A SUMMARY OF BUILDING ENERGY ANALYSIS AND DESIGN TOOL EVALUATION RESULTS FROM IEA TASK VIII

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ABSTRACT

This paper summarizes the results of numerous building energy analysis and design tool evaluation exercises carried out under IEA Task VIII: Passive and Hybrid Solar Low Energy Buildings. These exercises have included:

- Empirical validation of detailed simulations using passive solar test room data from Canada, Switzerland and the U.S.
- Code to code comparison of detailed simulations for several passive solar system types in Copenhagen and Denver.
- Comparison of simplified design tool performance prediction to detailed simulation prediction for realistic passive solar buildings (direct gain, storage wall and sunspace), light and heavy weight construction, in three climates (Denver, Geneva and Copenhagen).
- Comparison of simplified design tool performance prediction to detailed simulation performance prediction for simplified (shoebox) passive solar test cases in three climates (Denver, Geneva and Copenhagen).
- Evaluation of the capability and userfriendliness of residential energy design tools.
- Development of 28 benchmark test cases for simplified design tool evaluation, based on the results of six detailed simulations.

INTRODUCTION

The International Energy Agency Solar Heating and Cooling Program undertakes cooperative research, development, demonstration and exchanges of information in order to advance the activities of member countries in the field of solar heating and cooling (1). Thirteen research tasks have been approved by the Executive Committee since December 1976 with five tasks currently active. In October 1981 the Executive Committee approved Task VIII entitled Passive and Hybrid Solar Low Energy Buildings. Task VIII was not formally initiated until February 1982. Table 1 lists the participating countries.

Austria
Belgium
Canada
Denmark
F.R. Germany
Italy
Netherlands
New Zealand
Spain
Norway
Sweden
Switzerland
United Kingdom
United States

Table 1: Task VIII Participating Countries

TASK OBJECTIVE

The overall objective of Task VIII is to accelerate the development and use of passive and hybrid heated and cooled low energy building in the participants' countries. This will be done, in general terms, by:

(1) Increasing the understanding of the design and performance of buildings using active and passive solar and conservation technologies, the interactions of these technologies and their effective combination in various climatic regions; and

(2) Verifying 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.

Task VIII is concerned with only new single and multi-family residential buildings. A unique aspect of Task VIII is its emphasis on "integrated residential energy design," combining solar heating and cooling, energy conservation and advanced mechanical/electrical systems into optimized energy-efficient dwellings. The underlying intent of Task VIII is to gather, organize, evaluate, apply and share the current body of knowledge on passive and hybrid solar low energy building design and construction. The research results are designed to provide the home building industry in each participants' country with the understanding, experience and tools to apply current knowledge of passive and hybrid techniques to current design and construction projects.

APPROACH

Task VIII is organized into five major Subtasks, each coordinated by a lead country (Lead Country):

Subtask O:	Technology Baseline Definition (U.S.A.)
Subtask A:	Performance Measurement and Analysis (Denmark)
Subtask B:	Modeling and Simulation (Denmark)
Subtask C:	Design Methods (U.S.A.)
Subtask D:	Building Design, Construction and Evaluation (Netherlands)

Subtask "O" establishes a technology baseline in terms of cost and performance of a conventional reference building from which to compare the results (improvements) obtained from designs developed during Task VIII research. Also, candidate passive and hybrid solar and energy conservation techniques and cost/performance goals are identified in Subtask "O". Subtask "A" collects, analyzes and reports performance data on passive and hybrid solar techniques for comparison against simulation results (validation studies of Subtask "B") and for characterizing system performance parameters. Common measurement procedures for monitoring passive and hybrid solar low energy buildings are developed within this Subtask.

