NBSIR 80-2068

Review of Current Calculation Procedures for Building Energy Analysis

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by

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ABSTRACT

Existing calculation procedures for building energy analysis, both computer-based and manual, were surveyed by means of questionnaires to determine the extent to which they were used, and their technical content. It was found that most of the Nation's building energy consumption analyses are done by computerized simulation of HVAC system and equipment performance. This report provides brief descriptions of some energy analysis procedures which merit further study. It also identifies items not covered in the existing procedures which need to be developed for the improvement of energy calculation technology.

Keywords: Calculation procedures; computer simulation; energy analysis; energy conservation.

FOREWORD

This is one of a series of working reports documenting National Bureau of Standards (NBS) research efforts in developing the energy and economic data and related research needed to support the Department of Energy (DoE) Building Energy Conservation Criteria research program. The work described in this report of the Energy Calculation Review project was sponsored by DoE under Task Order No. A008-BCS of DoE/NBS Interagency Agreement No. EA-77-A-01-6010.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

1. INTRODUCTION

National emphasis on improved building design for energy conservation has resulted in the development of numerous energy consumption analysis procedures, both manual and computer-based. Over 300 energy analysis procedures are in use throughout the United States. The proliferation of these energy analysis procedures and computer programs is creating confusion among code enforcement officials, architect-engineer firms, and private citizens who use energy calculations to evaluate energy-saving features for buildings.

The pupose of this report is to review the currently available energy analysis calculation procedures, both manual and computer-based, to support officials of the U. S. Department of Energy (DoE) for their selection of suitable energy analysis procedures for the effective implementation of Building Energy Performance Standards (BEPS).

In order to assess the existing state of the art, detailed information from the users of as many of these procedures as possible has been collected by private contact and by questionnaires which were designed to determine the technical content of the calculation procedures, as well as user-related information. The technical information obtained by the questionnaires includes, but is not limited to, that listed below:

1. Heat loss/gain calculations--steady, steady-periodic, transient hourly
2. Type of weather data
3. Conversion of heat loss/gain to heating/cooling loads
4. Room temperature and humidity fluctuation calculations--thermostat setback, natural cooling, and passive solar heating
5. Type of solar data used
6. Air-side system simulation options
7. Water-side system simulation options
8. Central heating/cooling equipment simulation options
9. Economic analysis options
10. Input data requirements
11. Output data format
12. Intended users and uses
13. Validation records
14. Data preparation time
15. Computing time
16. Documentation
17. Program maintenance and management.

Based upon the information thus gathered, each calculation procedure was evaluated. It is found that many of the procedures are similar, differing only in the degree of sophistication. Calculation procedures that are unique and seem to merit further study are described briefly in this report. Also included at the end of this report are items which have not been considered in the current energy analysis procedures, and recommendations for future work.

2. QUESTIONNAIRE

Jointly with the American Institute of Architects Research Corporation (AIARC), the National Bureau of Standards developed a detailed energy questionnaire to evaluate the technical capability of the various energy analysis procedures for use in Building Energy Performance Standards (BEPS) being developed by DoE under Title III of PL 94-385. As shown in Appendix A, the questionnaire was designed to reveal in-depth information on the building and systems heat transfer calculations, and the method of interfacing building heat loss/gain with the performance of building heating/cooling systems. The questionnaire attempted to reveal the ability of each of the programs to evaluate the explicit advantages of various energy conservation options, such as improved building envelope design, improved daylight utilization, choice of HVAC systems and equipment, and control strategies.

Using attendance records of various past technical meetings related to energy analysis, and technical publications dealing with computerized energy analysis procedure, 800 individuals were selected to receive the questionnaire. A total of 276 responses were received. Appendix B provides names of contacts who responded to the questionnaire for commercial and public-domain energy analysis procedures.

Not included in the survey are 78 in-house energy analysis procedures, most of which are not well documented for public use. Also, not included in the survey are many of the passive solar house simulation programs, which have been well covered in a recent Arthur D. Little report entitled, "Building Energy Analysis Computer Programs with Solar Heating and Cooling System Capabilities," by S. J. Feldman and R. L. Merriam.

The authors are certain that there are several noteworthy energy analysis programs which were not covered by this survey since new energy analysis procedures are being generated at a rapid pace.

Appendix C lists numbers and users of selected energy analysis programs. It shows that some of the commercial programs such as TRACE and ESP-1 are very popular among energy analysts.

Appendix D shows a gross review of the selected energy analysis procedures with respect to publication status, proprietorship, type of analysis, and application.

Including the proprietary and in-house procedures, there are 160 in-house independent annual energy calculation procedures, of which 19 are manual procedures. Most of these procedures are claimed to address HVAC system analysis as well as heating and cooling load calculations, although the exact nature of their algorithmic details is unknown. Judging from the reputation of the authors and the procedures, however, it is reasonable to assume that their HVAC system analysis consists of standard psychrometric heat balance calculation of air systems and some form of seasonal equipment efficiency analysis.

3. EVALUATION PARAMETERS

The following technical evaluation parameters were considered in this review to select energy analysis procedures to be used for BEPS for for both residential and non-residential applications.

1. Nature of the dynamic heat conduction calculation through building envelope
2. Type of infiltration calculations
3. Method for handling effective solar radiation and cloud cover for conduction heat gain as well as for fenestration heat gain
4. Manner in which indoor environmental conditions are either specified or determined by the computations
5. Method of handling ventilated and non-ventilated attic and crawl spaces
6. Heat loss to the ground through slab-on-grade floors, basement walls and floors
7. Method of converting heat loss/gain into heating/cooling load and into equipment energy consumption
8. Extent of the HVAC system-simulation and equipment-performance analysis
9. Manner of operation of HVAC systems and equipment
10. Manner of handling system capacity and load imbalance
11. Capability for correlation of passive and active solar systems
12. Capability for daylighting analysis.

It has been found that many procedures use steady-state heat transfer calculations or are not suitable for non-residential applications because of their limited HVAC system simulation capabilities. On the other hand, there are numerous and comprehensive dynamic heat gain simulation programs which do not go into the HVAC system and equipment simulation phases. Although these latter procedures could readily be expanded to deal with HVAC system simulation, they were not considered adequate for this evaluation.

Based upon these 12 parameters, 17 energy analysis procedures were selected. Brief descriptions of these procedures are given in the following section. All of these procedures covered most of the questionnaire entries by indicating that they would address the 12 evaluation parameters, although the algorithmic details for handling the specific items are not known. Table 1 shows the list of these 17 procedures, all of which employ computer simulation technique. Seven proprietary computer programs that are not available for public access are identified with the symbol "P".

Table 1 Energy Analysis Procedures that Meet Initial Twelve Evaluation Parameters

1.	ASHRAE	
2.	AXCESS	
3.	BECON	
4.	BLAST	
5.	DOE-1, 2	
6.	E-CUBE-4	P
7.	EP	
8.	ESAS	P
9.	ESP-I	
10.	NECAP	
11.	SCOUT	P
12.	TRACE	P
13.	Westinghouse	P
14.	BUILDSIM	P
15.	DEROB	P
16.	ENCORE	
17.	NBSWHF	

P = Proprietary

4. ASHRAE WEIGHTING FACTORS

Except for the BECON, BLAST, DEROB and NBSWHF programs, all the programs listed in Table 1 indicated that they use ASHRAE weighting factors for the conversion of heat loss/gain into heating/cooling loads. The ASHRAE weighting factor concept is also used to determine the space temperature deviation from the set point as a result of inbalance between the room heating/cooling requirement and heating/cooling capacities of the HVAC systems. The basic objective of ASHRAE weighting factors is to determine the peak cooling load from the hourly profiles of instantaneous heat gains into the building from various sources such as solar heat gain, conduction heat gain, infiltration, heat gain from lights, and heat gain from the occupants.

