ended on a winter day.

One reason for the different pattern of air temperatures during the day calculated by SERI-RES and the other programs is in the definition of "air temperature". For the other programs than SERI-RES the air temperature is purely the average room air temperature, but for SERI-RES it is a weighted temperature in which the effects of surface temperatures are also taken into account. It is natural that the variation of interior air temperature is smaller if the values of surface temperatures are included.

When comparing the present results with previous studies, e.g. BESTEST /1/, ESP seems to underestimate annual heating energies in both studies. In addition, S3PAS seems to give higher annual heating energies in the present study than in earlier studies.

The absolute values calculated varied between the cases. It cannot, however, be concluded on the basis of a comparative study like this which program is the best or whose results are the most correct. To get more accurate results, a more detailed analysis should be done. When interpreting the results, it should also be remembered that not only the program itself, but also its user affects the results. In the present study there were several users, which may partly explain the variation of the results.

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1. Judkoff, R. & Neymark, J., Building Energy Simulation Test (BESTEST) and Diagnostic Method. International Energy Agency, Solar Heating and Cooling Programme, Task 12 B: Model Evaluation and Improvement. National Renewable Energy Laboratory, Golden, Colorado, USA, 1994.

APPENDICES

Code Reports

APPENDIX A1

ESP-r Code Report

1. Introduction

This report describes the modelling strategy used for the Commercial Building Simulations carried out at De Montfort University Leicester (DMU) with ESP-r. Any modelling assumptions that had to be made in addition to the building specification issued by Simo Kataja and Timo Kalema (IEA21RN325/92) and any modelling difficulties that occurred are also noted. The report supersedes BRE Support Contract Reports 11 (IEA21RN195/92) and 11a (IEARN205/92).
Previously, the simulations had been carried out using ESPsim version 6.18a. Anomalous results had been experienced in some cases of the parallel BESTEST exercise with this version. After consultation with the authors of ESP, all simulations were therefore repeated using the latest version of the ESP software. This is ESP-r version 8 series. The following program modules were used: prj v8series, bps v8.1a, ish v1.2a, win v2.2a, clm v6.3b and res v4.7a.
A pre-conditioning time of 19 days and 4 time steps per hour were used throughout.

2. Building Specification

Boundary Conditions: ESP requires the specification of an 'index of exposure'. An index of 1 (city centre location, normal case) was used throughout.

3. Construction

Glazing: Windows can be modelled in two ways in ESP. The TMC (transparent multi-layered construction) option was used here, where windows are assigned a nodal scheme so that convective, conductive and long-wave radiative exchanges are handled separately and explicitly, with solar absorption treated in an exacting manner.
ESP requires the absorptivity of each glazing pane, but these values were not given in the specification document. The program module 'win' was used to calculate them. 'Win' requires the average transmission at normal incidence of each glazing pane, which was given as 0.86156 in the specification (IEARN239/92). The transmissivity values calculated at various angles of incidence by 'win' differed slightly from those given in the specification. (The largest deviation occurred at 80°, where the 'win' value was 0.242 compared with the specified value of 0.263. At normal incidence the difference was negligible.) The specified values were used together with the absorptivity values calculated by 'win'. Any small discrepancies are therefore in the reflectivity values.
The following thermophysical properties were used for the glass: $\lambda = 1.13 Wm^{-1}K^{-1}$; $\rho = 2500 kgm^{-3}$; $c = 750 Jkg^{-1}K^{-1}$. None of these values was given in the specification, but the above values had been agreed upon earlier for the BESTEST simulations.

Doors were modelled as separate constructions according to the specification.

4. Building Operation

Casual gains:
All internal gains were assumed to be sensible.

Ventilation: The altitude correction given in the specification was used to produce infiltration rates for Denver of 0.41 ac/hr from 17:00 to 07:00 and 2.46 ac/hr from 07:00 to 17:00.

5. Shading

The program module 'ish' was used to calculate hourly varying shading patterns on the external facades and windows. (The patterns are calculated for one day per month).