Subtask "B" evaluates the capabilities, accuracy and limitations of current building energy analysis simulations and conducts parametric sensitivity studies to understand the design and integration issues of passive and hybrid systems. The results of this Subtask are used in preparation of the national design guidelines. Subtask "C" surveys and evaluates available passive/hybrid design tools, improves existing design tools and prepares a Design Information Booklet series. Subtask "D" involves the design, construction and evaluation of a state-of-the-art passive and hybrid solar low energy building(s) based upon the research results and information obtained from Subtasks "O", "A", "B", and "C".

The primary results of the Task are:

(1) Eight Design Information Booklets addressing topics concerned with the design, construction, evaluation and use of passive solar low energy homes;

(2) Exemplary passive and hybrid solar low energy buildings designed, constructed and evaluated; and

(3) Technical reports on performance measurement procedures, design tool evaluation, simulation model evaluation, parameter sensitivity studies, etc.

The work was conducted by researchers and designers in the participating countries who met regularly over the last six years to share and review the results, plan future activities and compile summary reports. A number of working groups were established to enable closer cooperation among a smaller number of participants to accomplish a more focused research activity.

BUILDING ENERGY ANALYSIS AND DESIGN TOOL EVALUATION

As part of Subtasks B and C research activities, a number of building energy analysis and design tool evaluations exercises were undertaken. These included:

(1) Empirical validation of detailed simulations using passive solar test room data from Canada, Switzerland and the U.S.

(2) Code to code comparison of detailed simulations for several passive solar system types in Copenhagen.

(3) Comparison of simplified design tool performance prediction to detailed simulation prediction for realistic passive solar buildings (direct gain, storage wall, and sunspace),

light and heavy weight construction, in three climates (Denver, Geneva and Copenhagen).

(4) Comparison of simplified design tool performance prediction to detailed simulation performance prediction for simplified (shoebox) passive solar test cases in three climates (Denver, Geneva and Copenhagen).

(5) Evaluation of the capability and user-friendliness of residential energy design tools.

(6) Development of 28 benchmark test cases for simplified design tool evaluation, based on the results of six detailed simulations.

Empirical Validation

Over 30 building energy analysis simulations were identified from a survey of the participating countries (2). Few of the simulations could model integrated residential energy systems using active, passive and hybrid solar features. Other than for direct gain windows, validation of these simulations was extremely limited.

To assess the ability of available building energy analysis simulations to accurately model the most common passive system types, three empirical validation tests were developed:

(1) Direct gain test room in Ottawa, Canada;

(2) Thermal storage wall test room near Lausanne, Switzerland; and

(3) Sunspace test room in Los Alamos, New Mexico.

Eleven simulations from seven countries (Table 2) were used to predict the heating energy consumption of a 24.3 m² test unit at the National Research Council of Canada's Passive Solar Test Facility in Ottawa. The building itself (containing Units 3 and 4) is a one-story insulated wood-frame superstructure over a basement. The exterior walls and the roof of the above-grade construction have thermal resistance values of 2.1 and 3.5 m²-°C/W, respectively. Since the basements are being used for the study of basement heat loss, the floors of the solar units were insulated to a resistance value of 7 m²-°C/W. The measured air exchange rate was close to zero for all rooms and units. All interior walls of the units are lined with a 100 mm course of solid concrete bricks, as shown in Figure 1, except for the wall between the south and north rooms which is made of a single course of the same brick.

Country	**Simulation Program**
Canada	ENCORE-CANADA
Denmark	BA4, PASOLE, SOLMAT
Italy	SMP
Norway	ENCORE
The Netherlands	BFEP, KLI/PAS
United Kingdom	ESP
United States	BLAST-3.0, DOE-2.1A, SERIRES-1.0