The sum of the instantaneous heat gain is not necessarily equal to the instantaneous cooling load because a portion of the heat gain will be absorbed by the building structure. The weighting factors would allow the determination of instantaneous cooling load by knowing the historical values of the instantaneous heat gains from various sources for the cooling design days. There is also another weighting factor that permits the determination of temperature deviations from the set point by knowing the histories of space temperatures and cooling load. It is rather unfortunate that the ASHRAE weighting factors have been generated only for the three "typical" office buildings of light, medium, heavy structure. These weighting factors were calculated by detailed heat balance equations between the building envelope and air, for a specific set of conditions representing three "typical" buildings, by Gint Mitalas of the National Research Council of Canada.* Although it has been recognized

* "Procedure for Determining Heating and Cooling Loads for Computerizing Energy Calculations," ASHRAE Energy Calculation 1, 1976.

that these weighting factors would be dependent upon the building construction material, characteristics of windows, and characteristics of internal heat sources, it is assumed that three typical sets of values derived from the light, medium, and heavy office buildings are sufficient for the determination of peak heating/cooling loads for typical design days.

In addition, the weighting factor concept basically assumes that all the heat losses/gains, if integrated over a sufficient time span, would eventually become equal to the integrated cooling load. In reality, however, some fraction of the heat gains could be lost to the outdoors, hence a correction factor is necessary. ASHRAE Handbook uses a factor F_c to account for the loss of the heat gains as a function of the overall envelope heat transfer factor.* There is, however, no guarantee that these weighting factors and F_c factor are valid for heating load calculations when outdoor temperatures are lower than indoor temperatures, and a large amount of the heat gained is lost through the envelope.

Although simple to use, weighting factor methodology does not allow the accurate evaluation of heating and cooling loads or space temperature profile when the building designs are considerably different from the buildings for which ASHRAE weighting factors were originally derived. One way to resolve this problem would be to make available sets of weighting factors for a variety of building structures and configurations, so that the energy analyst could have a reasonable number of choices to represent design features of his specific building. This requires a large number of weighting factors in the data file. Even if sufficient sets of weighting factors were available to satisfy most of the design variations, there still are inherent ambiguities about the choice of the right set of weighting factors, as well as the use of the F_c factor for the heating load calculations. The only way to eliminate this uncomfortable situation is to perform the detailed heat balance computation that is the basis for the weighting factor calculations, for every hour. The NBSWHF and BLAST programs, and presumably the BECON program, do exactly that. Since the published information available for BECON is very limited and it is available only from the CDC computer network, its immediate value to the Building Energy Performance Standards (BEPS) application is questionable.

The comprehensive energy analysis procedure needed by BEPS for detailed building heat transfer simulation and the subsequent thermal performance of the HVAC system, especially under the thermostat dead-band control mode and the passive heating and cooling mode, cannot be accurately handled by the procedures using the ASHRAE weighting factor approach.

This is a reason that the DOE-2 program is currently being modified to accommodate the detailed heat balance calculation procedure.

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* ASHRAE Handbook of Fundamentals, Chapter 25, Air Conditioning Cooling Load, p. 25.36, 1977

5. BRIEF DESCRIPTIONS OF COMPUTER-BASED ENERGY ANALYSIS PROCEDURES

Procedures that meet the selection criteria of Section 3 and merit further considerations are briefly described as follows:

5.1 ASHRAE

According to Mr. Stephen D. Heath, this program satisfies most of the twelve criteria mentioned above. Although comprehensive HVAC system and equipment calculation routines are included, the procedure does not compute the temperature variation from the set point as a result of the inbalance between the heating/cooling requirements and heating/cooling capacity of the equipment. The program is developed for the use of the WANG calculator, but documentation seems to be incomplete as the program is designed for internal use. The procedure employs the daylighting calculations, and the ventilated attic and crawl space are also treated. The ASHRAE weighting factors are used extensively for converting the heat loss/heat gain into heating/cooling load.

5.2 AXCESS

Electric utilities developed this very popular energy analysis program for commercial buildings. The program has been extensively used for the generation of the DoE Design Energy Budget for new buildings (Advanced Notice of Proposed Rulemaking Title 10, Chapter II - Part 435). Although extremely comprehensive for HVAC system and equipment simulation, its value for residential applications, especially for the passive solar house, is questionable because the program does not address the heat transfer processes of attic, crawl space and ground floor (including basement walls). Also, the building air leakage calculation for AXCESS is somewhat limited. This program does not address ventilated or non-ventilated attic and/or crawl spaces at all.

5.3 BECON

BECON is a group of subroutines that are used in conjunction with "MITAS", which is a finite-difference thermal analyzer that has been used by aerospace industries for more than fifteen years.

Mr. Donald C. Pedreya, the developer of BECON, claims that the program is very comprehensive and can simulate virtually any building energy problem. For the heating/cooling load computation, this program solves the detailed heat balance equations among the various interior surfaces similar to NBSWHF. Details of the program are described in a technical paper entitled "Building Heating and Cooling Load Predictions Using a Finite Element Thermal Analyzer," which is published in the Proceedings for the Third Symposium on the Use of Computers for Environmental Engineering Related to Buildings, Banff, 1978.

The system and equipment simulation portion covers most of the air side and water side distribution systems and major heating/cooling equipment, details of which are similar to the SINDA program. Although very comprehensive, this program has not been used as widely as other programs of similar nature, thus published documentation is rather incomplete.

5.4 BLAST

The Department of the Army developed this very comprehensive energy analysis procedure based upon the detailed heat balance algorithms of NBSLD heating/cooling load calculation procedures and NECAP system/equipment simulation subroutines. The heating/cooling load computation is said to be improved both in its scope and algorithmic efficiency. The equipment simulation portion, especially the part-load performance simulation, employs numerous modifications from the original NECAP version. The program is suitable for the simulation of both active and passive solar houses, although daylighting calculation is not available at present. The program also uses Building Description Language (BDL) to simplify the input data preparation.

5.5 DOE-1 and DOE-2

These public domain computer programs were developed by Lawrence Berkeley Laboratories under the auspices of the Department of Energy. They are an extension of the NECAP program with some modification in the variable temperature routine and addition of HVAC systems and equipment. They use BDL (Building Description Language) to simplify the input preparation effort by means of the Standard Data File and default system to minimize the redundancy of data preparation for similar building construction. Although very comprehensive, its value for temperature prediction and for a passive solar house is questionable until the detailed heat balance algorithms are included to supplement the ASHRAE weighting factors method. However, DoE-2 is currently being considered as a standard reference energy analysis program for the implementation of BEPS, with the assumption that the foregoing limitations will be removed from the current version by the end of August.

5.6 ECUBE-4

According to Mr. Don Deyoe, unlike the previous versions of ECUBE (ECUBE-1-ECUBE-3), ECUBE-4 follows very closely the energy analysis procedure recommended by the ASHRAE Task Group and has extensive HVAC system/equipment simulation capabilities. Daylighting calculations, however, are not included. Although the program has been well documented, widely publicized and extensively used through the CDC 6600 computing network, the program is proprietary.

5.7 EP

This is another of the extensive HVAC systems simulation programs suitable for evaluating commercial buildings. Although the program does not address daylighting and passive solar designing, it appears to follow very closely the ASHRAE Task Group procedure and weighting factor methods.

5.8 ESAS

This program, developed by Ross Meriwether, is one of the oldest and most widely used energy analysis programs for commercial buildings applications.

It is, however, proprietary, and its detailed algorithmic structure has never been published. The popularity of this program is based upon its excellent technical support, versatility for the simulation of the very common HVAC systems and equipment, and good economic analysis. The program is not designed for the simulation of residential applications, and thus excludes simulation of passively heated or cooled buildings.

5.9 ESP II

This program was developed under the auspices of the Automated Procedures for Engineering Consultants (APEC), to have energy analysis procedures available for computer-oriented consulting firms. The program is an extension of NECAP, with the addition of system/equipment simulation subroutines and variable temperature subroutines. Although very extensive in HVAC system/component simulation, heat pump simulation and daylighting calculations are not available at the moment. Documentation is excellent but the program currently is available only through the APEC membership.

