INTERNATIONAL ENERGY AGENCY

SOLAR HEATING AND COOLING PROGRAMME

TASK VIII PASSIVE AND HYBRID SOLAR LOW ENERGY BUILDINGS

DESIGN TOOL EVALUATION EXERCISE - TECHNICAL REPORT

Dave Bloomfield
Building Research Establishment, Garston, Watford, Herts., England

6 April 1988

TABLE OF CONTENTS

PREFACE

INTRODUCTION TO THE INTERNATIONAL ENERGY AGENCY

The International Energy Agency was formed in November 1974 to establish co-operation among a number of industrialized countries in the vital area of energy policy. It is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD). Twenty-one countries are presently members, with the Commission of the European Communities also participating in the work of the IEA under a special arrangement.

One element of the IEA's program involves co-operation in the research and development of alternative energy resources in order to reduce excessive dependence on oil. A number of new and improved energy technologies which have the potential of making significant contribution to global energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), comprising representatives from each member country, supported by a small Secretariat staff, is the focus of IEA RD&D activities. Four Working Parties (in Conservation, Fossil Fuels, Renewable Energy, and Fusion) are charged with identifying new areas for co-operation and advising the CRD on policy matters in their respective technology areas.

SOLAR HEATING AND COOLING PROGRAM

Solar Heating and Cooling was one of the technologies selected for joint activities. During 1976-77, specific projects were identified in key areas of this field and a formal Implementing Agreement drawn up. The Agreement covers the obligations and rights of the Participants and outlines the scope of each project or 'task' in annexes to the document. There are now eighteen signatories to the Agreement:

Australia	Federal Republic of Germany	Norway
Austria	Greece	Spain
Belgium	Italy	Sweden
Canada	Japan	Switzerland
Denmark	Netherlands	United Kingdom
Commission of the European Communities	New Zealand	United States

The overall program is managed by an Executive Committee, while the management of the individual tasks is the responsibility of Operating Agents. The tasks of the IEA Solar Heating and Cooling Program, their respective Operating Agents, and current status (ongoing or completed) are as follows:

Task I	Investigation of the Performance of Solar Heating and Cooling Systems - Technical University of Denmark (Completed).
Task II	Co-ordination of Research and Development on Solar Heating and Cooling - Solar Research Laboratory - Girin, Japan (Completed).
Task III	Performance Testing of Solar Collectors - University College - Cardiff, UK (Ongoing).
Task IV	Development of an Insulation Handbook and Instrument Package - US Department of Energy (Completed).
Task V	Use of Existing Meteorological Information for Solar Energy Application - Swedish Meteorological and Hydrological Institute (Completed).
Task VI	Performance of Solar Heating, Cooling, and Hot Water Systems Using Evacuated Collectors - US Department of Energy (Completed).
Task VII	Central Solar Heating Plants with Seasonal Storage - Swedish Council for Building Research (Ongoing).
Task VIII	Passive and Hybrid Solar Low-Energy Buildings - US Department of Energy (Ongoing).
Task IX	Solar Radiation and Pyranometry Studies - Canadian Atmospheric Environment Service (Ongoing).
Task X	Solar Materials R&D - Dept. of Ceramic Science-GIRIN, Japan (Ongoing).
Task XI	Passive and Hybrid Solar Commercial Buildings - EMPA, Switzerland (Ongoing).

The participants in Task VIII are involved in research to study the design integration issues associated with using passive and hybrid solar and energy conservation techniques in new residential buildings. The overall objective of Task VIII is to accelerate the development and use of passive and hybrid heated and cooled low-energy buildings in the participants' countries. The results will be an improved understanding of the design and performance of buildings using active and passive solar and energy conservation techniques, the interaction of these techniques, and their effective combination in various climatic regions and verification that passive and hybrid solar low-energy buildings can substantially reduce the building load and consumption of non-renewable energy over that of conventional buildings while maintaining acceptable levels of year-round comfort. The subtasks of this project are:

0 - Technology Baseline Definition

A - Performance Measurements and Analysis

B - Modelling and Simulation

C - Design Methods

D - Building Design, Construction, and Evaluation

The participants in this Task are: Austria, Belgium, Canada, Denmark, Federal Republic of Germany, Italy, The Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United States, and United Kingdom. The United States serves as Operating Agent for this Task.

This report documents work carried out under a subgroup on Design Tool Evaluation set up at a fairly late stage in the Task. It is made up of some members of subtasks B and C and is led by the United Kingdom.

The IEA participants who have contributed to this report are:

S. Barakat
D. Bloomfield
M. Bruck
P. van Haaster
M. Holtz
R. Judkoff
B. Poel
R. Stricker
D. Wortman

EXECUTIVE SUMMARY

Within the IEA Task VIII project much use has been made of computerised methods of calculating the thermal performance of buildings. Their main use has been to allow the investigation of the effects of some design change on the thermal performance of a residential building, e.g. the effect of redistributing glazing from North to South facades, the choice of optimum levels of glazing and insulation etc. The use of such methods is the only practical way to enable a wide range of combinations of individual components to be explored.

Some of the effort within the Task was directed at evaluating the best building energy analysis simulation methods that were available to the Participants by performing comparisons with experimental data obtained from test cells and buildings. These more detailed calculation methods (or 'models') typically involved the numerical representation of the physical thermal processes from first principles. There are, however, many approximations that have to be made and, in a number of areas, appropriate input data is difficult if not impossible to obtain in practice. Even these detailed simulation models involve many physical, engineering and numerical assumptions.

The detailed models are not usually very easy to use, require a significant effort to learn, and can be expensive on actual run time. Detailed simulation models were used by most Participants to generate information which could be passed on to designers as simple, easy-to-use guidelines. It is not, however, an easy matter to ensure that guidelines of sufficient generality can be produced by such a process. All too often this fact has been ignored in the past and the guidance resulting has not spelt out the many detailed assumptions which have been made in producing them. Another complementary and attractive approach is to explore the use of simpler computational methods which could allow greater freedom for the designer to explore innovative designs and still to ensure that the assumptions made are appropriate to his own design problem. Many such simpler design models (or 'design tools') have been produced, but the level of evaluation that has been carried out is usually much less than for the detailed models. In addition, in order to obtain their greater speed and simpler user interface, more assumptions, approximations and default values will have been incorporated into them. As a result, the tools may be of questionable quality and the need for a rational means of testing them becomes of great importance.

A survey of design tools was conducted and a number of comparative checks carried out within Subtasks B and C of Task VIII. The results showed large differences between both the absolute results and the resulting design guidance, obtained with these tools. Interpreting the results of these tests was far from straightforward as attempts had been made to mirror a 'real' situation where the building investigated was quite complicated (i.e. the real world) and where the tool user may not have detailed knowledge of the field of thermal modelling. It was therefore not clear where the major reasons for the differences lay. Clearly this information is essential if future research is to be properly directed - is more effort needed on numerical analysis, on human computer interfaces or on education?

This report documents the simulation work conducted by the participants to an IEA Task VIII working group on Design Tool Evaluation. The goal of the working group was to investigate the practicality of producing a series of references, or benchmark test cases, which could be used as part of a rational process for choosing a thermal design tool for residential buildings.

Reference cases were devised, consisting of specifications for simulations of variants of a very simple rectangular plan building. A number of well-respected detailed simulation models were chosen by the national experts within the group and these were used to generate target ranges for two fairly extreme climates, Denver (sunny, with high heating and cooling loads) and Copenhagen (moderately cool and cloudy). The set of test cases was designed so that additional levels of complexity were introduced one at a time in order that maximum information could be derived from the results of each test case. The functioning of different algorithms can be checked by comparing differences in loads predicted between test cases. This is an important feature, since many design tools do not provide individual energy components separately.

A great deal of care was taken in devising the specifications for the runs (i.e. the description of the problem to be simulated) and in checking the input data for errors. Experience has shown that this has rarely been given sufficient attention in previous exercises and, as a result, genuine differences in results due to the model could not be distinguished from those due to the model user.

The ranges produced are not claimed to span the 'correct' values. Indeed, much work is still needed in the field of validation of thermal models. However, the work presented here has led to a practical methodology which can be used to estimate the range of applicability of a particular design tool for a limited set of conditions. The methodology has been tested using several national design tools and the results are presented in this report.

A reasonably narrow set of ranges in loads and in peak temperatures has been obtained by the use of five detailed simulation models. These ranges have been compared with the results from a few design tools and a first attempt has been made to suggest how a procedure for applying these tests might work.

The detailed simulation models used have all been subjected to previous 'validation' testing, and the participants have selected them for this reason and for the relatively *high* level of support and credibility that they enjoy. It is, however, accepted that these models are based upon a number of approximations and shortcomings and that they will almost certainly contain some errors. In the current state of the modelling world, this is inevitable. It was therefore expected from the outset that a range in results would be obtained from these models. It is argued that the narrowness of the ranges actually obtained is encouraging, whilst in no way proving 'correctness'. If a design tool is tested using the procedures developed here and produces a result that is outside only one of the ranges, this does not show that the tool is inadequate. If, however, it differs markedly from several of the ranges and gives rise to very different relative results from case to case, it certainly merits further examination or at least the exercise of caution in using results obtained with it.

A number of the working group participants intend to develop national procedures using the IEA Design Tool Evaluation methodology. This will involve producing user guides and actual test procedures tailored to the climatic conditions and building practices in each individual country. The IEA results presented in this report could be used directly as an aid to the selection of a suitable design tool and their adoption should lead to a real improvement in the quality of thermal design of residential buildings.

1. INTRODUCTION/BACKGROUND

The main aim of this exercise was to investigate whether a 'useful' set of simulations could be obtained for simple idealised buildings to be used as references against which the results of design tools could be compared as part of a selection process.

A number of IEA Task VIII participants have conducted these simulations for two fairly extreme climates (Copenhagen and Denver) using what they regard as 'good' simulation models. Copenhagen is moderately cool and cloudy, while Denver is a sunny climate with both high heating and high cooling loads.

The group members were:

Canada	- Sherif Barakat,	National Research Council
West Germany	- Rolf Stricker,	Fraunhofer Institut
Netherlands	- Bart Poel,	Bouwcentrum
	- Piet van Haaster,	
United Kingdom	- Dave Bloomfield,	Building Research Establishment (BRE)
United States	- Michael Holtz,	Architectural Energy Corporation (AEC)
	- Dave Wortman,	
	- Ron Judkoff,	Solar Energy Research Institute (SERI)

In addition some results were contributed by the following:

Austria	: Manfred Bruck,	ASSA
United Kingdom	: Don Alexander,	University of Wales Institute of
	: Peter Lewis	Science & Technology

For the purposes of this study, a design tool is defined to include both simulation models and methods employing other analysis techniques (e.g. correlations) used to predict heating and/or cooling loads in residential buildings. The cases presented in this study are designed to evaluate building envelope loads only, not system or plant performance.

If the range in the predicted results for the whole set of Cases considered is reasonably small, the ranges could be published as typical of what should be expected from a useful design tool or simulation model. The prospective user of such a 'tool' could then be advised to conduct some/all of the benchmark tests as part of his selection procedure. As the buildings themselves are extremely simple, they should cause a minimum of difficulty to the tool evaluator. They are structured to allow a range of conditions to be investigated, e.g. mass, glazing and type of control (heating, cooling/venting set-points). The tests should be useful for both design tool users and developers.

The set of simulations specified in Phase I of the exercise is restricted to continuous (as opposed to intermittent), plant control. The results of these were presented and discussed at the Denver meeting in February 1987. The exercise was subsequently extended to cover more realistic conditions such as internal gains, shading, night set-back and east-facing windows. A meeting was held in July 1987 at the Architectural Energy Corporation/Solar Research Research Institute in the USA to discuss the results and future plans of the Group. This Group met frequently over a two-week period, revised and extended the specification and conducted further simulations using BLAST, DOE2.1C, ESP and SERIRES. The DOE2 runs were performed by R Judkoff (SERI, USA), the BLAST ones by D Wortman (AEC, USA) and the ESP and SERIRES ones by D Bloomfield (BRE, UK).

The original set of buildings and control conditions was devised by BRE with the help of other members of the sub-group. This consisted of two basic buildings - a 'lightweight' and a 'heavyweight' version. The intention was to find a simple, single zone building with approximately the same thermal performance as a typical residential building. The final design represented a compromise, both for technical reasons and due to the variety of building types to be found in the IBA member countries. Any exercise such as this one has to be conducted in the face of the conflicting requirements of realism and simplicity. The need for the former is obvious; those for the latter have not been sufficiently well understood in the past. The experience of previous studies does show very clearly how important the complexity of a building is in a modelling study. For a 'realistic' building specification, many approximations and assumptions will have to be made by the model user and it is extremely difficult to achieve comparability between results obtained by different modellers and between different models. This problem is, of course, present in any real application of a model or design tool. The goals of the current exercise imply, however, that all possible sources of confusion should be eliminated in order that tests of the basic capabilities of a design tool can be investigated. The use of design tools in practice would merit a separate Task.

It should be pointed out that a somewhat similar exercise has been carried out as part of the IEA Buildings and Community Systems Annex I [1]. Other relevant work has also been conducted by SERI [2-4], and more recently by the UK BRE/SERC Validation Group [5] in devising analytical tests of the conduction algorithm. The current tests go further than these analytical ones in that they apply more realistic meteorological conditions to something that is recognisable as a building. The analytical tests involved the application of simple excitations to what was, effectively, a single wall. There is a very real difference between these two approaches in that, for the current set of tests, there is no known 'exact' solution.

It is important to realise that the purpose of the current exercise is different from that of the previous work cited. It will not and can not 'validate' a design tool; it is intended, however, to lead to a pragmatic aid to enable a practitioner to come to an informed decision as to what tool to use, based upon the best information available to experts in the modelling field. This would be a very valuable supplement to the work already conducted within the Task on design tool evaluation [6], in which large differences in predictions, both between design tools and between simulation models, were found for realistic buildings.

In this exercise, the detailed simulation models BLAST, DOE2, ESP, HTB2 and SERIRES have been used to determine the range of results which could reasonably be expected from a model. These have been chosen because of their availability, familiarity of the participants with their use and the assumptions made within them, and because they have all been subjected to some previous validation. Results were also obtained with several versions of DEROB. The simulation results presented here were obtained with the official International Users' Association version.

The models BREDEM, EASI, EBIWAN and ENERPASS can be regarded as simpler design tools, in that they employ a greater level of approximation in the modelling procedures or in the input data required. Some results for these have been obtained and compared with the ranges resulting from the use of the detailed models. The DEROB results for cases 0-12 are also included under the category of design tool. This is because there was more doubt as to their reliability and as the results only became available at a late stage in the Task.

2. PHASE I EXERCISE

2.1 THE EXERCISE AND PROBLEMS ENCOUNTERED WITH THE SPECIFICATION

The Cases are numbered 0 to 12 and brief details are given in Table 1. The full specification is given in the Appendix, together with a summary of the climatic data for Copenhagen and Denver, and information on how to obtain the full hourly data.

CASE NO.	SET POINTS C heating	cooling	MASS	WINDOW	SURFACE PROPERTIES E.A.	E.E.	I.A.	I.E.	OTHER
0	20	20	l/w	opaque	0.5	0.9	0.6	0.9	no ventiln.
1	20	20	l/w	opaque	0.5	0.9	0.6	0.9	
2	20	20	h/w	opaque	0.5	0.9	0.6	0.9	
3	20	20	l/w	real	0.5	0.9	0.6	0.9	
4	20	20	h/w	real	0.5	0.9	0.6	0.9	
5	20	27	l/w	opaque	0.0	0.9	0.6	0.9	
6	20	27	h/w	opaque	0.0	0.9	0.6	0.9	
7	20	27	l/w	opaque	0.5	0.9	0.6	0.9	
8	20	27	h/w	opaque	0.5	0.9	0.6	0.9	
9	20	27	l/w	real	0.5	0.9	0.6	0.9	
10	20	27	h/w	real	0.5	0.9	0.6	0.9	
11	free floating		l/w	real	0.5	0.9	0.6	0.9	
12	free floating		h/w	real	0.5	0.9	0.6	0.9	

TABLE 1

KEY

l/w - lightweight
h/w - heavyweight
E.A. - external absorptivity (shortwave)
E.E. - external emissivity (longwave)
I.A. - internal absorptivity (shortwave)
I.E. - internal emissivity (longwave)

The results presented at the February meeting gave the participants sufficient encouragement to proceed with the exercise. The Appendix contains the latest specification as provided to the participants in February 1987. The omissions and ambiguities in the first specification (which inevitably occur in the initial stages of such exercises!) noted at the February meeting have been addressed in this current version. The extra details provided concern glazing properties, distribution of solar radiation to internal surfaces, infiltration rate, the atmospheric pressure to be used with the Copenhagen weather file and the definition of the 'opaque window'.

Some programs such as DEROB made assumptions about the properties of glass which could not be bypassed by the user. The normal transmittance of a single glazed window made of standard glass is 0.847. For glazing consisting of two panes of single glass this value is 0.72. In the course of the ESP modelling a number of checks were carried out (see later) and a value of 0.74 for the direct normal transmittance was obtained from calculations based on the window properties specified.

A number of the models used make quite gross simplifications in their modelling of the glazing, in effect using a simple, constant conductance model - e.g. SERIRES, ESP (when used in the standard default mode - there is a facility recently added, but not fully tested, to allow 'transparent walls').

The specification was not sufficiently detailed for models such as DEROB and HTB2 and this led to some difficulties. In addition, as already noted, some models (e.g. DEROB) make assumptions internally as to the properties of e.g. glazing, so that exact equivalence is hard to obtain.

The distribution of solar to internal surfaces was specified as uniform over all surfaces apart from the ceiling (this was in an attempt to maintain some realism). This poses no problem for e.g. SERIRES, where the Netherlands group applied this exactly, taking into account both sides of the internal walls. The BRE group revised their first set of assumptions to correspond with this. For other models such as DEROB, the proportion of radiation incident on each surface is calculated for the mid-month day using the actual solar geometry. In ESP a number of options are allowed, including a rigorous calculation. The latter is rather complicated to achieve in practice, and a simpler option of splitting the radiation uniformly between all surfaces was adopted. In addition, a sensitivity analysis was performed and is described in section 4.5. The sensitivity predicted was fairly small (less than 5X).

Some of the codes, notably SERIRES, require constant, combined values for surface coefficients to be specified, whilst others (e.g. BLAST, DEROB, ESP) calculate their own values at each time step. The BLAST runs for Denver gave similar values on average to those specified. Initially, an option in ESP was used to bypass the detailed calculation and use the fixed coefficients as specified. An issue of principle clearly arises here - should the exercise be most concerned with:

(a) obtaining agreement between models
(b) understanding the reasons for disagreement, or
(c) producing results which are regarded as being the most accurate?

In the early stages of the exercise, emphasis was placed on (a) and (b); in the later stages, the participants were able to build upon the understanding developed and place greater emphasis on (c).

The definition of an infiltration rate gave rise to some confusion. The intention was that a volumetric air change rate of 1 room volume per hour be used. For locations significantly different from sea level such as Denver, clearly the equivalent mass flow rate will be quite different, and will vary with air temperature and barometric pressure. Programs such as ESP rely upon the user to make a correction to the specified rates, whereas others (e.g. DEROB, SERIRES) apply a formula internally to correct the ventilation heat loss to account for altitude. Others such as BLAST rely upon data supplied from the climate file (atmospheric pressure). In the latter, some problems arose for those without access to the full climate tapes. In the case of the Copenhagen TRY, such data was unavailable to the participants and the assumption of a constant value appropriate for sea level was used from another sea level location (Seattle). From the graphs presented later it can be seen that good agreement was obtained for infiltration losses between models using these two approaches.

One further slight problem arose with the Copenhagen runs due to slight differences in the versions of weather files obtained at various stages by the participants. A difference between the versions of the Copenhagen weather files obtained from the sub-Task B leader was noticed. In the first version obtained it appeared that the wind speeds were all 10 times too large. This had been corrected in the second, compressed version obtained (the one that BRE has distributed). In addition, there were some differences in the solar radiation values. BRE conducted an investigation into these differences and concluded that they had arisen from rounding errors. SERIRES simulations were conducted using both versions and only very small differences in heating loads resulted.

The effect of some of the different assumptions discussed above was investigated by a number of sensitivity analyses, which are discussed in section 4.

Following the February meeting, and in view of the reasonably close agreement between the predictions, it was decided that some of the artificial restrictions on the specification should be removed. In particular, those codes which could either use dynamically calculated or user-supplied fixed values for surface coefficients were allowed to use the more rigorous method. This decision was made because such flexibility does not exist in all of the models being used and can reasonably be regarded as part of the model itself. It was also agreed that detailed longwave radiation and solar lost should be modelled if possible, i.e. it was decided that the most accurate use of the models should be made, albeit for idealised buildings and run conditions. The results presented here refer to those obtained from this latter stage of the exercise.

2.2 RESULTS FROM PHASE 1

Results were obtained as follows:

AUSTRIA	EBIWAN	- Copenhagen and Denver ,	Cases 1-10
CANADA	EASI	- Copenhagen ,	Cases 0-4,7-12
	ENERPASS	- Copenhagen and Denver ,	Cases 0 -12
GERMANY	DEROB	- Copenhagen and Denver ,	Cases 0-12
NETHERLANDS	SERIRES	- Copenhagen and Denver ,	Cases 0-12
UK (BRE)	SERIRES	- Copenhagen and Denver ,	Cases 0-12
	BREDEM	- " " ,	Cases 1-10
	ESP	- " "	Cases 0-12
UK (UWIST)	HTB2	- Copenhagen and Denver ,	Cases 1-12
USA-AEC	BLAST	- Denver ,	Cases 0-4,7-12
USA (SERI)	DOE2.1C	- Copenhagen and Denver ,	Cases 0-12

It was decided that Cases 5 and 6, in which the external solar absorptances had been set to zero, should be dropped from the final set of reference cases, mainly because very few design tools allowed the model user any control over this process. Accordingly, results obtained for these cases will not be discussed in this report.

The annual heating and cooling loads predicted by the five detailed simulation models BLAST, DOE2.1C, ESP, HTB2 and SERIRES are shown in Figs 1-4. The results for BREDEM, EASI, EBIWAN and ENERPASS are plotted separately in Figs 17-20 as these are regarded as simpler design tools, the results of which need to be checked against the ranges produced by the detailed models. The results for DEROB are also plotted in Figs. 17-20 as some algorithms did not perform satisfactorily. The reasons for this will be discussed later.

Fig. 5 shows the monthly net plant load (i.e. the heating-cooling load) for Denver Case 4. The remaining graphs show some of the input and intermediate calculated quantities. Figs. 6 and 7 show the infiltration loads for those models that can provide this output, Fig. 8 shows the annual solar gains received by the space, Figs. 9 and 10 show the solar radiation incident on the external South-facing surface. Figs. 11 and 12 show hourly values of the solar gains received by the space for May 30 and Figs. 13-16 show the predicted free-floating temperatures for Cases 11 and 12.

2.3 CONCLUSIONS - PHASE I SIMULATION MODEL RESULTS

It is appropriate to give some conclusions on the results obtained with the detailed models at this stage. It was consideration of these which led to the specification of a further phase of simulations.

1. The annual heating loads showed reasonably good agreement; for Denver the maximum difference was +-19% (900 kWh) from the average of the five models; for Copenhagen the maximum difference was +-4% (394 kWh) from the average.

2. The relationships between the models' load predictions for cases 0-10 remained the same, i.e. the relative performance of heavy vs light-weight construction (less than 3% with no glazing) etc.

3. For the annual cooling loads, similar differences were obtained although these appear larger if expressed in percentage terms.

4. For both heating and cooling, Case 4, the heavyweight real window case, showed the largest differences.

5. For Denver Case 4, the predicted monthly values can be seen to be in reasonable agreement, as well as the annual values.

6. The infiltration loads predicted by DEROB, DOE2.1, ESP, HTB2 and SERIRES are in good agreement with each other for both Copenhagen and Denver (the maximum difference is 5%). This tends to confirm the adequacy of the different inputs used by DOE2.1 and BLAST.

7. The predicted solar input to the building shows substantial differences between ESP and the other models, particularly for Denver. The ESP values are greater than the HTB2, SERIRES and BLAST ones by approx. 15-30%. Both ESP and DOE2.1C assume an anisotropic sky model so that higher values of solar gain should be expected. However, this seems to be too large for Denver. ESP, DOE2.1 and HTB2 calculate the solar radiation reflected back through the window, although the output values plotted here are the gross values with no allowance for this effect. SERIRES requires as input a user-defined constant, which has been set to zero in these runs. The solar reflected back through the window is therefore not allowed for at all. It is not known whether the values output from BLAST allow for this effect or not.

8. Figs. 9 and 10 show that for a single day, May 30, the solar radiation incident on the South wall (which has been obtained by processing the original meteorological data making particular assumptions about the sky distribution) is predicted by ESP to be 20-40% greater than by HTB2 and SERIRES. The shape of the curves are reasonably similar. The calculated solar gain to the building on 30 May is shown in Figs. 11 and 12. The same shape and differences are apparent, and for Denver the BLAST, HTB2 and SERIRES results can be seen to be in good agreement with each other. It seemed likely that the differences in solar gain and hence in calculated loads are due largely to the procedures used for calculating incident radiation rather than for the transmission of solar radiation through windows. A separate calculation of solar transmissivity from the model results obtained was performed by SERI. This led to very close agreement (within a few %) for both annual

and May 30 hourly values in Copenhagen and Denver. The results compared were DOE2.1 and SERIRES for annual values in Denver, and DOE2.1, ESP and SERIRES for May 30 hourly values in Copenhagen and Denver.

9. For the free floating cases 11 and 12, predicted temperatures are plotted in Figs. 13-16. Differences between the predictions are obtained in mean values, ranges and in phase.

10. In the case of ESP and HTB2 both air and mean radiant temperatures were calculated. These two temperatures are predicted to differ by up to 2 C for this building. The comparisons are difficult to interpret given the different solar inputs to the building as demonstrated above. For SERIRES, BLAST and DOE2.1 the temperatures predicted for Denver are in fairly good agreement (differences of approximately 0.5 C).

11. The disagreement in temperatures is greatest for Copenhagen.

12. It would be expected that the ESP mean radiant temperatures would give a better fit to the SERIRES values, but this does not seem clear from the results obtained.

13. In Figs. 17-20 the ranges obtained from the detailed models' results have been superimposed on the design tool results. The following conclusions can be drawn (14-18).

14. EASI predicts high heating loads for opaque windows (probably because it does not account for opaque solar absorption).

15. EBIWAN gives results inside or close to the ranges throughout. It should be noted, however, that the input data for EBIWAN was chosen after reference to the SERIRES results.

16. BREDEM gives high heating load predictions for opaque windows (probably for the same reason given above in 12).

17. As BREDEM does not deal with mass or different control schemes, the adequacy of its predictive capability is very dependent on its intended application. It performs in a similar way for both Denver and Copenhagen.

18. The ENERPASS results seem somewhat unreliable in their treatment of mass (see section 3).

19. The following factors relating to the DEROB - IUA results are expected to have contributed to differences in predictions as compared to those of the other detailed models:

- envelope heat losses are expected to be higher due to the assumptions made about external longwave radiation to the atmosphere (this is calculated according to Brunt, using the Dines coefficients)

- in calculating the longwave radiation exchange between ground and building, the ground temperature has been approximated as equal to the outdoor air temperature

- convection at the indoor surfaces have been calculated based on an air velocity of 2 mph

- the window U-value is not under user control, the value used here was 3.31 W/sq.m.K

- a perfect energy balance may not be maintained at all times, a temperature tolerance being set at 0.5 C

- for some cases, the calculation of surface temperatures of the lightweight elements (window, floor) failed to converge in the iteration loop; this numerical problem was overcome by coupling the temperatures of successive iteration steps in order to cause a damping of the temperature amplitudes

- the solar input to the building is smaller than for the other models for two reasons:

  (a) splitting the internal surfaces into a 3x3 grid caused some inaccuracies
  (b) diffuse radiation is calculated using a form factor between exterior surface and sky.

It is difficult to draw conclusions based only on absolute predictions. Also, these may not be the quantities of most interest to the eventual design tool user. The differences between predictions resulting from some design change may be more useful to a designer, depending on the purpose for which the model is being used. For this reason some of the results have been presented in a form to show this explicitly.

Figs. 21-24 show the difference in load between the corresponding light and heavyweight cases as predicted by the detailed models, i.e. the load for Case 1 minus that for Case 2, Case 3 minus Case 4 etc. This leads to the following conclusion for the five detailed models.

19. The effect of mass is always given as in the same direction for these continuous heating cases and with a substantial level of agreement (the same scales have been used in Figs. 21-24 as in Figs. 1-4).

3. MODEL DESCRIPTIONS, MODELLING ASSUMPTIONS AND PROBLEMS ENCOUNTERED IN PHASE I

This section is devoted to explaining in more detail what problems were encountered by the modellers in carrying out this exercise. It was revised following the discussions at the February and July meetings.

It must be stressed that an exercise such as this can not sensibly be carried out without a great deal of attention being devoted to ensuring that the assumptions made both internally and externally by the detailed models are compatible and, further, that efforts have been made to guard against mistakes being made in the data input process. This section and the equivalent one for Phase II (section 6) should be regarded as an important part of this report.

3.1 ESP

ESP (Environmental Systems Performance) was developed by the ABACUS unit of the University of Strathclyde, Glasgow, UK. The version used for this exercise was that implemented on a Whitechapel Computer Works MG1 workstation at BRE. The simulation program part of the overall suite was version 5.3d.

Surface coefficients are normally calculated dynamically in ESP. An option exists which allows this to be bypassed. In the first part of the exercise, prior to the February meeting, this option was used and the constant values for convection coefficients were as follows:

	internal	external	
walls	3.0	30.0	W/sq.m K
ceiling	4.3	30.0	W/sq.m K
floor	1.5	[3.0]	W/sq.m K

TABLE 2

In the second part of the exercise, dynamic calculation was invoked and these results are documented in this report.

In ESP the results are accessed by a separate program OUT from a results library. In order to save space, the values of the heat convected to the opaque surfaces are not saved in the file; they are recalculated separately by OUT. Some approximations are made at this stage e.g. average time step values are used, and for the version used in the first part of the exercise, an error was present in this routine. The values quoted for opaque surface convection were therefore incorrect. They were therefore not used in the previous interim report. The results presented here have been obtained using an updated version of the OUT program, so that the routines used in SIM and OUT are consistent. There is however, an unresolved question as to the accuracy of the convection routines used. The ESP developer and UK researchers in this field are still trying to resolve this.

An indication of the importance of using the ESP default dynamic calculation of convection coefficients instead of the constant values above can be obtained from the sensitivity analyses shown in section 4.1 (approx. 3% in annual heating loads for Copenhagen).

In calculating the external longwave radiation, a 'site index of exposure' of 3 has been assumed. This defines a 'rural' site where the proportions of sky vault, surrounding buildings and ground 'seen' are 45, 10 and 45% respectively.

The glazing properties were calculated essentially from the equations given in the SERIRES manual (page 6-10 in [7]). In order to check the solar data specified to ESP in the standard set of runs, the exact equation for normal transmittance (as opposed to the approximation used in [7]) was used with the values for refractive index, extinction coefficient and pane thickness specified. The resulting value of normal transmittance for a single pane (0.8611) plus the other data was then used as input to the program WIN to calculate the transmittances at the required angles of incidence for input to ESP. This procedure was necessary because values of normal transmittance are not available for pane thicknesses of 3.175 mm. The results do lie within the range expected, based upon values for 4 and 6 mm glass given by Pilkington's in [8]. The values used in the second set of runs were those resulting from the above procedure and are given in Table 3:

angle of incidence	direct transmissivity standard	direct transmissivity WIN	heat gain factor standard	heat gain factor WIN
0	0.75	0.7460	0.79	0.7899
40	0.73	0.7274	0.77	0.7751
55	0.69	0.6819	0.73	0.7320
70	0.52	0.5066	0.55	0.5553
80	0.26	0.2415	0.28	0.2828

Note: heat gain factor is defined to include the energy absorbed and then re-transmitted by the window

TABLE 3

The differences between these two sets of values can be seen to be very small in real terms (less than 1% for angles up to 55 degrees, and a maximum of 8% for 80 degrees. It can therefore be concluded that the values used in SERIRES are consistent with those predicted by the ESP suite of programs.

The results of slightly different assumptions with respect to the glazing are shown in section 4.2 (less than 1%).

The definition of time is not absolutely straightforward - it was assumed that the climatic data used in this exercise was corrected to local time.

Prior to the February meeting, the standard results presented used ESP's default view factors in calculating the internal long-wave radiation exchanges. It is possible to use a separate program VWF to calculate exact values and then to substitute these into the simulation by setting a flag in the utilities file. This was done in the second set of runs reported here. The difference that this makes (negligible) can be seen from the sensitivity analysis described in section 4.3. It should be noted that long-wave radiation to the windows is not modelled explicitly in the approach adopted here.

The building was modelled as two separate zones mainly in order to avoid confusion in the specification of appropriate boundary conditions for the internal mass. In view of the slight asymmetry between the two zones, an interzone airflow was modelled as suggested in the specification; this was set to 10 ac/h.

3.2 BLAST 3.0

BLAST 3.0 is a detailed hourly simulation developed by the Construction Engineering Research Laboratory in Champaign, Illinois. It can handle building types ranging from simple residential to large commercial buildings. The model is divided into separate programs which perform separate calculations on the zone, system and plant portions of the problem. Only the zone-level program is used in this work. The version used by Architectural Energy Corporation is Version 107 of BLAST 3.0. The code is run on a CDC Cyber 850 mainframe computer at the NOAA facility in Boulder, Colorado, USA.

The building is treated as a single zone, with the dividing internal wall modelled using the "INTERNAL MASS" command in the BLAST building input language. The walls, floors and ceilings are described in BLAST as "MATERIALS", which contain bulk material properties, and "WALLS", which are made up of the previously described "MATERIALS". These were specified exactly as required for the exercise. The heat flow through massive elements is calculated on an hourly basis, and uses conduction transfer functions. The film coefficients are calculated at each time step, with values being a function of surface orientation and temperatures and other relevant factors. The interior surfaces are connected through the interior film coefficients to a central air node. There is a radiation heat flow path, parallel to the convection heat flow path, which models surface radiation heat flow via a mean radiant temperature node. Ground coupling is modelled as a one-dimensional heat flow path to a user-specified ground temperature.

Infiltration is modelled as a constant volumetric flow rate, with the air mass flow rate being a function of outdoor temperature and air pressure. The air pressure used for the Denver runs is read from a Denver TMY weather file, while the air pressure used for the Copenhagen runs is taken from a Seattle TMY file. Seattle is at sea level with weather reasonably similar to that of Copenhagen.

The window optical properties are modelled by specifying their normal transmissivity, with inputs equivalent to those used in SERIRES.

3.3 SERIRES

SERIRES is the public domain version of SUNCODE. The specification for the program was devised by the Solar Energy Research Institute, USA and the coding was produced by Palmiter and Wheeling, Ecotope Ltd. The version used for this exercise by both the Bouwccentrum and the Building Research Establishment was that produced by Ecotope for an IBM-PC. This is known as SUNCODE 5.4. SERIRES was used by a number of participants to Task VIII for other subtasks (e.g. for the parametric studies performed in developing design guidelines).

No departures from the specification were necessary. In the first set of runs performed by BRE the incoming solar radiation was distributed uniformly to all internal surfaces. Subsequently the more accurate scheme devised by the Netherlands team was adopted. Care was taken to ensure that both sides of the internal wall were accounted for. Neither the BRE or the Netherlands results presented at the February meeting had allowed for the solar radiation absorbed in the opaque window. This was corrected in the results presented here by putting the opaque window in the WALLS section rather than the WINDOWS section.