Table 2: List of Simulation Programs

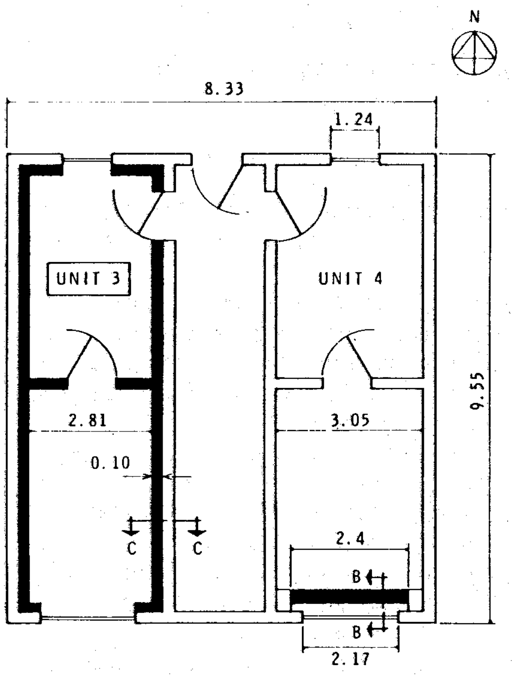


Figure 1: Floor Plan of Test Unit 3

Figure 2 presents the results of a comparison between simulation predictions and measured data for a 14-day period. All models except one predicted the total heating load within 10 percent of the measured value. Also, most of the models tracked the dynamic behavior of the building (Figure 3).

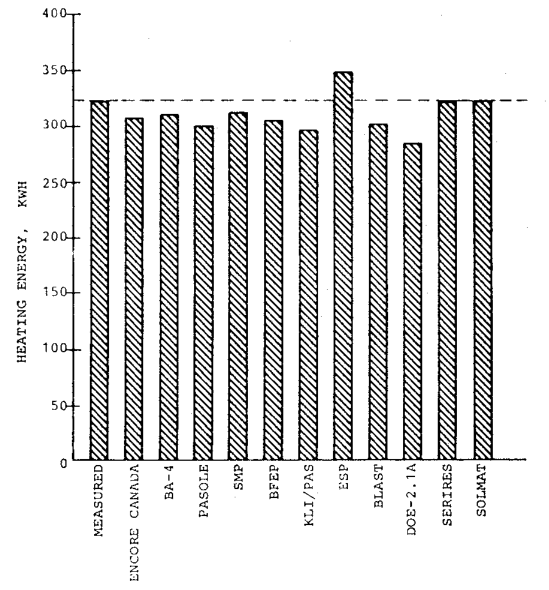


Figure 2: Comparison of Measured and Simulated Heating Energy of a Direct Gain Test Room in Ottawa

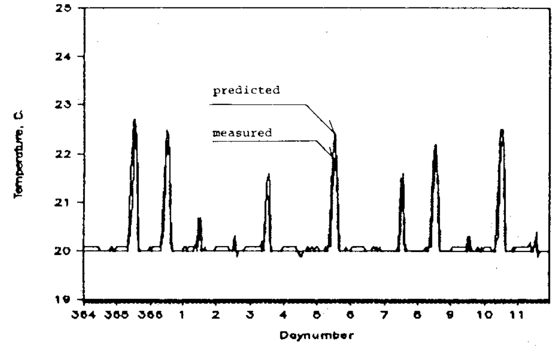
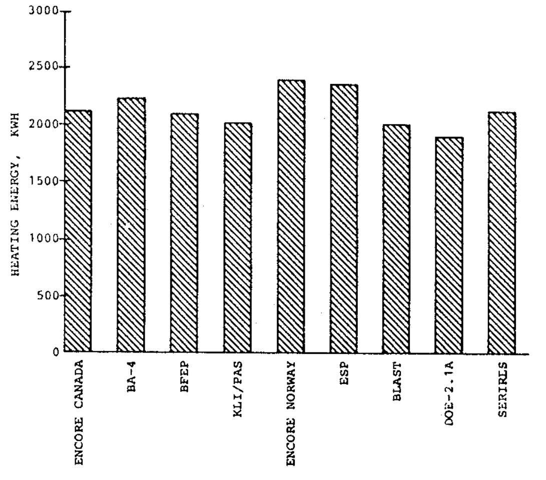
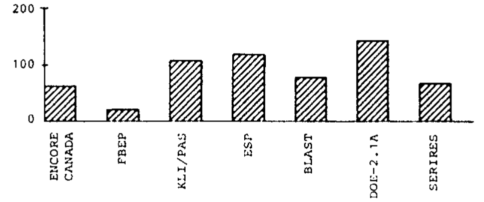