5.10 NECAP

This comprehensive building energy analysis program is based upon ASHRAE weighting factor methodology suitable for commercial building application. The program was developed by NASA from the original U.S. Post Office program, USPOD. It was constantly updated, and has a good documentation. Many of the third generation programs, such as ESP-1, SCOUT, DOE-2, and even BLAST, used this program as the starting point.

5.11 SCOUT

Gard, Inc., developer of the historical U.S. Post Office program,is responsible for the creation of this versatile energy analysis program suitable for commercial building application. Most of the features attributable to DOE-1 and DOE-2 and ESP-1 are applicable to this program, except for the Building Description Language.

5.12 TRACE

This is a proprietary program developed by the Trane Co. and considered to be one of the most comprehensive and well supported energy analysis procedures. The program follows the ASHRAE weighting factor methodology for the determination of heating/cooling load from heat loss/gain, and covers all the possible heating/cooling systems and equipment available in the market. The procedure is well documented for input data description and basic algorithmic details. Although the program does not compute the daylighting, it has been used for the evaluation of several passive and active solar energy utilization systems. The program is well supported by the Trane Co. and widely used by practicing engineers for the energy analysis of commercial buildings. It is questionable, however, that this program is suitable for residential applications because of lack of ground floor and basement wall heat transfer calculations.

5.13 WESTINGHOUSE PROGRAM

Judging from the questionnaire responses, this appears to be an extremely comprehensive hourly simulation energy analysis program that meets most of the twelve criteria described in the questionnaire. The program is an extention of the version which was developed by L. Russell of Westinghouse as one of the pioneering computer simulations of building thermal performance. The methodology used for converting the heat loss/gain into the heating/cooling load of the HVAC system, however, is not clear. The questionnaire response indicates that the daylighting calculation also is included to compensate for the artificial lighting. Attic, crawl space and ground floor heat transfer calculations are also covered. The program is proprietary.

5.14 BUILDSIM

This Honeywell program is the only program that attempts to simulate the effect of HVAC controls in a truly dynamic sense. Since the control dynamics require very small time-step calculations, this program requires minute-by-minute simulation of HVAC system performance. Details of the building load calculation are, however, unclear. No documentation is published.

5.15 DEROB

According to Dr. Areemi, author of DEROB, this program appears to be one of the most comprehensive building simulation programs that takes into account detailed interreflective heat and light transfer processes within a building. The program is suitable for passive solar building analysis. It is not suitable for commercial buildings, however, because of the insufficient HVAC system and equipment simulation. Because of its ability to simulate passive solar design, the program is currently considered a standard reference program for BEPS application on the passive solar design. Its algorithms are not published.

5.16 ENCORE

ENCORE was developed by the National Research Council of Canada to simulate the complex combination of building heat transfer and air leakage processes. The heating and cooling load computation portion of the program is based upon ASHRAE weighting factor methodology. HVAC system and equipment simulation, although limited to residential heating systems, is very comprehensive.

5.17 NBSWHF

This research program of the National Bureau of Standards is an updated version of NBSLD and is designed to make a comprehensive simulation of building thermal performance, heating/cooling load, floating temperature and humidity, attic ventilation, wholehouse fan, comfort index, and daylighting. This program is limited to the determination of heating/cooling requirements; output of this program is used for other programs that have system and equipment subroutines. The current version includes part-load efficiencies of gas- and oil-fired furnace and boiler, central air-conditioner, and heat pump. Thus the program is suitable for the residential energy analysis. The program is based upon detailed heat balance computation among the interior surfaces and room air for the determination of heating/cooling load, thus independent of the ASHRAE weighting factor approach. There are several in-house hourly simulation energy analysis programs which have been developed from the predecessor of NBSWHF, or NBSLD. Some examples are BLAST, EQUINOX, SEE, and NBSGLD.

6. TECHNICAL EVALUATION OF THE MANUAL PROCEDURES

The NBS/AIARC survey revealed that a majority of energy calculations are performed by the computer-based hourly simulated techniques or bin methods by taking into account the detailed building construction data, coincident hourly weather data, building occupancy schedule, and types of different HVAC systems performance. The purpose of the survey also was to reveal the type and the existing content of manual energy analysis procedures and the extent to which the manual procedures are used by consulting engineers.

Recent work of ASHRAE Technical Committee 4.7, with respect to their effort in the development of a simplified energy analysis procedure disclosed that the manual procedure, if properly done by an experienced engineer, could result in annual energy consumption estimates suprisingly close to those obtained by using sophisticated hourly simulation procedures. A summary of the ASHRAE TC4.7 efforts to compare the simplified procedure with the hourly simulation procedure is presented in Appendix E, together with a comparative analysis on larger non-residential buildings, which was done under the AIA Research Corporation.

The following manual procedures were selected from the nineteen questionnaire responses on the basis of their ability to handle HVAC system analysis as well as the building heat loss and heat gain evaluation.

6.1 BRUCE BIRDSALL IN-HOUSE PROCEDURES

This manual energy analysis procedure was developed primarily to teach HVAC systems performance concepts to Ohio State University students. It is based upon a bin method, yet an accuracy of $\pm$10% error is claimed. Very comprehensive system simulation and equipment analysis are available based upon a simplified heating and cooling load calculation. Payback period is used in the economic analysis.

6.2 HUBER H. BUEHRER IN-HOUSE PROCEDURE

This manual energy analysis procedure is based upon the degree-hour concept. It is designed for commercial building applications, yet accuracy of the 10% error is claimed. Solar heat gain effect is treated in a very comprehensive manner. Details of HVAC system simulation are not given.

6.3 JIM COCHRAN IN-HOUSE PROCEDURE

This is a degree-day energy analysis program suitable for residential and non-residential applications. Mr. Cochran, author of the program, claimed that this program can perform comprehensive heat loss/gain computations on conventional HVAC systems, such as single-duct and double-duct systems and most of the residential heating/cooling systems. The procedure includes economic analysis and passive design modeling.

6.4 GREGORY CONNIFF IN-HOUSE PROCEDURE

The procedure uses degree-day and bin methods, and includes extensive analysis of HVAC systems and active solar systems. Economic analysis includes life-cycle cost and payback period and appears to be very comprehensive. The program was used in the evaluation of underground structures and heat recovery systems.

6.5 HOME ENERGY AUDIT (Robert D. Busch, Bickle/CM)

This SDC 6000-based home energy audit program has been used very widely and is claimed to have an accuracy within 15% deviation from measured value. It is based upon a dynamic simulation of building thermal response.

6.6 MAD-II (L. A. Abbatiello, Oak Ridge National Laboratory)

This program is designed to provide a simple, easy-to-use Annual Cycle Energy Storage System (ACES) design procedure considering all the major variables for residential design. It is basically a bin method but has extensive solar simulation using the Liu-Jordan technique. Although it appears to be very comprehensive and well validated by many ACES houses, documentation is incomplete.

6.7 MILTON MECKLER PROGRAM, (MECKLER ENERGY GROUP)

The California State Energy Resources Conservation and Development Commission developed a manual energy analysis procedure based upon annual degree hours. This program is unique in that complex HVAC system simulation is done by a simple system performance factor which has been pre-calculated for 16 equivalent systems. A step-by-step calculation procedure with extensive look-up tables has been developed.

6.8 MANFRED MOSES IN-HOUSE PROCEDURE

This is a steady-state-based energy analysis procedure with ability to model passive design and most of the heating/cooling equipment with limited number of HVAC systems. Economics analysis is also available. Program is developed for non-residential application.

6.9 REAP (ASHRAE TC4.7 PROCEDURE)

This is an extended "bin" method procedure and was originally developed by the Carrier Corp. to analyze energy consumption in non-residential buildings expected to have 15% deviation from the measured value. It is very comprehensive in standard non-residential HVAC system equipment analysis and includes an economic analysis. Although the procedure is for manual analysis, a computerized version of the procedure is also available.

This procedure was adopted as a starting point for the ASHRAE TC4.7 method. Comparative analyses between the ASHRAE TC4.7 method and seven comprehensive computer simulation methods on a typical office building for four different HVAC systems were conducted recently under the auspices of ASHRAE and results of this study are given in Appendix E.