6. Interior Solar Distribution

The program module 'ish' was used to calculate hourly varying internal solar distribution patterns for both the unshaded and the shaded cases. (As above, these patterns are calculated for one day per month).

7. Location and Climate

In addition to/instead of the parameters contained in the climate file DRYCOLD.TMY, ESP requires diffuse horizontal radiation. This was calculated from the direct normal radiation, the global horizontal radiation and the solar altitude using a small program written at DMU. The resulting climate file had to be converted to binary format via the program module 'clm'.
A problem arose because ESP expects the first record of the weather data to be a spot value taken at 01:00. However, the file DRYCOLD.TMY was assumed to contain data centered on the half hour, i.e. starting with the period 00:00 to 01:00, and the diffuse horizontal radiation values were calculated accordingly. As a result, the direct normal radiation values in the ESP climate file are consistent with the values in DRYCOLD.TMY, but an unavoidable time shift of $^1/_2$ hour remains in the way ESP interprets the data.

8. Output

ESP produces output in a binary file. The program module 'res' was used to obtain the required outputs. The results are stored on a floppy disc in LOTUS format.

1. Introduction

This report describes the modelling and results for running the commercial building benchmark study cases described in the specification IEA21RN325/93, (a revision of IEA21RN239/92), as done at the Building Research Establishment using SERI-RES Version 1.2. It gives assumptions made where the specification did not cover information needed, interpretation of requirements and features of SERI-RES needing modifications to data.

2. Building Specification

Boundary conditions: the interior surface coefficient was taken as specified, that is 8.30 W/m^2K for vertical surfaces, 9.30 W/m^2K towards horizontal surfaces and 6.1 W/m^2K from horizontal surfaces.

3. Construction

SERI-RES 1.2 gives a simple representation of double glazing. The effect of surface coefficients and the air gap between panes is covered by the overall air-air U-value. SERI-RES then calculates other required values from the extinction coefficient, refractive index and thickness of the glass.

All boundary constructions including doors were modelled as multilayer walls. In the elements of each opaque wall construction, it was recommended that each element be given 3 nodes to give as much accuracy as possible, with the exception of the carpet which was modelled as a simple resistance of 0.013 m^2K/W. This choice of node numbering produced 60 timesteps per hour.

4. Building Operations

SERI-RES does not model the operation of equipment; heating and cooling are taken as direct energy gain or loss to the zone. Infiltration is modelled as air exchange with ambient conditions. Radiative/convective heating splits are not defined. As a result of occasional difficulty experienced with using 1000 kW as maximum heating or cooling capacity, this was changed to the SERI-RES default of "adequate", that is, enough to achieve the required temperature change at any time step.

5. Interior Solar Distribution

The interior solar coefficients were calculated according to the recommendations of the Performance Assessment Method documentation (Pamdoc) for the study of overheating risk using SERI-RES, Ref. no. 3429/003V6-Com, section 7.7.1.3., in which the fraction of solar radiation absorbed by each interior surface is taken as proportional to the area od that surface weighted by its absorptance.

The fraction of solar radiation absorbed directly by the zone air is taken as 0.06, leaving .94 to be transferred to walls and windows. The specification gives the transmissivity of double glazing as 0.74745 and the absorptivity of opaque interior surfaces as 0.3. For SERI-RES it was assumed that no solar radiation would fall on the ceiling. The other solar coefficients were calculated as follows.

Room outside wall	$= 0.3A_{ew}/D$	= 0.098
Room side wall	$= 0.3A_{pw}/D$	= 0.190
Room corridor wall	$= 0.3A_{cw}/D$	= 0.107
Door on room side	$= 0.3A_{d}/D$	= 0.035
Room floor	$= 0.3A_{f}/D$	= 0.210
Window loss	$= 0.74745A_{w}/D$	= 0.110

where:
- A_{ew} = area of outside wall
- A_{pw} = area of side wall
- A_{cw} = area of corridor wall
- A_{d} = area of door
- A_{f} = area of floor
- $D = [0.3\ (A_{ew} + 2A_{pw} + A_{cw} + A_{d} + A_{f}) + 0.74745A_{w}]\ /\ 0.94$

Solar coefficients are not needed in the corridor, since there are no windows in it and solar transmittance is therefore zero.