Figure 3: Measured and Predicted (SOLMAT) Temperatures in South Zone of Ottawa Test Unit 3

The Ottawa test unit models were then run on one-year Copenhagen TMY data. Figure 4 summarizes the results for nine simulations. Agreement is good (mean = 2,147.1, st. deviation = 160.6, max. deviation = 26%) for heating load calculation and not as good (mean = 86.2, st. deviation = 41.0, max. deviation = 650%) for cooling load calculation.



Heating Load



Cooling Load

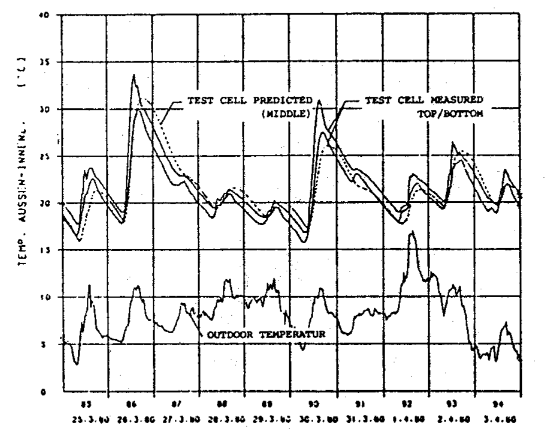
Figure 4: Comparison of Annual Heating and Cooling Loads for Copenhagen

Agreement between measured data and predicted performance for a thermal storage wall test room in Switzerland and a sunspace test room in New Mexico for 4 and 5 simulations, respectively, was not as good as the direct gain comparison. For the thermal storage wall case, computed and measured room and surface temperatures were in reasonable agreement (Figure 5); however, computed convective heat flows did not match measured data although mass flow rates did agree.

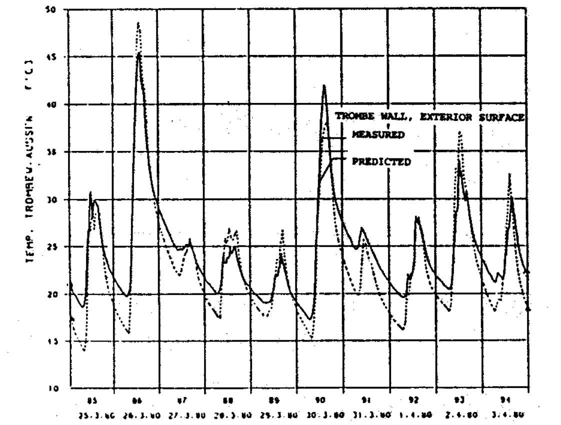
For the sunspace case, 2 of 3 simulations showed acceptable agreement to measured temperatures in the sunspace and test room but large differences in auxiliary heating energy (Figure 6). However, annual predictions of heating energy for Copenhagen were in good agreement for 3 of the 4 simulations (Table 3).

	Aux. Energy, kWh		Peak Load, kWh	
Program	**Heating**	**Cooling**	**Heating**	**Cooling**
SERIRES	2324	25	1.0	0.2
BLAST	2298	12	1.0	0.2
DEROB	2235	117	1.0	0.5
DOE-2.1C	2099	19	0.9	0.2