6.10 GREG F. SANDS IN-HOUSE PROCEDURE

This program is based upon a combination of degree-day and bin methods. The program is being used for non-residential buildings with an accuracy of $\pm 10\%$ error. Comprehensive treatment of HVAC systems and equipment and an economic analysis is available. This procedure was developed at the Energy Division at Ohio State University and is suitable for manual calculation for energy analysis and retrofit savings and payback.

6.11 PETER B. SHERWOOD IN-HOUSE PROCEDURE

This degree-day analysis procedure is designed for annual computation for both non-residential and residential applications. It is supposed to handle solar influence and comprehensive treatment of ventilated attic and crawl spaces and ground heat transfer. Mr. Sherwood claims that this program could analyze most conventional HVAC systems and equipment as well. An economic analysis is also included.

6.12 SOLAR ANALYSIS (by Terry Jackson)

This degree-day analysis procedure developed for Arkla Industries is suitable for residential and non-residential applications, with a limited amount of HVAC system simulation available. Simulations for the absorption chillers, waste heat recovery system, and active solar system are included, as is the economic analysis. A dynamic simulation algorithm is being added.

6.13 TLF (by Taghi Alereza, Hittman Associates)

A simplified residential energy analysis procedure has been developed from the comprehensive hourly energy simulation model (BEAM) of Hittman Associates. Thermal Load Factors (TLF) are available for different types of houses and different localities in terms of Btu per square foot per degree day.

6.14 R. G. WERDEN IN-HOUSE PROCEDURE

This bin-method manual energy analysis procedure is designed for non-residential application with very comprehensive HVAC system simulation and equipment analysis. Mr. Werden claims that although the system is very simple, deviation of the annual energy estimates from the metered energy consumption data is no more than 2%.

6.15 HEAP (by T. Kusuda of NBS)

This steady-state-type home energy audit procedure was developed for DOE and has been used by several states. The calculation uses the monthly normal weather data and Liu/Jordan solar calculation. The heating energy consumption results agree with hourly simulation calculation. The cooling energy consumption analysis, however, needs improvement.

7. POCKET CALCULATOR PROGRAMS

In addition to the energy analysis procedures mentioned above, several pocket calculator versions of building heat loss/gain calculation are currently available, such as follows:

7.1 SCOT-WARE PROGRAMS

This company markets TI-59 programs for commercial heating load (HL1), commercial cooling load (CL2), residential heating and cooling loads (RL4), commercial air conditioning load (CL4), and several solar energy applications.

The CL4 program follows very closely the 1977 ASHRAE Handbook of Fundamentals procedure by applying solar heat gain factors (SHGF), cooling load factors (CLF), cooling load temperature differences (CLTD), and shadow factors. The program accepts 99 inputs and prints out 61 output quantities. In fact, the program logic is so large that customized solid-state software (SSS) is used, in addition to conventional program cards. The program cards are provided to determine separately the heating load, fan loss, motor loss, air infiltration, coil selection, and opaque wall/roof thermal performance factors.

7.2 RIBA PROGRAMS

These programs are generated in England and deal with gross energy consumption by empirical method (E/1B), degree-day method (E/1C) and U value (E/1F) calculation programs. A TI-59 calculator is used.

7.3 SOLAR ENVIRONMENT ENERGY CO. PROGRAMS

The package has TI-59 and/or HP-67/97 versions of solar energy analysis program (SECI), solar heating system optimization (SECIII), and thermal storage wall, passive solar heating and life-cycle cost program (SECVI).

7.4 <u>TEANET</u>

This is a numerical thermal network analyzer to simulate passive solar systems on TI-59.

7.5 <u>HEWLETT PACKARD LIBRARY FOR HP-67/97</u>

The Hewlett Packard library has several programs for economic analysis of insulation thickness, heat conduction through composite walls and cylinders, solar simulation, and semi-infinite thermal heat conduction systems.

7.6 <u>REAPXTI</u>

This is a Carrier Corporation system on an SR-60A calculator designed to do the energy analysis of commercial buildings by a bin method described in their REAP manual.

7.7 <u>HONEYWELL HOME ENERGY ANALYZER</u>

This is a specially engineered system for specially designed desk-top computers, details of which are unknown.

8. VALIDATION EFFORTS

Appendix F shows the summary of the item 11 responses to the NBS/AIARC questionnaire. A majority of the respondees claimed that their energy analysis procedures could predict the metered building annual energy consumption for heating and cooling to within ±10%. NBS is currently in the process of checking these claims by asking for detailed documentation or references from those responsible for the questionnaire returns.

9. SUMMARY OF THE ENERGY ANALYSIS SURVEY

The vast majority of the calculation procedures identified by this survey, both in-house and publicly available, use computers as opposed to handheld calculators in performing energy analysis.

Appendix D reflects some of the general capabilities of publicly available energy calculation procedures. The information given stems partly from the respondents' replies to the questionnaire and partly from discussions with persons identified as knowledgeable about particular procedures.

The following conclusions and recommendations were derived from this study:

- o There are a large number of in-house as well as publicly available procedures, most of which claim to have extensive HVAC system simulation capabilities. In-depth study on the extent of these HVAC system simulations is needed. This requires highly technical evaluation methodology to "smoke out" the strengths and weaknesses of the HVAC system simulation methodology, since it appears that most of them use simple psychrometric heat balance calculations.

- o The majority of the energy analysis procedures currently used are proprietary.
- o The public-domain energy analysis programs such as DOE-1 and BLAST are not yet widely accepted.
- o Different users of the same procedure perceive the overall capabilities differently.
- o Further detailed examination of procedures meeting minimum criteria will facilitate identification of thorough, cost-effective procedures.

10. ITEMS THAT ARE NOT COVERED BY THE EXISTING ENERGY ANALYSIS PROCEDURES

Although some of the comprehensive energy analysis procedures such as BLAST, DOE-2, and BUILDSIM are designed to handle very complex interactions of a building with its HVAC systems, controls, and equipment, there are several areas which thus far have defied incorporation into even the most sophisticated computer programs on energy analysis.

10.1 AIR INFILTRATION

In heating and cooling load calculations, the most important, yet uncertain, component of energy loss is air infiltration. Despite increased research activity in infiltration measurement of various buildings under different climatic conditions, air leakage determination is still very much guesswork based upon experience.

10.2 MULTI-DIMENSIONAL HEAT CONDUCTION

The heat conduction process through the building envelope has been treated as one-dimensional flow in most of the energy analysis procedures, ignoring the complex multi-dimensional heat flow process for building corners, slab-on-grade floors, and basement walls. These multi-dimensional effects could be handled by numerical calculation techniques such as finite-difference technique and finite-element methods, for any type of building geometry provided that thermal property values of the heat conduction media and the boundary temperature conditions are well defined, and provided that ample computer time and computer memories to perform such calculations are available.

10.3 CONVECTION OR AIR MOVEMENT SIMULATION

The building heat transfer process in a space is affected by the convective air motion inside the space, which controls the stratification of the room air temperature as well as the air leakage through the room envelope. Although it is possible to simulate the convective air flow pattern in the space by solving the basic fluid-dynamic differential equations by numerical integration, such calculation is impractical except for the simple air space geometry.

10.4 MULTI-ROOM PROBLEM

A challenging aspect of building heating/cooling load computation is the so-called multi-space or multi-room problem. When a large building consisting of many rooms is subjected to a situation in which the heating and cooling system for the different zones is partially or completely shut off, or undersized, or oversized, each of the spaces in the building is expected to assume a different temperature and humidity. This is contrary to most of the existing energy analysis procedures in which the temperature and humidity levels of all of the interior spaces are either identical or pre-determined at known levels. In the multi-room problem, detailed heat balance equations among the air, interior surfaces, and heating/cooling systems of all the rooms in the building have to be solved simultaneously. This requires an enormous computer and an excessive amount of computer time.