3.4 DOE2.1C

DOE2 is a public-domain computer program which was developed by the U.S. Department of Energy for detailed, hourly thermal analysis of residential and commercial buildings. The program is divided into several modules including an input language pre-processor, a Loads subprogram, a Systems subprogram, and a Plant subprogram. The Loads program uses response factors to determine the transient or dynamic flow of heat through building envelope elements as they respond to randomly fluctuating climatic excitations. The Loads program can also use 'custom weighting factors' to determine the thermal lag associated with interior mass elements.

In the Loads program heat gains and losses through walls, roofs, floors, windows, and doors are calculated separately. All the Loads calculations are performed assuming a fixed internal temperature for each space as specified by the user. Because of this the output from Loads may have little bearing on the actual thermal requirements of the building. The Systems program modifies the output from the Loads program to produce actual thermal loads based on hourly variable internal temperatures.

Outputs from the Loads and Systems programs were sufficient to meet the requirements of this study. A very simple oversized 'ideal' heating and cooling system was specified as input to the Systems program.

Specific modelling approaches, problems, and issues are discussed below:

a) The building was modelled as a single zone. The internal mass was modelled using a command in DOE2.1C, 'Interior-wall-type=Internal'. This facility is intended to allow modelling of a mass wall which is internal to a single zone. The internal wall contributes only to the calculation of custom weighting factors. A bug was discovered in this routine which does not correctly calculate the '(film-U)*(area)' product. In order to correct for this so that both the thermal capacitance, and the '(film-U)*(area)' product were correct, the wall thickness was halved and the wall length doubled. This will have a small incorrect effect on the calculation of interior radiation exchange, and the calculation of cavity albedo within the weighting factor portion of the program.

b) The glass conductance input in DOE2.1C excludes the exterior film coefficient which is calculated hourly. The glass conductance input is therefore defined as from the inside air to the glass exterior surface = 2.9296 W/sq.m.K.

c) The weighting factor calculation routine calculates the quantity of solar energy lost optically back out of the space through the windows based on internally fixed assumptions about room geometry and interior surface optical properties. Thus it was impossible to fix this quantity to 0, as specified.

d) Exterior film coefficient is calculated hourly. The inside film coefficient is a user-defined constant.

e) The minimum allowable thermostat throttling range was O.1F. Thus the setpoints were defined for the 20/20 cases as 67.95 - 68.05F. (A bug in the Systems program required English Unit inputs).

f) The DOE2.1C program uses an anisotropic sky model. This model gives greater incident solar gain on South facing surfaces than does the isotropic model used in BLAST, HTB2 and SERIRES.

g) Glazing optical properties are predefined via glass 'library' entries. Therefore, the glazing optical properties in DOE are not exactly equivalent to the specification. The library entry which most closely matched the specification was chosen. This gave at normal incidence over the whole solar spectrum:

transmittance = .75
reflectance - .16
absorptance = .09

h) The Copenhagen weather tape did not contain all the fields of data used by the DOE2.1C weather preprocessing program. To compensate for this, missing fields of data were spliced in from the Seattle TMY weather tape. Seattle has a cloudy maritime climate, is at sea level, and is in the northern USA.

i) DOE2.1C corrects the density of air for pressure and temperature. Barometric pressure from the weather tape is used for this correction. Since Barometric Pressure was not reported on the Copenhagen weather tape, hourly values from the Seattle weather tape were used. This yielded only very slight differences for 'infiltration heat loss' from those modellers who used a constant standard sea level barometric pressure in their weather file.

j) The thermostat control temperature is the zone air temperature.

k) 12 midnight to 1AM is defined as hour 1 in the DOE2.1C scheduling routings, and in the weather routines. All time is local time with no daylight savings.

1) The DOE2.1C program calculates 'response', and 'weighting factors' for calculation of space loads. In the loads portion of the program it is assumed that interior space temperature is maintained at a user defined constant temperature. In the 'systems' portion of the program a 'perturbation' routine is used to calculate actual space temperatures. This approach has two serious limitations from the point of view of the designer:

(1) Component envelope loads can only be obtained for the user-defined constant zone temperature. Component envelope loads cannot be obtained based on actual varying internal temperatures.

(2) The selection of the constant user-defined space temperature affects both the systems loads and zone temperatures predicted by the 'systems' portion of the program. In conventional building spaces these effects are very minor. In spaces which have free-floating temperatures, or which have large deadband control strategies, and which are also strongly solar driven, this can lead to large uncertainties in temperature and equipment energy predictions. Atria and sunspaces are examples of these kinds of spaces.

3.5 HTB2

HTB2 is an explicit finite difference model developed at the University of Wales Institute of Science and Technology (UWIST), UK. The version used for this exercise was release 2, running on a DEC microVax. HTB2 uses a very small time step of the order of minutes and employs detailed solar algorithms.

Transmitted radiation is treated in the normal way, while radiation absorbed in each pane of glass is treated by the normal conduction algorithms. The solar radiation reflected back out through the window is calculated internally using form factors. Solar radiation is absorbed by the opaque window.

The surface heat transfer coefficients used in these runs were set to the constant values given in the original specification.

Both control temperature definition and the radiative/convective proportion of heat inputs can be varied.

The runs conducted for this exercise have been performed by Don Alexander and Peter Lewis of UWIST although they are not formally participants to the Task.

The initial sets of results provided showed large differences from the results of the other codes. It was subsequently reported that a number of input data errors had been made in the course of the modelling. After alteration of these files, the current results shown in this report were obtained. The UWIST team did have access to the results from the other codes at this time, so that the results presented here do not represent a blind test.

The reasons given for the differences between the two sets of results by UWIST were as follows. A number of errors were made in preparing the data description files due to misunderstandings and misinterpretations of the operation of HTB2. The major errors were:

meteorological data was time shifted by at least 1/2 hour

British Summer Time time changes were not switched off, leading to another shift of 1 hour in meteorological data for part of the year

the explicitly defined solar patching (direction of solar radiation to a particular surface inside the room) included the misdirection of some solar gains to the external surface of the roof, representing a significant loss of solar gains

the program's default cavity resistance was used for the glazing this increased the glazing U-value from 2.5 to 3.5 W/sq.m K and affected the calculated loads

for the Denver runs the correction for altitude was incompletely applied; only the appropriate air density was specified - this does not affect the heat capacity of internal air which needs to be altered separately; heating and ventilation exchanges were affected and would have represented those appropriate to sea level in the original runs.

3.6 EASI

EASI is a simplified version of ENCORE and should properly be described as a design tool. As such, its results should not be included in the setting of the ranges which will constitute the test reference cases. It was developed by D. Sander of the National Research Council of Canada's Institute for Research in Construction.

The inclusion of such a design tool allows an additional check on how easy the benchmark tests are to apply to tools other than simulation models.

The building is modelled as a single zone because EASI is not designed to deal with multi-zone buildings.

A floor is not explicitly modelled in EASI but its mass is allowed for.

Short-wave solar radiation is assumed to be spread uniformly amongst all the surfaces, with solar transmission through windows calculated hourly using the ASHRAE shading coefficient concept. The angles of incidence for direct solar radiation are calculated for every hour of the day for a single day of each month (15th). These values are then applied to the actual hourly values of incident radiation for each day of the year.

EASI does not make any allowance for solar radiation absorbed on external opaque surfaces, nor for external longwave radiation. For EASI, therefore, in the original set of Phase I runs, Cases 7/8 were identical to Cases 5/6. In fact, as already stated, the latter Cases gave rise to difficulties for several of the models so that they were discarded; no results for them are presented in this report.

Although ENCORE, the model from which EASI was derived, calculates the response factors for each wall, EASI uses a simple (area x conductance) concept. Response factors are, however, used internally to calculate loads and temperatures. Response factors used correspond to light and heavy houses assuming 46 and 535 kg/sq.m. floor area respectively [9]. Errors in hourly values may be caused by this approximate treatment.

For the Denver runs, the incident solar radiation values were over-estimated. These results were therefore discarded and are not presented here.

3.7 EBIWAN

The version used by the Austrian participant was EBIWAN2.1; this is described as a design tool. As for EASI, therefore, these results should not be used in determining the reference case ranges.

The building mass is modelled by the use of a simplifying concept adopted by the Austrian Standards body; this concept makes use of a 'useful storage mass'. This is the mass of a standard body having a specific heat capacity of 0.29 Wh/kgK with a 'useful storage capacity' equal to that of the wall considered. The 'useful storage capacity' is defined as the ratio of the amplitudes of heat flow to surface temperature at the interior wall surface. For each of the walls in the building, values for this were calculated prior to running EBIWAN.

Energy flows are calculated on a monthly basis using distributions of radiation/air temperature calculated from the weather files supplied.

Energy flows through windows were calculated by means of 'total energy transfer coefficients'. These involve the use of surface coefficients for which values of 8 and 20 W/sq.m K have been used for internal and external surfaces. These values differ from those specified. They were chosen in order to lead to minimum deviations of EBIWAN results from SERIRES ones and so the results do not represent a blind test of the model's capabilities.

3.8 ENERPASS

ENERPASS is an explicit finite difference model developed by a Canadian private company ENERMODAL ENGINEERING LTD which has been supported financially by the Canadian Government. It is not in the public domain.

Some of the assumptions made in developing this model were intended to simplify the input data required. Only three different types of mass wall are allowed and average, equivalent homogeneous properties for each have to be specified. For this exercise, the roof properties were approximated by assuming they were equal to those of the external walls. For this reason the group that met in July 1987 decided that ENERPASS should be designated as a design tool.

An anisotropic sky model is used.

3.9 BREDEM-8 (Monthly BREDEM)

BREDEM (Building Research Establishment Domestic Energy Model) is a name used to identify a family of models with varying levels of complexity and intended end uses. The individual versions, identified by an index number, can all be described as semi-empirical, making use of information gained from monitored building performance for e.g. occupancy patterns, hot water usage, plant efficiencies, temperature decay during plant 'off-periods' etc. The version used here, BREDEM-8, accepts monthly average weather data which have been derived from the hourly information provided. The method used for the calculation of solar utilisation is based upon a correlation approach due to Roulet [10].

BREDEM assumes that a building can be divided into two zones, reflecting the fact that living room heating standards are usually better than in the rest of a dwelling. For this exercise, however, zone 1 was defined to occupy the whole building, and outputs referring to the non-existent zone 2 were ignored. It was also necessary to make minor amendments to the program code in order to model the extremely simple buildings specified. For example, BREDEM would normally assume that a building is occupied and, therefore, would calculate heat inputs due to the presence of household appliances (TV, refrigerator, lights etc) as well as metabolic heat inputs from the occupants. To obtain zero internal gains for this exercise small modifications to the code were made.

In the latest version of BREDEM, used in this exercise, there is no specific allowance for mass, cooling or for deadband temperature controls (results for Cases 1-4 are, therefore, identical to those for 7-10, those for Case 1 equal to those for 2, 3 for 4 etc).

Solar absorption at external surfaces is not allowed for.

3.10 DEROB-IUA 1.0

DEROB (Dynamic Energy Response of Buildings), a suite of six programs, was originally developed by Prof. F. N. Arumi at the Numerical Simulation Laboratory of the University of Texas, Austin, USA in 1979.

The present exercise was conducted with the International Users' Association current version IUA 1.0. As some algorithms (e.g. solar processor, heat transfer at external surfaces) were found not to perform satisfactorily it was designated as a design tool rather than a detailed simulation model. The reasons for these shortcomings have been detected and a new DEROB-IBP 1.0 version has been prepared.

DEROB is a multi-zone model that translates a building description into an analogous electrical network and then solves the network using the Gaussian method for hourly weather conditions.

A feature of the program is the more detailed treatment of the long and short wave radiation both inside and outside the building. The convective heat transfer is dependent on both temperature and air velocity. This leads to a dynamically varying, radiation and convection dependent film coefficient at both inside and outside surfaces of a building.

The heating system modelled is idealised, with no time delays.

Several significant boundary conditions (e.g. solar glazing transmittance and window U-values) can not be defined by the user since they are fixed in the program code. The data used internally for double glazing are:

direct normal transmittance	=	0.72
direct normal reflectance	=	0.12
direct normal absorptance	=	0.12
U-value	=	3.31 W/sq.m K

Using these values, the total solar transmittance is calculated hourly, depending on the angle of incidence of direct solar radiation; the hourly Sun position is only calculated for the mid-month day.

Ground temperature can be fixed in the code as equal to the daily mean ambient temperature, or it can be user-specified, the values being read hourly from the weather tape. For this exercise it was set to a constant 10 C.

The building was modelled as two zones, connected by a fan with a capacity of 10,000 cu.m /hr.

3.11 DEROB-IBP 1.0

The IBP 1.0 version was developed from the IUA 1.0 version with the modifications described below.

(a) For lightweight building elements the iteration process for determining surface temperatures may:

-fail to converge
-introduce an energy imbalance if too wide a temperature tolerance (0.5 K) is used within the iteration loop; this imbalance increases with decreasing weight of the building elements, and when the internal temperature is allowed to free float.

This strictly numerical problem was solved by:

(i) coupling the temperatures of successive iterative steps to each other, causing a damping of the temperature amplitudes from one iteration step to the next one, and by

(ii) reducing the temperature tolerance to a value of 0.01 K.

Because of these modifications, temperatures converge faster within the iteration limit and the accuracy of the energy balance is improved.

(b) For computations of convection at indoor surfaces, the air velocity has been changed to 0.2 mph.

(c) Window data are entered using a separate file (WINDOW.DAT).

(d) For calculating the internal solar distribution, surfaces are divided into 5x5 sub elements.

(e) In calculating external longwave radiation, Dines' coefficients have been replaced by Anderson's coefficients.

4. SENSITIVITY ANALYSES CONDUCTED IN PHASE I

4.1 Internal convection coefficients

As mentioned above, the initial specification called for modellers to provide values which correspond to what are regarded as standard combined surface coefficients in the UK Chartered Institution of Building Services Guide [11]. The implementation of this has caused some difficulties and differences in predictions have arisen due to non-comparability of these quantities. The importance of such discrepancies has been investigated using ESP by comparing results where standard fixed values were assumed, with those obtained by allowing the program to perform a dynamic calculation of the coefficients at each time step according to the temperatures and direction of heat flow pertaining at that time. The heating loads for Cases 1 and 9, Copenhagen weather, were changed by 382 and 149 kWh (or 3.2, 1.7%) respectively. The cooling loads changed by +15, -60 kWh (or 14.6, 7.1%).

4.2 Glazing properties

Both BRE and the Netherlands performed some sensitivity analyses using SERIRES (SUNCODE PC version) for values of extinction coefficient 0.0197 and 0.0196. There was a negligible effect on the results.

The ESPWIN values from Table 3 were used in Case 3 for Copenhagen. Differences from the standard values adopted were -7, +28 kWh in the annual heating and cooling loads (less than 1%).

4.3 Radiation view factors

One of the most apparent differences between models is the level of detail required with respect to the specification of the geometrical description of a building. One reason for adopting the often more time-consuming, detailed approach is in order to calculate accurate exchanges of heat between surfaces by longwave radiation. ESP was used for Cases 1 and 9, Copenhagen weather, to investigate two levels of approximation to these heat exchanges. The normal, default way of using ESP is to specify the full geometrical description of the building via a coordinate system, but to use view factors derived from a simple area weighting formula. In the standard set of runs, a separate program from the ESP suite was used to calculate more accurate values, using an approximate numerical technique. For these two Cases, the maximum difference in annual plant loads was 2 kWh.

4.4 Climate

BRE performed a test involving the comparison of results obtained with SERIRES by using the two different versions of the Copenhagen climate data provided by the subtask B leader. The differences were negligible.

4.5 Internal solar distribution

The specification called for shortwave radiation transmitted into the building to be uniformly distributed to all the internal surfaces apart from the ceiling. It was felt that this represented a reasonably practical and simple approximation to reality.

It was possible to model this in the SERIRES runs. In the ESP runs, the standard assumption was altered so that the radiation was distributed uniformly to all surfaces including the ceiling. To carry out the specification exactly would have been difficult, and would probably most easily have been done by program modifications. To investigate how important the assumptions with regard to solar distribution are for this particular building, ESP was used to model another, extreme assumption where all the radiation was incident on the floor. ESP does calculate the amount of radiation that would be directly lost back out through the glazing and also the amount of radiation that is input to the zone air after undergoing reflections from the surfaces. It should be noted therefore that this will introduce some differences between it and some of the other models. In particular, with ESP (and DOE2) it is not possible to satisfy the specified zero cavity albedo loss fraction. The ESP results do however purport to represent reality more closely. The inclusion of this condition in the specification was intended to simplify the execution of the tests for most design tools.

The ESP sensitivity analyses were conducted for Copenhagen weather for both the light and the heavyweight building - Cases 9 and 10. For all solar incident on the floor, the changes in annual heating load were -52 and -91 kWh (or -0.6, -1.2%), and in cooling loads were +36 and -3 kWh (or +4.3, -2.4%) for Cases 9 and 10 respectively. It should be expected that the importance of these effects would be larger for the sunnier conditions in Denver.

Tables 4 and 5 are reproduced from the DEROB report and illustrate the calculated shortwave solar distribution between internal surfaces. Table 6 shows the area of each internal surface as a percentage of the total internal surface area (these are the values used in ESP runs), together with the range in values calculated by DEROB for a February and a May day.

It can be seen that there is, according to the DEROB values, a large range in the areas of each surface that is irradiated throughout the day. No single, simple area weighting formula can reproduce reality. The area-weighting scheme used by ESP does give values within the correct range for the most part.

TABLE 4 DISTRIBUTION OF SOLAR RADIATION - FEBRUARY 17 Basic Run 4 Copenhagen

hour	vol-ume	Total radia-tion inside	Radiation absorbed by Surface													
			Floor		Roof		West Wall		East Wall		North Wall		South Wall		Window	
		W	W	%	W	%	W	%	W	%	W	%	W	%	W	%
5	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	1	208.7	24.0	11.5	24.1	11.5	127.5	61.1	21.2	10.2	8.3	4.0	2.7	1.3	1.0	0.5
	2	208.7	24.0	11.5	24.1	11.5	127.5	61.1	21.2	10.2	8.3	4.0	2.7	1.3	1.0	0.5
9	1	2773.2	483.2	17.4	333.5	12.0	1487.1	53.6	294.5	10.6	125.9	4.5	35.8	1.3	13.2	0.5
	2	2761.1	481.9	17.5	330.0	12.0	1484.1	53.8	291.5	10.6	125.1	4.5	35.5	1.3	13.0	0.5
10	1	2942.4	838.0	28.5	369.8	12.6	1207.2	41.0	327.0	11.1	147.4	5.0	38.9	1.3	14.2	0.5
	2	2904.5	833.9	28.7	358.9	12.4	1197.8	41.2	317.6	10.9	144.8	5.0	37.8	1.3	13.7	0.5
11	1	2555.4	1177.7	46.1	341.7	13.4	541.6	21.2	302.4	11.8	144.5	5.7	35.0	1.4	12.5	0.5
	2	2487.7	1170.5	47.1	322.2	13.0	524.8	21.1	285.6	11.5	140.0	5.6	32.9	1.3	11.7	0.5
12	1	2328.4	1196.8	51.4	332.4	14.3	296.5	12.7	296.5	12.7	161.3	6.9	33.2	1.4	11.7	0.5
	2	2258.4	1189.3	52.7	312.2	13.8	279.1	12.4	279.1	12.4	156.7	6.9	31.1	1.4	10.9	0.5
13	1	2164.0	1054.3	48.7	302.3	14.0	269.1	12.4	355.9	16.4	141.3	6.5	30.6	1.4	10.8	0.5
	2	2103.2	1047.8	49.8	284.7	13.5	253.9	12.1	340.8	16.2	137.2	6.5	28.7	1.4	10.1	0.5
14	1	1188.2	301.5	25.4	171.6	14.4	155.1	13.1	439.7	37.0	97.0	8.2	17.1	1.4	6.1	0.5
	2	1177.6	300.3	25.5	168.5	14.3	152.5	13.0	437.1	37.1	96.3	8.2	16.9	1.4	6.0	0.5
15	1	340.1	68.9	20.3	69.7	20.5	65.6	19.3	65.6	19.3	61.8	18.2	6.4	1.9	2.1	0.6
	2	340.1	68.9	20.3	69.7	20.5	65.6	19.3	65.6	19.3	61.8	18.2	6.4	1.9	2.1	0.6
16	1	26.9	5.5	20.4	5.5	20.4	5.2	19.3	5.2	19.3	4.9	18.2	0.6	2.2	0.2	0.7
	2	26.9	5.5	20.4	5.5	20.4	5.2	19.3	5.2	19.3	4.9	18.2	0.6	2.2	0.2	0.7
17	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 5 DISTRIBUTION OF SOLAR RADIATION - MAY 30 Basic Run 4 Copenhagen

hour	volume	Total radiation inside	Radiation absorbed by Surface													
			Floor		Roof		West Wall		East Wall		North Wall		South Wall		Window	
		W	W	%	W	%	W	%	W	%	W	%	W	%	W	%
5	1	3.8	0.8	21.5	0.8	21.5	0.7	18.4	0.7	18.4	0.7	18.4	0.0	0.0	0.0	0.0
	2	3.8	0.8	21.5	0.8	21.5	0.7	18.4	0.7	18.4	0.7	18.4	0.0	0.0	0.0	0.0
6	1	57.2	11.6	20.3	11.7	20.5	11.0	19.2	11.0	19.2	10.4	18.2	1.0	1.8	0.4	0.7
	2	57.2	11.6	20.3	11.7	20.5	11.0	19.2	11.0	19.2	10.4	18.2	1.0	1.8	0.4	0.7
7	1	212.5	43.1	20.3	43.5	20.5	41.0	19.3	41.0	19.3	38.6	18.2	3.9	1.8	1.3	0.6
	2	212.5	43.1	20.3	43.5	20.5	41.0	19.3	41.0	19.3	38.6	18.2	3.9	1.8	1.3	0.6
8	1	327.8	66.4	20.3	67.1	20.5	63.3	19.3	63.3	19.3	59.6	18.2	6.1	1.9	2.1	0.6
	2	327.8	66.4	20.3	67.1	20.5	63.3	19.3	63.3	19.3	69.6	18.2	6.1	1.9	2.1	0.6
9	1	562.4	114.0	20.3	115.2	20.5	108.5	19.3	108.5	19.3	102.2	18.2	10.6	1.9	3.5	0.6
	2	562.4	114.0	20.3	115.2	20.5	108.5	19.3	108.5	19.3	102.2	18.2	10.6	1.9	3.5	0.6
10	1	779.7	227.7	29.2	132.2	17.0	186.5	23.9	121.8	15.6	94.5	12.1	12.7	1.6	4.3	0.6
	2	771.9	226.8	29.4	130.0	16.8	184.6	23.9	119.9	15.5	93.9	12.2	12.3	1.6	4.1	0.5
11	1	2861.9	1340.8	46.9	400.1	14.0	520.7	18.2	356.4	12.5	189.3	6.6	40.3	1.4	14.3	0.5
	2	2785.8	1332.7	47.8	378.1	13.6	501.7	18.0	337.5	12.1	184.2	6.6	38.1	1.4	13.4	0.5
12	1	2676.3	1460.1	54.6	365.3	16.7	323.0	12.1	323.0	12.1	154.9	5.8	36.9	1.4	13.1	0.5
	2	2587.8	1450.6	56.1	339.7	13.1	301.1	11.6	301.1	11.6	149.0	5.8	34.4	1.3	12.1	0.5
13	1	2477.3	1338.7	54.0	340.7	18.8	301.7	12.2	301.7	12.2	148.0	6.0	34.5	1.4	12.2	0.5
	2	2396.6	1330.1	55.5	317.3	13.2	281.6	11.8	281.6	11.8	142.7	6.0	31.9	1.3	11.3	0.5
14	1	1822.3	696.6	38.2	257.2	14.1	230.4	12.6	472.7	25.9	130.3	7.2	25.9	1.4	9.2	0.5
	2	1786.7	692.8	38.8	246.9	13.8	221.6	12.4	463.9	26.0	128.0	7.2	24.9	1.4	8.8	0.5
15	1	550.8	111.6	20.3	112.8	20.5	106.3	19.3	106.3	19.3	100.1	18.2	10.2	1.9	3.4	0.6
	2	550.8	111.6	20.3	112.8	20.5	106.3	19.3	106.3	19.3	100.1	18.2	10.2	1.9	3.4	0.6
16	1	531.4	107.7	20.3	108.8	20.5	102.5	19.3	102.5	19.3	96.5	18.2	10.0	1.9	3.3	0.6
	2	531.4	107.7	20.3	108.8	20.5	102.5	19.3	102.5	19.3	96.5	18.2	10.0	1.9	3.3	0.6
17	1	429.9	87.1	20.3	88.1	20.5	83.0	19.3	83.0	19.3	78.1	18.2	8.0	1.9	2.7	0.6
	2	429.9	87.7	20.3	88.1	20.5	83.0	19.3	83.0	19.3	78.1	18.2	8.0	1.9	2.7	0.6
18	1	274.0	55.5	20.3	56.1	20.5	52.9	19.3	52.9	19.3	49.8	18.2	5.2	1.9	1.7	0.6
	2	274.0	55.5	20.3	56.1	20.5	52.9	19.3	52.9	19.3	49.8	18.2	5.2	1.9	1.7	0.6
19	1	83.2	16.9	20.3	17.0	20.4	16.1	19.4	16.1	19.4	15.1	18.2	1.6	1.9	0.5	0.6
	2	83.2	16.9	20.3	17.0	20.4	16.1	19.4	16.1	19.4	15.1	18.2	1.6	1.9	0.5	0.6

	area sq.m.	Feb %	May %
floor	22.3	11-53	20-56
roof	22.3	11-20	13-21
North	7.5	4-18	6-18
South	3.3	1- 2	1- 2
window	4.2	c.0.5	c.0.5
East+	20.2	10-37	11-26
West+	20.2	12-61	11-24

+These values include the internal wall facing in this direction.

TABLE 6

4.6 Plant and temperature control

There has been much debate recently in the UK as to the significance of what temperature the sensor(s) controlling the plant respond to, and also to the proportion of the plant output that is radiant. In many of the European countries it is common to use systems that are 50% or more radiant. Although most thermostats sense temperatures close to that of the local air, there is a strong argument, especially in comparative studies, for using a control that more nearly corresponds to a measure of comfort, and therefore to control on a mixed radiant/convective temperature. There is also a considerable dispute about what is actually simulated by models that use a single zone temperature with fixed coefficients. For this reason an investigation has been included to quantify the effect of different assumptions on temperature and plant control.

The SERIRES type of model is often argued to represent most closely a 2/3:1/3 split between radiant and convective effects, provided that the values in e.g. the CIBSE Guide are used for the fixed internal surface coefficients. These were the values specified for the exercise. This argument is a contentious one and it does not seem appropriate to enter into it in detail in this paper. It was, however, felt to be useful to investigate the range in values of plant loads that would be obtained by assuming both pure convective (as in the specification) and environmental (i.e. 2/3 radiant) control and input. ESP was used to perform this investigation, and fixed convection coefficients were used.

ESP asks the user to specify the proportion of the heating system output to the zone that is radiant/convective and, similarly, the ratio of mean radiant/ air temperature to which the room sensor controls.

The changes in Copenhagen annual heating loads for the environmental control and input cases with respect to the standard Cases 1 and 9 (convective) were +1165 and +1808 kWh (or 9.8, 21.1%) and +34, +2954 kWh (or 36.6, 349%) for annual cooling loads. The infiltration and window conduction losses were increased by 92, 52 kWh for Case 1 and 697, 392 kWh for Case 9.

Differences in these assumptions are predicted therefore to be of significant importance. Similar results have been obtained using HTB2.

This topic is returned to in Phase II of the exercise and the interested reader should see section 6.3

4.7 Internal mass

The ability of a design tool to correctly estimate the effect of changing levels of internal mass is clearly important for solar design. Accordingly, it was suggested that a parameter study form part of this exercise. Results for the heavyweight construction with both 20/20 and 20/27 C heating/cooling setpoints (Cases 4 and 10) for Copenhagen weather have been produced by the Netherlands using the IBM PC version of SERIRES. In this study the area of internal mass was doubled and then trebled from that in the original specification. This was achieved by altering the area of the internal wall. The results are as follows:

Case 4 - heavyweight version with a real window, with both heating and cooling setpoints of 20 C

loads kWh heating	cooling	area of internal wall sq. m.
8642	2391	21.6
8672	2450	43.2
8692	2488	64.8

Case 10 - heavyweight version with a real window, with heating and cooling setpoints of 20, 27 C respectively

loads kWh heating	cooling	area of internal wall sq. m.
7663	158	21.6
7613	130	43.2
7575	108	64.8

TABLE 7

Some additional simulations were conducted by BRE with the same version of SERIRES, but using Denver weather. The results are shown

case 4

loads kWh heating	cooling	area of internal wall sq. m.
5721	5941	21.6
5782	6049	43.2

case 10

loads kWh heating	cooling	area of internal wall sq. m.
3609	1046	21.6
3491	981	43.2

TABLE 8

These studies suggest that the addition of extra internal mass has only a relatively small effect on the predicted loads for both climates. It should be noted that the assumption made about the internal distribution of solar radiation (i.e. area weighting amongst all internal surfaces) leads to some difficulty in interpreting the effect of internal mass on loads in a real situation. A more rigorous model which performs geometrical calculations of internal distribution is really needed to address this problem.

5. PHASE 2 EXERCISE

Following the generally good agreement obtained between the predictions of the five detailed models for the Phase I exercise, it was decided to conduct a further round of simulations in which a wider range of building features could be investigated and in which slightly greater realism was present. The sensitivity studies described in section 4 suggested that the model results were not critically dependent on the detailed modelling assumptions investigated, with the exception of the type of plant and temperature control. The basic specification of the buildings used in Phase I was therefore adopted for this second round, Phase II. As far as possible, the new specifications were designed to add or change a single feature only, so that additional value could be obtained from the runs by investigating the effects of that change on the desired output parameter. The additional features investigated were:

window size
orientation
shading from overhangs
night setback
a variant of the building, configured as an apartment

All of these runs were conducted with a constant internal heat gain; this had been set to zero in the Phase I exercise.

5.1 THE EXERCISE

The Table below describes the original set of Phase II runs by reference to a base case, together with any necessary modifications.

Case No.	Base Case No.	Modifications to Base Case	Climate (C/D)**	Brief Description
13	9	4 sq m south, window*; internal gains.	C,D	Small window lightweight.
14	10	4 sq m south, window*;	C,D	Small window heavyweight.
15	13	Rotate 90˜ anti-clockwise ie East window	C,D	lightweight.
16	14	Rotate 90˜ anti-clockwise ie East window	C,D	heavyweight.
17	10	Overhang at top of window, 0.75 m wide; internal gains.	D	Large window heavyweight.
18	10	As above, free floating.	D	
19	13	Night setback to 10˜C from 2300 h to 0700 h.	C,D	Small window lightweight
20	14	As above.	C,D	heavyweight.
21	10	E,W & N walls are adiabatic***; internal gains.	C,D	Large window heavyweight.

TABLE 9

* 2 windows, each 1 m high and 2 m wide.
** located 1 m from the floor.
** C = Copenhagen, D = Denver.
*** No heat flow occurs in the east, west and north external walls at the cavity insulation layer.

NB: All of the Phase II runs have a constant internal gain of 200 W, split in the ratio 50% radiant and 50% convective.

The outputs requested for these runs were:

(a) Monthly and annual heating and cooling loads, including infiltration loads if possible.

(b) Hourly loads/temperatures (air and mean radiant, if possible) for 2 July and 2 December as appropriate.

(c) Annual total solar radiation incident on south (kWh/sq m).

(d) Annual total solar input to the building (kWh).

(e) As for (c), hourly values for 2 July and 2 December.

(f) As for (d), hourly values for 2 July and 2 December.

In the course of the July meeting a number of extensions/modifications to the above cases were suggested. These are described below.

Case No.	Base Case No.	Modifications to Base Case	Climate (C/D)	Brief Description
22	9	Internal gains.	C/D	Large window version of case 13, lightweight.
23	10	As above.	C/D	Large window version of case 14, heavyweight.
24	19	9 sq m window as in Phase I.	C/D	Large window version of case 19, lightweight.
25	20	As above.	C/D	Large window version of case 20, heavyweight.
26	22	Free floating.	D	Lightweight.
27	23	As above.	D	Heavyweight.

TABLE 10

It was also decided to obtain some extra outputs for these runs:

(g) Peak, mean and minimum temperatures (air and mean radiant if possible) for the two days specified (2 July and 2 December) and for 17 October.

(h) Annual peak loads.

5.2 RESULTS FOR PHASE II

Results were obtained as follows:

CANADA	EASI	Copenhagen,	Cases 13-21
	ENERPASS	Copenhagen and Denver,	Cases 13-21
UK (BRE)	ESP	Copenhagen and Denver,	Cases 13-27
	SERIRES	Copenhagen and Denver,	Cases 13-27
UK (UWIST)	HTB2	Copenhagen and Denver,	Cases 13-21
USA (AEC)	BLAST	Denver,	Cases 13-27
USA (SERI)	DOE 2.1C	Copenhagen and Denver,	Cases 13-27

Figures 25-28 show the annual loads for Cases 13-21 (note that Case 17 was only run for Denver, and that Case 18 was a free floating case and so is not shown here). Figures 29-32 show the annual loads for the cases defined at the July meeting, Cases 22-25. Cases 26 and 27 were free floating and so are not shown here - maximum and minimum temperatures for these cases are shown in Figures 36-37.

The results for Cases 13-21 show generally the same level of agreement as for those found in Phase I of the exercise, but with ESP results being generally lower for both heating and cooling loads in Denver.

There are particular doubts as to the comparability of results for Cases 17 and 21 with the other models. Problems were encountered in performing the shading runs with ESP and, initially, slightly different boundary conditions were used for SERIRES and ESP as compared to BLAST and DOE2. These were re-run to produce the results shown here which should be comparable. It is, however, very easy for differences in boundary conditions to arise for a building with substantial internal walls, and it may not be sensible to adopt Case 21 as a standard reference case.

The results presented for Copenhagen seem to be in better agreement than for Denver.

The main reason for introducing the additional Cases 22-25 was to enable greater comparability between the other cases. While Figures 29-32 show the absolute values of annual loads for these cases, Figures 33-35 show the differences in heating load between continuous heating and night setback control schemes (Cases 13-19 and 14-20), between no shading and shading (Cases 23-17) and between the 9 sq m and the 4 sq m south window (Cases 22-13 and Cases 23-14).

All of the five detailed models give results for the annual loads which imply the same direction of change and with quite similar magnitudes.

It is important to realise that design tools will be used in practice to predict other quantities such as temperature and peak loads and the adequacy of a design tool can not be stated without first specifying what it is to be used for. Figures 36 and 37 show that for the free-floating cases 26 and 27, good agreement is obtained in both maximum and minimum temperatures. Figures 38-41 show the peak heating and cooling loads for BLAST, DOE and SERIRES. With the exception of the night setback runs (Cases 19, 20, 24 and 25), the values seem to be in reasonable agreement. The reasons for this are discussed further in section 6.3

Figs. 42-44 show how the performance of some design tools compare with the ranges obtained with the simulation models.

In conclusion, these results show that reasonably tight ranges in predictions of annual loads and maximum/minimum temperatures can be obtained for buildings with continuous plant operation by the careful use of simulation models. Further work would have to be done in order to fully explain the reasons for differences in the predictions of peak loads and of the detailed hourly evolution of internal temperatures.