Table 3: Comparison of Annual Heating and Cooling Loads for Copenhagen



Computed (—) and measured (—) room air temperatures



Computed (—) and measured (—) Trombe wall surface temperatures

Figure 5: Computed (SERI/RES) and Measured Air and Surface Temperatures

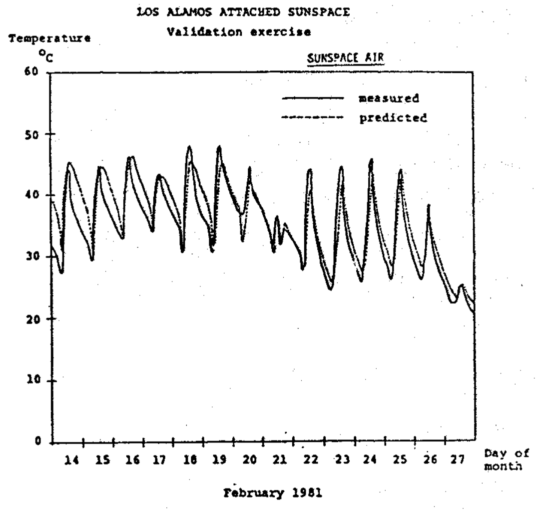


Figure 6: Computed (BFEP) and Measured Sunspace Air Temperature

As a general conclusion, prediction inaccuracy increased as (1) the solar forcing function becomes stronger and (2) the solid conduction heat transfer mode becomes dominated by other more complex heat transfer mechanisms. Sources of error in most simulations are: calculation of interior and exterior radiative and convective surface coefficients; calculation of interior and exterior incident solar radiation; interzone natural convection heat transfer; stratification; ground heat transfer; and calculation of latent cooling loads.

Comparative Studies

A separate design tool evaluation exercise was carried out as part of Subtask C. The purpose of this exercise was to evaluate the user-friendliness and technical capabilities of commonly used residential energy design tools. A 1984 survey of participating countries identified over 225 residential energy tools; 162 of these tools were developed in the United States (4). Two evaluation approaches were used: (1) realistic test cases, and (2) simplified test cases.

The realistic test cases involved the modification and analysis of two "real" passive solar buildings and comparison of results between a detailed simulation prediction and simplified design tool predictions. A single family detached house and a townhouse were modified into a lightweight and heavyweight designs incorporating direct gain, storage wall and sunspace passive system types. Each variation was analyzed with Copenhagen, Geneva and Denver meteorological data.

Home designers and builders were asked to analyze a number of passive solar design variations of the test case homes with a design tool and assess its user-friendliness and technical capabilities and accuracy. SERI/RES analysis of the same test case houses established the "truth reference" energy performance.

The second evaluation exercise focused only on the technical capabilities and accuracy of the selected design tools and used a "simplified building" as the test case. Six design variations -- add south glazing, add mass, etc. -- were made to the simplified building to assess the ability of the design tools to respond to these changes.

In general, large discrepancies were found between the design tool prediction and the

SERI/RES predictions of heating and cooling loads of both the test case "real" house and the "simplified" buildings (5). The discrepancy increased as the buildings were analyzed in sunnier climates. Most of the design tools predict the correct energy performance trend as design parameter changes are made. For example, as south-facing glazing and thermal mass area increase, the heating load decreases.

The major sources of error or limitations of the simplified design tools appear to be in the following areas:

(1) Solar radiation processing -- conversion of total horizontal radiation to tilted surfaces and separation into direct and diffuse components.

(2) Compensating errors -- inaccuracies in component level modeling offsetting one another.

(3) Utilization of solar gains -- inaccurate calculation of the percent of transmitted solar gains that offset the heating load.

(4) Thermal mass effects -- inaccurate calculation of the effectiveness of thermal mass to store solar gains and to offset heating loads.

(5) Component losses -- many tools do not consider the sol-air effect to calculate component heat losses or gains.

Design tool evaluation is an extremely complex undertaking that requires an exceptional attention to detail to ensure comparable input, understanding of modeling assumptions and algorithms and evaluation of output.