10.5 SYSTEM-LOAD-EQUIPMENT INTERFACING UNDER MISMATCH CONDITION

Most of the existing energy analysis procedures first determine the heating and cooling load of each of the spaces in the building. This is done separately for each of the building spaces under pre-determined temperature and humidity levels. The rate of conditioned air and/or water flow required to provide heating and cooling of each of the spaces will then be determined depending on the type of distribution system and the supply temperatures. The heating and cooling plant output requirements are then computed on the basis of total heating and cooling loads of all the spaces in the building and the ventilation air requirements; this phase of computation is the HVAC system simulation.

The heating/cooling requirement thus determined will then be compared against the heating/cooling capacities of boilers/chillers to calculate the energy or fuel consumption. This is done by the procedure called equipment simulation. Although the systems and equipment simulation procedures are relatively simple, it is virtually impossible to cover all the possible combinations.

In addition, when the capacity of the heating and cooling equipment or the capacity of the air/water supply system does not match the heating/cooling requirements of the spaces, the temperature and humidity levels of the room would deviate from the pre-determined values for which the original room heating/cooling loads were computed. When this happens, the entire energy simulation procedure previously described has to be repeated several times until the temperature and humidity levels in all the rooms in the building are stabilized. These iterative procedures have to be performed every hour for 365 days in order to account for hour-by-hour variations in climatic conditions and building use schedules that affect the dynamic performance of building energy consumption. This type of computation requires, once again, an extremely efficient and large-scale computer not available in the foreseeable future.

10.6 CONTROL SYSTEM SIMULATION

It has also been recognized that the dynamic performance of the heating/cooling system is strongly affected by the operating characteristics of control system components such as thermostat, humidistat, and pressurestat, whose time constant is much shorter than the hourly cycle. In order to account for the dynamic interactions between the control systems, building spaces, and building HVAC systems, it is necessary that simulation computation be carried out on a minute-by-minute basis rather than on the commonly practiced hour-by-hour basis. There is one computer program that performs the minute-by-minute energy calculations, but such computations are beyond routine energy analysis; under special circumstances this program may be used to determine detailed control characteristics critical for annual energy consumption analysis.

10.7 MOISTURE ABSORPTION AND DESORPTION

None of the present energy analysis procedures are able to account for the absorption and desorption of moisture by the building structure and by the interior furnishings. When the building is operated to take advantage of the cool night air, a large amount of moist air may be introduced into the building and will be absorbed by the interior building surfaces and by interior furnishings. This absorbed moisture is removed from the conditioned air space during the mechanical cooling period. In order to account for the energy requirements to accomplish this dehumidification process and to estimate the space relative humidity during the nighttime period, it is necessary to simulate the absorption and desorption processes of building components and interior furnishings.

10.8 DAYLIGHTING

It is believed that use of daylighting to supplement electrical lighting, by on/off switches and dimmers, is extremely effective for cutting down electric consumption for lighting and air-conditioning. This is especially true for office buildings in which artificial lights are used throughout the occupied hours at a time when daylight is plentiful. In order to account for the potential energy savings brought about by the use of daylighting, consideration must be given to: lighting levels for the task area, window designs, optical characteristics of interior surfaces, outdoor conditions, and the reduction of cooling requirement during the summer as well as the increase of heating requirement during the winter. Although a limited number of computer programs are available to predict the available daylight characteristics, such computations are usually extremely complex and computer time consuming.

10.9 RADIATION EXCHANGE AMONG INTERIOR SURFACES

Current procedures used for interior surface radiation heat exchange in some of the advanced load programs such as NBSWHF and BLAST are somewhat oversimplified. Other programs ignore the problem completely. Since infrared reflectivity is different from surface to surface, for example 0.1 for the opaque wall and 0.16 for window glass, it cannot be accurately handled in current surface heat balance calculations. Radiocity calculation techniques to handle the interreflective radiation heat exchange are needed, as are convective heat transfer coefficients that are a function of temperature difference between the surface and air.

11. SUMMARY AND RECOMMENDATIONS

The NBS/AIARC survey on existing energy analysis procedures revealed that most comprehensive energy calculations are being done on proprietary computer programs using hourly simulation techniques the closely follow the procedures recommended by the ASHRAE Task Group on Energy Requirements (Technical Committee TC 4.7: Energy Calculation). Although several manual or pocket calculator procedures are used, they are carried out by a limited number of experienced engineers and not widely publicized. The survey showed that two prominent public-domain energy analysis programs, DOE-2 and BLAST, have not yet gained wide acceptance. Most of the proprietary energy analysis programs claim to have addressed critical elements needed for the simulation of HVAC systems and equipment, in addition to providing comprehensive load analysis. Yet the extent to which these critical elements are handled is not disclosed by the survey. Judging from the conversations with the developers of the programs, their publications, and from the general background information on the state-of-the-art, it is believed that no existing program handles the systems-load linkage in a satisfactory manner.

Some proprietary programs, such as TRACE, ESP-1, and ESAS, are very popular among practicing engineers and appear to be supported by the developer of the program to accommodate a wide variety of system configurations. Intimate and expeditious program support capability seems to be an essential part of successful commercial energy analysis programs.

It is recommended that technical evaluation procedures be developed for the examination of algorithmic reliability and versatility of simulation algorithms for HVAC systems and equipment. At the same time, practicing design engineers of modern commercial buildings should be contacted to indicate types of systems most commonly used, and the kind of simulation technique that needs improvement or development. Users of the energy analysis program should also be contacted to identify the limitations of the currently available HVAC/equipment and systems simulation algorithms.

12. NEED FOR ENERGY CALCULATION STANDARDS

The several energy analysis procedures reported on in this survey tend to yield different results, even for the well defined simple building (such as used by the ASHRAE TC 4.7, shown in Appendix E) and are a major source of concern among those involved with building energy conservation standards activities.

Energy analysis procedures use building data differently, depending upon the specific algorithmic structure of the particular procedure. A listing of items that are handled differently would include the following:

air leakage;
wall construction....treatment of studs;
zone designation;
control strategy;
hour designation (beginning, mid-hour, end) for the occupancy and use schedule;
ceiling height;
partition walls;
interstitial spaces;
gabled roof, attic space;
crawl space;
ground temperature;
basement wall;
time or date when the heating and/or cooling plant becomes operational;
solar radiation;
internal heat gains;
surface convective coefficients.

The differences in the annual energy consumption calculations are due not only to the difference in the procedures and the input data requirements, but also to the qualification of the users. This results from difficulties in interpreting the actual building system data into input data for specific computer programs. Full understanding of HVAC system operation by the user is essential. No matter how sophisticated the calculation procedure, simulation techniques include numerous simplifying assumptions as to the room shape, wall construction, air distribution and system controls. Even the simplest data such as room floor area or room ceiling height require interpretation and affect the air results. Thus it is imperative that as a prerequisite to energy analysis standards, clear and concise guidelines must be developed to ensure consistent interpretation of drawings and other sources of basic building data.

Algorithmic standards for heat loss/gain may readily be developed and adopted. But this is only the beginning of the complex energy analysis calculations. Calculation standards for heating and cooling loads from the basic heat loss and heat gain are difficult, because the existing ASHRAE weighting factor method used by a majority of the popular programs is, in many cases, incompatible with the exact detailed heat balance calculation, which requires highly complex algorithms and larger computers and more computing time.

Standards acceptable to the majority of the existing energy analysis procedures may not be technically valid for the energy conservation design of certain buildings, especially the building with passive solar heating design. Although it appears relatively straightforward, standards for HVAC system and equipment simulation calculation are by no means less difficult than the load calculation. Again the rigorous calculation requires simultaneous solution of a set of system and equipment performance equations, which has been implemented in only a small number of energy analysis programs.

The consensus standards acceptable to the majority of popular commercial energy analysis programs must be based upon many simplifying assumptions that, when implemented, may yield technically incorrect results, especially when evaluating the control strategies.

Although difficult in the basic heat transfer and thermodynamic calculations, many commercial or proprietary energy analysis programs have included several unique features on certain HVAC system operations and equipment combinations, the advantages of which cannot be adequately evaluated by the standardized procedure.