6. MODELLING ASSUMPTIONS AND PROBLEMS ENCOUNTERED IN PHASE II

This Section describes problems specific to Phase II of the exercise. Section 3 describes those encountered in Phase I.

6.1 ESP

In order to model the specified shading by an overhang at the top of the windows, ESP offered two options, both of which were explored, with advice sought from the model developers. Both methods calculate hourly shading values using one day of each month. The resulting shading values are assumed to be the same for all days in the month. Only user--specified external surfaces are shaded by the overhang, and in the absence of an INSOLATION file, solar radiation entering the zone falls onto the default insolation plane, specified here to be the floor.

In the first option, ASHRAE algorithms are used to calculate hourly shading values. This option is not fully integrated into the ESP suite of programs, and the transfer of data between programs is normally time-consuming, although a small program was written to automatically transfer results. The ASHRAE method calculates shading on the window surface only, not on the surrounding walls, and this can lead to errors if the overhang is large.

In the second option a more accurate, fully integrated method is used, in which the overhang is treated as an obstruction block. This shades both the window and surrounding wall, but is mainly intended for shading by remote objects, not overhangs. Consequently the 'overhang' must be placed at least 0.001m away from the plane of the surface.

Two errors, reported to ABACUS, were found when running this method:

(1) the program SHD cannot open the shading file unless it has previously been created and filled with 'rubbish' by running IMP.
(2) In certain circumstances, negative shading values can occur.

6.2 BLAST 3.0

The modelling of the Phase II cases was straightforward with two exceptions. The first is the definition of the geometry of the overhang in Cases 17 and 18. This was modelled in BLAST as being located at the top edge of the windows and extending across the 6 m width of the south wall. The second is the ambiguity in the specification of the adiabatic wall in Case 21. This was modelled in the same way as the conventional wall but with an insulation R-value equal to 100,000 W/m(2} ~K in place of the conventional insulating foam.

6.3 SERIRES

Internal gains cannot be divided into convective and radiant proportions. The user can only specify the total amount.

The manual input description section describes the overhang input quantities as vertical distance from the top of the surface and width of overhang. Initially the former quantity was taken to mean the distance from the top of the South surface down to the overhang (ie the top of the window in Cases 17 and 18). Comparison of the SERIRES results with those of other codes, and then for consistency showed that this was incorrect; the inputs used had actually defined the overhang to be above the wall surface. It was found that SERIRES will not accept a negative value for this displacement. The final values were found by resorting to either of two tricks (giving identical results):

(a) move the windows from their correct positions to the top of the wall and specify the overhang displacement as zero,

or

(b) define the South wall as two surfaces, meeting at the top of the window. The overhang can then be defined as having a zero displacement from the top of the lower surface. Corresponding changes to the WALLS section also have to be made.

It should be noted that SERIRES assumes that the overhang is of infinite horizontal extent and therefore the effect of shading will be over-estimated.

Initially, no cooling was specified during the setback periods (as for ESP). These were re-run with night cooling for Denver during the July meeting so that the results presented here for the various models are on a comparable basis.

Figs. 38 and 40 show clearly that the SERIRES predictions of annual peak heating loads are much larger than those of the other simulation models, for the night setback cases, despite the good agreement obtained for the other cases in the Phase II exercise. A major difference between SERIRES and the other models is the way in which the internal zone temperature is defined. This has already been discussed in section 4.6, where it was concluded that the effects of different assumptions about exchanges of heat between zone nodes and surrounding surfaces could be of importance. In the night setback cases, the peak heating load will occur at the hour of thermostat 'setup'. The more closely coupled the building mass is to the control node, the harder the heating system has to work to bring the 'air' temperature up to the new thermostat setting. Since the heating plant capacity was specified as effectively infinite, the peak loads can be expected to be affected markedly. Some further sensitivity analyses were therefore conducted to investigate this as a possible reason for the discrepancies seen in the peak load results.

SERIRES simulations were conducted by SERI for the heavyweight building with night setback, case 25. In order to obtain conditions more similar to those modelled by the other models, the following changes were made to the standard input files used previously:

(a) suppress radiation by reducing the combined surface coefficients to those corresponding to convection only (3.35, 4.31, 1.25 W/sq.mK for horizontal, upward and downward heat flow)
(b) adjust the resistances of the insulation layers so that there is no change in the total building load coefficients
(c) increase the number of nodes used on all internal mass layers to 3, and the number of timesteps to 41/hour.

This had the effect of altering the Denver peak load from the original 8.95 to 6.45 kW. This result is much more in line with the results obtained by BLAST (6.27 kW) and DOE (6.14 kW) and would seem to confirm the hypothesis stated above. A separate simulation was conducted in which only change (c) was made. This also had a fairly significant effect, but in the opposite direction (new peak load was 9.68 kW).

6.4 DOE2.1C

a) The radiative - convective split for internal gains is not within user control. It was possible to achieve a split of:

59% = Radiative
41% = Convective

by specifying recessed fluorescent lighting cooled by a return vent, and a 'light-to-space' fraction of 1.0.

b) The overhang routine only calculates shading from beam radiation. However, the user may externally calculate and input a constant 'sky-form-factor' to account for the diffuse sky radiation obstructed by the overhang. The overhang was defined as extending across the entire South wall plane at the upper edge of the window. The view factor from the window to the overhang was hand calculated assuming the overhang to extend just across the window top. The hand calculation gave a view factor of 0.15 from the window to the overhang. Thus the 'sky-form-factor' was calculated as 0.5-0.15=0.35. The DOE2.1C program does not assume an infinitely long overhang. It treats end and corner conditions in the 'beam' shading calculations.

7. DISCUSSION OF RESULTS

The ranges in annual loads for the results available to date are sufficiently close for a useful set of standard ranges to be presented in the form of an easy-to-use booklet.

For the discrepancies seen so far, it seems likely that the most serious is that of the calculation of solar radiation incident on the external surfaces of the building. This is an area where different assumptions are made by the detailed models, and how appropriate these are may vary significantly between climates. It must be borne in mind that a good level of agreement between all but one model does not imply that it is the outlier that is in error.

To explain the differences in predicted temperatures and in peak loads would take more effort than was available within IEA Task VIII.

It can be argued that the prediction of peak temperatures is an obvious and practical task that a design tool user might want to perform. The results obtained so far could be formulated in such a way as to give a standard range in maximum temperature for use as a 'benchmark'. Similarly, ranges in peak loads could be given for continuous plant operation.

Further work would be needed to develop a procedure for using these results. The following section represents a first attempt to see what form this might take and, it is hoped that this can be used as a starting point for the production of national design tool evaluation procedures outside Task VIII.

8. APPLICATION OF THE TEST PROCEDURES

The procedures presented in this document are used to evaluate selected thermal and control mechanisms found in most building energy analysis methods. These procedures are not intended to be used to validate the accuracy of any method. Instead, they represent necessary steps through which an analysis method must pass in order to be able to accurately predict building energy loads and interior temperatures. However, these tests are not sufficient to guarantee that any energy analysis method will accurately predict such loads and temperatures. This would require a complete validation of the accuracy of the method, and that is completely outside the scope of this document and of Task VIII.

It should also be noted that the tests presented here are only applicable to the shell and the zone control aspects of building energy analysis methods, generally known as the 'loads' portion of the model. The testing of methods for predicting the performance of building fan systems and plants is outside the scope of the Task.

8.1 REVIEW OF THE TEST CASES

The test procedures consist of several cases, each of which represents a simple, idealized building which can be analysed with the design tool in question. Each of these cases can be used singly or in conjunction with results from other cases to determine the reasonableness of specific thermal, solar and control mechanisms in the design tool. A listing of all of the test cases, along with the reason for their use, is shown in Table 11.

Case	Description Base Case	Output	What it Tests
0	1,NI	A	The assumptions associated with the infiltration algorithms.
1		A	The base case for cases 0, 2, 3, 7 and 9.
2	1,H	A	The effect of increased mass on the thermal driving functions associated with the preceding case. The base case for cases 4, 8 and 10.
3	1,W	A	The effect of solar gains through south-facing windows.
4	2,W	A	See (2).
7	1,D	A	The effect of a temperature deadband between the heating and cooling setpoints.
8	2,D	A	See (2).
9	1,D,W	A	The effect of a temperature deadband and solar gains through south-facing windows. The base case for cases 10, 11, 13 and 22.
10	2,D,W	A	See (2). The base case for cases 12, 14, 17, 18 and 23.
11	9,FF	T	The temperature dynamics of (9).
12	10,FF	T	See (2).
13	9,SW,I	A	The effect of a smaller window and internal gains. The base case for cases 15 and 19.
14	10,SW,I	A	See (2). The base case for cases 16 and 20.
15	13,EW	A	The effect of an East-facing window.
16	14,EW	A	See (2).
17	10,O	A	The effect of an overhang.
18	10,O,FF	T	The effect of an overhang on the temperature dynamics of (10).
19	13,SB	A	The effect of night setback. The base case for case 24.
20	14,SB	A	See (2). The base case for case 25.
22	9,I	A	The effect of internal gains. The base case for case 26.
23	10,I	A	See (2). The base case for case 27.
24	19,W	A	The effect of increased solar gains.
25	20,W	A	See (2).
26	22,FF	T	The temperature dynamics of (22).
27	23,FF	T	See (2).

TABLE 11

Abbreviations

A Annual Loads, Monthly Loads, Annual Incident South Vertical Solar Flux, Annual Total Building Solar Gains.

D Temperature Deadband.

EW East Facing Window

FF Free Floating Temperatures

H High Mass

I Internal Gains

NI No Infiltration

O Overhang

SB Night Setback

SW South Facing Window

T Hourly Temperatures, Loads and Solar Gains for Specified Days

W Large Window

8.2 Suggested Procedure for Use of Tests

Detailed descriptions of each of these test cases have been presented previously in this report. The column titled 'Description' in this table contains information on how to generate the inputs appropriate to **apply** these test procedures to any analysis method. First, the inputs for case number 1 must be developed. However, it may prove to be unnecessary to run this case. Then, inputs for other test cases are developed by adding the features specified under the 'Description' column in the Table. For example, to generate the inputs for case number 9, a temperature deadband and a South facing window must be added to the inputs for case number 1. The abbreviations used in this column are all described at the bottom of the Table.

The suggested order in which the tests are to be executed are shown in flow chart form in Figures FC1 - FC4. The general flow chart is shown in Figure FC1, while the details of each of the letters in the decision diamonds are shown in Figures FC2 - FC4. The movement through this flow chart requires 'passing' the test numbers shown in the decision diamonds. Passing a test requires that the output from the application of the test method on a particular test case agrees reasonably well with the range of outputs from the rigorous analysis procedures presented elsewhere in this report. The passing of a test may also require that the differences between specified quantities, such as annual heating and cooling loads, from the test case and its base case specified in the above Table, are within certain ranges. The specifications of what constitutes a pass and what constitutes a failure need to be developed further before the tests can be said to constitute a procedure suitable for α , Design Information booklet. It is unlikely that a simple prescription can be given as to how many kWh outside a range is permissible. In practice, only the user of a design tool can judge this after due consideration of what application he is using the tool for and what accuracy is needed. Some examples will, however, have to be given in order for the test user to successfully use them. The passing of a test enables movement through the flow chart to other tests. The failure to pass a test points out a specific problem with the analysis procedure. The user should evaluate these problems with regard to the types of building analysis that they intend to pursue, and decide if the analysis method is appropriate. For example, the failure to adequately handle thermal mass effects may be extremely important for passive solar applications, but relatively unimportant for the analysis of many conventional building designs.

The flow chart begins with test case number 9, which represents a reasonably realistic building. If the application of the analysis method in question on this test case shows reasonable agreement with the acceptable test range, then test case numbers 10, 11, 12 and so forth should be analysed. If, however, there is not good agreement with the acceptable results for test case 9, then the flow chart should be followed to the letter 'A', and test case 1 should be analysed. The other paths through the flow chart follow a similar pattern.

General flow chart

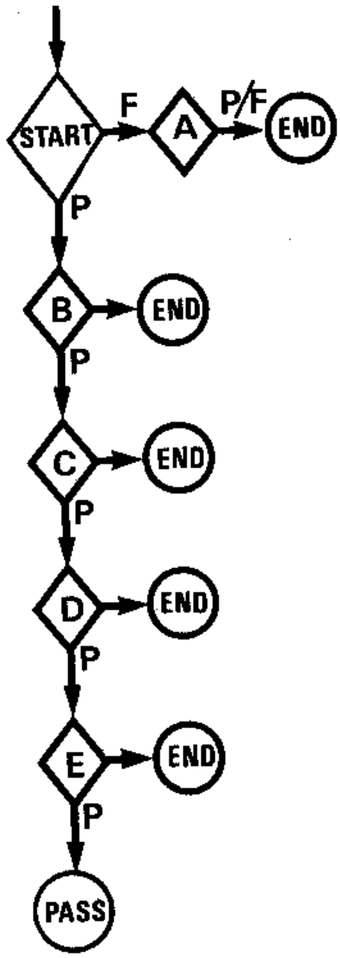


FIGURE FC1

Detailed flow charts

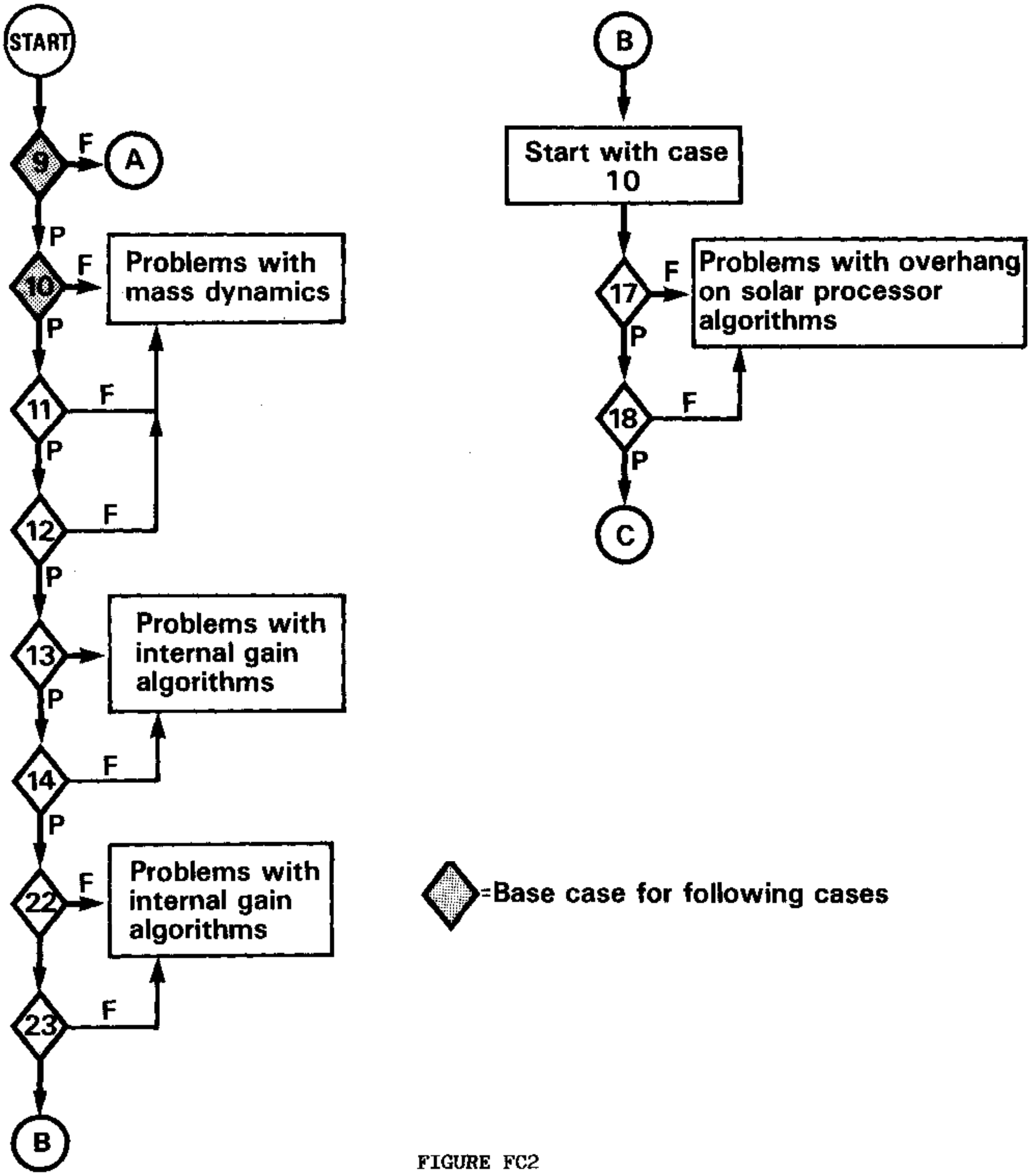


FIGURE FC2

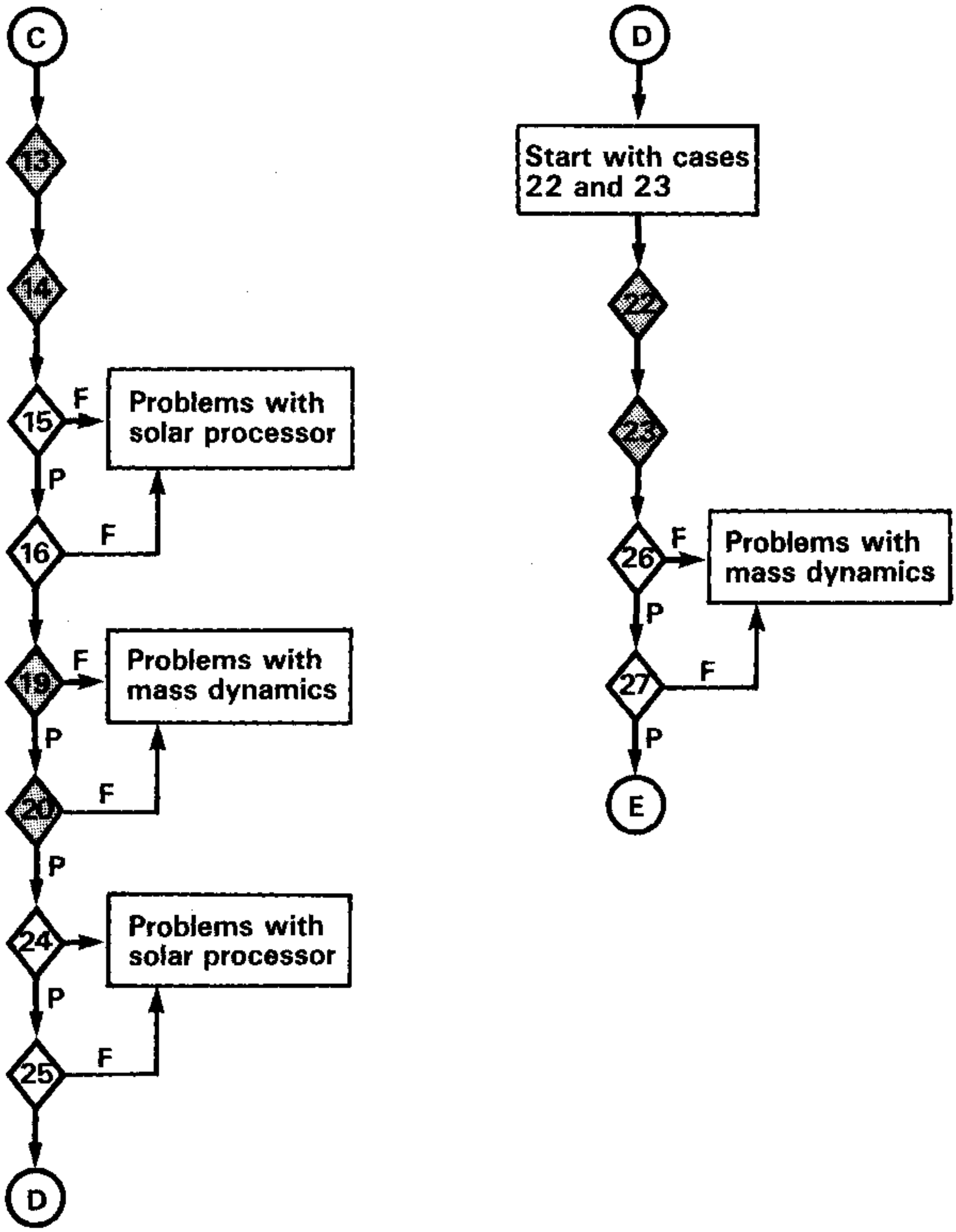

C
13
14
15
F
Problems with solar processor
P
16
F
19
F
Problems with mass dynamics
P
F
P
24
Problems with solar processor
P
25
F
D
D
Start with cases 22 and 23
26
F
Problems with mass dynamics
P
27
F
P
E

FIGURE FC3

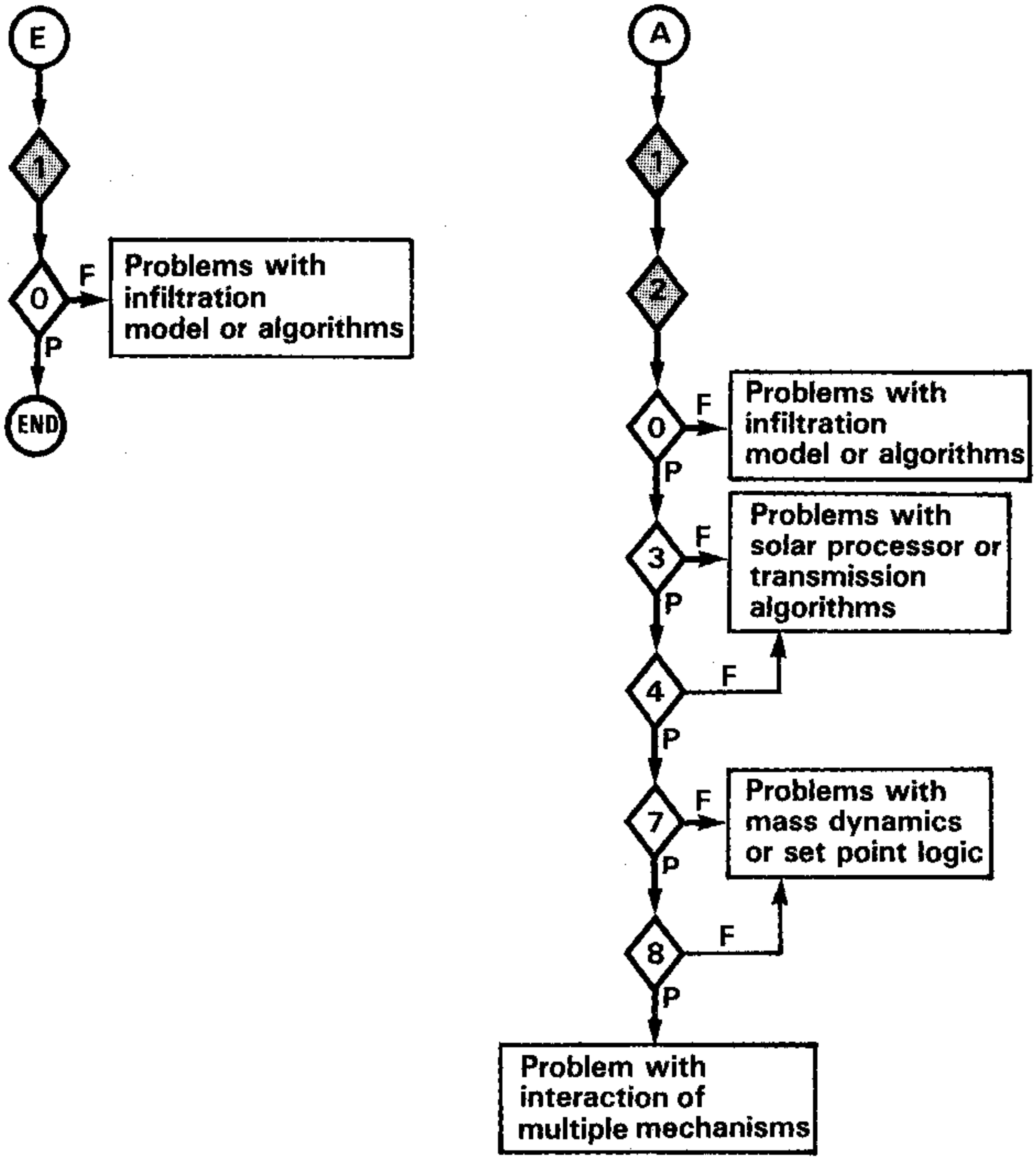

E
1
0
F
Problems with infiltration model or algorithms
P
END
A
1
2
0
F
Problems with infiltration model or algorithms
P
3
F
Problems with solar processor or transmission algorithms
P
4
F
P
7
F
Problems with mass dynamics or set point logic
P
8
F
P
Problem with interaction of multiple mechanisms

FIGURE FC4

9. CONCLUSIONS

A practical methodology has been developed whereby thermal design tools that deal with residential, direct gain buildings can be tested. Good agreement between design tool results and the benchmark test cases does not imply validation of the tool; rather, it should be seen as the first stage in such a process. However, application of the design tool evaluation methodology is expected to prove of great value in the selection of a design tool for use in a project, and should ensure that the basic physical processes occurring in real buildings are adequately modelled.

Advantage has been taken of experience gained in previous comparative modelling exercises, and, as a result a very careful, detailed approach to the specification, modelling and analysis of results has been adopted. Once again, it has been demonstrated how easy it is for misunderstandings and mistakes to arise; success has been achieved in minimising these. The specifications for the test cases have been revised in the light of the experience gained as to where ambiguities arise due to the different input requirements of the models investigated.

A reasonably narrow set of ranges in loads and in peak temperatures has been obtained by the use of five detailed simulation models. These ranges have been compared with the results from a few design tools and a first attempt has been made to suggest how a procedure for applying these tests might work.

The detailed simulation models used have all been subjected to previous 'validation' testing, and the participants have selected them for this reason and for the relatively high level of support and credibility that they enjoy. It is, however, accepted that these models are based upon a number of approximations and shortcomings and that they will almost certainly contain some errors. In the current state of the modelling world, this is inevitable. It was therefore expected from the outset that a range in results would be obtained from these models. It is argued that the narrowness of the ranges actually obtained is encouraging, whilst in no way proving 'correctness'. If a design tool is tested using the procedures developed here and produces a result that is outside only one of the ranges, this does not show that the tool is inadequate. If, however, it differs markedly from several of the ranges and gives rise to very different relative results from case to case, it certainly merits further examination, or at least the exercise of caution in using results obtained with it.

The design tool evaluation methodology developed in this report would need to be developed further in order to obtain a user-friendly test procedure. Insufficient resources were available for this to be achieved within the Task, but several of the working group participants intend to produce national versions.

10. ACKNOWLEDGEMENTS

The UK contribution to this work forms part of the research programme of the Building Research Establishment of the UK Department of the Environment, and this report is published by permission of the Director.

11. REFERENCES

1. International Energy Agency Final Report, Annex I; Comparison of load determination methodologies for building energy analysis programs, December 1979.
2. Judkoff R., Wortman D. et al; A methodology for validating building energy analysis simulations; Solar Energy Research Institute report TR-254-1508,59c, August 1983
3. Judkoff R., Wortman D. et al; A comparative study of four passive building *energy* simulations: DOE2.1, BLAST, SUNCAT-2.4 & DEROB-III; Proc. 5th National Passive Solar Conf., 1980.
4. Judkoff R., Wortman D., O'Doherty B.; A comparative study of four building energy simulations: Phase II; Proc. 6th National Passive Solar Conf., 1981.
5. Bland B.H. & Bloomfield D.P.; Validation of conduction algorithms in dynamic thermal models; Proc. 5th CIB Int. Symposium on the Use of Computers in Environmental Engineering related to Buildings, Bath UK, July 1986
6. IEA Task 8 Design Tool Evaluation Design Information booklet 4.
7. Palmiter L. & Wheeling T.; Solar Energy Research Institute Residential Energy Simulator, Version 1.0 manual, <date??>.
8. Pilkington's Environmental Advisory Service; Thermal Transmission of Windows, August 1979.
9. BARAKAT S. 1987 Experimental determination of z-transfer function coefficients for houses. ASHRAE Trans. Vol 93, p1.1
10. C Roulet. Utilisation factor, technical report. Working document of ISO TC 163/SC2 WG5, Jan 21st 1985.
11. Chartered Institute of Building Services Guidebook A3, 1981.

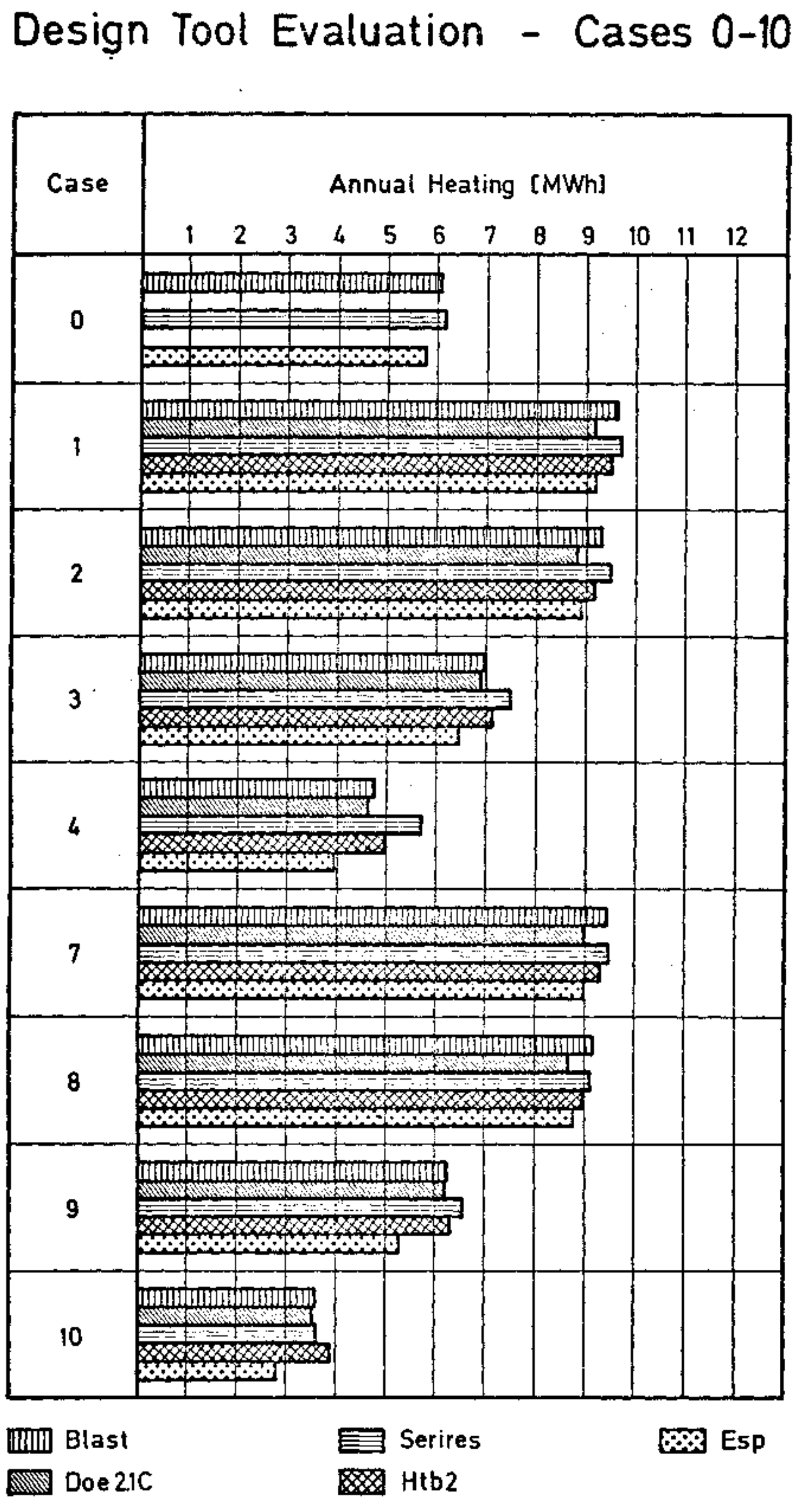


Fig. 1 Annual heating loads of Phase I calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

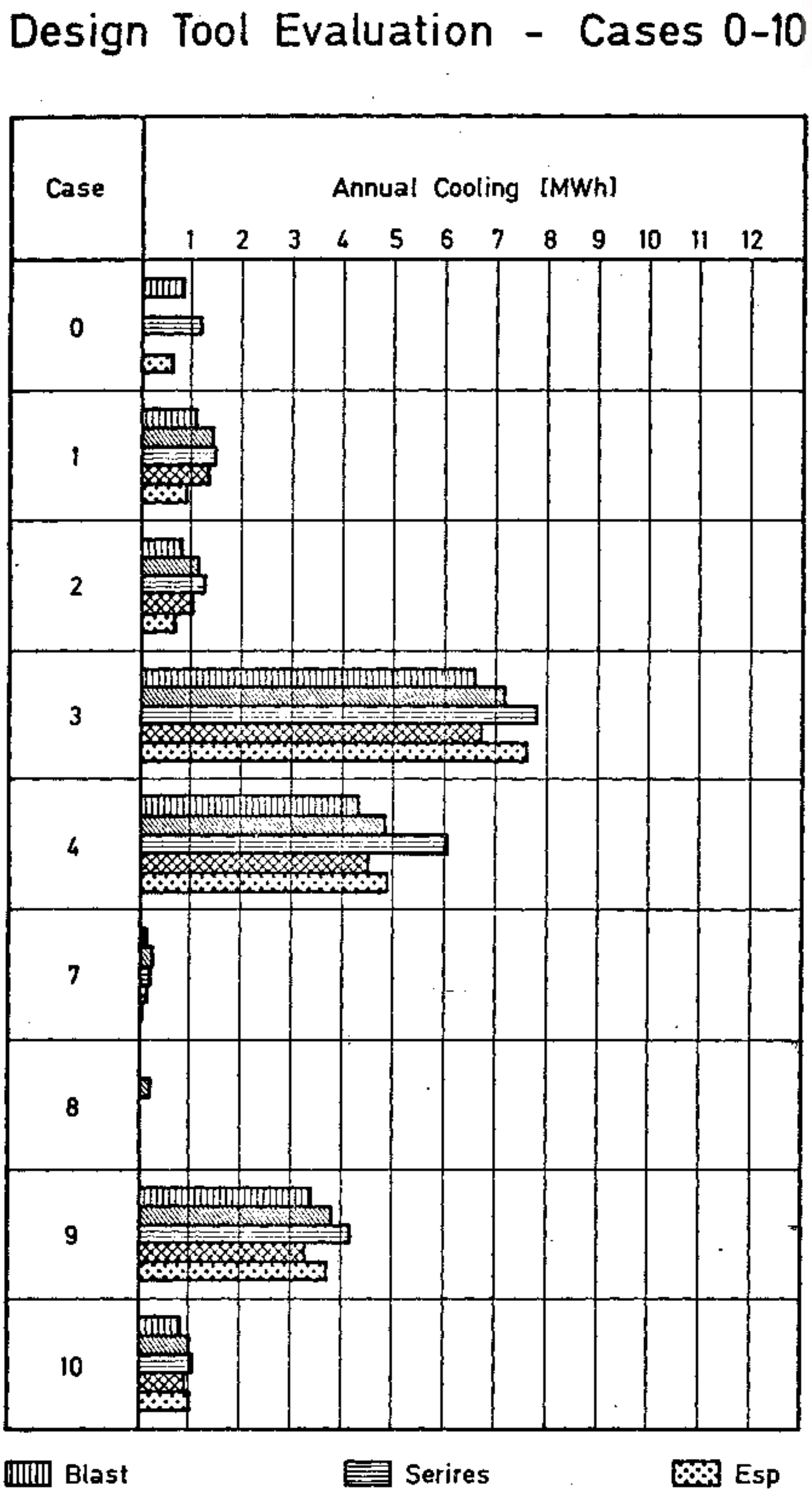


Fig. 2 Annual cooling loads of Phase I calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