6. Shading

Shading has been modelled using the skyline profiles option. In this, obstructions are noted as skyline altitude angles, required at 20° intervals between 100° East of South and 100° West of South.

For cases 1 and 3, the only effective shading is to the South on Room 1. For a 40m wide building centred opposite the room, 20m above the floor level of the cell and 25m distant, the skyline angles are 38.7° at 0° and 36.9° at 20° East of South and 100° West of South.

For case 2, shading is observable for both rooms. Here it gives skyline angles of 38.2° at 100° and 80°, and 34.7° at 60° to East and West of South.

7. Location and Climate

It was assumed from the location details that the climate file to be used was the same DRYCOLD.TMY as was provided for the BESTEST benchmark study. SERI-RES did not require any extra information, and does not use the wind direction.

8. Output

It was shown in the BESTEST benchmark study that SERI-RES 1.2 calculates solar incidence on external surfaces so as to give values very different from the average for all contributing programs, (TRNSYS (2 versions), S3PAS, TASE, DOE2.1D, SERI-RES (US versions) and ESP), except for the South surface. On the North and West faces the values are low, being 8% and 17% below average respectively. The East value is high, 14% above average. This may cause annual heating and cooling to vary correspondingly compared with other programs, even when other input data are in agreement.

SERI-RES 1.2 uses Hays anisotropic sky model for diffuse insolation; Moon and Spencer's distribution model is used for low values of global insolation, and at circumsolar component. Gruter's model is used for solar declination.

For heat losses from windows, through walls and by way of ventilation, SERI-RES 1.2 puts out two forms. One is the net loss of heat, measured positive inwards. The other is "useful loss"; this is the heat flow defined as the difference between the actual loss and an estimate of the comfort level 21°C. SERI-RES 1.2 does not split heat loss into the actual outward and inward flows. The outward heat losses when zone temperatures exceed ambient conditions have therefore not been supplied.

APPENDIX A3

TASE 3.0 CODE REPORT

1. Introduction

This report describes the modelling strategy used for the Commercial Building simulation test carried out at Tampere University of Technology with the TASE 3.0 program. Any modelling assumptions that had to be made in addition to the building specification issued by Simo Kataja and Timo Kalema (IEA21RN325/92) are also noted.

2. Principles of modelling and calculation

For the TASE the building was described as a module consisting of two rooms and a corridor between them. Every surface was undivided, and calculated temperature and heat flux of the surface was the average value of the whole surface. Similary the room air temperature was the average value of the whole room space. The energy consumption was calculated using a one-hour time-step for the whole calculation period. No precalculation time was used. All times were local with no daylight savings. The termostat control temperature was the dry air temperature.

3. Heat conduction through walls, ceiling and floor

Transient heat conduction through the walls, ceiling and floor was calculated using transfer factors calculated with the computer program developed by Mitalas and Arsenault /1/. For interior walls a symmetric boundary condition was used and for the ceiling and floor an implicit boundary condition.

4. Heat conduction through windows and solar radiation into room

For windows the heat conduction was considered steady-state using a constant effective thermal transmittance (U*). This is the thermal transmittance of the window between the inside surface of the interior pane and outside air. The U*-value used was 4.698 W/(m^{2}K). There was only one node in the window. The direct solar radiation transmitted through and absorbed by the window was calculated using angle-dependent values and the diffuse solar radiation using constant values, Figure 1.

Interior solar radiation distribution was calculated internally in the TASE program. Short-wave radiation transmitted through the window from inside to outside was also taken into account.

5. Heat transfer coefficients of inside surfaces

Convective heat transfer between room air and inside surfaces was calculated using variable convective heat transfer coefficients. The convective heat transfer coefficients depended on temperature differences and the orientation of the surface. The walls, ceilings, floors and windows all had their own correlations /2/. Figure 2 shows the convective heat transfer coefficients used.