These are some of the reasons that standardization of energy analysis procedures has not been well accepted by the developers of the popular energy analysis procedures as well as by practicing energy analysts and computer programmers. The standard energy analysis procedure should first be technically accurate for different types of buildings under different operating conditions, and their HVAC systems. It should also be easy and economical to use, and less susceptible to input preparation error. Such a procedure should be identified or developed, evaluated and demonstrated so that existing popular energy analysis programs could make use of it.

ENERGY ANALYSIS CALCULATION PROCEDURES

AIA Research Corporation

December 1978

AIA/RC is participating in a major research program to develop energy performance standards for new buildings, under contract to the Department of Housing and Urban Development and the Department of Energy. In the course of this work it has become apparent that there is a recognized need for the design community in general to have access to accurate, cost effective, and easy-to-use energy calculation procedures as building design tools.

The purpose of this questionnaire is to collect information about energy analysis calculation procedures availiable and used by practicing design professionals. If you use or have developed an energy analysis calculation procedure, please complete all of the questionnaire. If you use more than one procedure, please copy the questionnaire and complete as many as needed.

If convenient, we would also appreciate recieving you input forms, sample output, and any documentation or descriptions of the procedure. Because the focus is on the practical use of such tools during building design, the information will be reviewed by an advisory committee of practicing professionals.

PLEASE CHECK ✓ ALL APPLICABLE ANSWERS AND COMPLETE BLANKS WHERE REQUIRED

GENERAL INFORMATION

1. Person completing this form:

Name ____________

Firm ____________

Address ____________

City ____________ State ____ Zip ________

Phone ____________

2. Type of firm:

________ Arch. ________ Eng. ________ A/E

________ Other (specify) ____________

3. Number of people in firm: ________

4. Name of calculation procedure:

(If a proprietorship or public procedure is specified, please give the generic name, e.g. REAP, TRACE, etc. and give the date of the version or the version number if known (e.g. DOE-1 version 1.3).)

Name ____________ Date or version ________

(If an inhouse program, please indicate so)

5. Availability of the procedure:

Distributor ____________

Address ____________

City ____________ State ____ Zip ________

Phone ( ) ____________

Cost of materials $____________

6. Documentation of the procedure or program:

____ Published ____ Proposed Publication

____ Proprietary ____ Internal Use Only

____ Non-proprietary

____ Other (specify) ____________

7. Indicate the general nature of the procedure:

____ Degree Day

____ Bin Method

____ Dynamic Simulation over time

____ Other (specify) ____________

USE OF THE PROCEDURE

8. What do you use the procedure for: (check all applicable)

_____ Energy Audit

_____ Peak heat loss/heat gain for equipment sizing

_____ Thermal loads analysis over time

_____ Design aid

    _____ HVAC system optimization

    _____ Energy analysis during:

        _____ Conceptual design

        _____ Design development stage

        _____ Construction documents stage

    _____ Post-design performance check

    _____ Retrofit design

_____ Other (specify) _____________

9. How often do you use the procedure per year: _____

10. What type of personnel are required to perform the analysis:

_____ Experienced professional

_____ Technical

_____ Non-technical/clerical

_____ Other (specify) _____________

11. Validation information:

_____ Never validated with actual metered energy consumption

_____ Validated with actual metered energy consumption

    Percent deviation (1) _____

Note: (1) Average of differences in actual metered and calculated data.

12. Calculations are done by:

_____ Manual (Hand-held calculator)

_____ Computer

Computer Type _____________

13. For computerized procedures indicate which computer network(s) you use it on:

_____ Inhouse computer

_____ University Computing System

_____ CSC/Infonet

_____ CDC/Cybernet

_____ IBM

_____ GSA (RAMUS)

_____ Boeing

_____ MACAUTO

_____ Other (specify) _____________

14. Calculations are done for the following building types:

_____ Single family detached

_____ Single family attached

_____ Multifamily Low-rise

_____ Multifamily High-rise

_____ Offices

_____ Commercial Buildings

_____ Schools

_____ Hospitals

_____ Industrial buildings

_____ Others (specify) _____________

15. Please answer questions 16 and 17 for one of the following:

_____ Residential: A typical 2-story, 2000 square foot single family detached house.

_____ Non-Residential: A typical 4-story, 40,000 square foot office building.

16. Time required to prepare input data for calculation procedure:

_____ Half day

_____ Day

_____ Two days

_____ Three days

_____ Week

Other (specify) _____

17. Calculation time and cost for energy analysis:

_____ Computer (please give best estimate):

    _____ Preparation cost $ _____

    _____ Computer cost $ _____

    _____ CPU time (if known) _____ sec.

_____ Manual

    Number of person days _____

LOADS

The following questions address the loads portion of the calculation procedure. Note: For questions requiring time step, use the following code:

Code	Time Step
1	Minute-by-minute
2	Hourly
3	Daily
4	Monthly
5	Heating/Cooling Season
6	Yearly

18. Conduction heat transfer through the building envelope:

_____ Steady state calculation

_____ Dynamic calculation involving:

  _____ Heat storage

  _____ Time lag

  _____ Decrement

19. Conduction heat transfer calculation including non-linear (multi-dimensional) heat flow through:

_____ Wall studs _____ Basement floors

_____ Basement walls _____ Slab-on-grade

_____ Other (specify) ____________________

20. Infiltration:

_____ Not considered

_____ Air change method

_____ Crack method

_____ Wind effect if considered, indicate the basis of wind velocity:

  _____ Monthly average

  _____ Seasonal average

  _____ Yearly average

_____ Stack effect

_____ Other method (specify) ____________________

21. Solar effect on the building exterior surfaces:

_____ Sol-air temperature used

_____ Heat balance calculation used

_____ ASHRAE TLTD method

_____ Cloud cover effect considered

_____ Material absorptivity considered

_____ Material moisture content considered

_____ Sides fins shadow effect

_____ Overhang shadow effect

_____ Adjacent building shadow effect

22. Heat loss through the sky:

_____ Roof heat loss to the sky

_____ Cloud cover considered

_____ Dry roof only

_____ Wet roof included

_____ Wind speed consideration

23. Solar heat gain (Glazing):

_____ Summer only

_____ Winter heat gain considered

_____ Cloudless sky

_____ Cloud cover considered

_____ Exterior shading

  _____ Side fins

  _____ Overhangs

  _____ Adjacent buildings

_____ Interior shading device

  _____ Venetial blinds

  _____ Drapes

  _____ Other (specify) ____________________

_____ Varying shading coefficients

_____ Varying glazing systems

_____ Daylighting

_____ Skylight calculation

24. Interior environment:

_____ Constant temperature/humidity

_____ Variable temperature/humidity

_____ Temperature variation from room(zone) to room(zone)

_____ Radiation heat transfer between interior surfaces

_____ Two-position thermostat - deadband temperature between two setpoints when heating and/or cooling energy is zero

_____ Proportional thermostat control

_____ On-off thermostat control

_____ Comfort index

_____ Room to room air interchange

_____ Furniture heat storage

_____ Thermal mass heat storage

25. Internal heat gains considerations:

_____ Lighting _____ Equipment _____ Occupants

26. Lighting considerations:

Artificial lighting (check all applicable):

_____ Lighitng energy use is calculated for:

_____ Occupied period _____ Unoccupied

_____ Hourly profile of peak installed lighting used

_____ Percent of heat gain from lighting to return air considered

_____ Lighting profile can vary from zone to zone

_____ More than one lighting type per zone

_____ More than one profile for a zone

_____ Lighting types specified

_____ Any _____ Library of types

Daylighting

_____ Not considered

_____ Considered separate from artificial lighting

_____ Considered with artificial lighting

_____ Thermal impacts considered

_____ Artificial lighting reduced based on:

_____ Availiable daylighting

_____ Switching system (e.g. manual, photocell)

_____ Other (specify) ____________________

Time period used for daylighting:

_____ Hourly _____ Daily

_____ Monthly average _____ Yearly average

27. Attic or plenum heat transfer:

_____ Not considered

_____ Ventilated attic _____ Ventilated plenum

_____ Ventilation rate calculated

_____ Ventilation rate given or prescribed

_____ Non-ventilated attic or plenum

_____ Radiative heat exchange between attic ceiling and attic floor considered

28. Crawl space heat transfer:

_____ Not considered

_____ Ventilated crawl-space

_____ Ventilation rate calculated

_____ Ventilation given

_____ Non-ventilated crawl-space

29. Ground heat transfer:

_____ Not considered

_____ One _____ Two _____ Three Dimensional heat transfer

_____ Steady state calculation

_____ Transient calculation

_____ Basement walls

_____ Basement floor

_____ Slab-on-grade

Time step code

30. Load output:

Output for:

_____ Indiv. zones _____ Building _____ Both

_____ Peak Information	_____ Time Step Information
_____ Heat loss/gain	_____ Heat loss/gain
_____ Infiltration	_____ Infiltration
_____ Air Change (CFM)	_____ Ventilation (CFM)
_____ Heating/cooling load	_____ Heating/cooling load
_____ Comfort Index	_____ Comfort Index
_____ Interior Surface Temperature	_____ Interior Surface Temperature
_____ Interior Air Temp.	_____ Interior Air Temp.
_____ Humidity	_____ Humidity
_____ Mean Radiant Temp.	_____ Mean Radiant Temp.
_____ Heat transfer with adjacent rooms	_____ Heat transfer with adjacent rooms
_____ Heat flux of various surfaces	_____ Heat flux of various. surfaces
_____ Refrig. Load	_____ Refrig. Load Profile
_____ Other (specify) ____________________	_____ Other (specify) ____________________

31. Time step code used for loads analysis: _____

32. Passive design modeling:

_____ Passive Solar Heating

_____ Direct Gain (e.g. glazing)

_____ Indirect Gain (e.g. trombe wall)

_____ Sunspace (e.g. greenhouse)

_____ Passive cooling

_____ Natural ventilation

_____ Induced ventilation

_____ Internal Thermal Mass Storage (e.g. walls, rock beds, water)

_____ Other (specify) ____________________

Time step code used for calculations _____

The following questions address the energy or systems-plant (equipment) portion of the procedure. Note: For questions requiring time step, use the following code:

Code	Time Step
1	Minute-by-minute
2	Hourly
3	Daily
4	Monthly
5	Heating/Cooling Season
6	Yearly

33. How do you convert heat loss/heat gain to equipment loads:

_____ They are the same
_____ Not considered
_____ Other (specify) ____________________
_____ Carrier storage factor
_____ ASHRAE weighting factor

34. How do you convert equipment loads into energy consumption:

_____ Not considered
_____ Weighting factor
_____ Dynamic simulation or simultaneous solution
_____ Other (specify) ____________________

35. Check all of the following HVAC systems your procedure can simulate:

A. Residential   Time step code _____

Heating

_____ Central Forced Air
_____ Wall or Floor Furnace
_____ Hot Water or Steam
_____ Radiant Panels
_____ Other (specify) ____________________
_____ Heat Pump
_____ Baseboard Resistance
_____ Stove or Furnace
_____ Active Solar System

Cooling

_____ None
_____ Swamp/Evaporative Cooler on Roof
_____ Window/Wall Evap. Cooler
_____ Central Gas Refrig. Air Conditioning Unit
_____ Other(Specify) ____________________
_____ Window/Wall Refrig. Top Air Conditioning Unit
_____ Heat Pump
_____ Central Electric Refrig. Air Cond. Unit

B. Non-residential

Systems   Time step code _____

_____ Single duct
_____ Single duct w/reheat
_____ Constant volume dual duct
_____ Multi-zone
_____ Multi-zone with sub-zone heating
_____ VAV
_____ VAV w/reheat
_____ VAV w/dual conduit
_____ VAV double duct
_____ Whole house fan
_____ Unitary Heat Pump
    _____ Air source
    _____ Water source
_____ Radiant heating/cooling panels
_____ Other (specify)
_____ 2-pipe fan coil w/outside air
_____ 4-pipe fan coil w/outside air
_____ 2-pipe fan coil w/primary air
_____ 4-pipe fan coil w/primary air
_____ 2-pipe induction w/primary air
_____ 4-pipe induction w/primary air
_____ Economizer
    _____ Dry bulb
    _____ Enthalpy
_____ Permiter baseboard radiation
    _____ Hot water
    _____ Electric

Plant   Time step code _____

_____ Full load performance only
_____ Part load performance
_____ Room air conditioner
_____ Elect. centrifugal chiller
_____ Absorption chiller
_____ Reciprocating comp. chiller
_____ Engine-driven reciprocating chiller
_____ Boiler
    _____ Steam
    _____ Hot water
_____ Gas furnace
_____ Waste heat recovery system
_____ Heat pump
_____ Rankine cycle
_____ Evaporative cooling
_____ Other (specify)
_____ Double bundle condenser
_____ Aux. heating
_____ Cooling tower
_____ Dry cooler
_____ Evap. condenser
_____ Engine generators
_____ Fan performance
_____ Pump performance
_____ Electric motors
_____ Steam trubines
_____ Hot water heater
_____ Active solar systems
_____ Thermal storage
_____ Direct energy
    _____ District chilled water
    _____ District steam
    _____ Districe hot water

36. Does your procedure include heat exchanger simulation:

____ No ____ Yes If yes:

____ Cooling and dehumidifying coils

____ Heating coils (steam)

____ Heating coils (hot water)

____ Heat recovery wheels (or heat-pipe type, runaround coil)

____ Terminal devices

____ Shell and tube

____ Kathabor-type apparatus

____ Flat Plate

____ Others (specify) ____________

37. Does your procedure include temperature control simulation:

____ No ____ Yes If Yes:

____ Proportional control

____ Two position control - deadband

____ Proportional control w/deadband

Time step code used for calculations ____

38. Room (zone) temperature adjustment due to mismatch between the zone load and the HVAC system capacity:

____ Not considered ____ Variabel temp. routine

____ ASHRAE weighting factor

____ Other (specify) ____________

39. Which of the following fuels does your procedure consider:

____ Oil #2 ____ Oil #4,#6

____ Natural gas ____ Coal

____ Electric ____ District steam

____ District hot water ____ District chilled water

____ Wood

____ Solar

____ Bio-mass

____ Geothermal

____ Other (specify) ____________

40. Breakdown of energy consumption:

____ Daily total ____ Daily peak

____ Monthly total ____ Monthly peak

____ Annual total ____ Annual peak

____ Space heating ____ Space cooling

____ Dom. hot water ____ Lighting

____ Electric machinery or equip. ____ Non-electric machinery or equip.

____ Electricity and fuel separated

____ Monthly electricity bill

____ Monthly fuel bill

____ Monthly demand charge

____ Monthly solar fraction

____ Auxilliary energy requirement

41. Does your procedure include an economic analysis:

____ No ____ Yes If yes:

____ Cost benefit ____ Annual cost analysis

____ Present cost method ____ Owning-cost analysis

____ Life-cycle cost

____ Inflation rate ____ Pay-back period

____ Fuel escalation

____ Other (specify) ____________

COMMENTS

42. Describe how the calculation procedure or computer program is evaluated or reviewed for periodic updating highlighting the weakest part of the procedure and any plans you may have for improving the procedure.

43. If you use the procedure in any innovative way(s) or have developed innovative energy analysis procedures for specific design analysis please briefly describe those procedures here.

44. Please document all sources of climatic input data (e.g. temperature, humidity, solar, etc.) used in energy estimating methods.