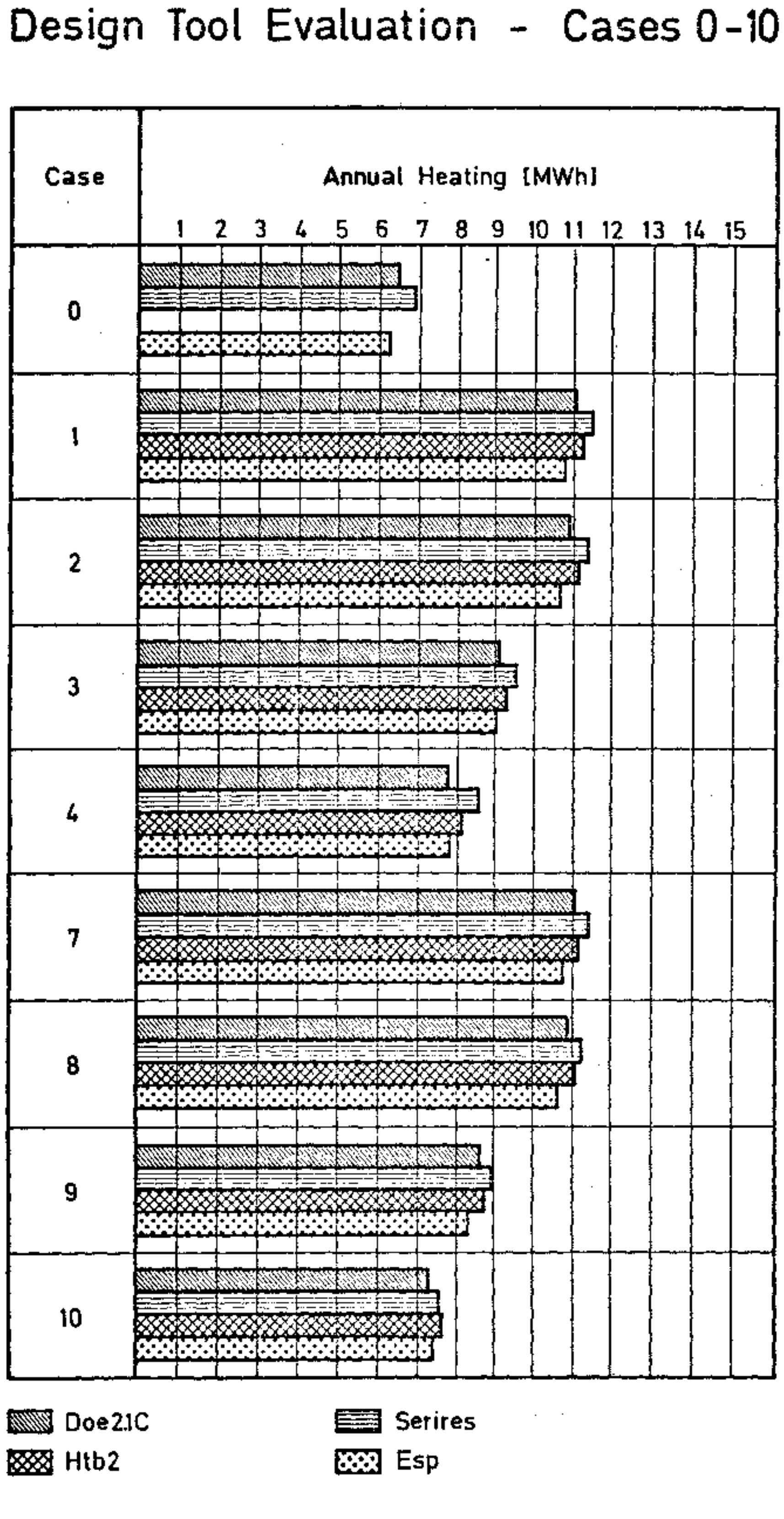


Fig. 3 Annual heating loads of Phase I calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

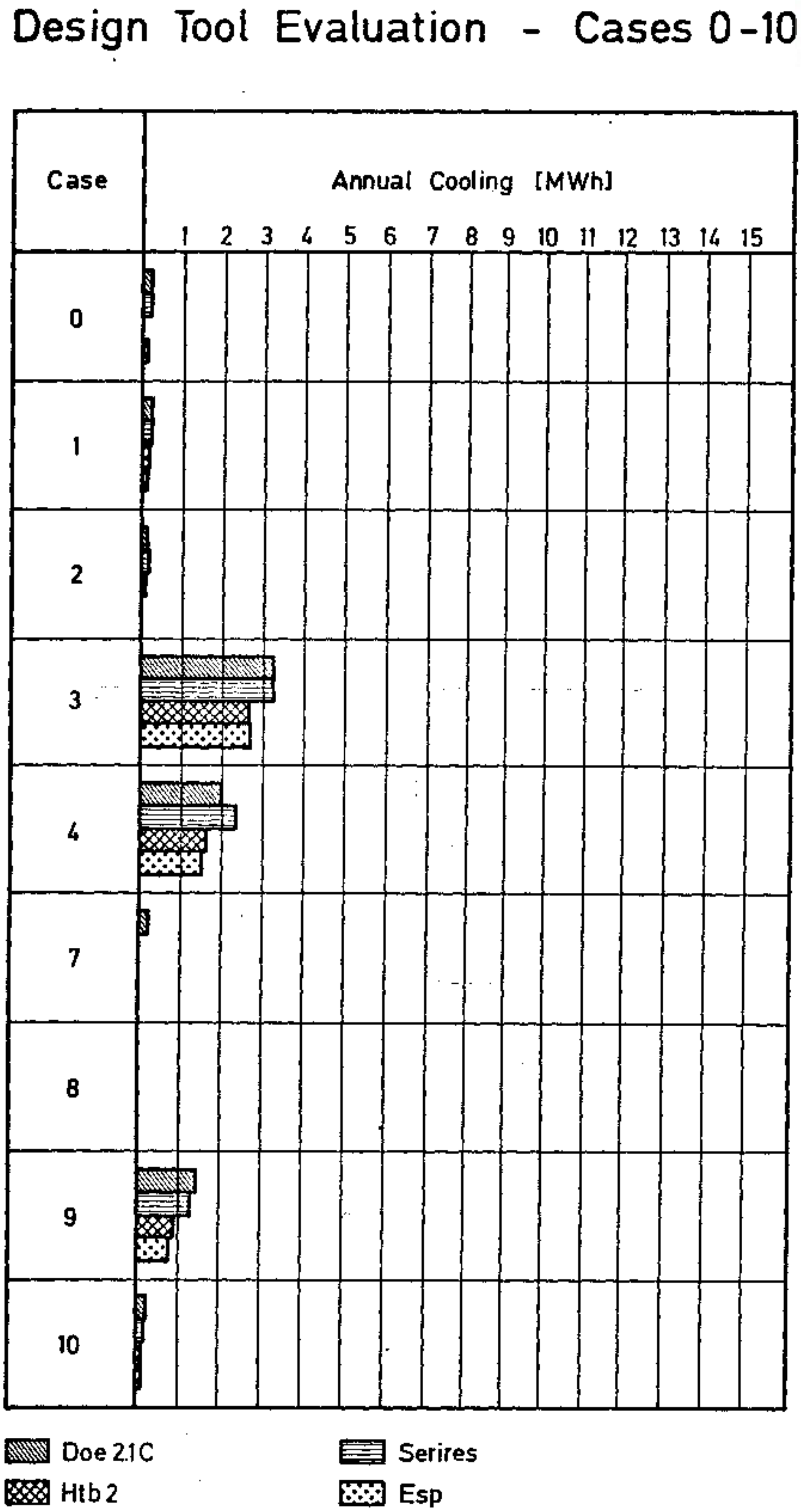


Fig. 4 Annual cooling loads of Phase I calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

Monthly Net Load - Case 4

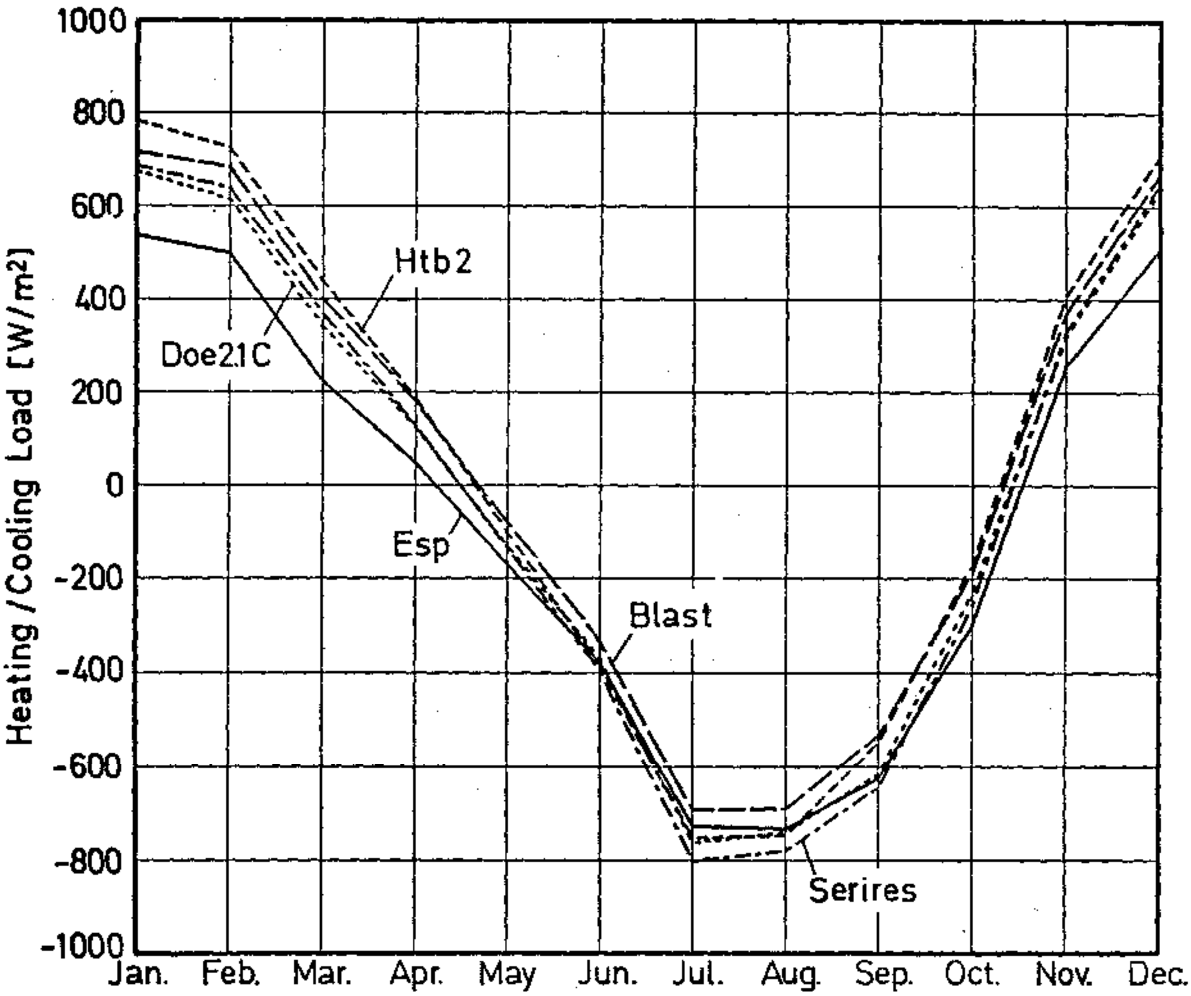


Fig. 5 Monthly net plant loads of Case 4 calculated by detailed building energy analysis simulation models with' weather conditions of DENVER.

Design Tool Evaluation - Cases 1 - 10

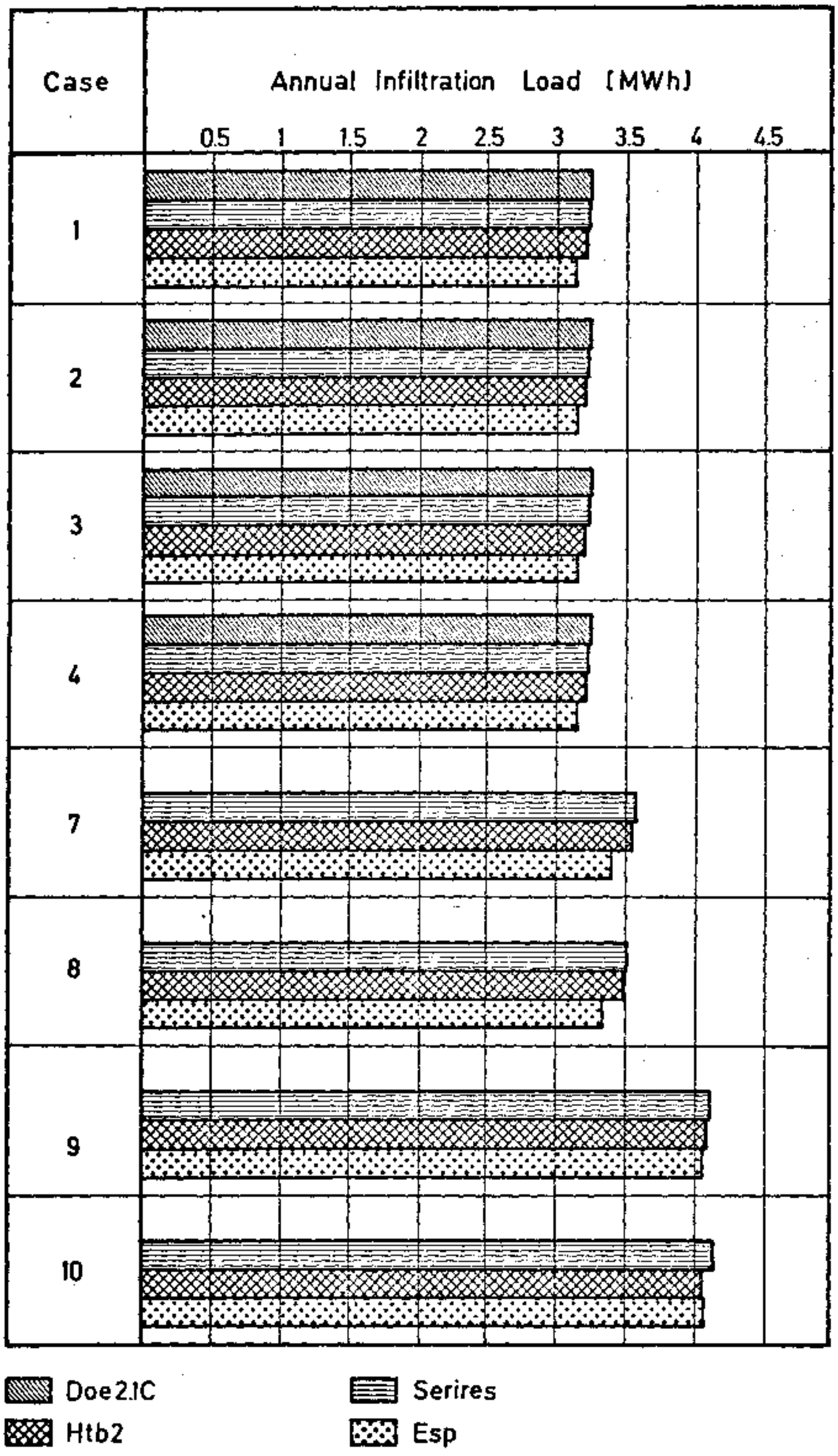


Fig. 6 Annual infiltration loads of Phase I calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

Design Tool Evaluation – Cases 1-10

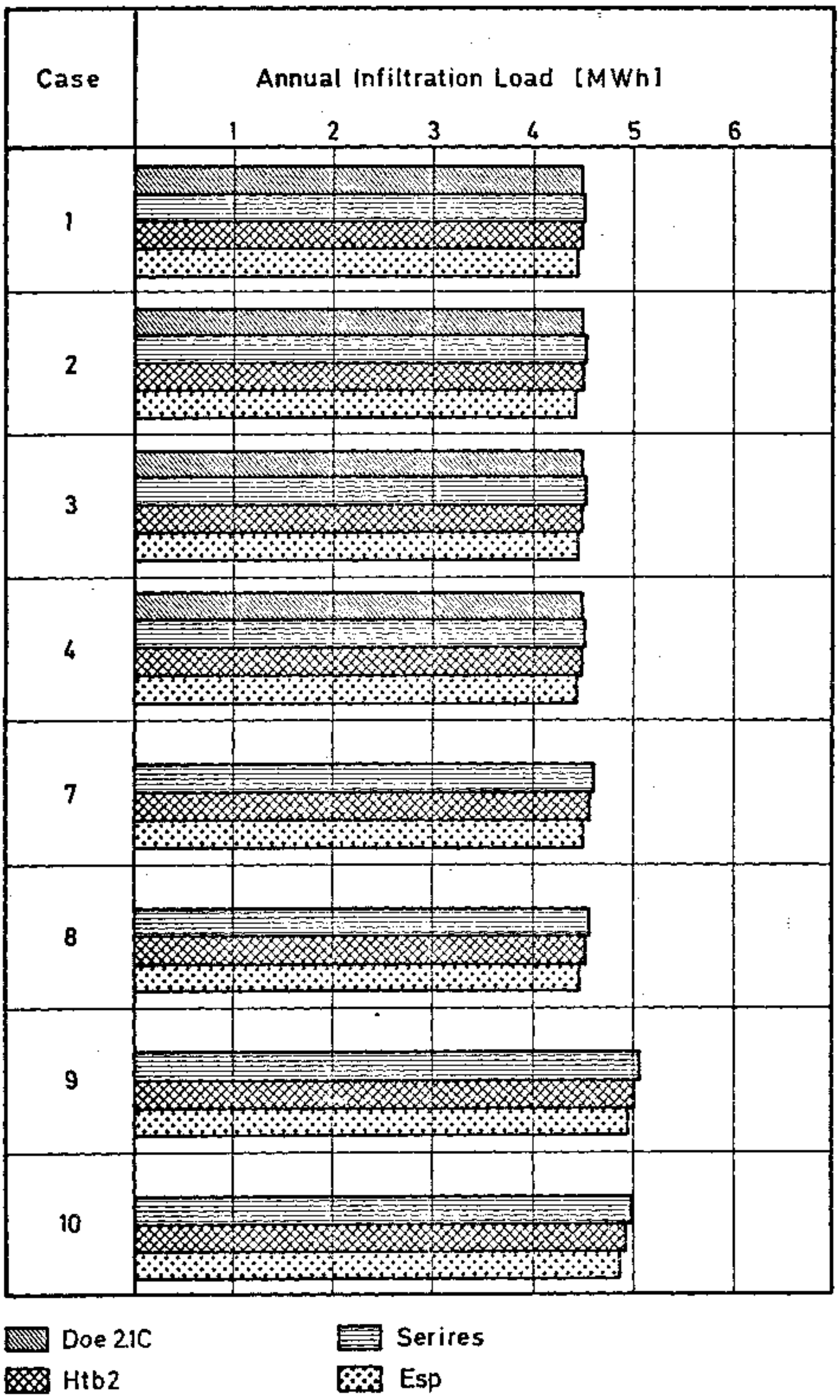
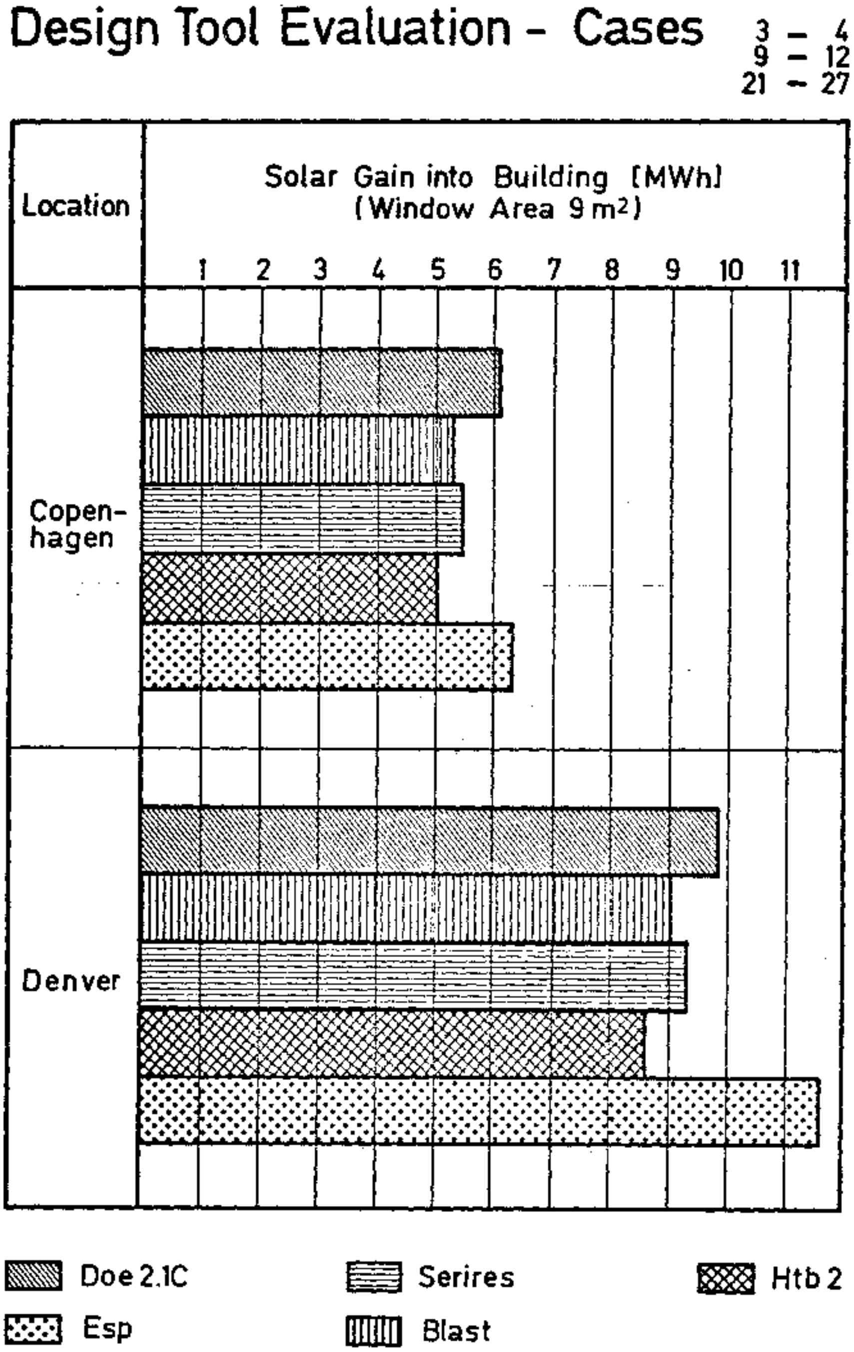


Fig. 7 Annual infiltration loads of Phase I calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.



<u>Fig. 8</u> Annual solar input of cases with window area 9 m' calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN and DENVER.

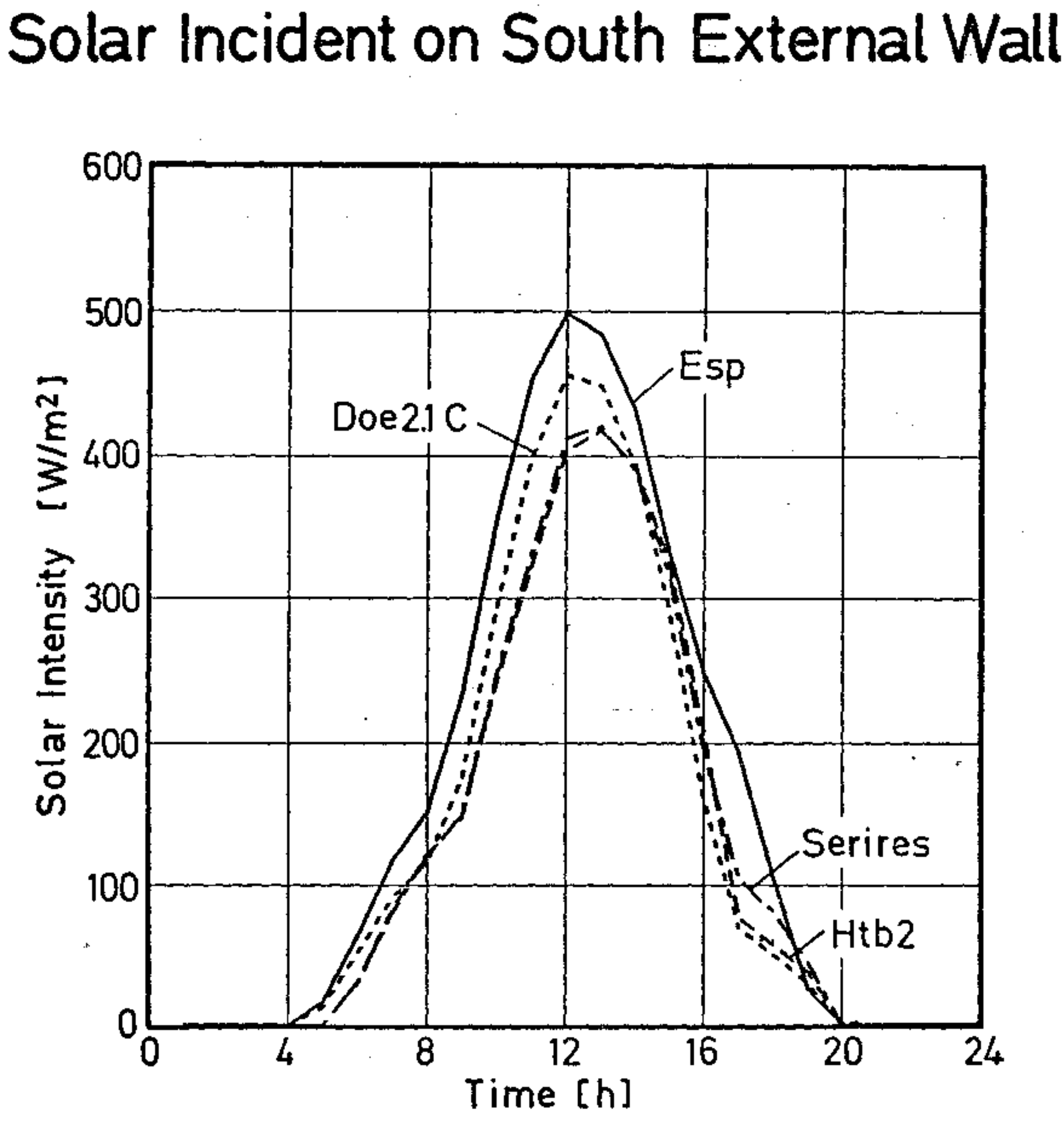


fig. 9 Hourly solar radiation incident on the external south facing surface calculated by detailed building energy analysis simulation models with weather conditions of DENVER, May 30.

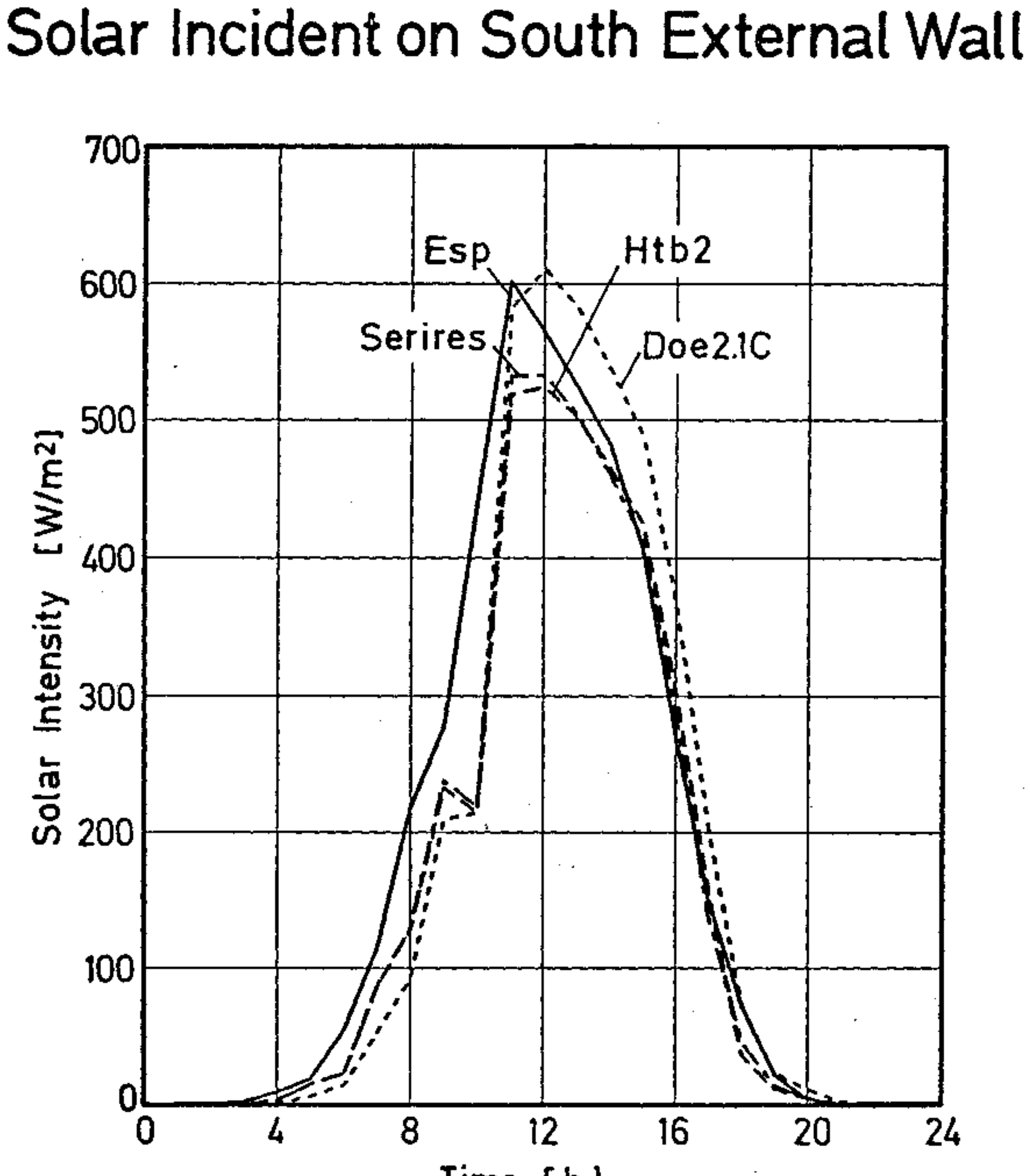


Fig. 10 Hourly solar radiation incident on the external south facing surface calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN, May 30.

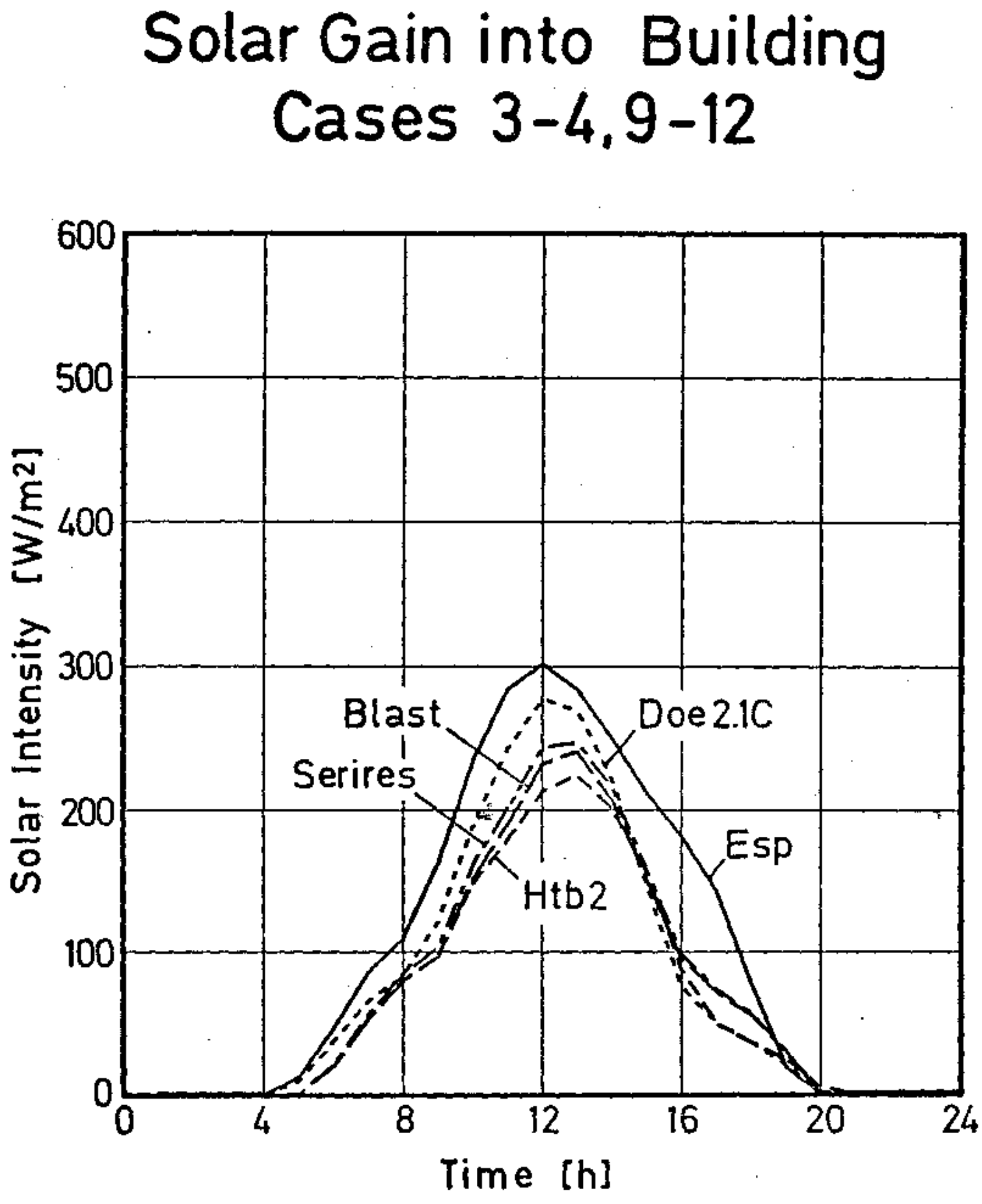


fig. 11 Hourly solar gain into building of Cases 3-4 and 9-12 calculated by detailed building energy analysis simulation models with weather conditions of DENVER, May 30.