The user-friendliness of building energy design tools varies widely between tools; however, in general, most of the 25 tools tested were unsatisfactory in at least one of the following areas -- ease of use, excessive hardware requirements, inadequate or poorly written documentation (user's manual or engineering manual), excessive set-up and run time, inadequate tool verification, inadequate user support, lack of default values, insufficient or poorly formatted output, no help screens or input error checking. In general, the design tools appeared to have been developed for computer experts and energy analysts and not for practicing architects and home builders.

Benchmark Test Cases

Building on the early Task VIII analysis and design tool evaluation experience, an activity was initiated to develop a series of benchmark test cases that could be used to assess the ability of design tools to analyze basic energy processes in passive solar buildings and to diagnose sources of inaccuracy in design tools (6).

Using six of the most detailed building energy analysis simulations available within the participating countries, 28 test cases were developed and analyzed for two climates -- Copenhagen, Denmark, and Denver, Colorado (Table 3 and Figures 7-8). An error band for each test case was established based on the results from the detailed simulations. Design tool predictions can then be compared to the error band for each test case to establish the degree of agreement (Figures 9 and 10). Not all 28 test cases need to be compared to establish the relative accuracy of the design tool. A number of the test cases have been developed as diagnostics to establish where a source of error may exist in the design tool.

Detailed documentation of the benchmark test cases as well as the modeling inputs and assumptions has been prepared as a starting point for developing a set of national benchmark test cases (6).

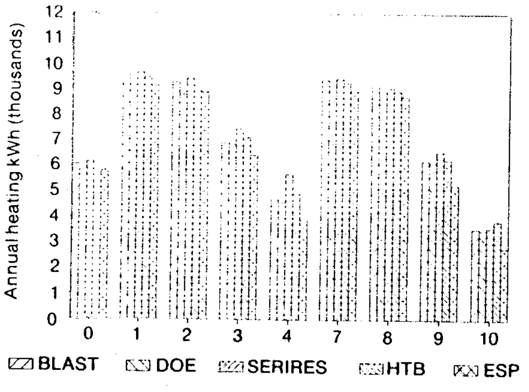


Figure 7: IEA Reference Codes Cases 0-10 (Denver TMY)

Case #	Set-Points Heat (°C)	Cool (°C)	Mass	Glass (m^2)		Infilt (ach)	Intgen (W)	Base Case	Other
0	20	20	LW	0	S	0	0		
1	20	20	LW	0	S	1	0		
2	20	20	HW	0	S	1	0		
3	20	20	LW	9	S	1	0		
4	20	20	HW	9	S	1	0		
7	20	27	LW	0	S	1	0		
8	20	27	HW	0	S	1	0		
9	20	27	LW	9	S	1	0		
10	20	27	HW	9	S	1	0		
11	FLOATING		LW	9	S	1	0		
12	FLOATING		HW	9	S	1	0		
13	20	27	LW	4	S	1	200	9	
14	20	27	HW	4	S	1	200	10	
15	20	27	LW	4	E	1	200	13	
16	20	27	HW	4	E	1	200	14	
17	20	27	HW	9	S	1	200	10	overhang Denver only
18	FLOATING		HW	9	S	1	200	10	overhang Denver only
19	SET-BACK		LW	4	S	1	200	13	
20	SET-BACK		HW	4	S	1	200	14	
21	20	27	HW	9	S	1	200	10	adiabatic E,W,N walls
22	20	27	LW	9	S	1	200	9,13	
23	20	27	HW	9	S	1	200	10,14	
24	SET-BACK		LW	9	S	1	200	19	
25	SET-BACK		HW	9	S	1	200	20	
26	FLOATING		LW	9	S	1	200	22	Denver only
27	FLOATING		HW	9	S	1	200	23	Denver only

Where:
LW = Lightweight
HW = Heavyweight
Infilt = Infiltration in air changes per hour
Intgen = Internally generated heat from lights, appliances, etc.
E,W,N,S = East, West, North, South
20 20 = Heat on if temp < 20°C
Cool on if temp > 20°C
20 27 = Heat on if temp < 20°C
Cool on if temp > 27°C
FLOATING = Temperatures in building allowed to float freely
SET-BACK = Set-back thermostat control from 2300-0700 hrs.
Set-back temperature = 10°C
(A blank cell contains the previous value in the column.)