Radiative heat transfer between inside surfaces was calculated using variable radiative heat transfer coefficients and view factors. The radiative heat transfer coefficients were calculated using the formula

$$h_r = 4\bar{\varepsilon}\sigma\bar{T}^3 \ ,$$

where $\bar{\varepsilon}$ is effective emissivity,
σ is Stefan-Boltzmann constant and
$\bar{T}$ is the mean value of the surface temperatures.

The effective emissivity has been constant over the whole calculation period. The convective and radiative heat transfer from all outside surfaces was calculated using constant total heat transfer coefficients.

6. Weather data

The weather data file used was DRYCOLD.TMY of Denver, which was the same as in the BESTEST simulation test. The diffuse solar radiation code of TASE needed two additional terms of weather data, which were not included in the weather data file given.

The first term was the total solar radiation reflected from the ground, calculated by multiplying the sum of the direct and diffuse solar radiation and the reflectivity of the ground. The other term was the relative cloud cover which was estimated from the ratio of diffuse radiation to direct radiation.

7. Shading

For the TASE program the site has been divided into eight independent sectors, for which the transmissivity for solar radiation is described using two angles, α and β, Figures 3 and 4. For height angles less than α the environment is opaque and for angles greater than β the environment is totally transparent. The transmissivity values for height angles between α and β are user specified.

In cases 1b and 3b the shading caused by the environment was taken into account by giving for both α and β the value 36.9° for sectors 2, 3, 6 and 7. In case 2b the value 36.9° for α and β was used for sectors 1, 4, 5 and 8. In these cases the rest of the sectors had values $\alpha = \beta = 0^{\circ}$.

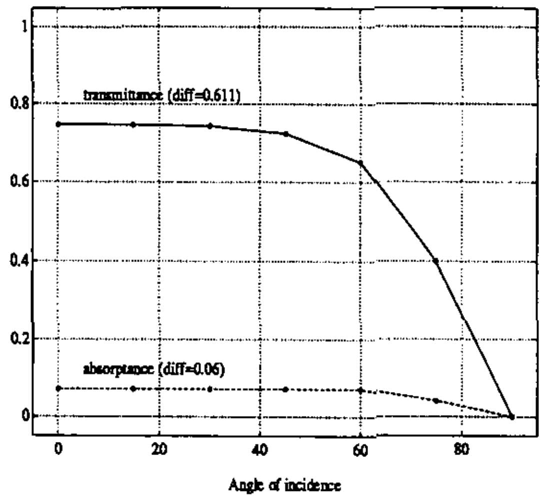

Figure 1. Transmittance and absorptance of window.

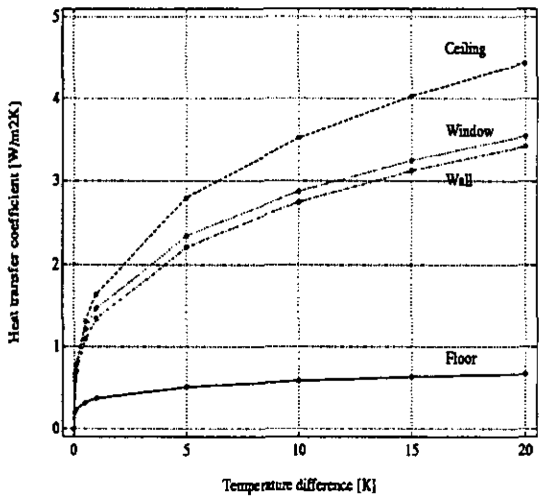

Figure 2. Convective heat transfer coefficients for interior surfaces.