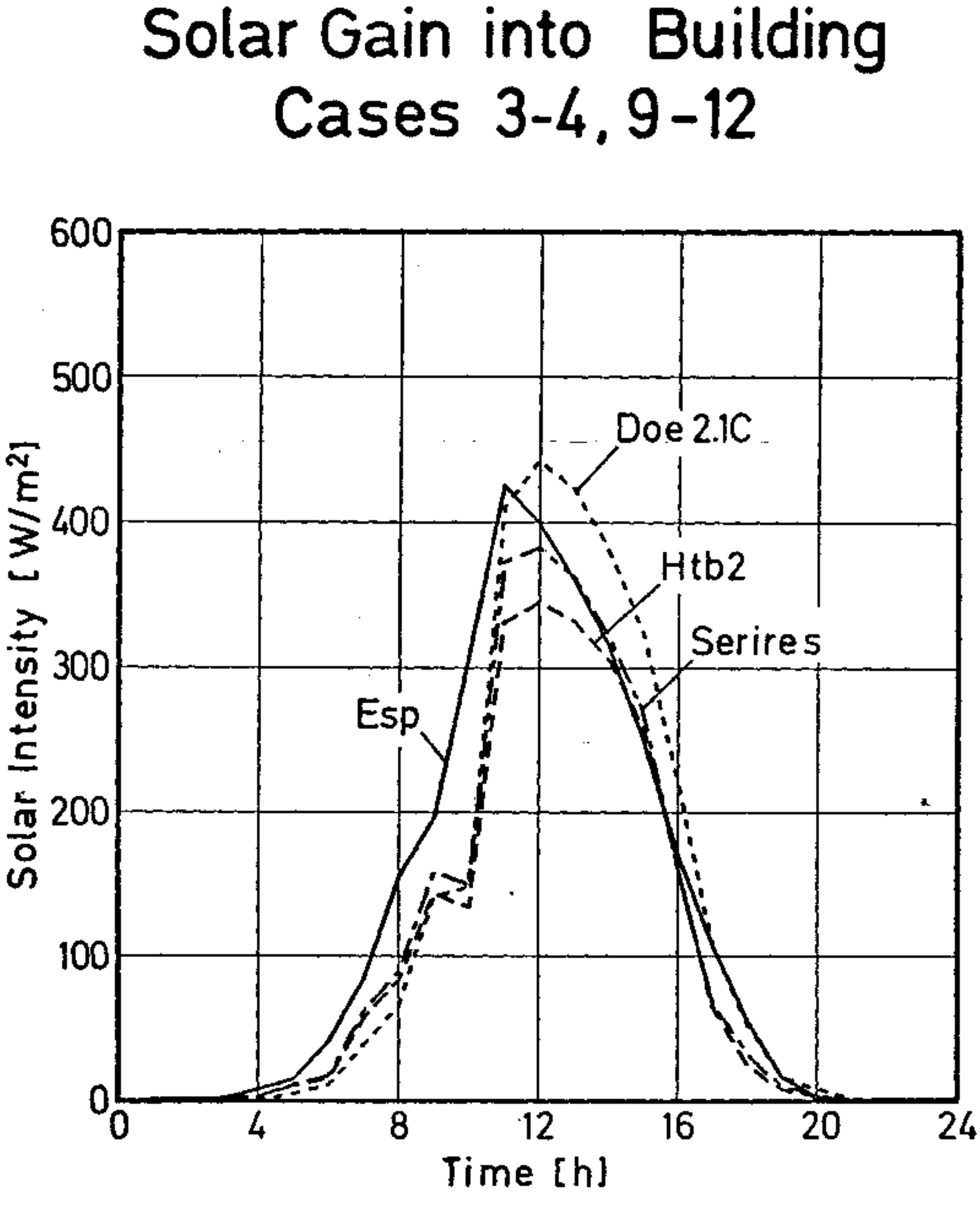


Fig. 12 Hourly solar gain into building of Cases 3-4 and 9-12 calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN, May 30.

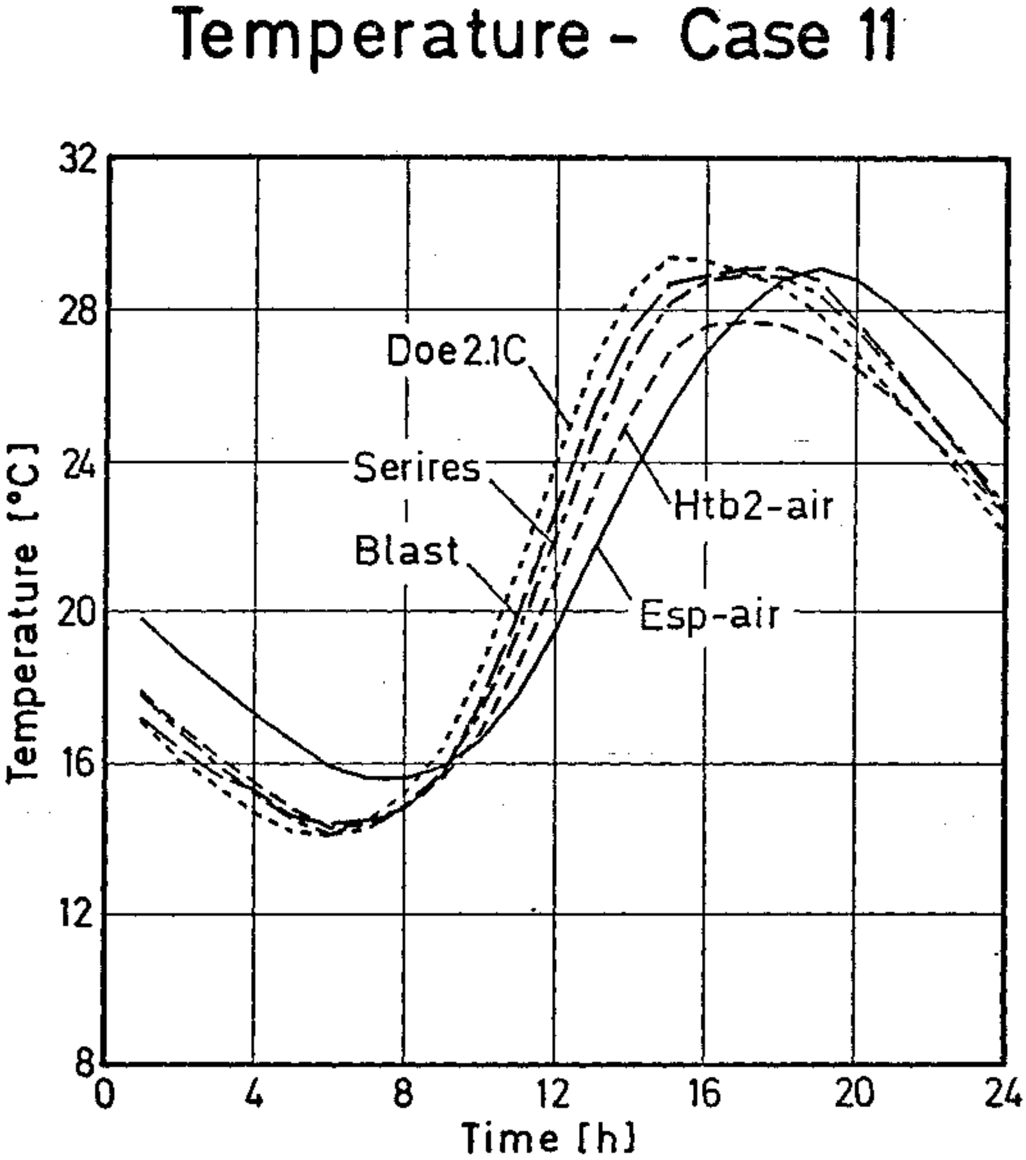


Fig. 13 Hourly free-floating temperatures of Case 11 (lightweight building) calculated by detailed building energy analysis simulation models with weather conditions of DENVER, May 30.

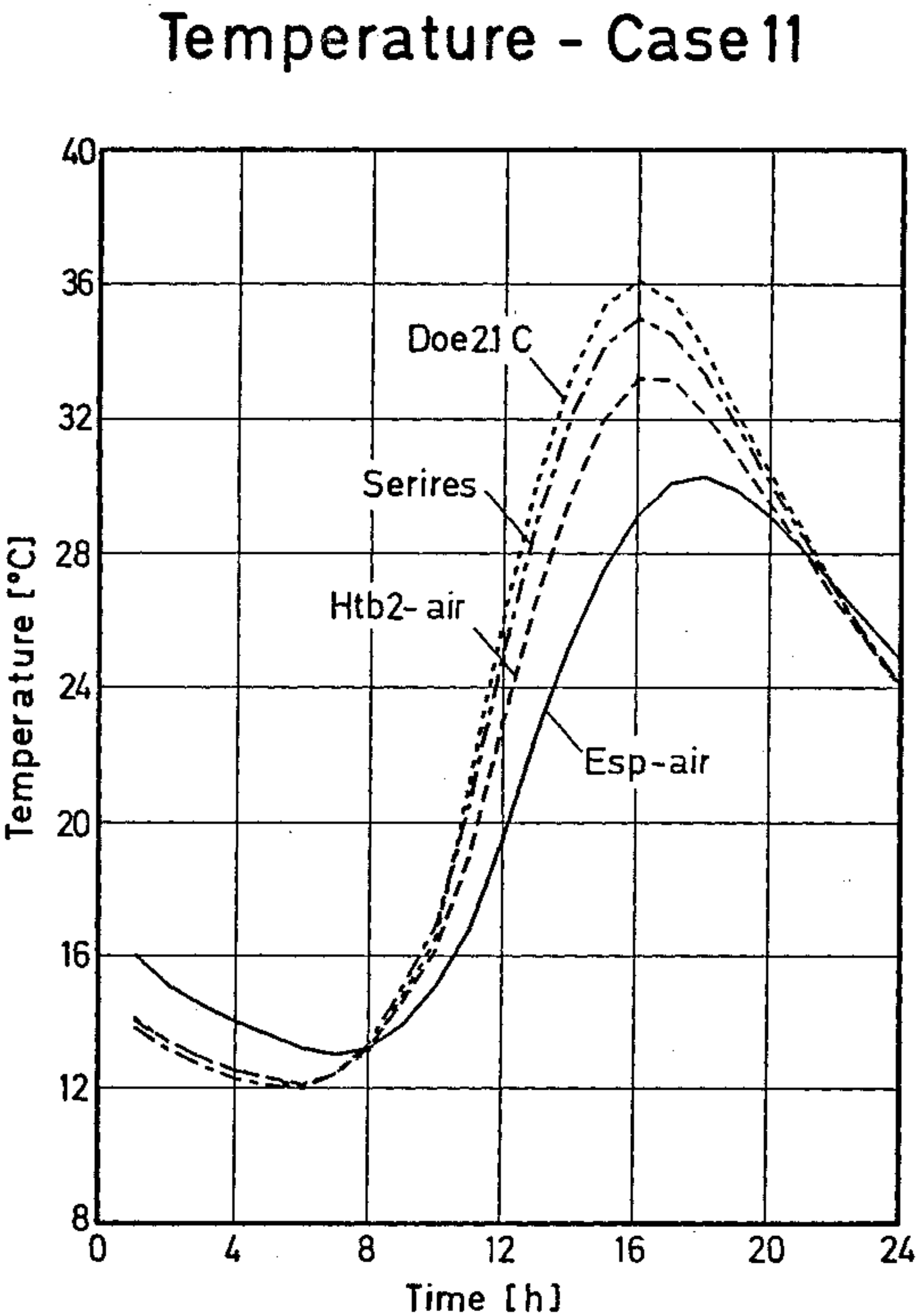


Fig. 14 Hourly free-floating temperatures of Case 11 (lightweight building) calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN, May 30.

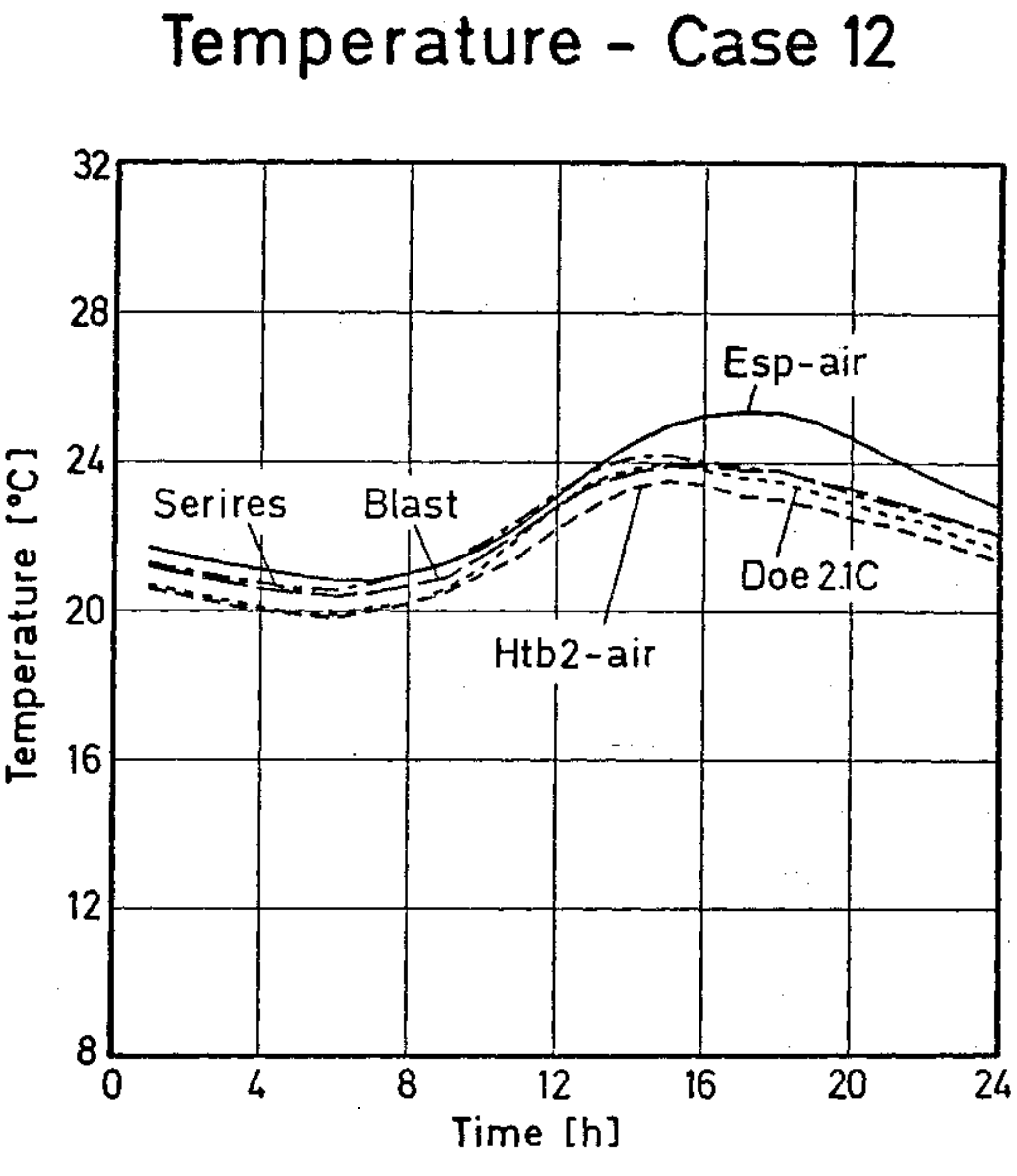


Fig. 15 Hourly free-floating temperatures of Case 12 (heavyweight building) calculated by detailed building energy analysis simulation models with weather conditions of DENVER, May 30.

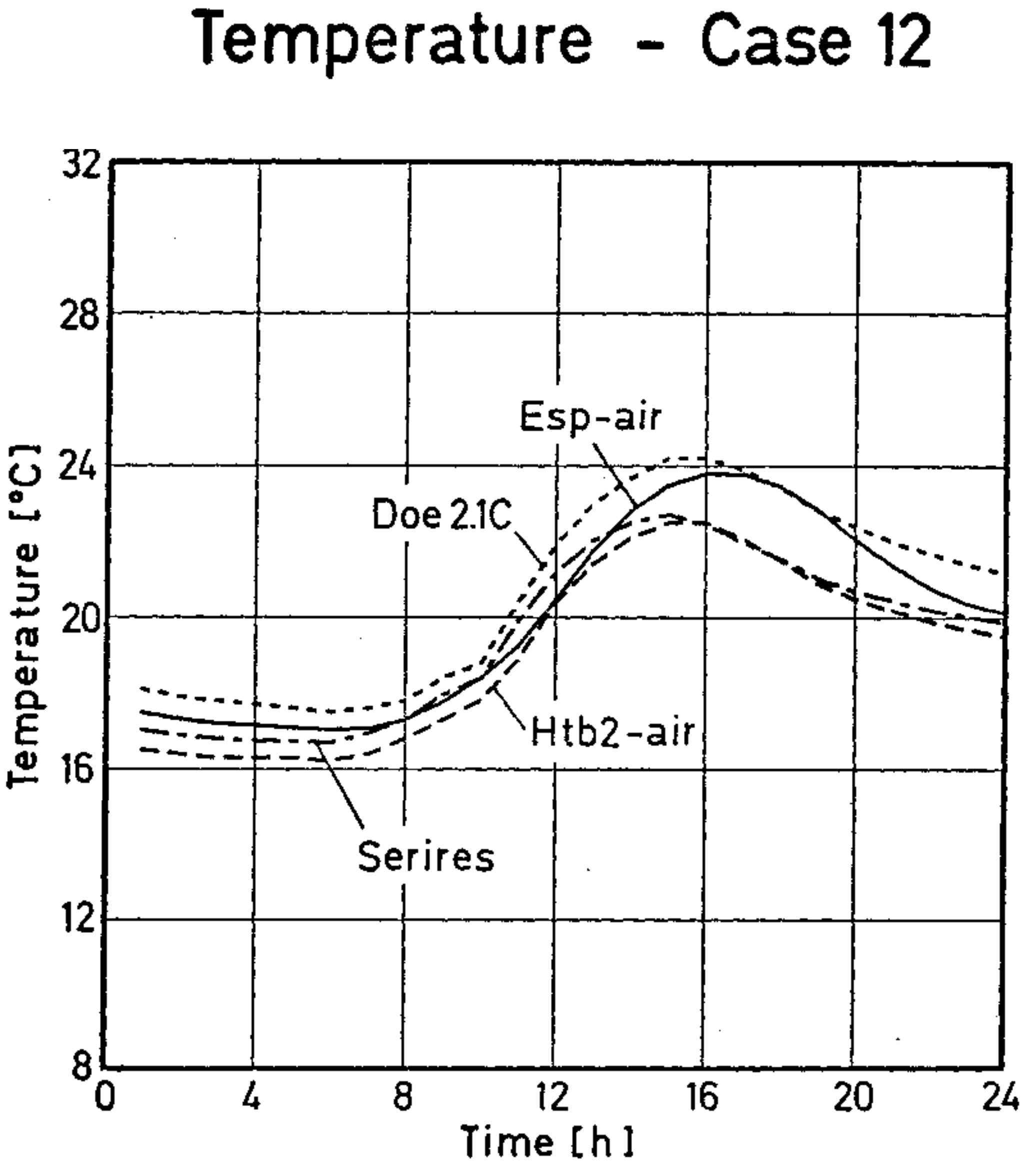


Fig. 16 Hourly free-floating temperatures of Case 12 (heavyweight building) calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN, May 30.

Design Tool Evaluation - Cases 0-10

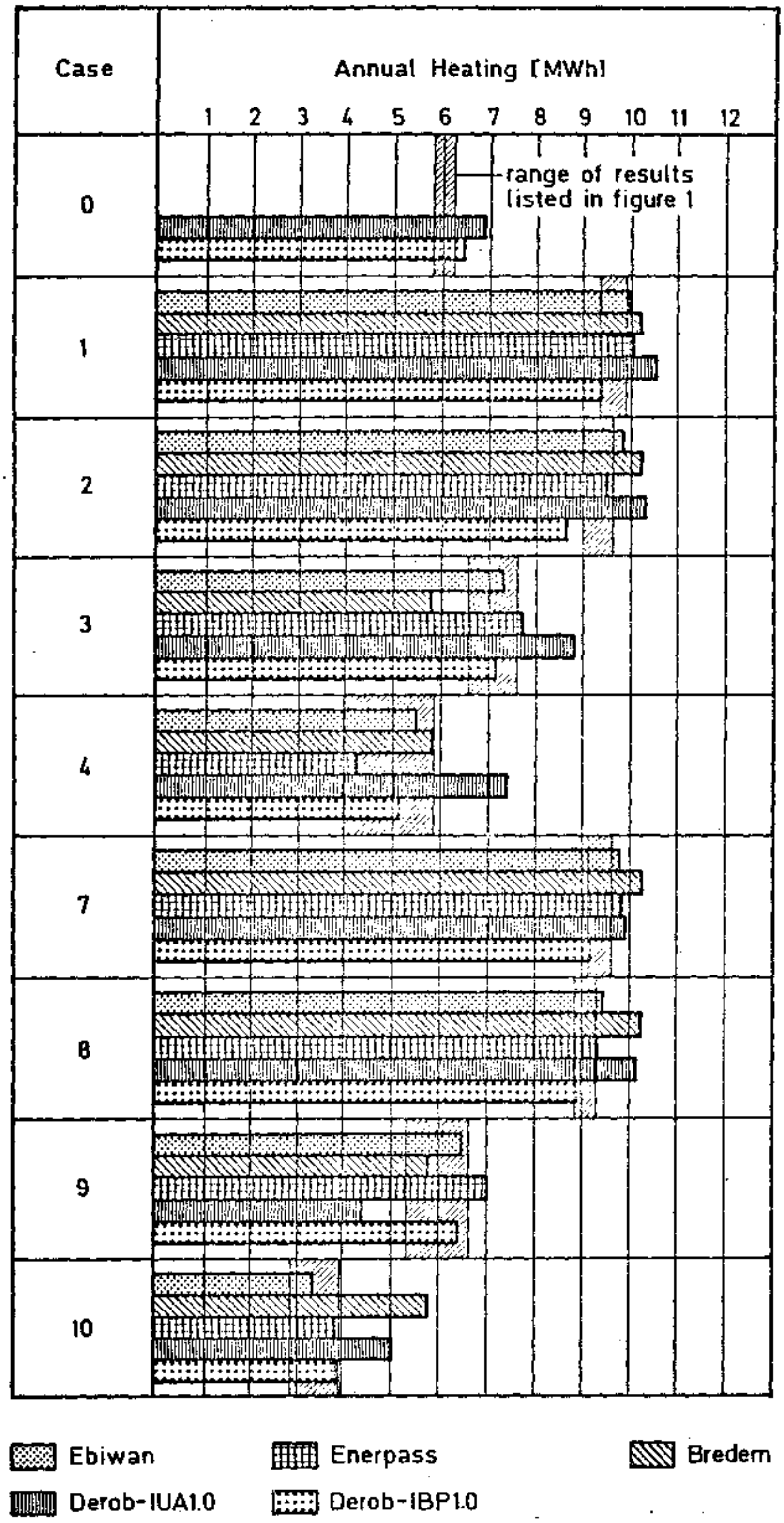


Fig. 17 Annual heating loads of Phase I calculated by design tools with weather conditions of DENVER. Hatched areas indicate the ranges of results obtained by detailed building energy analysis simulation models (BLAST, DOE 2.1C, SERIRES, HTB 2, ESP) in Fig. 1.

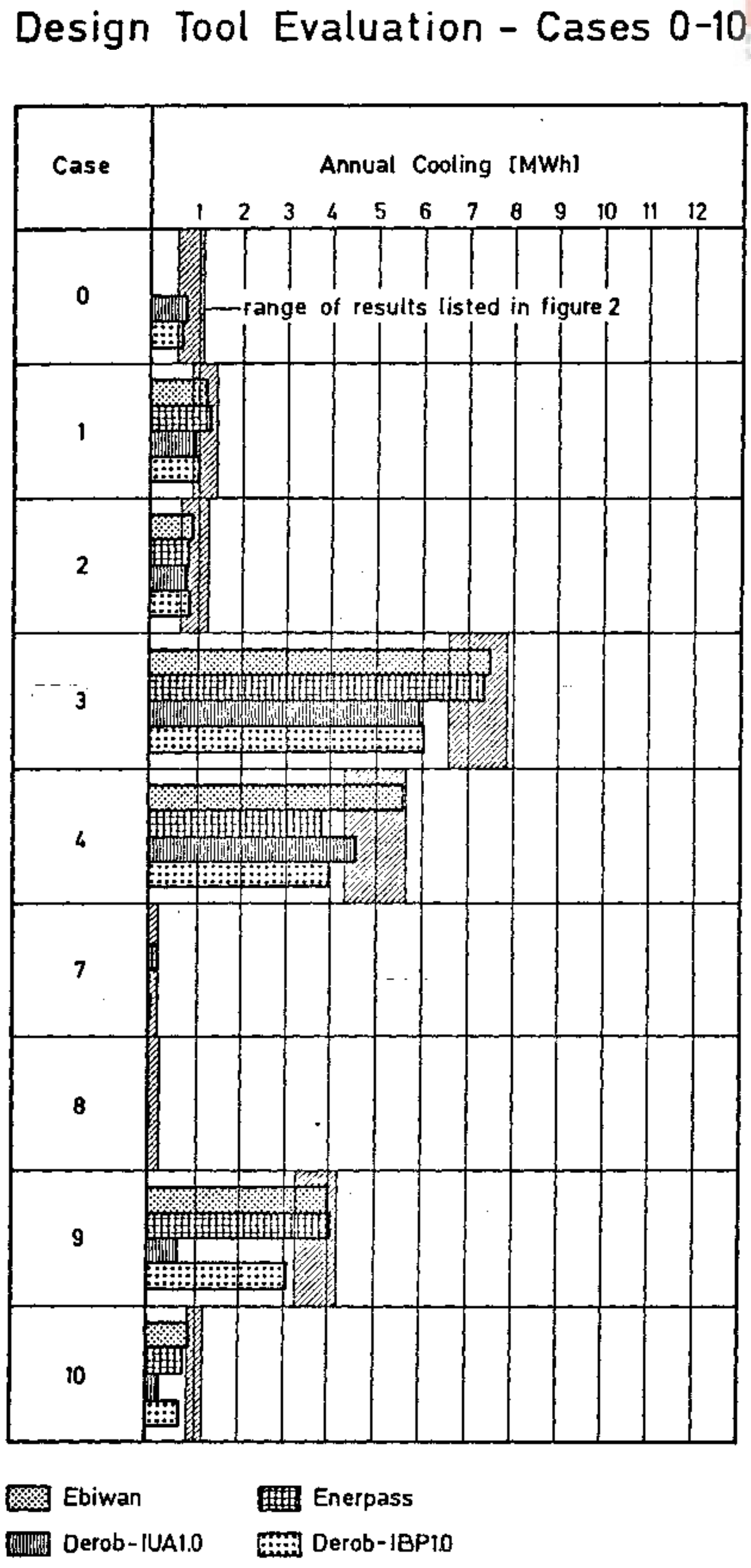
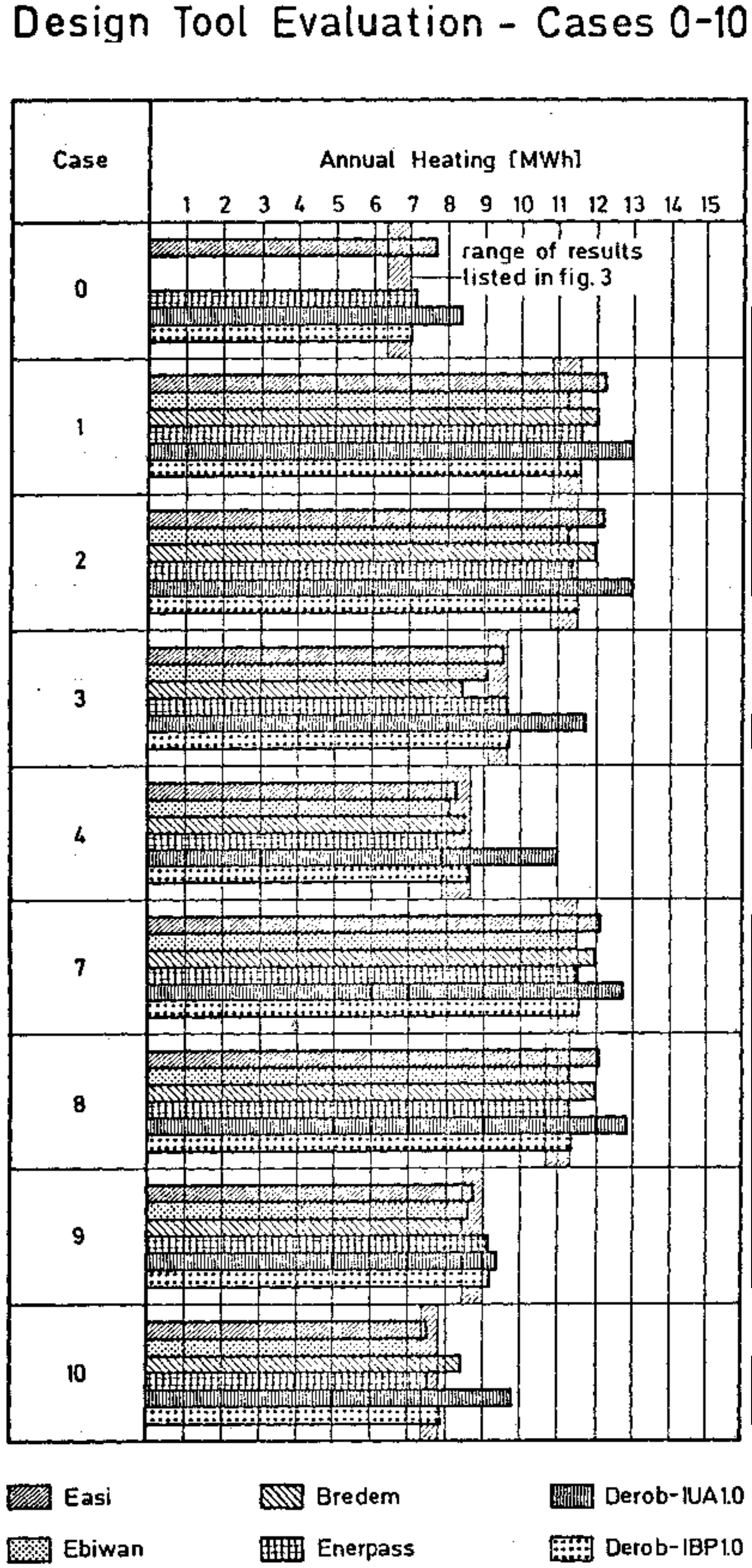


Fig. 18 Annual cooling loads of Phase I calculated by design tools with weather conditions of DENVER. Hatched areas indicate the ranges of results obtained by detailed building energy analysis simulation models (BLAST, DOE 2:1C, SERIRES, HTB 2, ESP) in Fig. 2.



[redacted]

[redacted]

[redacted]

[redacted]

fig. 19 Annual heating loads of Phase I calculated by design tools with weather conditions of COPENHAGEN. Hatched areas indicate the ranges of results obtained by detailed building energy analysis simulation models (BLAST, DOE 2.1C, SERIRES, HTB 2 , ESP) in Fig. 3.

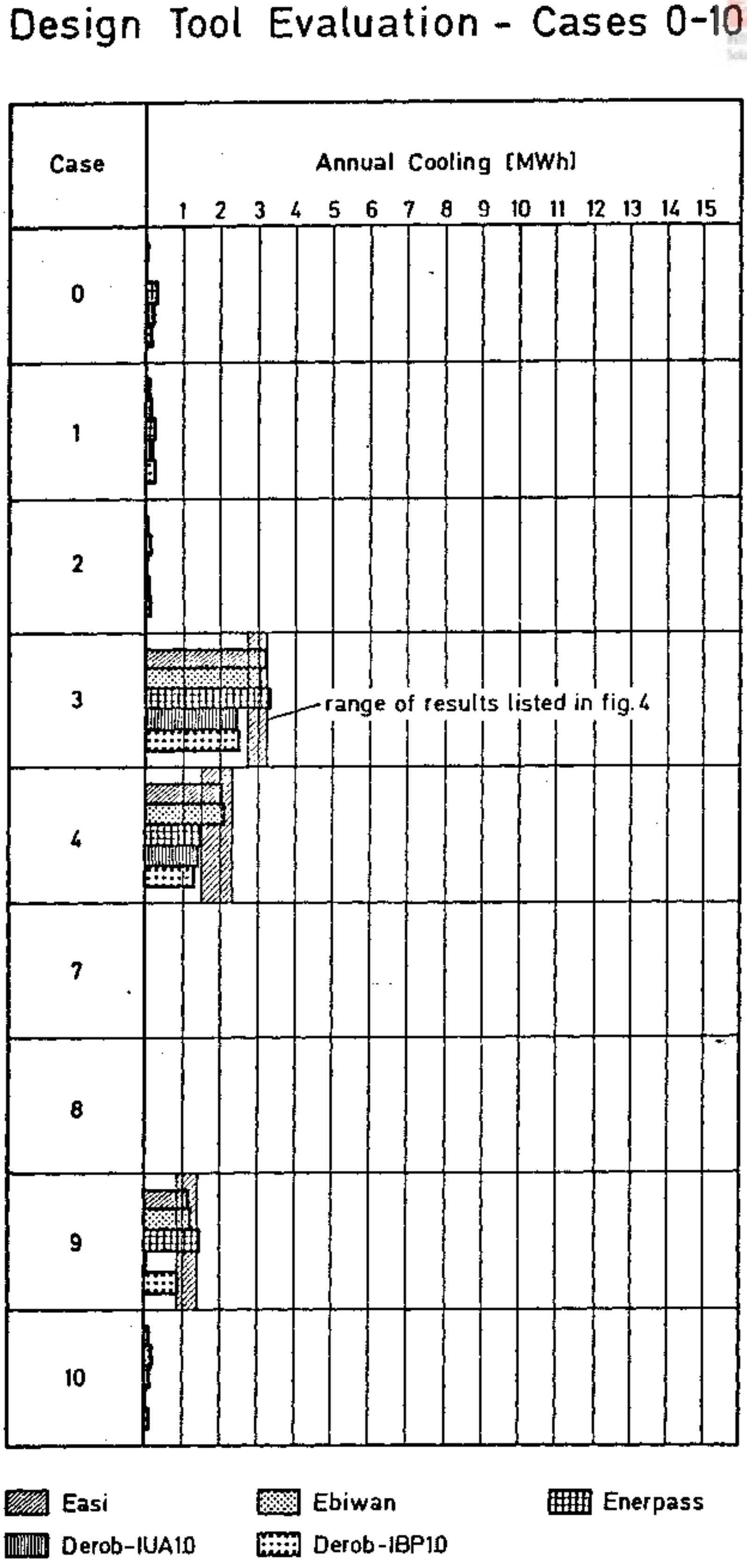


fig. 20 Annual cooling loads of Phase I calculated by design tools with weather conditions of COPENHAGEN. Hatched areas indicate the ranges of results obtained by detailed building energy analysis simulation models (BLAST, DOE 2.1C, SERIRES, HTB 2, ESP) in Fig. 4.