Table 3: Characteristics of the Benchmark Test Cases

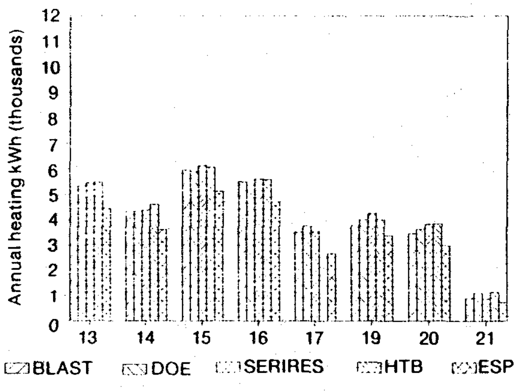


Figure 8: IEA Reference Codes
Cases 13-21 (Denver TMY)

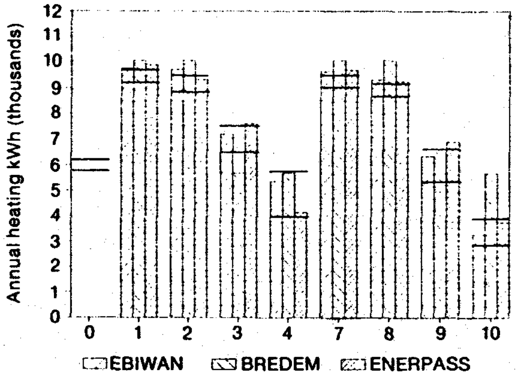


Figure 9: IEA Design Tool Examples
(Denver TMY Cases 0-10)

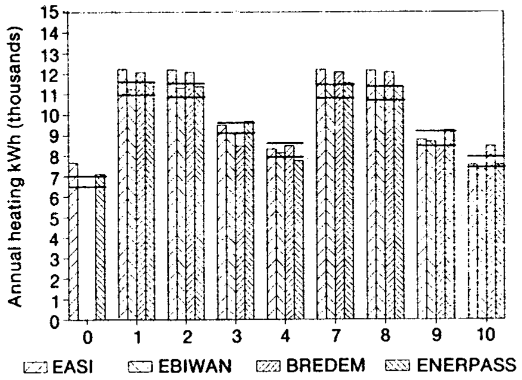


Figure 10: IEA Design Tool Examples
(Copenhagen TMY Cases 0-10)

CONCLUSION

IEA Task VIII has been instrumental in implementing a systematic evaluation of building energy analysis and design tools in 14 countries. As a result of numerous analysis and design tool evaluation exercises, the strengths and weaknesses of these tools has been established and in many cases improvements in theirtechnical capability, accuracy and user-friendliness have been made. A systematic procedure for evaluating design tools using benchmark test cases has been developed and used as part of national design tool evaluation efforts related to energy code compliance and home energy rating systems.

Many of the problems and limitations uncovered during the IEA Task VIII building energy analysis and design tool evaluation exercises will be addressed in a new IEA Task entitled "Building Energy Analysis and Design Tools for Solar Applications." This task will focus on model development, evaluation and use.

ACKNOWLEDGMENTS

The authors are indebted to all of the participants of Task VIII for their commitment to the Task goals and objectives and for their hard work and untiring support to undertake and complete the huge amount of work associated with this international cooperative research project. A special thanks and acknowledgment goes to the Subtask Leaders: Mr. Ove Morck of Denmark, Mr. Richard Rittelmann of the United States, and Mr. Hans Kok of the Netherlands.

The authors also wish to thank Mr. Fred Morse, Mr. Robert Hughey, Ms. Mary Margaret Jenior, Ms. Janet Neville and Mr. Michael Lopez of the U.S. Department of Energy for their technical and financial support of this program.

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