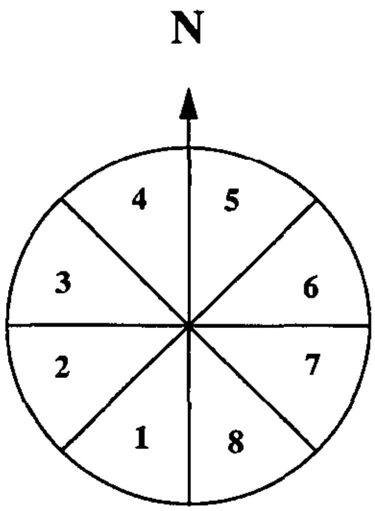

Figure 3. Division of environment into eight independent sectors.

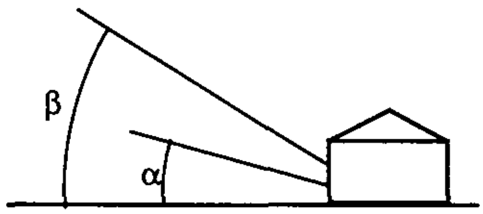

Figure 4. Definition of angles in an individual sector.

8. References

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APPENDIX A4

IEA21RN386/93
(Replaces IEA21RN233/93)

IEA ANNEX 21 SUBTASK C

REPORT OF THE COMMERCIAL BENCHMARK TRNSYS RUNS

by

F. Parand, BRE, UK, and P. Verstraete VUB, Belgium September 1993

REPORT OF THE COMMERCIAL BENCHMARK TRNSYS RUNS

by

F. Parand, BRE, UK, and P. Verstraete VUB, Belgium March 1993

1. Introduction

TRNSYS 13.1 was used in running all the COMMERCIAL BENCHMARK tests specified. This was a PC version of TRNSYS. In earlier runs some problems were experienced with the version that VUB obtained from Wisconsin. These are discussed in detail in the report on BESTEST using TRNSYS by authors pages 2-81 to 2-103. For information about the main assumptions inherent within TRNSYS refer to the same report. TRNSYS cannot produce required heat loss flows, so these were not supplied.

In preparing the input files for TRNSYS it was attempted to follow the specifications. No major additional assumptions were made in simulating the tests. However, a number of modelling assumptions have been made which are discussed below.

2. Time step

The time-step used in all calculations was 0.5 hour. This time-base proved to yield more accurate results as discussed in our BESTEST report (above report).

3. Revised cavity albedo

TRNSYS distributes solar radiation entering a zone to all opaque surfaces, part of which is then reflected back to windows through which solar radiation enters the room. Depending on the user given value of window reflectivity, the solar radiation lost is then calculated by the program. Based on sensitivity tests carried out for the BESTEST work, a reflectivity of 0.59 for radiation approaching windows from inside the room gives a solar distribution similar to that specified in BESTEST. It was, therefore, decided to use this value instead of the original value of 0.151 used in previous runs.

4. Modelling shading by adjacent buildings by using overhang and side-fin shading calculation

Since there is no direct method for evaluating shading by adjacent buildings in TRNSYS, the following method adapted from working document of the European Standards Committee (CEN) Technical Committee TC89 Working Group 6 was used. The method assumes that the receiver surface and the adjacent building are parallel to each other. First the normal projection of the adjacent building onto the receiver surface is determined. Notice that the normal planes containing the sides and top of the adjacent building form the shape of an overhang and two side-fins in the gap between the adjacent building and the receiver building (See fig. 1). Now assume that this imaginary overhang side-fin is in place and the adjacent building does not exist anymore. The area of the shadow caused by this imaginary overhang, on the receiver surface, is the actual lit area of the receiver surface when the adjacent building is in place. The reason is that any ray hitting this imaginary overhang would hit the projected area and possibly the receiver area had the overhang not been in place.

Using the standard overhang shading calculations, TRNSYS Type 34, it was possible to calculate, for each hour of the simulation, the area of the receiver surface that received sunlight with the imaginary overhang in place. This area was then subtracted from the receiver's lit area without the existence of any obstructions to get the area of the shadow of the overhang on the receiver surface.