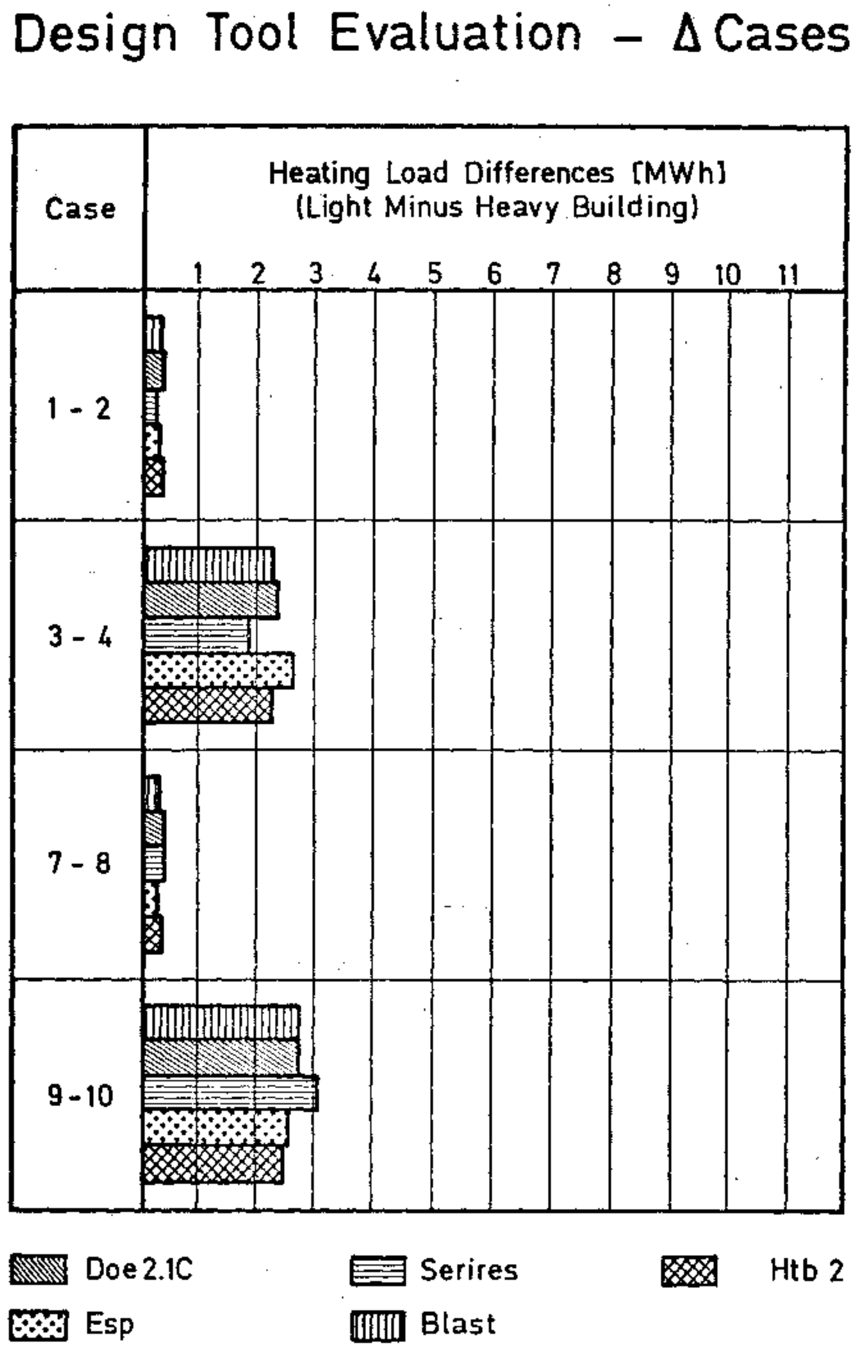


fig. 21 Differences in annual heating loads of Phase I between light and heavyweight buildings calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

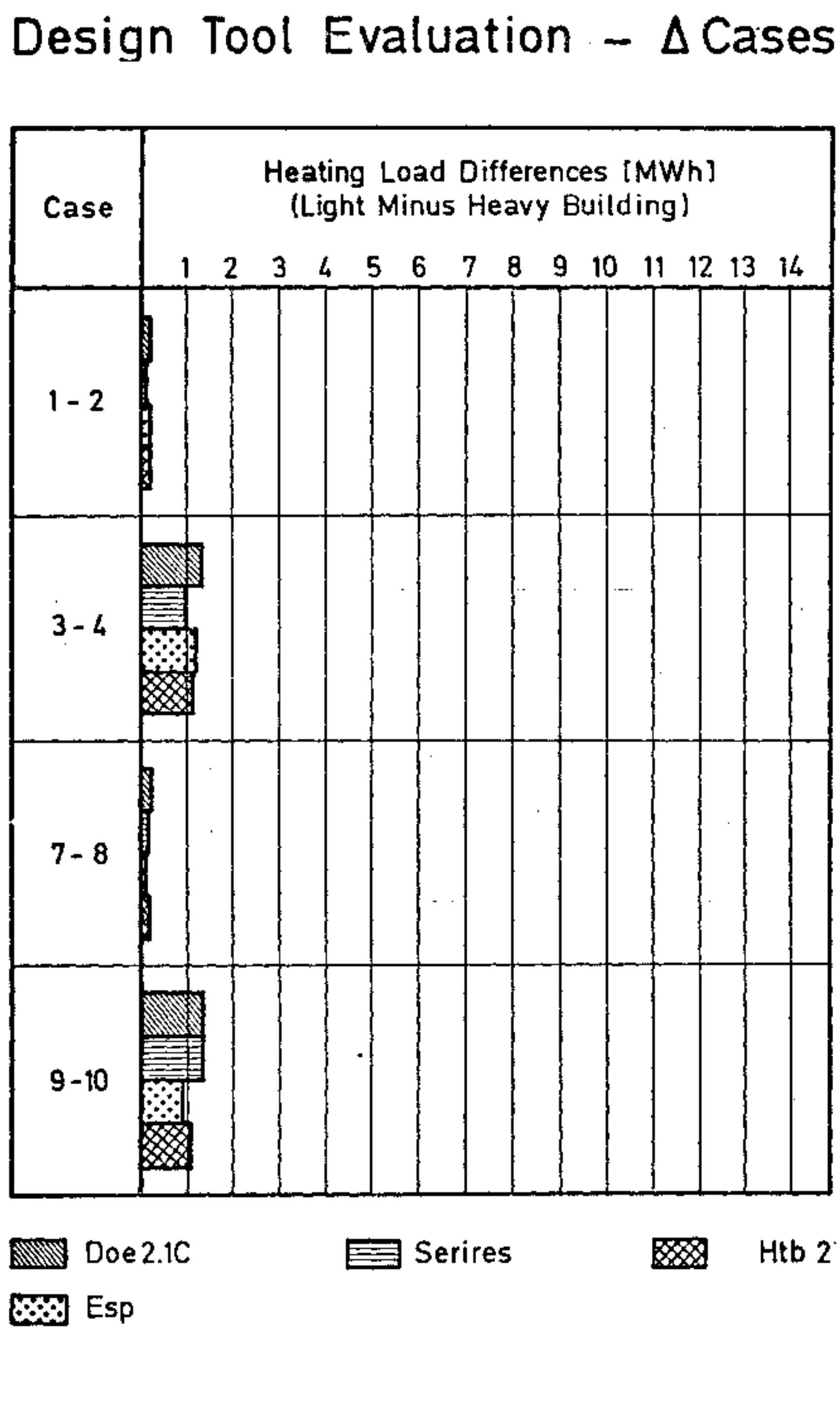


Fig. 23 Differences in annual heating loads-of Phase I between light and heavyweight buildings calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

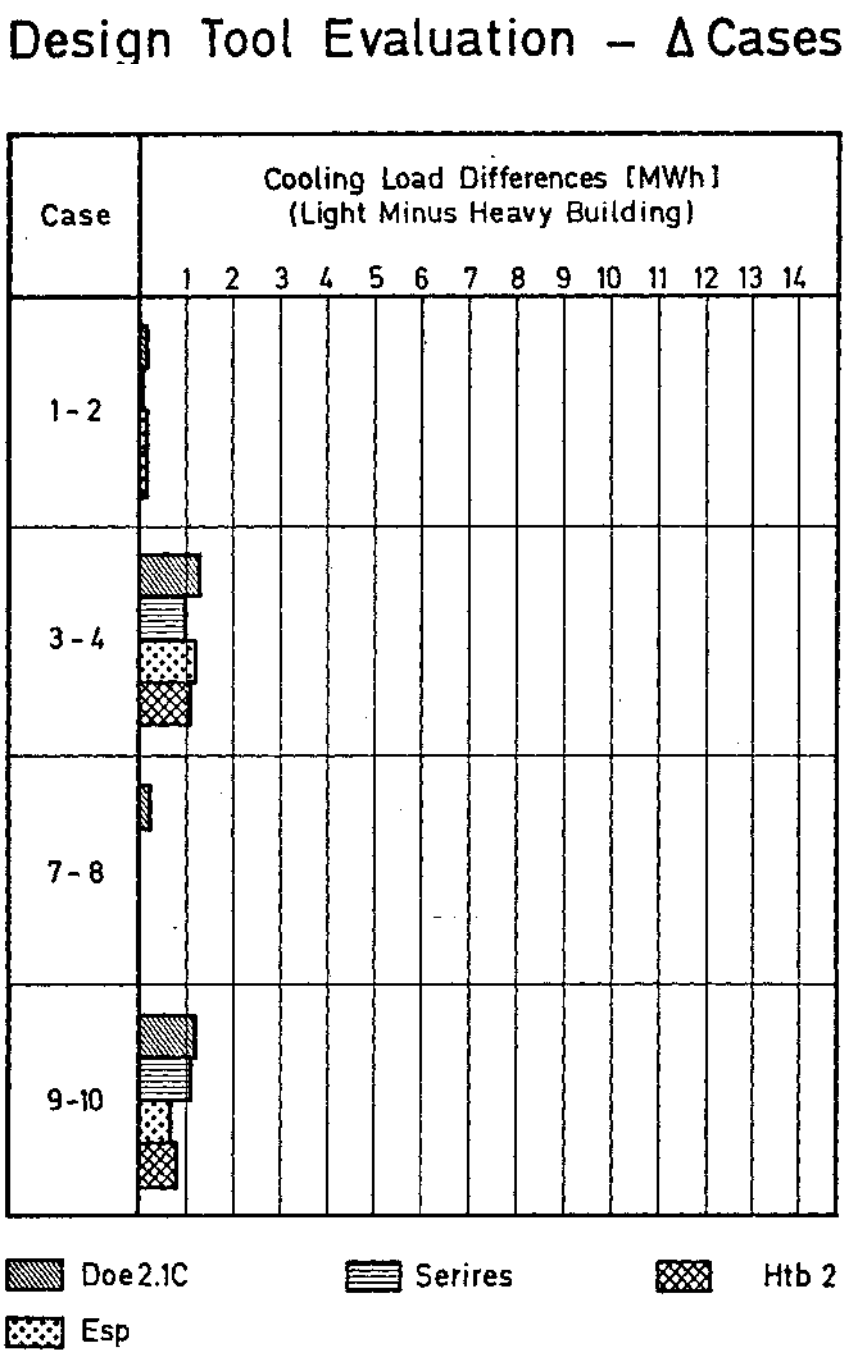


Fig. 24 Differences in annual cooling loads of Phase I between light and heavyweight buildings calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

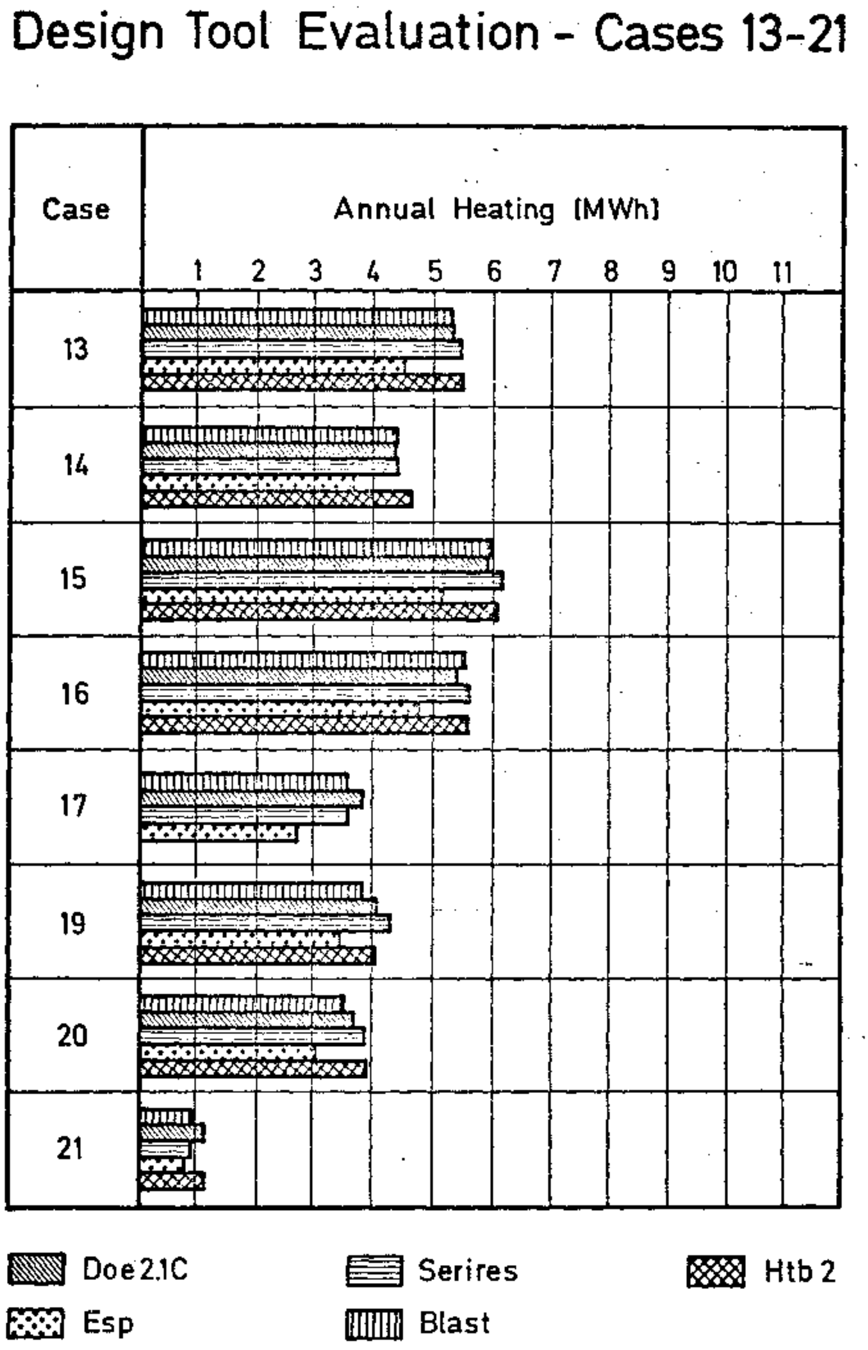


Fig. 25 Annual heating loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

Design Tool Evaluation - Cases 13-21

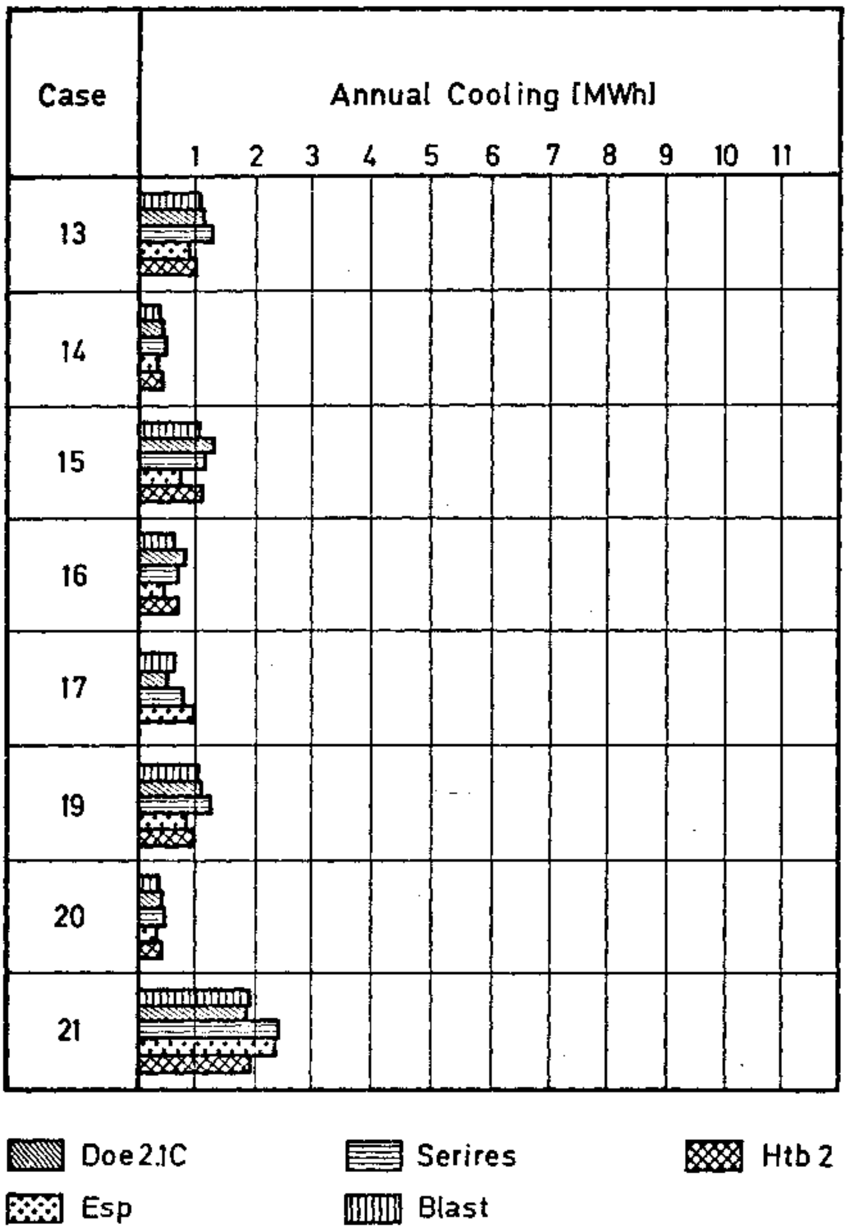
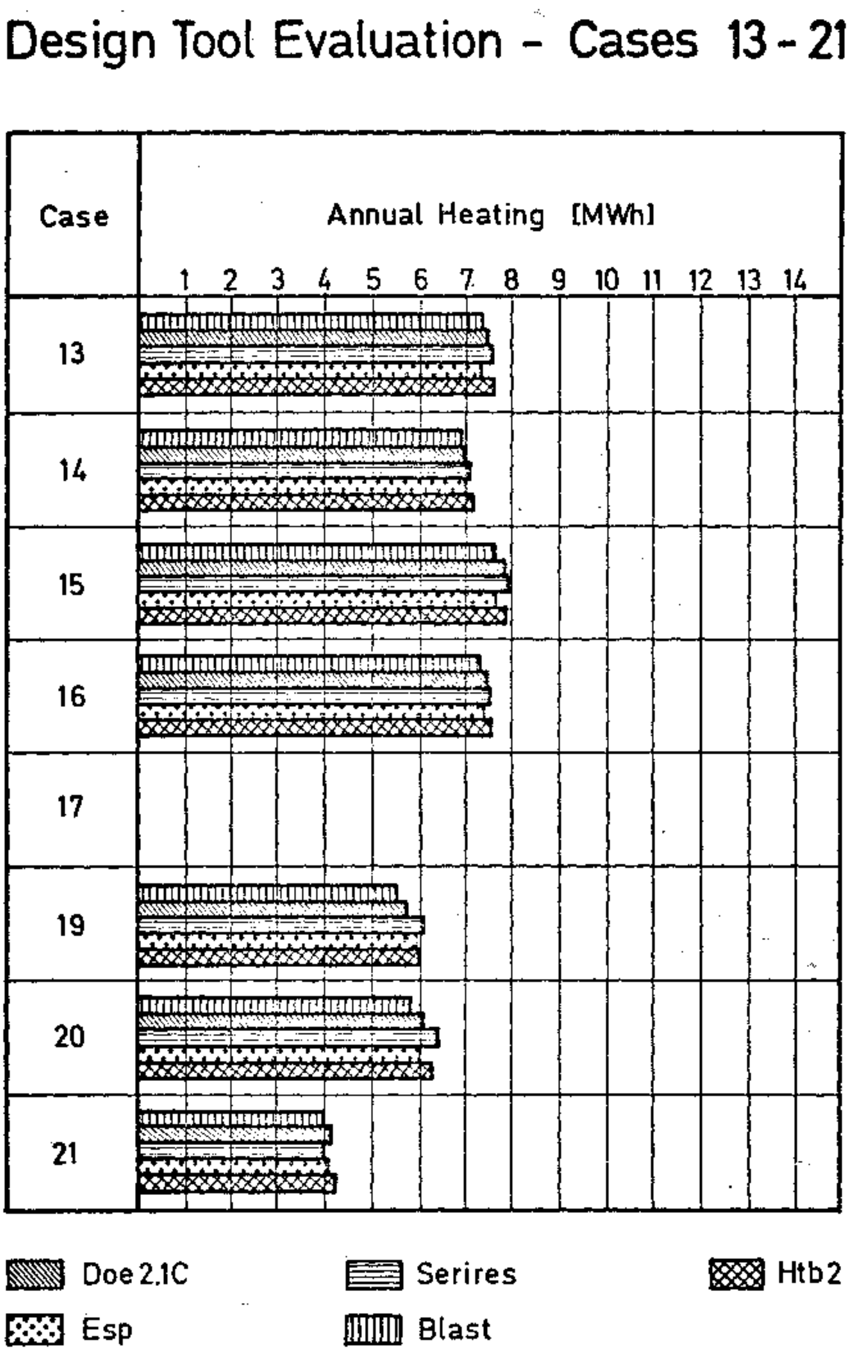


Fig. 26 Annual cooling loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of DENVER.



<u>Fig. 27</u> Annual heating loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