5. Modelling adjacent zones with identical conditions in TRNSYS

The method of modelling adjacent zone adopted is described below. During the course of this exercise it was noticed that there may be a bug in TRNSYS in the treatment of adjacent zones, if the manual is to be taken as correct. There may also be an inconsistency in the manual's description of the option for modelling adjacent spaces as having identical conditions. Some tests were carried out and it was decided to model adjacent zones as identical but with the separating wall specified as having half the real surface area. These tests are also described below.

TRNSYS allows the user to specify a known boundary temperature on room surfaces (wall, floor, ceiling etc.). There is a keyword "IDENTICAL" which instructs the program to assume that both sides of the surface have the same temperature. This modelling method was used in previous runs but found to be an erroneous assumption for modelling adjacent zones. Fortunately TRNSYS allows the user to assign run-time calculated temperatures to be allocated as boundary conditions, using TRNSYS 'INPUT' keyword. Using this facility, it was possible to assume, for example, that thetemperature of the outside surface of the left wall was the same as that of the inner surface temperature of the right wall. Similarly, the temperature of the floor of the room above the current room (the other side of the ceiling) could be assumed to havethe same temperature as that of the floor of the modelled room (See Fig. 2).

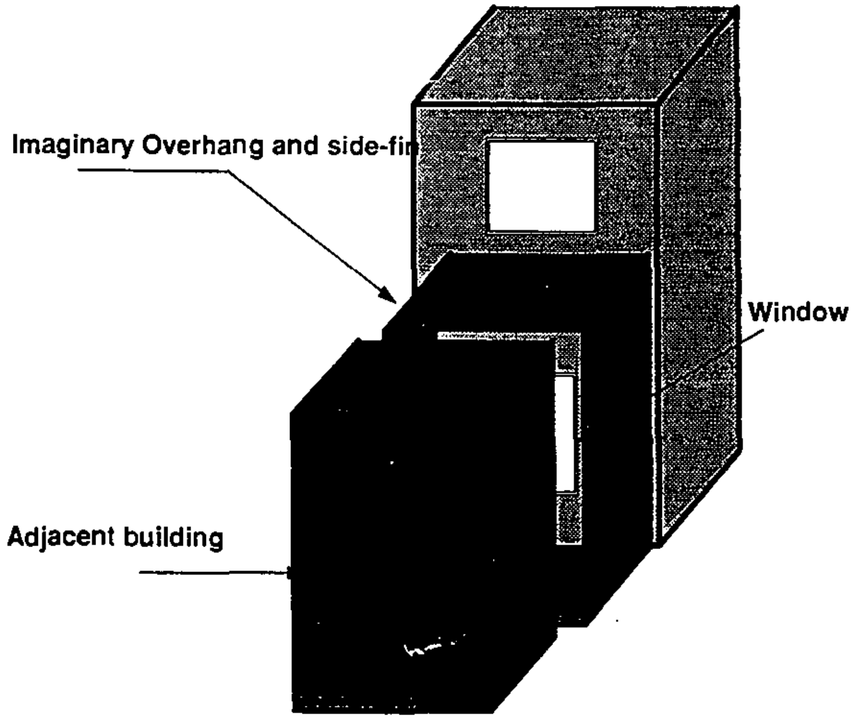

Figure 1. The gap between the adjacent building and the receiver surface is formed as an imaginary overhang/side-fin

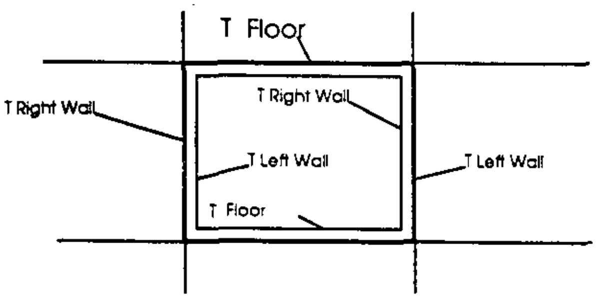

Figure 2 - Modelling adjacent zones with identical conditions in TRNSYS. The surface temperature used for the other side of separating fabric elements are assumed to be equal to that of the inside surface of their opposite elements.

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