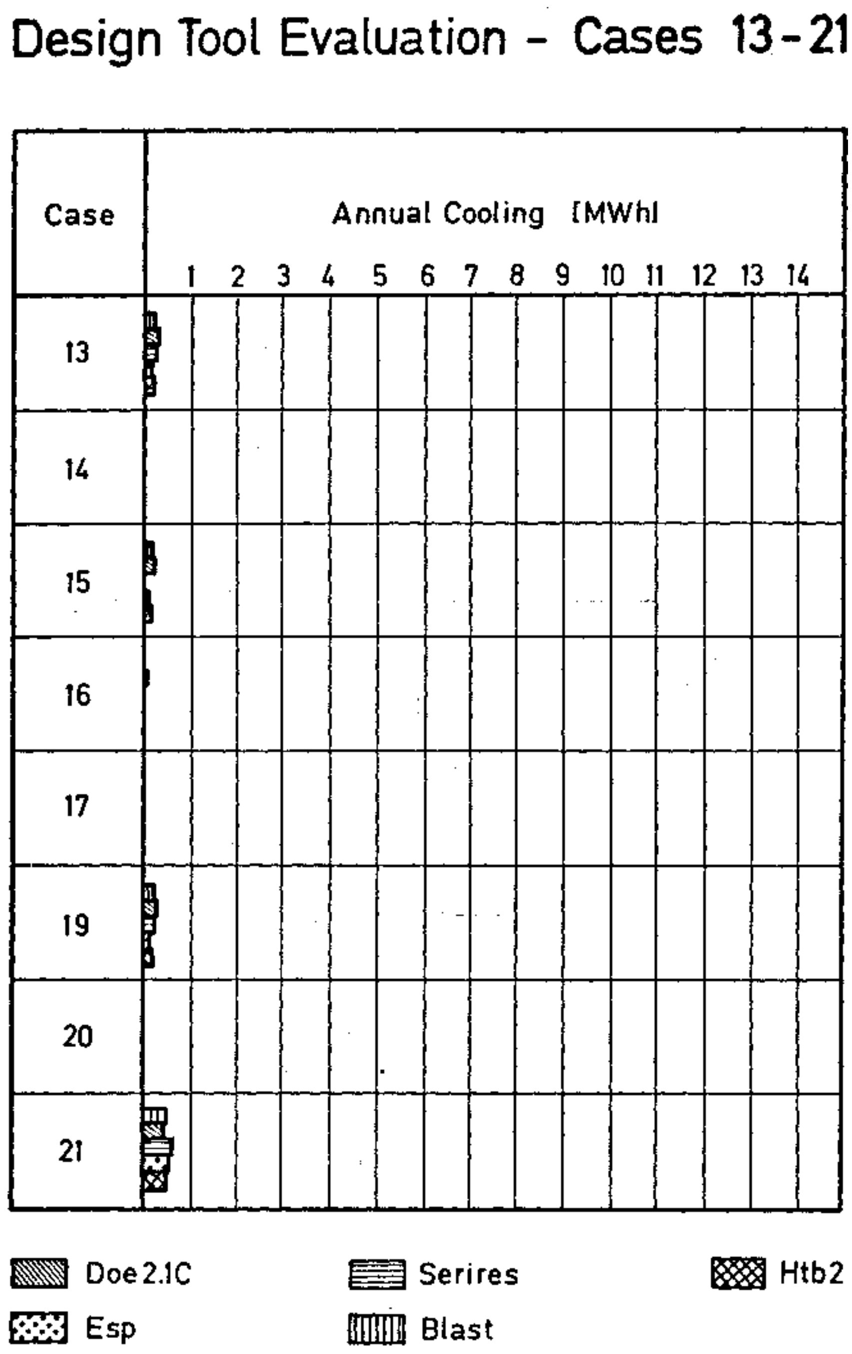


Fig. 28 Annual cooling loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

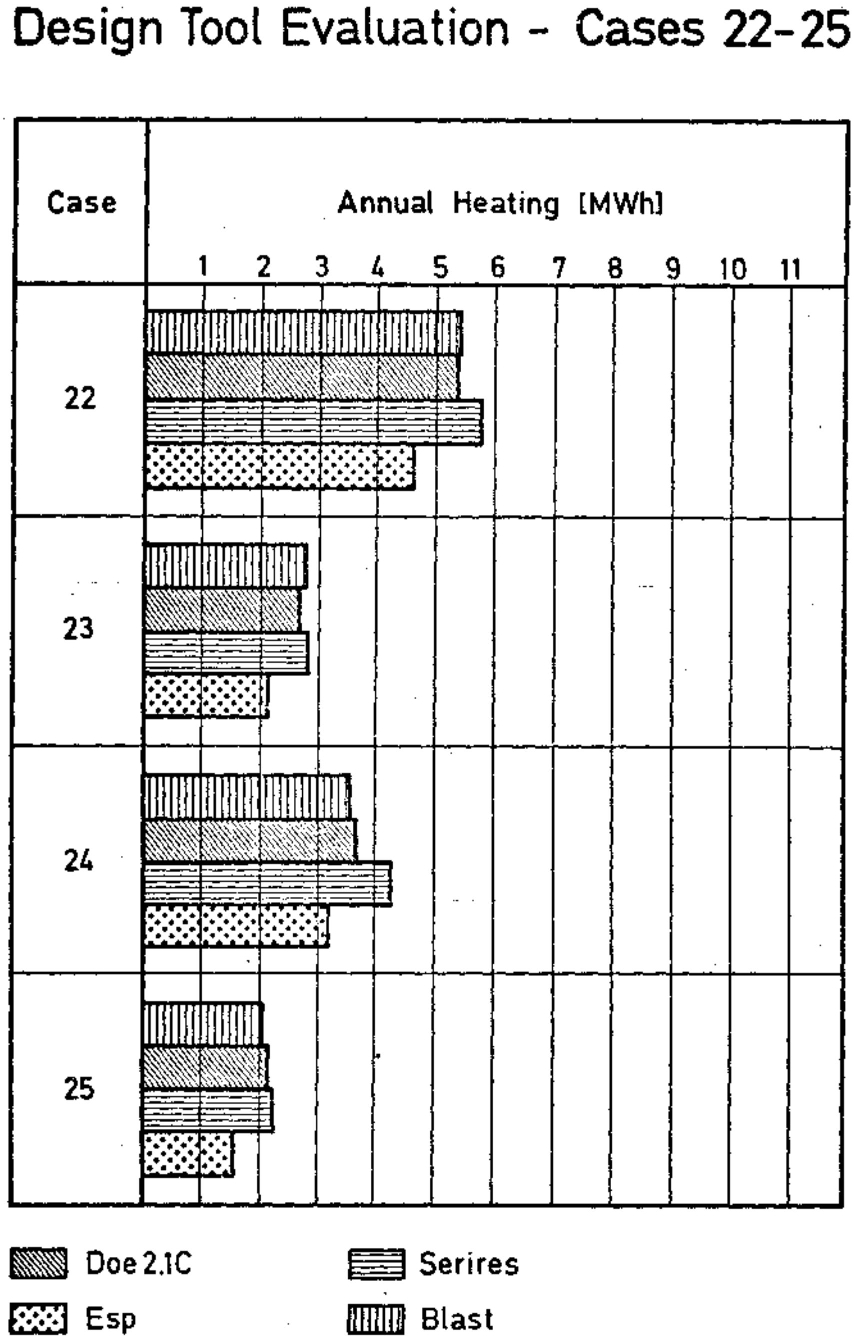


Fig. 29 Annual heating loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

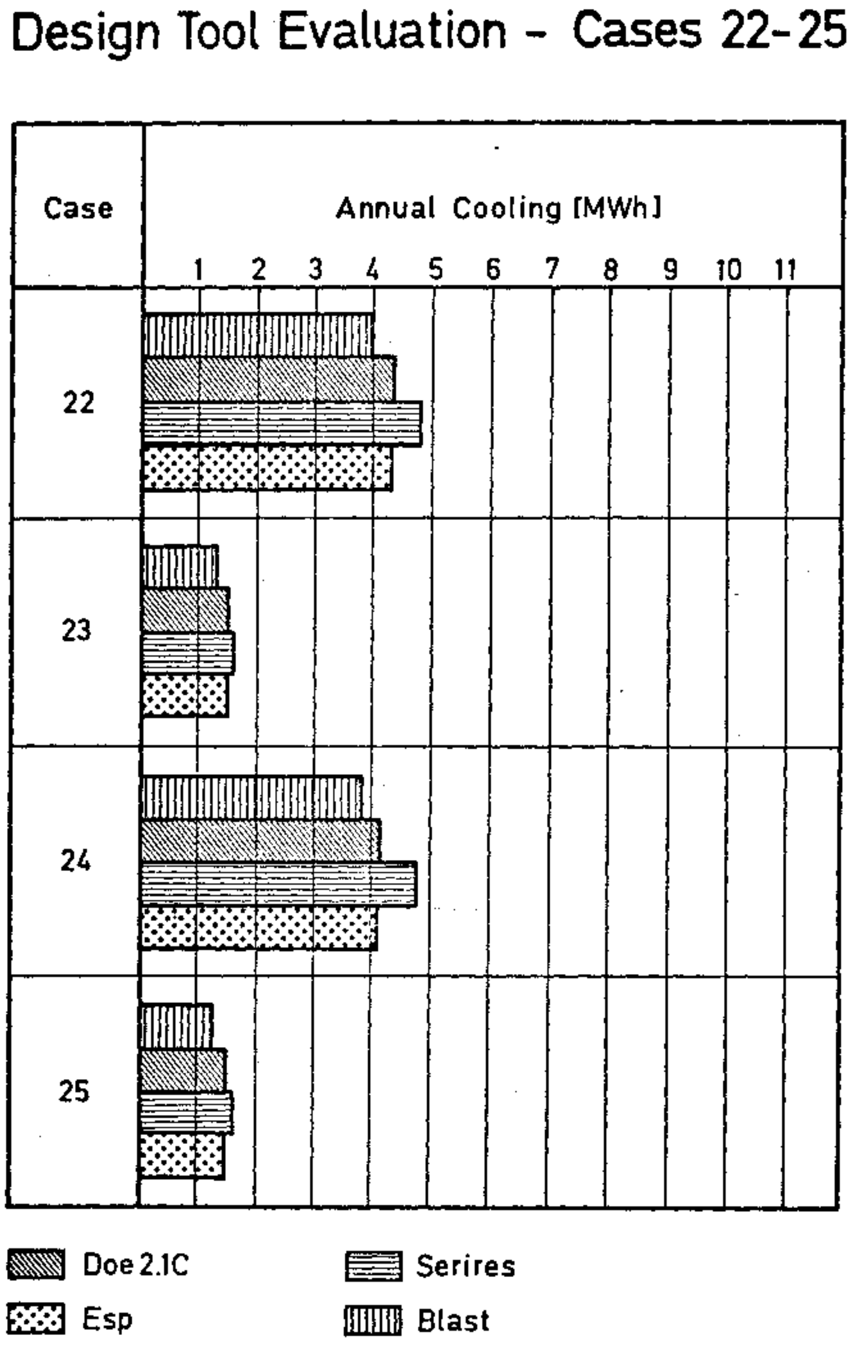


Fig. 30 Annual cooling loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

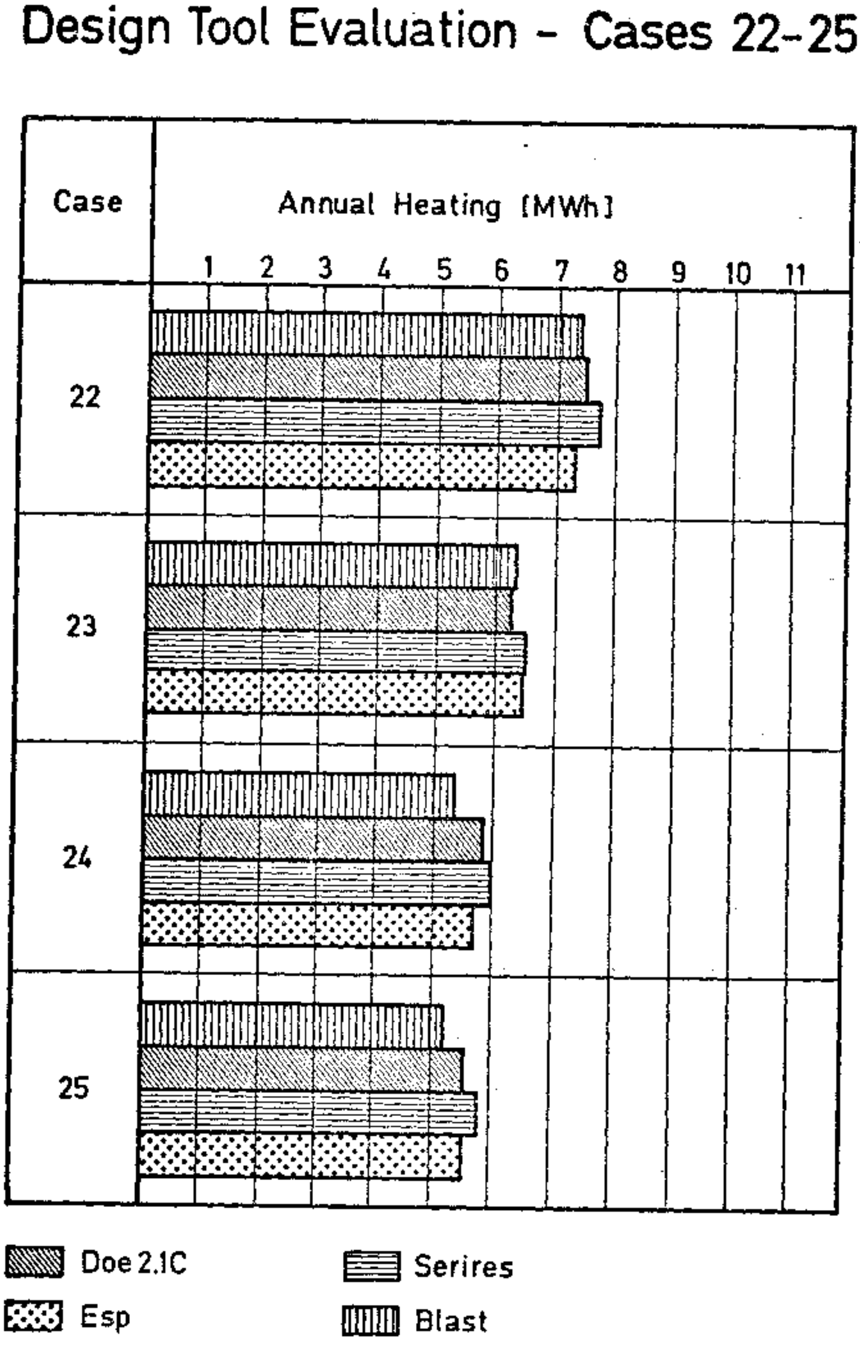


Fig. 31 Annual heating loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

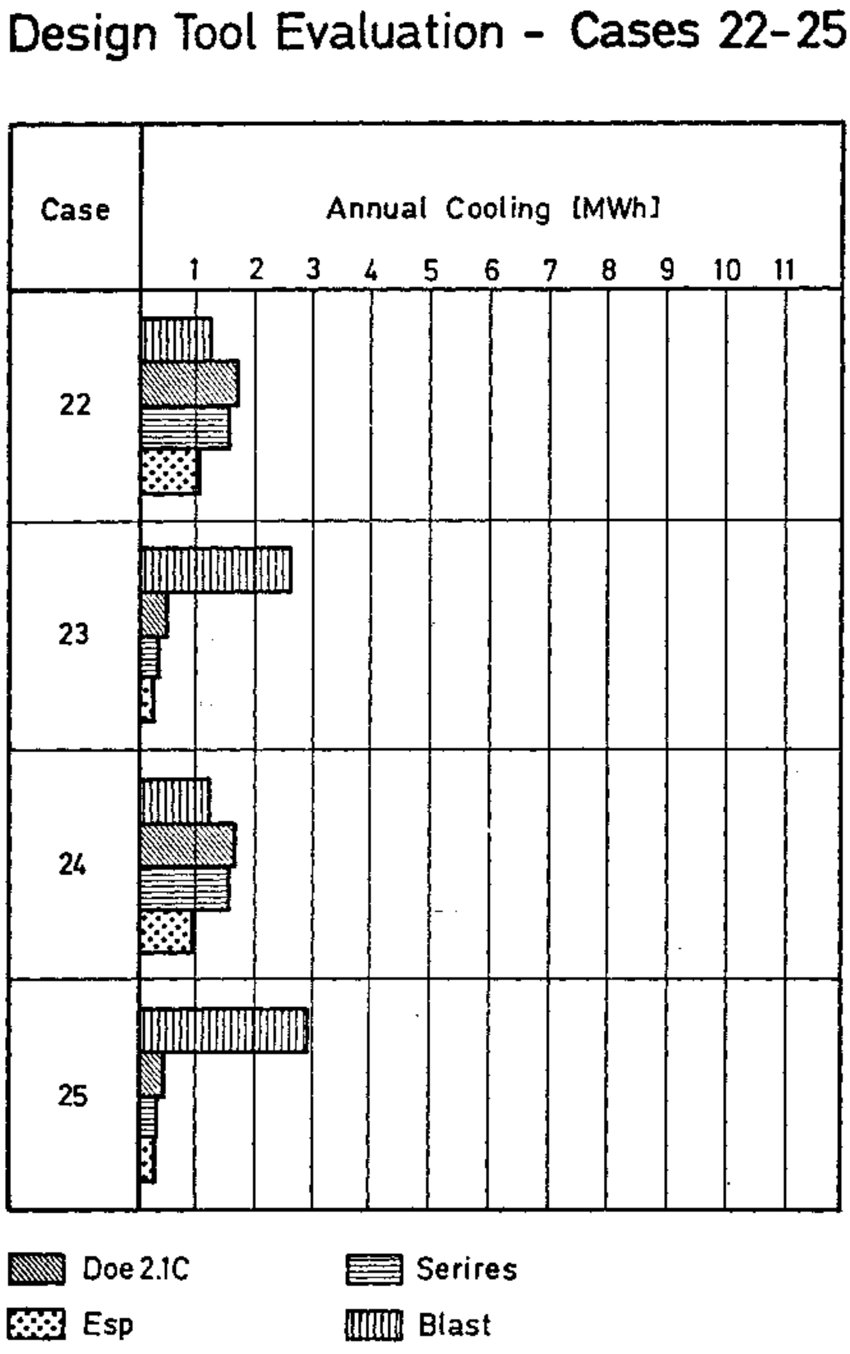


Fig. 32 Annual cooling loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

Design Tool Evaluation – ΔCases

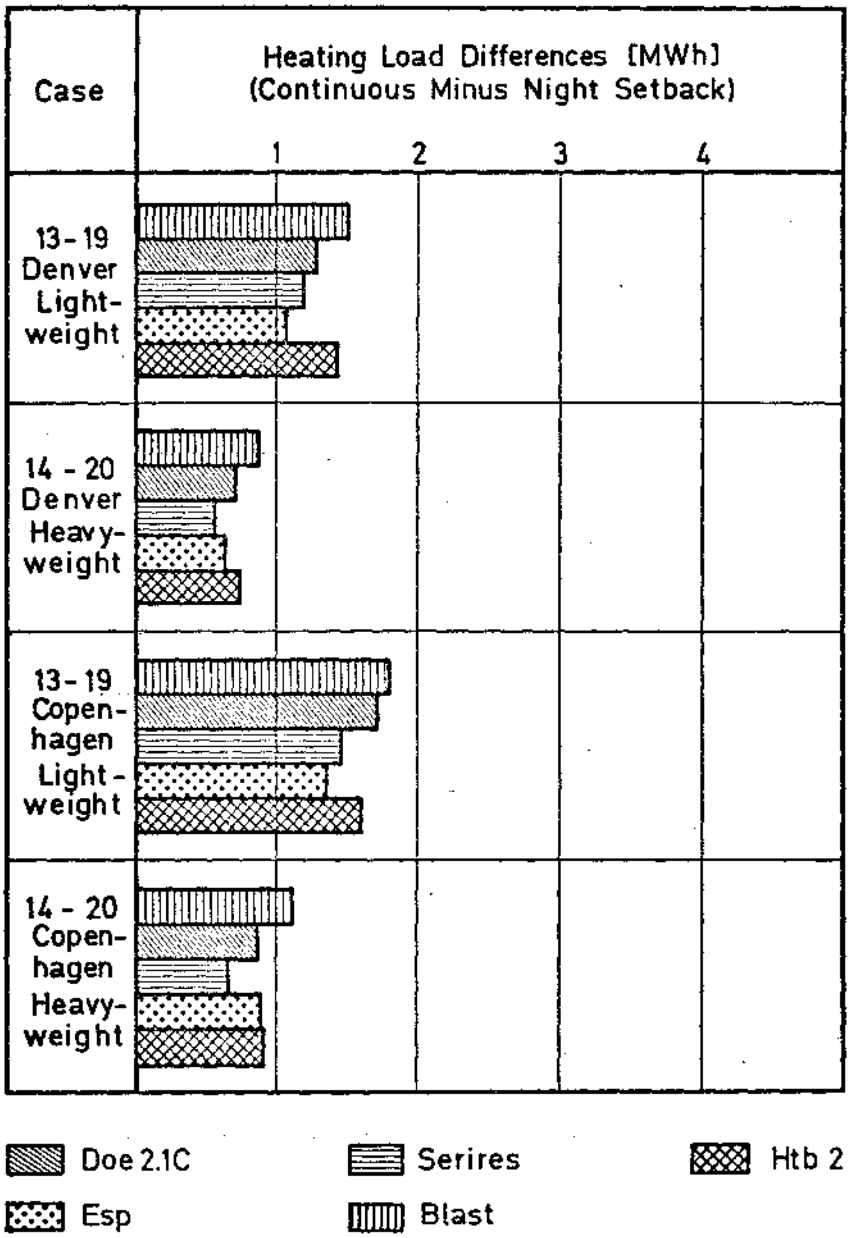


Fig. 33 Differences in annual heating loads of Phase II between continuous and night setback heating modes calculated by detailed building energy analysis simulation models with weather conditions of DENVER and COPENHAGEN.

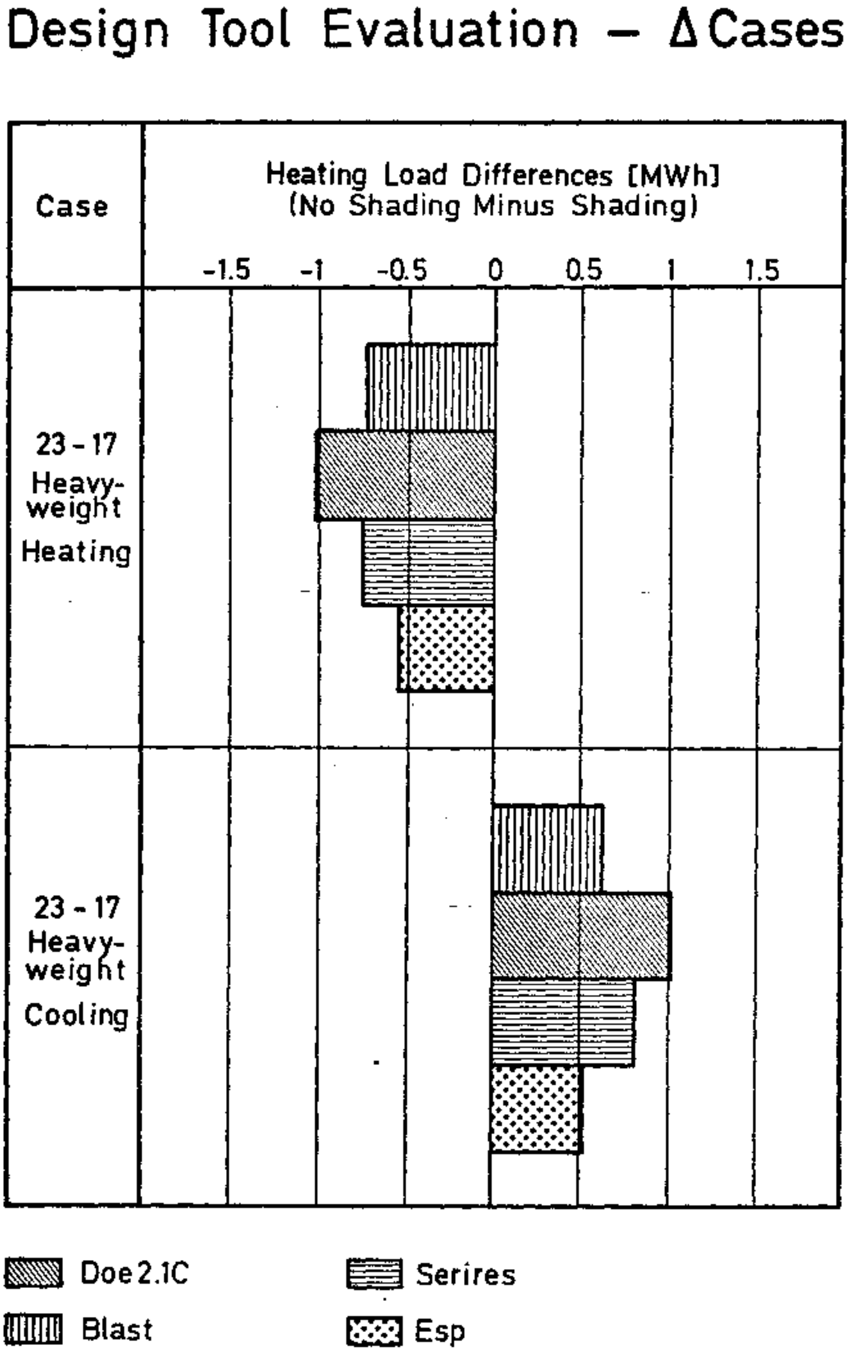


Fig. 34 Differences in annual heating loads of Phase II between no shading and shading calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

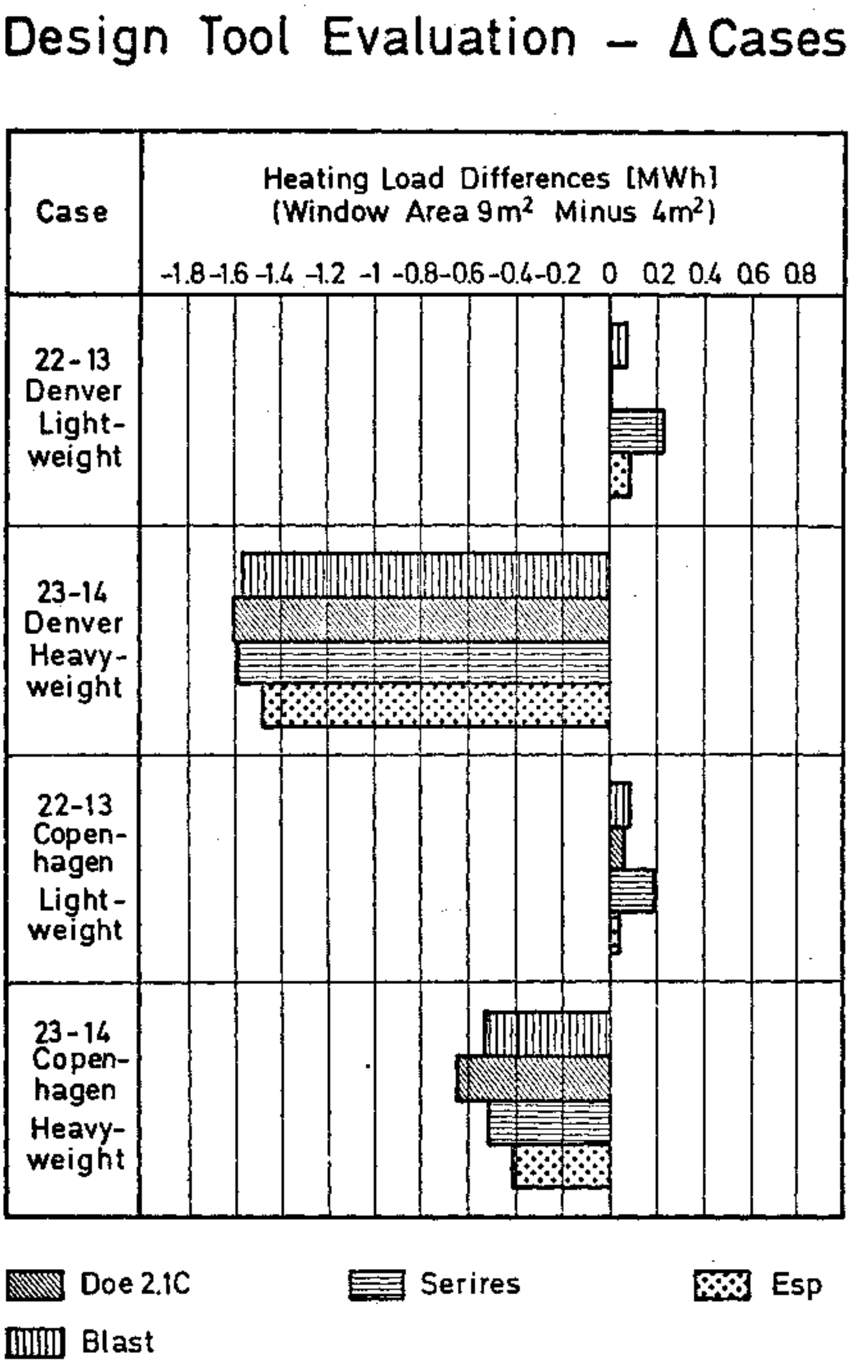


Fig. 35 Differences in annual heating loads of Phase II between 9 m' and 4 m' south window area calculated by detailed building energy analysis simulation models with weather conditions of DENVER and COPENHAGEN.

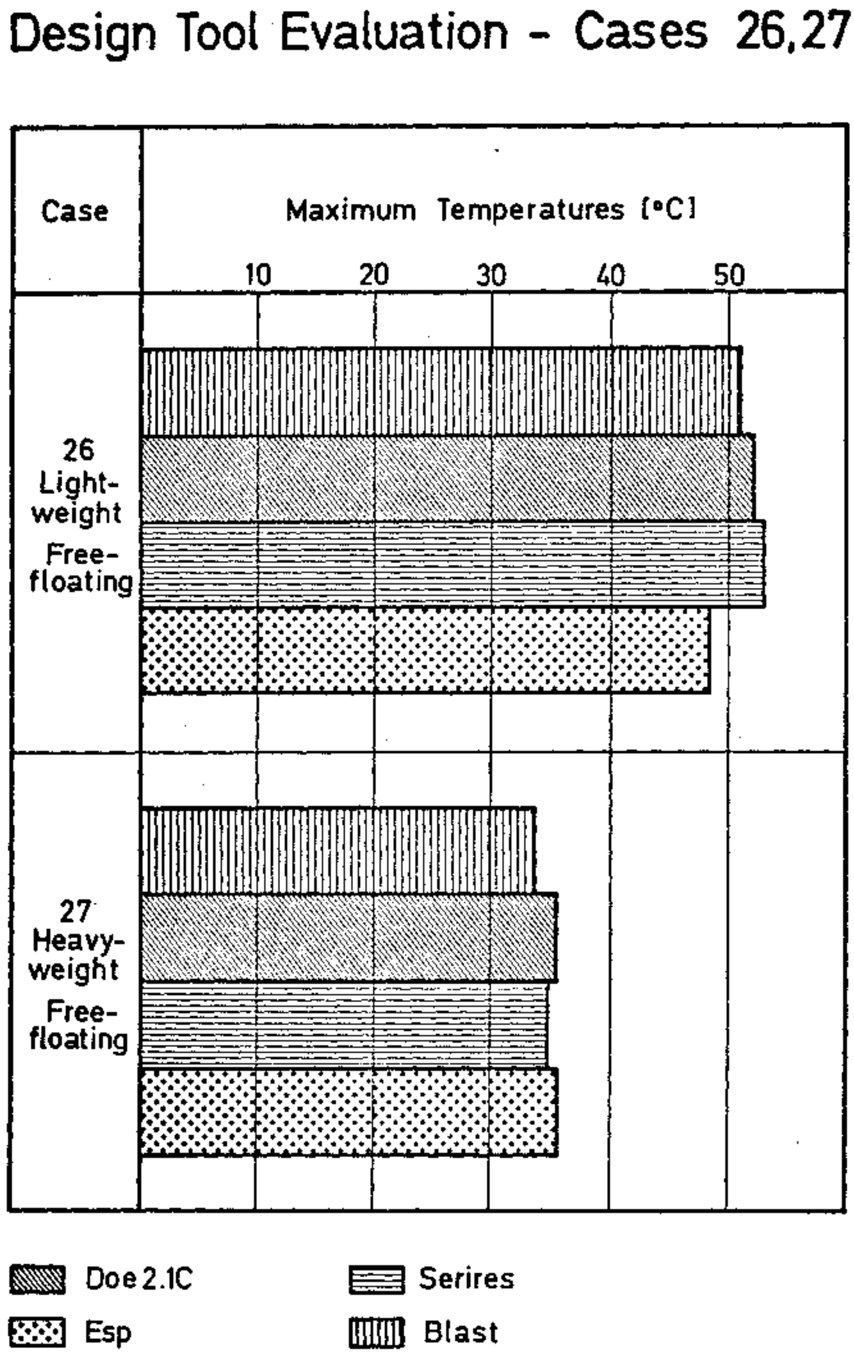
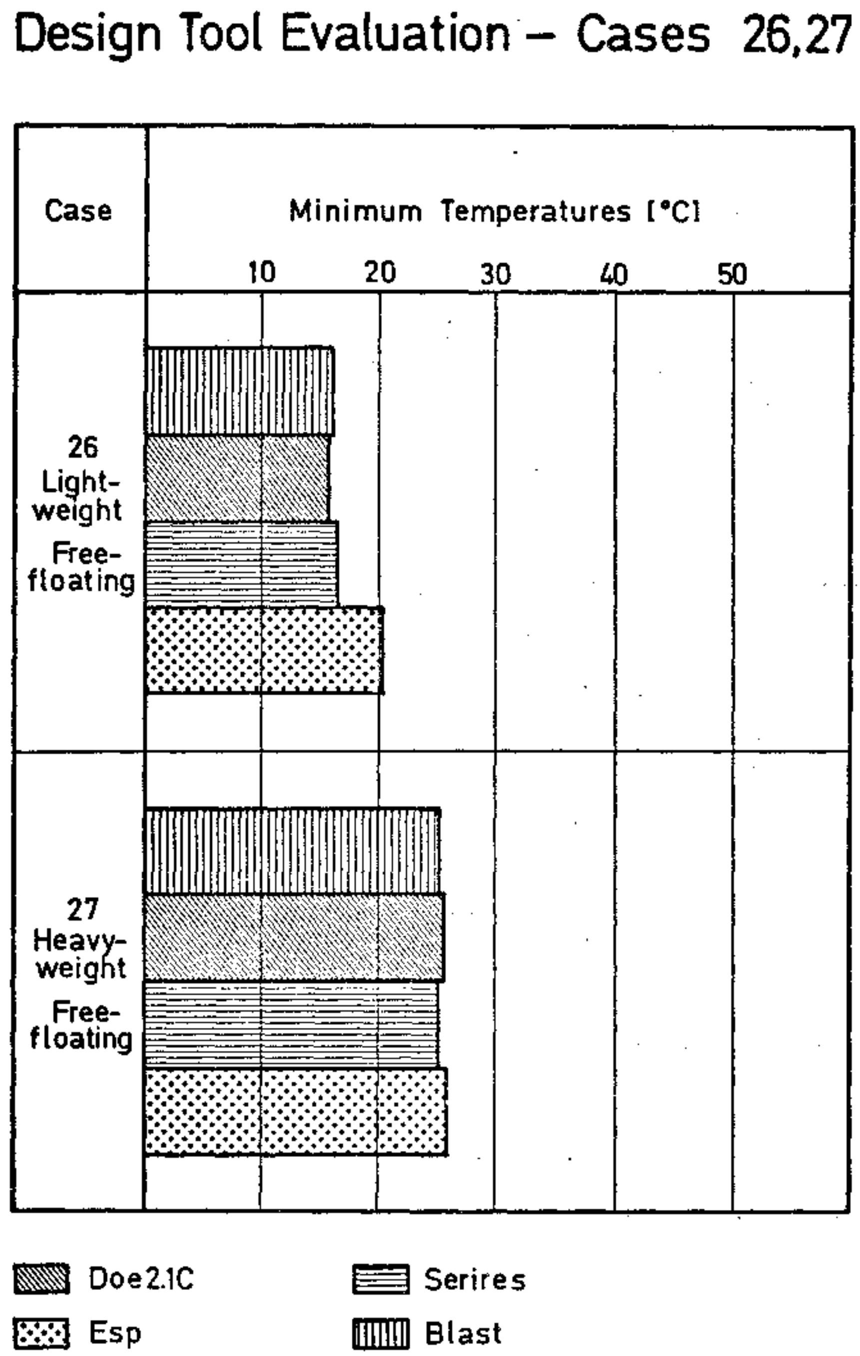


Fig. 36 Maximum daily free-floating temperatures of Case 26 (lightweight) and Case 27 (heavyweight building) calculated by detailed building energy analysis simulation models with weather conditions of DENVER, October 17.



<u>Fig. 37</u> Minimum daily free-floating temperatures of Case 26 (light-weight) and Case 27 (heavyweight building) calculated by detailed building energy analysis simulation models with weather conditions of DENVER, October 17.

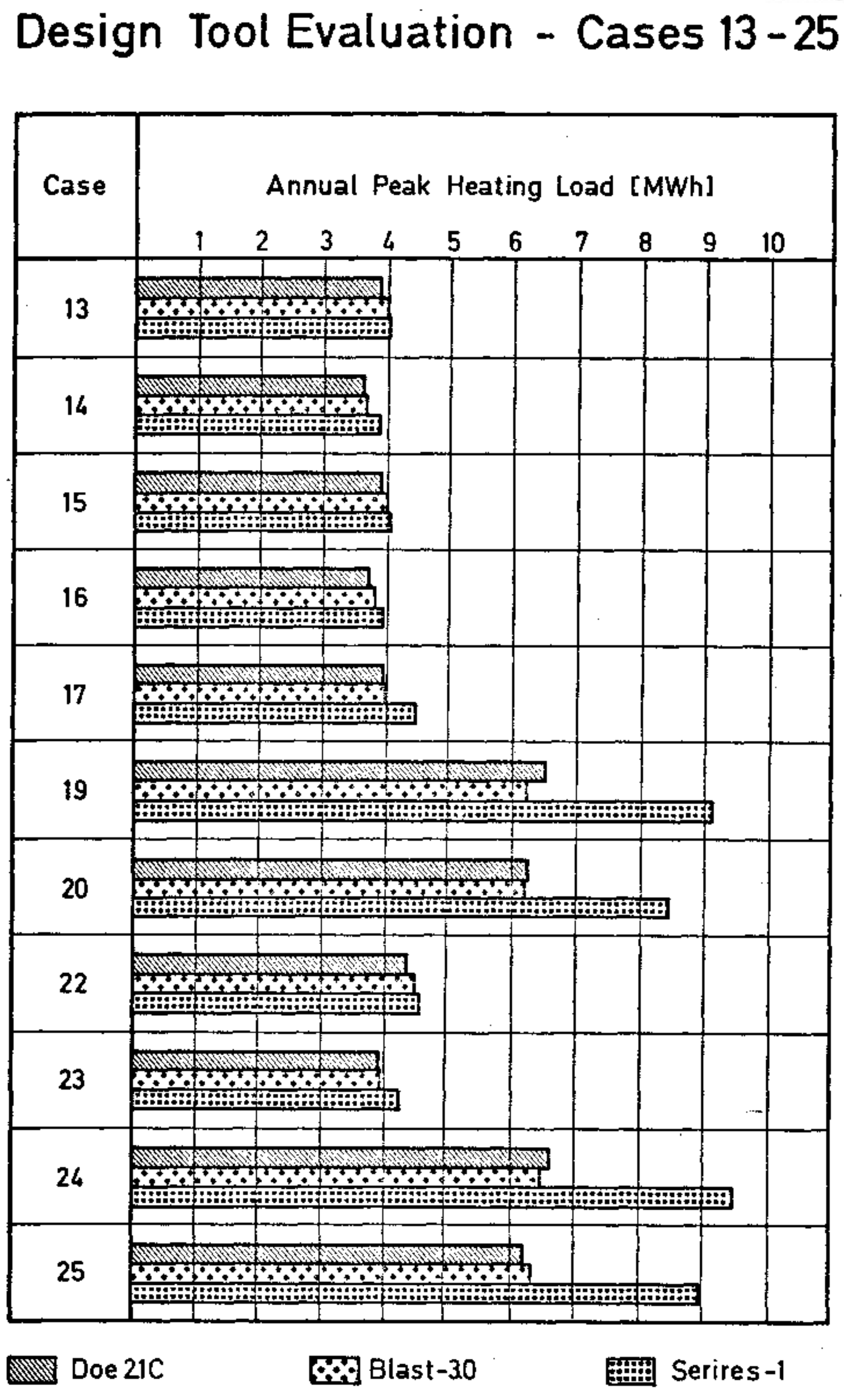


Fig. 38 Annual peak heating loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

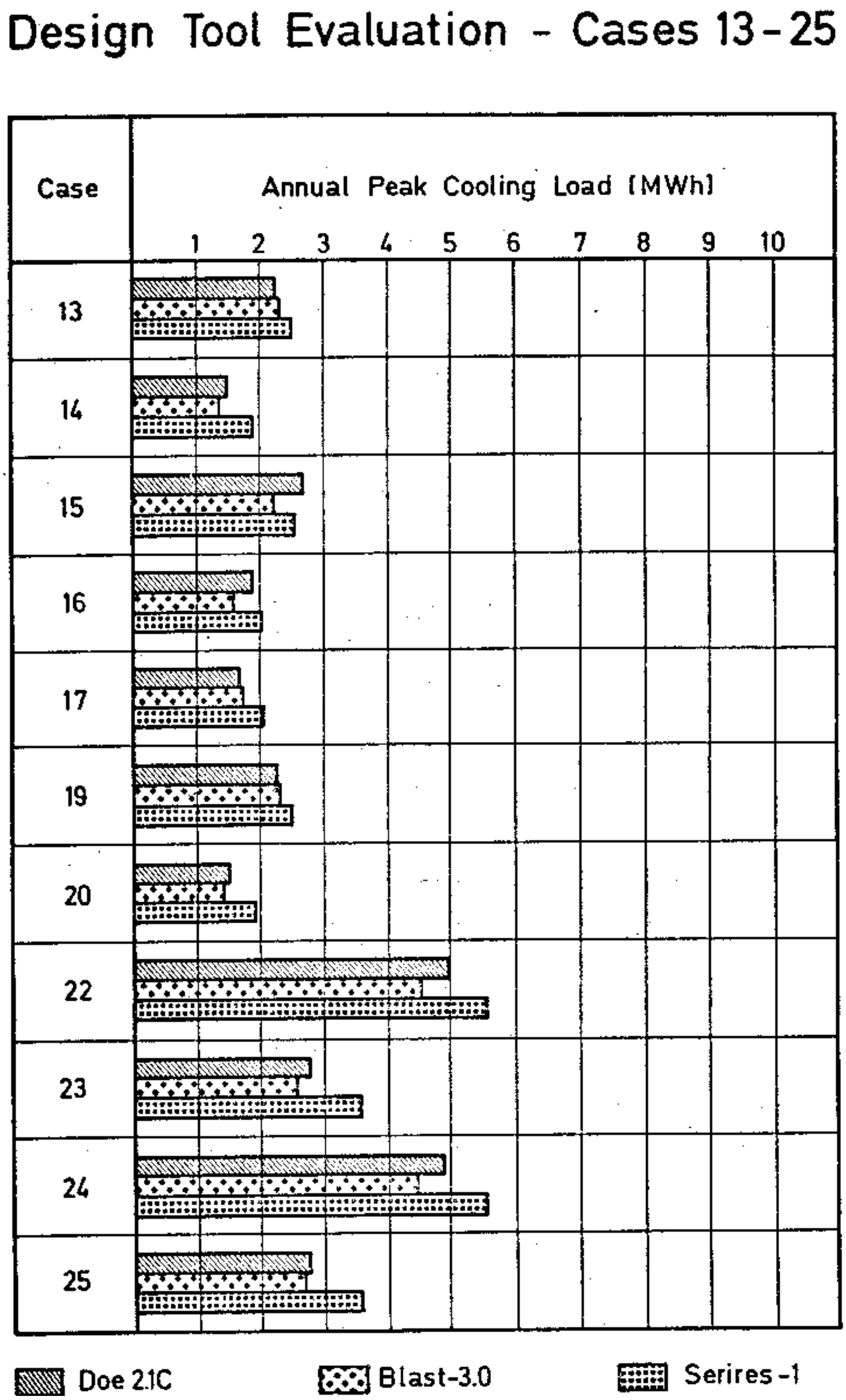


Fig. 39 Annual peak cooling loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of DENVER.

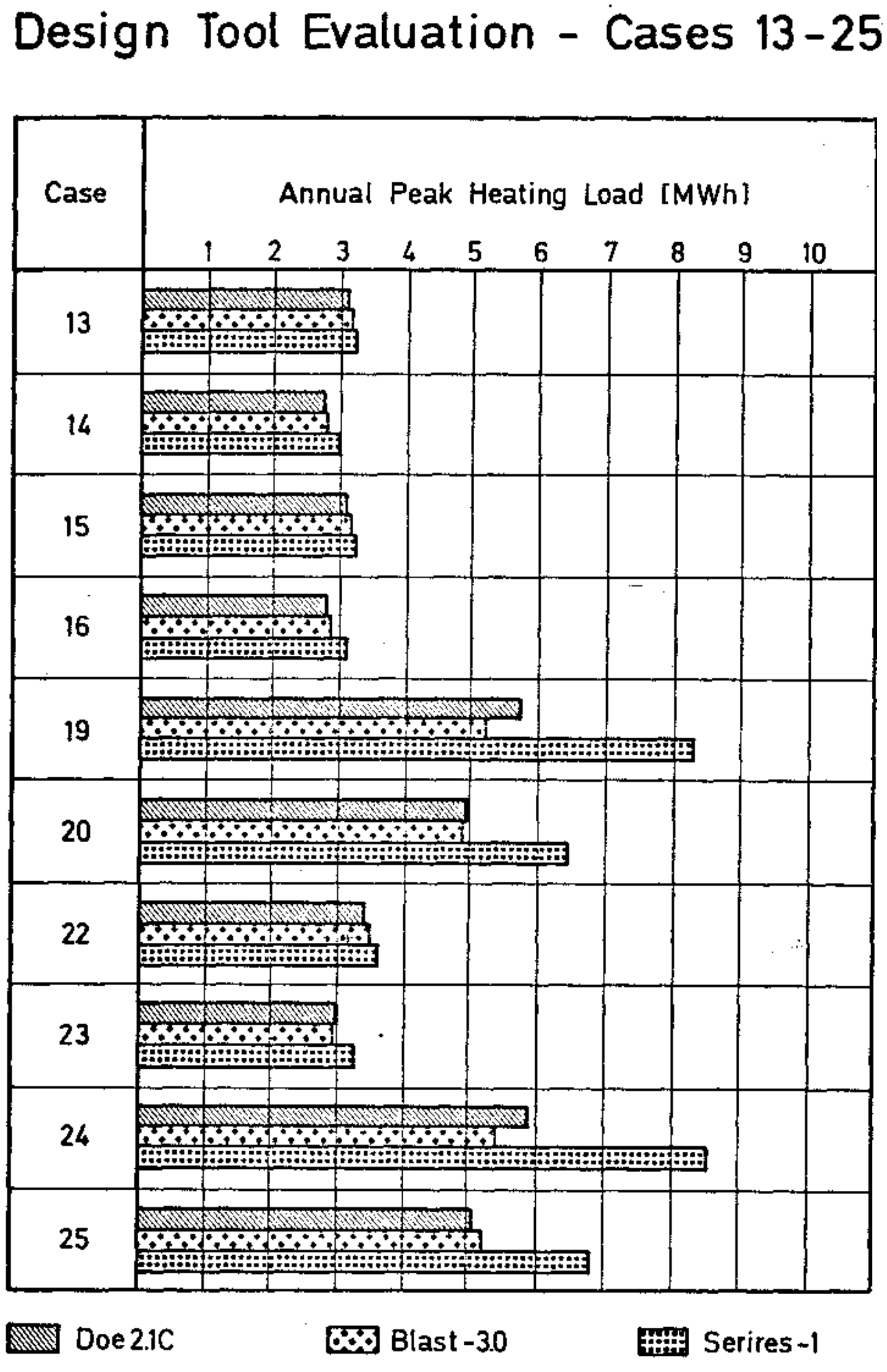


Fig. 40 Annual peak heating loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

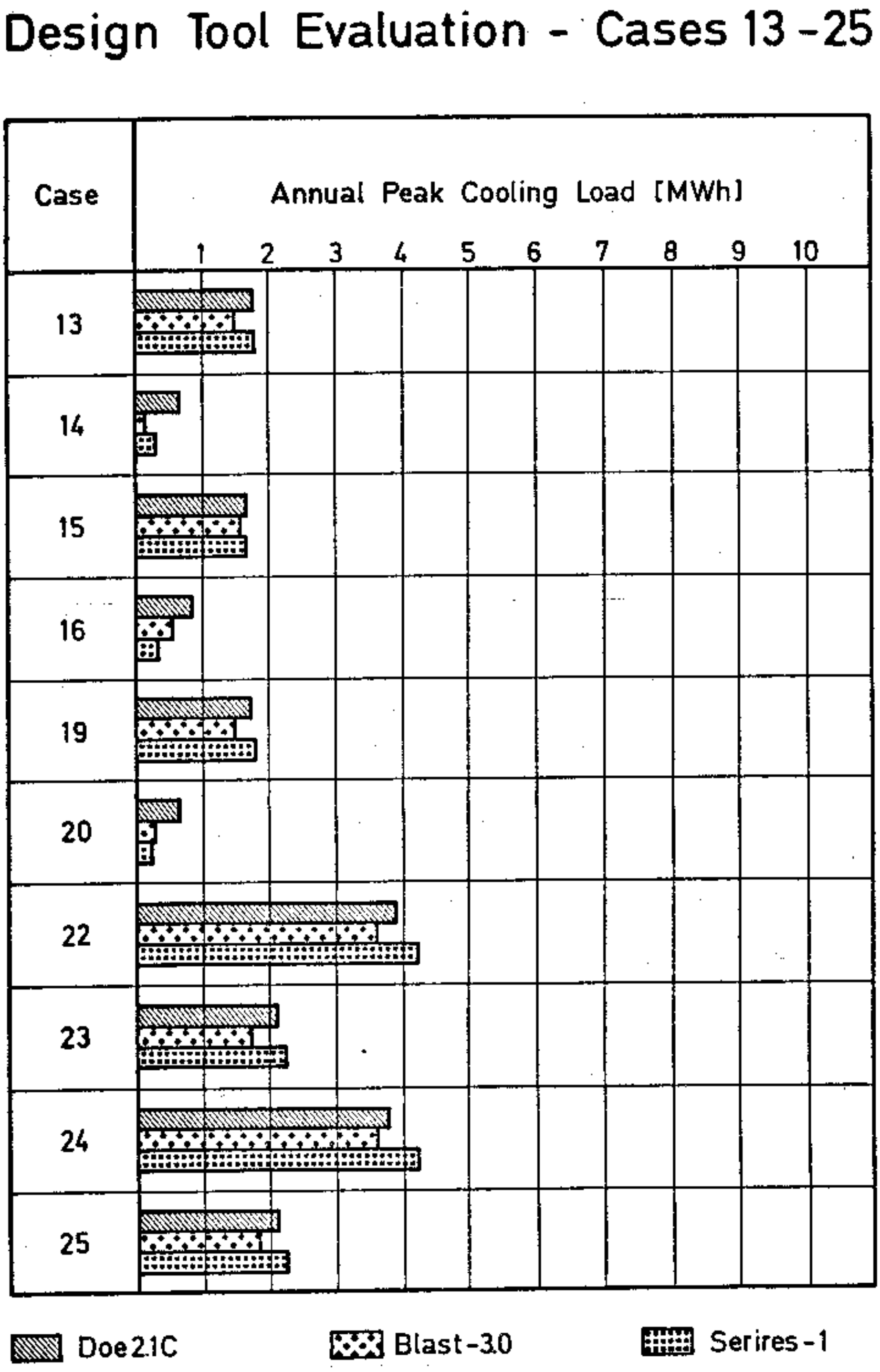


Fig. 41 Annual peak cooling loads of Phase II calculated by detailed building energy analysis simulation models with weather conditions of COPENHAGEN.

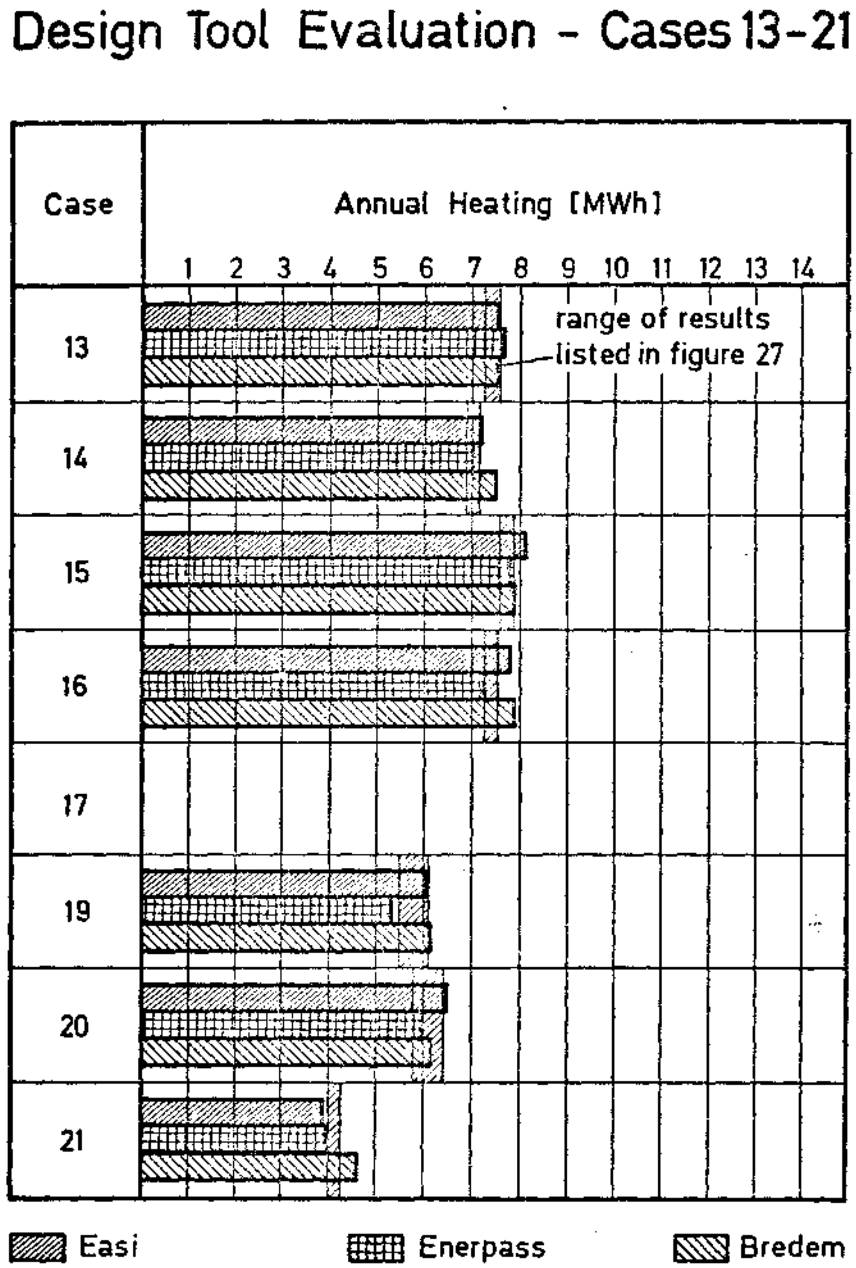


Fig. 42 Annual heating loads of Phase II calculated by design tools with weather conditions of COPENHAGEN. Hatched areas indicate the ranges of results obtained by detailed building energy analysis simulation models (BLAST, DOE 2.1C, SERIRES, HTB 2, ESP) in Fig. 27.

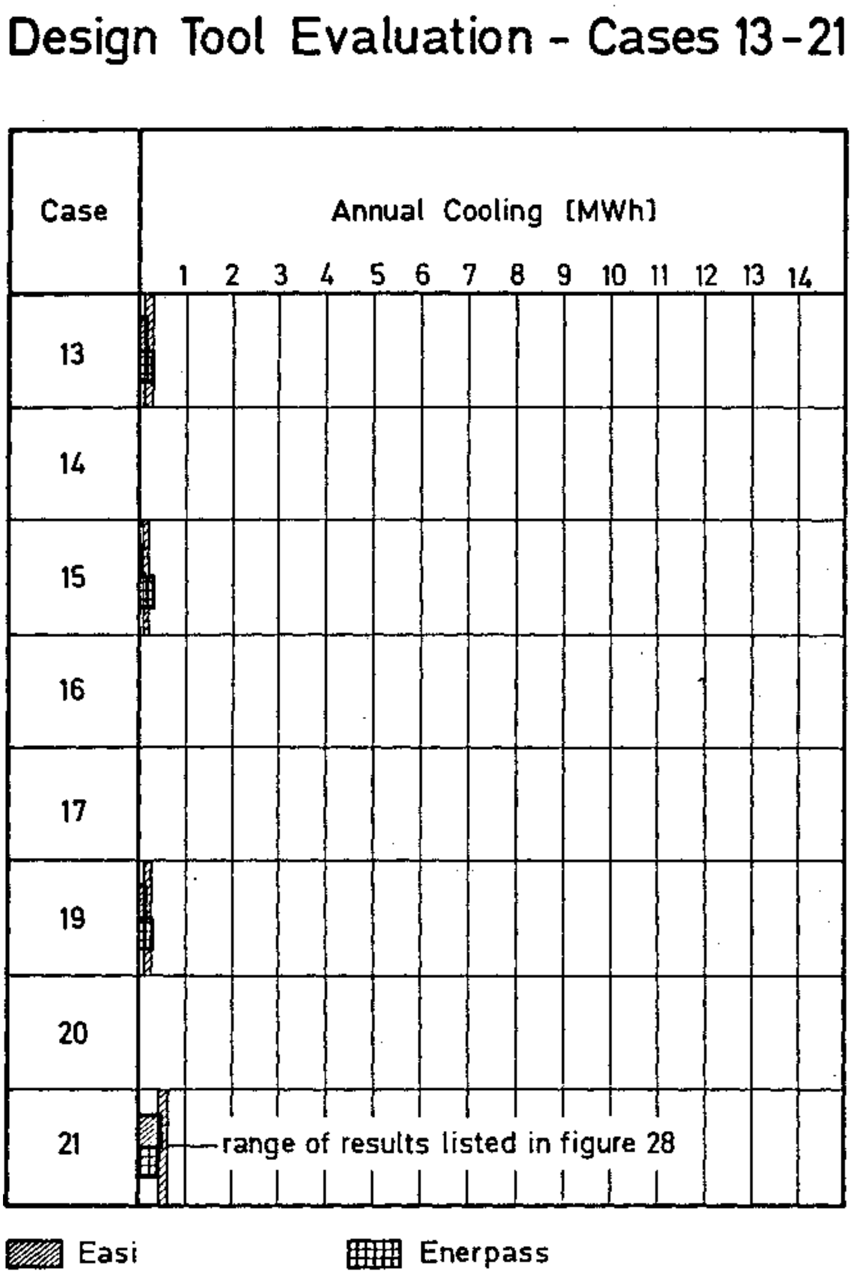


Fig. 43 Annual cooling loads of Phase II calculated by design tools with weather conditions of COPENHAGEN. Hatched areas indicate the ranges of results obtained by detailed building energy analysis simulation models *(BLAST, DOE* 2.1C, SERIRES, *HTB 2,* ESP) in Fig. 28.

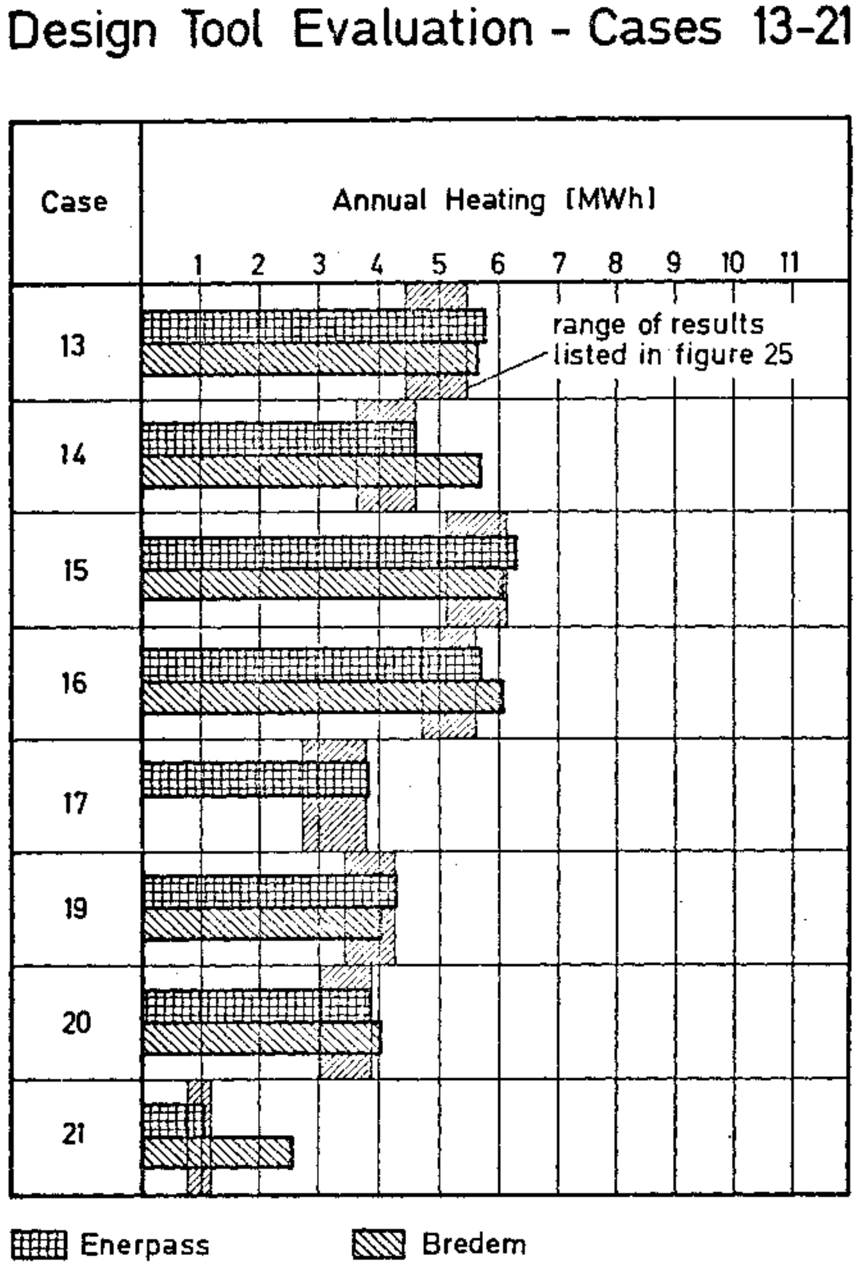


Fig. 44 Annual heating loads of Phase II calculated by design tools with weather conditions of DENVER. Hatched areas indicate the ranges of results obtained by detailed building energy analysis simulation models (BLAST, DOE 2.1C, SERIRES, HTB 2, ESP) in Fig. 25.

APPENDIX A

SPECIFICATION FOR IEA VIII DESIGN TOOL EVALUATION EXERCISE

(a) Size

Plan shape (6 m x 8 m) with the 6 m dimensions facing N/S. Height is 2.7 m, ie this corresponds to a 1-storey building.

(b) Boundary conditions

All walls and 'roof' in contact with outside air. The floor in contact with a fixed temperature source at 10°C (this has been chosen as it is fairly close to annual mean outside air temperature for both Copenhagen and Denver) via a large resistance. Ground reflectivity is 0.2.

(As some tools/codes would not be able to cope with a floating floor it was felt better to reduce the heat loss through it to negligible proportions, whilst allowing for its mass storage).

(c) Wall construction

Two cases should be considered:

(i) Lightweight

0.012 m plasterboard
0.047 m glass fibre quilt
0.029 m cavity (R = 0.18 m K/W)#
0.009 m plywood
0.050 m cavity (R = 0.18 m^2K/W)#
0.105 m brickwork (outer leaf)

U = 0.505 W/m^2K (this is defined as acting from air to environmental temperature, where the CIBSE Standard values of internal surface resistance 0.12 m^2K/W)# and external surface resistance 0.06 m^2 K/W have been assumed). Surface-to-surface resistance is 1.8 m^2 K/W.

(ii) Heavyweight

Brick/filled cavity/block/plaster

0.016 m plaster (medium weight)
0.100 m concrete block (medium weight)
0.050 m urea formaldehyde foam
0.050 m cavity (R = 0.18 m K/W)#
0.102 m brickwork (outer leaf)

U = 0.503 W/m^2K with same assumptions as above.

NB

1. Material properties to be assumed are given in Table A10. DO NOT USE STANDARD LIBRARY PROPERTIES.

2. No detailed modelling of cavities should be employed even if the program allows this - a pure resistance should be used with the value shown, or if this is not possible a fictitious, very low thermal capacity material should be introduced as an approximation to a pure resistance.

3. Assume these walls do not have studs - all materials should be considered as homogeneous layers.

These represent an attempt to cover a range of practical wall types, with the lightweight variant adjusted to obtain a similar conductance to that of the heavyweight one.

(d) Floor construction

(i) Lightweight

0.025 m timber flooring
1.003 m 'insulation' (k = 0.04 W/mK)#

U = 0.039 W/m^{2}K (air to environmental temperature based upon assumed value of internal surface resistance 0.14 m K/W). Surface-to-surface resistance is 25.25 m K/W.

*If a real material has to be specified, please state all properties assumed.

(ii) Heavyweight

0.050 m screed
0.150 m reinforced concrete slab
1.000 m 'insulation' (k = 0.04 W/mK)

U = 0.039 W/m^{2}K (air to environmental temperature based upon assumed value of internal surface resistance 0.14 m^2 K/W). Surface-to-surface resistance is 25.25 m K/W.

(e) 'Roof' construction

0.019 m asphalt
0.013 m fibreboard
0.025 m air gap (R = 0.17 m^{2}K/W)
0.100 m glass fibre quilt
0.010 m plasterboard

U = 0.32 W/m^{2}K (air to environmental temperature based on internal surface resistance 0.10 m K/W, external surface resistance 0.04 m K/W). Surface-to-surface resistance is 2.99 m K/W.

(f) Internal walls

An allowance for an internal wall having an area each side of 21.6 m^2, should be made, using the assumption that all the building air is well--mixed. For models which need to represent the building as two zones, the air in both zones should be well-mixed. If high inter-zone air movement is specified to ensure this, care should be taken so that the film coefficients still correspond to normal air flow rates.

For the heavyweight case the walls correspond to:

0.016 m plaster (medium)
0.100 m concrete block (medium weight)
0.015 m plaster (medium)

Internal surface coefficient 8.35 W/m^2K

For the runs with lightweight external walls the internal walls should be:

0.012 m plasterboard
0.050 m cavity (R = 0.18 m^2K/W)
0.012 m plasterboard

This could physically be accommodated by an arrangement such as shown in Figure Al.

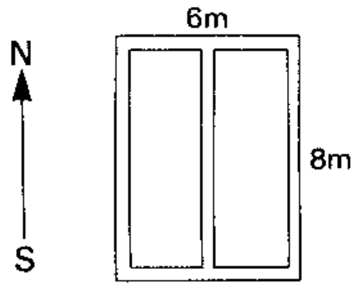


Figure Al: A possible internal layout. For the calculation of areas and volumes, assume all walls are of zero thickness.

For models requiring a detailed geometrical description, the above Figure should be followed with the additional assumption that the internal walls have zero thickness as far as positioning is concerned. The internal walls have been positioned to run along a NS axis in order to eliminate differences between N and S zones for any programs which do require separate zones to be set up.

(g) Plant and control system

Assume a convective#, infinite size system, no venting.

(i) Heating set point 20°C.
Cooling set point 20°C

(ii) Heating set point 20°C.
Cooling set point 27°C.

Use these set points throughout the whole year. They should control air temperature; where this is not possible, the program defaults should be used.

(h) Climate

Copenhagen TRY and Denver TMY. Table Al shows the monthly climatic data for Copenhagen and Denver produced from the SERIRES output.

The hourly data can be obtained on disc or tape from:

M Holtz
Architectural Energy Corporation
2540 Frontier Ave, Suite 201
Boulder, Co 80301
USA

and

0 Morck
Cenergia
Walgerholm 17
3500 Vaerloese
Denmark

Using the annual values for the mean wind speed in the ASHRAE formula for external surface coefficient for surfaces of roughness 2, gives:

$$h = 12.49 + 4.065\ V + 0.028\ V^2$$

or

$$32.6,\ 29.2\ W/m^2K.$$

Use 30 for both climates.

(i) Ventilation

A ventilation rate of 1 ach constant should be used in both Copenhagen and Denver.

Note:

Air density at 0 m altitude = 1.201385 kg/m^3
Air density at 13 m altitude = 1.199482 kg/m
and at: 1609 m altitude = 0.987298 kg/m

For eg SERIRES the ventilation rate should be specified as 1 ach for both, whereas for ESP, as 0.998 and 0.822 ach as no altitude correction is applied internally in the latter.

An altitude correction factor should be used if applicable.

(j) Glazing

2.25 x 4 m double pane on South wall, neglect effect of frames (see Figu re A2) - For the window prop erties see Table A7.

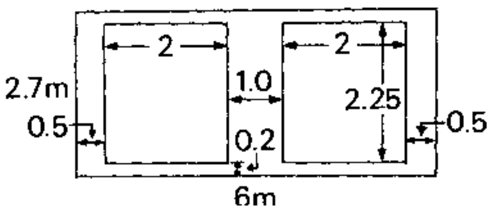


Figure A2: Glazing on South wall.

DENVER

AMBIENT SUMMARY

	- WIND SPEED -			MEAN GROUND TEMP	-- DEGREE DAYS --	
	MEAN	MIN	MAX		HEATING	COOLIN(
MON	M/S	M/S	M/S	C	CD	CD
JAN	4.7	1.0	12.9	10.0	620.6	.0
FEB	4.3	.0	12.4	10.0	530.1	.0
MAR	4.0	.0	12.9	10.0	462.3	4.5
APR	4.5	.0	13.9	10.0	280.7	10.1
MAY	4.1	.0	12.4	10.0	165.9	32.8
JUN	4.9	1.5	14.4	10.0	83.8	78.6
JUL	4.0	.0	12.9	10.0	20.2	155.2
AUG	3.4	.0	9.3	10.0	29.2	117.0
SEP	3.4	.0	9.3	10.0	115.8	71.2
OCT	3.7	.0	11.3	10.0	291.3	17.0
NOV	3.5	.0	12.9	10.0	445.8	.5
DEC	3.6	.0	14.9	10.0	590.5	.1
TOT	4.0	.0	14.9	10.0	3636.2	487.1

COPENHAGEN

AMBIENT SUMMARY

	- WIND SPEED -			MEAN GROUND GROUND	-- DEGREE DAYS --	
	MEAN	MIN	MAX		HEATING	COOLING
MON	M/S	M/S	M/S	C	CD	CD
JAN	5.6	.0	17.0	10.0	587.1	.0
FEB	5.2	.0	12.3	10.0	543.8	.0
MAR	6.4	.0	13.4	10.0	487.4	.0
APR	5.3	.0	12.9	10.0	352.0	.1
MAY	5.1	.0	11.3	10.0	240.0	1.6
JUN	3.5	.0	11.8	10.0	96.4	15.9
JUL	3.0	.0	9.3	10.0	81.0	22.4
AUG	5.2	.0	12.3	10.0	78.2	26.2
SEP	5.1	.0	12.9	10.0	140.6	1.4
OCT	3.5	.0	11.8	10.0	284.0	.0
NOV	5.0	.0	15.4	10.0	400.0	.0
DEC	4.8	.0	16.4	10.0	517.3	.0
TOT	4.8	.0	17.0	10.0	3807.9	67.6

TABLE A1.1

DENVER

AMBIENT SUMMARY

MON	----- SOLAR RADIATION ----- DIRECT NORMAL MJ/SM	DIRECT HORIZ. MJ/SM	----- DIFFUSE HORIZ. MJ/SM	AMBIENT TEMPERATURE MEAN C	MIN C	MAX C
JAN	632.001	230.361	63.215	-1.69	-24.4	17.8
FEB	554.220	249.188	94.250	-.60	-22.2	17.2
MAR	745.869	406.954	159.242	3.56	-14.4	27.2
APR	698.466	452.299	198.120	9.31	-6.1	25.6
MAY	757.238	532.318	244.055	14.04	-1.7	28.3
JUN	799.365	577.738	221.027	18.16	3.9	33.3
JUL	854.173	614.395	203.736	22.69	11.1	35.0
AUG	765.826	515.595	193.566	21.16	10.0	33.9
SEP	762.812	456.096	149.027	16.85	1.1	33.3
OCT	753.906	364.995	106.212	9.49	-4.4	26.7
NOV	562.202	218.862	81.226	3.49	-10.0	22.2
DEC	586.818	203.319	58.761	-.71	-19.4	19.4
TOT	8472.896	4822.120	1772.438	9.71	-24.4	35.0

COPENHAGEN

AMBIENT SUMMARY

MON	----- SOLAR RADIATION ----- DIRECT NORMAL MJ/SM	DIRECT HORIZ. MJ/SM	----- DIFFUSE HORIZ. MJ/SM	AMBIENT TEMPERATURE MEAN C	MIN C	MAX C
JAN	90.590	14.166	31.144	-.60	-12.6	5.0
FEB	202.900	57.144	62.566	-1.09	-13.7	6.5
MAR	214.870	82.471	129.019	2.61	-7.7	9.5
APR	451.820	226.433	201.337	6.60	-.9	20.8
MAY	514.830	295.570	264.510	10.64	3.1	24.8
JUN	650.310	385.346	282.874	15.65	5.6	25.2
JUL	496.940	292.615	286.385	16.44	7.4	27.4
AUG	488.070	263.950	221.460	16.65	5.2	28.8
SEP	317.220	137.466	162.114	13.69	6.6	21.4
OCT	215.060	68.191	89.599	9.17	-2.7	19.0
NOV	129.750	25.828	43.142	5.00	-4.0	10.2
DEC	134.470	19.502	23.298	1.65	-8.0	7.5
TOT	3906.830	1868.682	1797.448	8.09	-13.7	28.8

TABLE A1.2

RUNS TO BE PERFORMED

A basic set of 11 runs are to be performed for each climate. Table A2 describes the main variations in the run conditions, while Tables A7-A give the detailed information.

CASE NO.	SET POINTS C heating	cooling	MASS	WINDOW	SURFACE PROPERTIES E.A.	E.E.	I.A.	I.E.	OTHER
0	20	20	l/w	opaque	0.5	0.9	0.6	0.9	no ventiln.
1	20	20	l/w	opaque	0.5	0.9	0.6	0.9	
2	20	20	h/w	opaque	0.5	0.9	0.6	0.9	
3	20	20	l/w	real	0.5	0.9	0.6	0.9	
4	20	20	h/w	real	0.5	0.9	0.6	0.9	
5	20	27	l/w	opaque	0.0	0.9	0.6	0.9	
6	20	27	h/w	opaque	0.0	0.9	0.6	0.9	
7	20	27	l/w	opaque	0.5	0.9	0.6	0.9	
8	20	27	h/w	opaque	0.5	0.9	0.6	0.9	
9	20	27	l/w	real	0.5	0.9	0.6	0.9	
10	20	27	h/w	real	0.5	0.9	0.6	0.9	
11	free floating		l/w	real	0.5	0.9	0.6	0.9	
12	free floating		h/w	real	0.5	0.9	0.6	0.9	

NB: Ensure that equivalent window properties are used: see figures quoted in Tables A7 and A8.

NB:

l/w construction uses lightweight walls (internal and external) and lightweight floor.

h/w construction uses heavyweight walls (internal and external) and heavyweight floor.

TABLE A2 - PHASE I runs

OUTPUTS REQUIRED

	kwh heating	kwh cooling	solar available on South kwh/m²	total solar input* to zone kwh	ventilation load kwh	window kwh conduction	opaque kwh surface conduction
Jan							
Feb							
Mar							
Apr							
May							
Jun							
Jul							
Aug							
Sep							
Oct							
Nov							
Dec							
Total							

* This is intended to be the TOTAL amount transmitted through the glass, plus that absorbed and conducted into the space, minus that which is optically lost back through the glass. If it is not possible to obtain these values, please provide what information you can and specify the exact definition of solar input used.

TABLE A3

hour	Solar intensities on external surfaces W/m^2			
	N	S	E	W
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
Total				

May 31 for both Copenhagen and Denver

TABLE A4

hour	heating (+) or cooling (-) loads kW		
	February 17	February 18	February 19
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
Mean			
Max			
Min			

TABLE A5

hour	heating (+) or cooling (-) loads kW		
	May 29	May 30	May 31
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
Mean			
Max			
Min			

TABLE A6

WINDOWS	# PANES	PANE THICKNESS	REFRACTIVE INDEX	SHADE COEFF.	RESISTANCE GLASS-GLASS	SURFACE COEFFS.		AREA OF CLEAR GLASS	U-VALUE AIR-AIR
						EXT.	INT.		
	2	3.175 mm	1.526	1.0 OR 0.0	0.2109	30.0	8.35	9 m^2	2.669

TABLE A7

Angle of incidence°	0	10	20	30	40	55	60	70	80
Direct transmittance (including retransmitted)	0.747	0.746	0.744	0.739	0.729	0.686	0.652	0.516	0.263

TABLE A8

TABLE A9

		TITLE: INPUT COMPARISON	
		NEW SHOEBOX RUNS	
		DESCRIPTION/EXPLANATION	
PARAMETER	SPECIFICATION		
LOCATION		COPENHAGEN	DENVER
RUN START/STOP DATES	1 JAN - 31 DEC		
LATITUDE		55.7N	39.8N
LONGITUDE		12.6E (347.4 FOR SERIRES)	104.9W
TIME ZONE		GMT + 1	GMT - 7
ALTITUDE (metres)		13	1609
GROUND REFLECTIVITY	0.2		
GROUND TEMPERATURE	10°C		
INFILTRATION	1 ac/h	APPLY ALTITUDE CORRECTION FACTOR IF NECESSARY	
HEATING EQUIPMENT			
CAPACITY	1000 kW	EFFECTIVELY INFINITE	
EFFECTIVE EFFICIENCY	100 %		
SCHEDULE			
CONTROL STRATEGY	ON WHEN TEMP < 20°C		
VENTING EQUIPMENT	NONE		
CAPACITY (M^3/M)			
POWER			
WHERE DISSIPATED			
SCHEDULE			
CONTROL STRATEGY			
COOLING EQUIPMENT			
CAPACITY	1000 kW	EFFECTIVELY INFINITE	
LATENT LOAD CALCULATION	NO		
EFFECTIVE EFFICIENCY	100%		
SCHEDULE			
CONTROL STRATEGY	(1) ON WHEN TEMP > 20°C (2) " " " > 27°C	(1) is for runs 1-4; (2) is for runs 5-10	
INTERZONE FAN			
CAPACITY			
POWER	NOT APPLICABLE		
WHERE DISSIPATED			
SCHEDULE			
CONTROL STRATEGY			
OTHER INTERNAL HEAT SOURCES	NONE		
SOLAR TO AIR NODE FRACTION	0.0	uniformly distributed to all surfaces except ceiling	
CAVITY ALBEDO LOSS FRACTION	0.0		

				INPUT COMPARISON — NEW SHOEBOX RUNS				
ELEMENT	THICK (mm)	DENSITY (kg/m³)	Cp (J/kg K)	SURFACE COEFFICIENTS (W/m²K)		K (W/mK)	AREA (m²)	R (m²K/W)
N. EXTERNAL WALL							16.2	
LIGHT WEIGHT				30	8.35			
IN) PLASTERBOARD	12	950	840			0.16		
GLASSFIBRE QUILT	47	12	840			0.04		
CAVITY	29							0.18
PLYWOOD	9	530	900			0.14		
CAVITY	50							0.18
OUT) BRICK	105	1700	800			0.84		
HEAVYWEIGHT								
IN) PLASTER	16	800	1000			0.26		
CONCRETE BLOCK	100	1400	1000			0.51		
UF FOAM	50	10	1400			0.04		
CAVITY	50							0.18
OUT) BRICK	102	1700	800			0.84		
S. WALL		AS ABOVE					7.2	
E. WALL		AS ABOVE					21.6	
W. WALL		AS ABOVE					21.6	
HW INT. WALL				8.35	8.35		21.6	
PLASTER	16	800	1000			0.26		
CONCRETE BLOCK	100	1400	1000			0.51		
PLASTER	16	800	1000			0.26		
LW INT. WALL				8.35	8.35		21.6	
PLASTERBOARD	12	950	840			0.16		
CAVITY	50							0.18
PLASTERBOARD	12	950	840			0.16		
LW FLOOR								
TIMBER	25	650	1200			0.14		
'INSUL'	1003					0.04		25.075
HW FLOOR					7.15		48	
IN) SCREED	50	1200	840			0.41		
CONCRETE SLAB	150	2000	1000			1.13		
OUT) 'INSUL'	1000					0.04		25.0
ROOF				30	10.0		48	
IN) PLASTERBOARD	10	950	840			0.16		
G.F. QUILT	100	12	840			0.04		
CAVITY	25							0.17
FIBRE BOARD	13	300	1000			0.06		
OUT) ASPHALT	19	1700	1000			0.50		

THERMAL PROPERTIES OF BUILDING ELEMENTS

Element	Conductivity (W/m C)	Density (kg/m³)	Specific Heat Capacity (J/kg C)
Brickwork (outer leaf)	0.84	1700	800
Carpet	0.055	160	1000
Chipboard	0.16	950	2093
Concrete block (medium weight)	0.51	1400	1000
Earth	1.4	1900	1700
Glass fibre quilt	0.04	12	840
Hardcore	1.83	2200	712
Plaster	0.26	800	1000
Plasterboard	0.16	950	840
Plywood	0.14	530	900
Reinforced concrete slab	1.13	2000	1000
Roofing tile	0.84	1900	800
Screed	0.41	1200	840
Soft wood	0.12	230	2760
UF foam insulation	0.04	10	1400
Asphalt	0.50	1700	1000
Fibreboard	0.06	300	1000
Timber flooring	0.14	650	1200

TABLE A10

Table A11 describes the original set of Phase II runs by reference to a base case, together with any necessary modifications.

Case No.	Base Case No.	Modifications to Base Case	Climate (C/D)**	Brief Description
13	9	4 sq m south, window*; internal gains.	C,D	Small window lightweight.
14	10	4 sq m south, window*;	C,D	Small window heavyweight.
15	13	Rotate 90° anti-clockwise ie East window	C,D	lightweight.
16	14	Rotate 90° anti-clockwise ie East window	C,D	heavyweight.
17	10	Overhang at top of window, 0.75 m wide; internal gains.	D	Large window heavyweight.
18	10	As above, free floating.	D	
19	13	Night setback to 10°C from 2300 h to 0700 h.	C,D	Small window lightweight
20	14	As above.	C,D	heavyweight.
21	10	E,W & N walls are adiabatic***; internal gains.	C,D	Large window heavyweight.

TABLE All - PHASE II RUNS

* 2 windows, each 1 m high and 2 m wide.
* located 1 m from the floor.
** C = Copenhagen, D = Denver.
*** No heat flow occurs in the east, west and north external walls at the cavity insulation layer.

NB: All of the Phase II runs have a constant internal gain of 200 W, split in the ratio 50% radiant and 50% convective.

The outputs requested for these runs were:

(a) Monthly and annual heating and cooling loads, including infiltration loads if possible.

(b) Hourly loads/temperatures (air and mean radiant, if possible) for 2 July and 2 December as appropriate.

(c) Annual total solar radiation incident on south (kWh/sq m).

(d) Annual total solar input to the building (kWh).

(e) As for (c), hourly values for 2 July and 2 December.

(f) As for (d), hourly values for 2 July and 2 December.

In the course of the July meeting a number of extensions/modifications to the above cases were suggested. These are described in Table A12.

Case No.	Base Case No.	Modifications to Base Case	Climate (C/D)	Brief Description
22	9	Internal gains.	C/D	Large window version of case 13, lightweight.
23	10	As above.	C/D	Large window version of case 14, heavyweight.
24	19	9 sq m window as in Phase I.	C/D	Large window version of case 19, lightweight.
25	20	As above.	C/D	Large window version of case 20, heavyweight.
26	22	Free floating.	D	Lightweight.
27	23	As above.	D	Heavyweight.

TABLE A12 - ADDITIONAL PHASE II RUNS