45. Additional comments on areas you feel are not covered adequately by the quest–ionnaire.

APPENDIX B

List of Questionnaire Respondents

CALCULATION PROCEDURE	CONTACT
ASHRAE BIN, DD, TC4.7	ASHRAE, 345 East 47th St., NY, NY 10017.
AXCESS	Edison Electric Institute, 90 Park Ave., NY, NY 10016. Syska & Hennessy, 110 W. 50th St., NY, NY 10020.
BECON	Donald Pedreyra, 8531 Lehigh Ave., Denver, CO 80237
BLAST	NTIS, 5285 Port Royal Road, Springfield, VA 72150. U.S. Army CERL, P.O. Box 516, St. Louis, MO 63166.
BLESS	MCAUTO, Box 516, St. Louis, MO 63166.
BUILDSIM	Gideon Shavit, Honeywell, Inc., 1500 West Dundee Rd, Arlington Heights, IL 60004.
CALERDA	Control Data Corporation, P.O. Box 7090, Sunnyvale, CA 94086.
CALIFORNIA TITLE 24 COMPLIANCE	Donald T. Morton, P.O. Box 11129, Santa Rosa, CA 95406.
DIRECT GAIN	California State Polytechnic Univ., San Luis Obispo, CA 93407.
DOE-1	National Energy Software Center, Bldg. 221, Argonne, IL 60439.
DOE-2	National Energy Software Center, Bldg. 221, Argonne, IL 60439.
ECP	Cosmic, University of Georgia, Athens, GA 30602.
EP	Svendrup & Parrel, 311 Plus Park Blvd., Nashville, TN 37217.

ECUBE	American Gas Association, 1515 Wilson Blvd., Arlington, VA 22209. United Computing Systems, Inc., 2525 Washington, Kansas City, MO 64108.
ENCORE	National Res. Co., Div of Montreal Rd., Bldg. M24, Ottawa, Ontario, CAN K1A0K6.
ENERGY ANALYST	American Energy Service, 0425 S.W. Iowa, Portland, OR 97201.
ENERGY PROGRAM	Energy Management Service, 0425 S.W. Iowa, Portland, OR 97201.
EQUINOX	Keith Harrington, Arga Ass., 1056 Chapel St. New Haven, Conn. 06510
ESA	Ross F. Meriwether & Associates, 1600 N.E. Loop 410, San Antonio, TX 98209. SDL 106 St & Jasper 201, Edmonton, Alta, CAN, T8A3 SDL, 770 Brookfield Rd., Ottawa, Ontario, CAN, RUI655 SDL, 111 Avenue Rd., Toronto, Ontario, CAN, M4A1H8.
ESP-1	APEC, 44 Ludlow St., Dayton, OH 45402.
F-CHART	University of Wisconsin, Solar Energy Laboratory, 1500 Johnson Dr., Madison, WI 53706.
FREHEAT	Dept. of Mechanical Engineering, Colorado State Univ., Ft. Collins, CO 80523.
GAIN	Holguin & Associates, 2820 Stanton, El Paso, TX 79902.
H-33 & H-34	Sunshine Power Co., 1018 Lancer Dr., San Jose, CA 95129.
HEAP	National Bureau of Standards, Washington, D.C. 20234.
HEAT LOSS	Sunsearch Inc., 669 Boston Post Rd., New Haven, CT 06511.

HOME ENERGY ANALYSIS	New Mexico Energy Institute, 117 Richmond Drive, N.E., Albuquerque, NM 87106.
HVAC	Hewlett Packard, 1041 Kingsmill Parkway, Columbus, OH 43229.
MAD-II	Oak Ridge National Laboratory, Box Y, Bldg. 9102-I, Oak Ridge, TN 37830.
NECAP	Cosmic, University of Georgia, Athens, GA 30303.
NBSWHF	National Bureau of Standards, Washington, D.C. 20234.
OPT TWO	Johnson Controls, Inc., 507 E. Michigan St., Milwaukee, WI 53201.
PASOLE	LASL, Los Alamos, NM 87545 (505) 667-2629.
PASSIVE	Gerard & Associates, 1312 Post, Spokane, WA 99203.
PDP	Louis M. Weitzman, 20 St. Charles St., Boston, MA 02118.
PEGFLOAT	Princeton Energy Group, 729 Alexander Rd., Princeton, NJ 08450.
PROJECT CONSERVE 1	Applied Urbanetics, Inc., 1701 K St., N.W., Washington, D.C. 20006.
REAP	Richard Arnold, Carrier Corp., Syracuse, NY 13201
RSVP	NTIS, 5285 Port Royal Rd., Springfield, VA 22161.
SCOTCH	Robert S. McClintock, Box 430734, Miami, FL 33143.
SCOUT	Boeing Computer Services, P.O. Box 24346, Seattle, WA 98124.
SIMSHAC	Colorado State Univ., Dept. of Mechanical Engineering, Ft. Collins, CO 80523.
SINDA	Cosmic, University of Georgia, Athens, GA 30303.
SMEAP	State of California, ERCDC, 1111 Howe Ave., Sacramento, CA 95825.

SOLCOST	Solar Environmental Engineering, P.O. Box 1914, Ft. Collins, CO 80523.
TEANET	Total Environmental Action, Church Hill, Harrisville, NH 03450.
TEMPMASTER	Long Associates, 2080 W. Cornell, Englewood, CO 80110.
TLF	Teghi Alereza, Hittman Assoc., Suite 200 555 University Ave., Sacramento, CA 95825.
TRACE	MCAUTO, 370 Lexington Ave., NY, NY 10016. MCAUTO, Box 516, St. Louis, MO 63166. MCAUTO, 100 Pine St., San Francisco, CA 94101. MCAUTO, 3855 Lakewood Blvd., Long Beach, CA 94101. TRANE Co., 3600 Pammel Creek Rd., La Crosse, WI 54601. Local TRANE Co. Sales Representative. Boeing Computer Services, 505 2nd St., S.W., Calgary, Alta, Canada T2ROX.
TR8-35	NTIS, 5285 Port Royal Rd., Springfield, VA 22161.
T-33 & T-34	Sunshine Power Co., 1018 Lancer Drive, San Jose, CA 95129.
TRNSYS	University of Wisconsin, Solar Energy Laboratory, 1500 Johnson Drive, Madison, WI 53706.
TSD & GLASIM	G. K. Associates, 157 Stanton Ave., Auburndale, MA 02166.
TWO ZONE	National Energy Software Center, Bldg. 221, Argonne, IL 60439.
UDC	New Mexico Energy Institute, Univ. of New Mexico, Albuquerque, NM 87103.
UWENSOL	Dept. of Mechanical Engineering, Univ. of Washington, Seattle, WA 98125.

In addition to the above list of distributors for calculation procedures, 78 in-house energy analysis calculation procedures were received.

APPENDIX C

Summary of Various Procedures

Annual Energy Analysis

NAME OF PROCEDURE	NO. OF USERS
APEC (ESP-1, HCCIII)	35
ASHRAE (BIN METHOD)	2
ASHRAE (MANUAL DD)	7
AXCESS	8
BLAST	6
CALERDA	2
DOE-1	5
DOE-2	1
ECUBE	7
ECP	1
EP	2
ENCORE - CANADA	1
ENERGY ANALYST	1
ENERGY PROGRAM	4
ESA (R.F. MERIWETHER)	7
HOME ENERGY ANALYSIS	1
NECAP	1
OPT TWO	1
PROJECT CONSERVE 1	1
REAP	1
SCOUT	1
SINDA	1
SMEAP	1
TRACE	32
TWO ZONE	1
UWENSOL	1

Building Heating/Cooling Load

NAME OF PROCEDURE	NO. OF USERS
BLESS	1
GAIN	1
HEAT LOSS	1
HVAC	1
NBSLD	3
SCOTCH	1
TEMPMASTER	1

Active and/or Passive Solar

NAME OF PROCEDURE	NO. OF USERS
DIRECT GAIN	1
F-CHART	3
FREHEAT	1
H-33 & H-34	1
PASOLE	1

Active and/or Passive Solar

NAME OF PROCEDURE	NO. OF USERS
PASSIVE	1
PDP	1
PEGFLOAT	1
RSVP	1
SIMSHAC	1
SOLCOST	1
TEANET	14
TRNSYS	1
TR8 - 35	1
TSD & GLASIM	1
T-33 & T-34	

Other

NAME OF PROCEDURE	NO. OF USERS
CALIFORNIA TITLE 24 COMPLIANCE	2
UDC PROCEDURE (CH.53)	1

APPENDIX D

Program Capabilities

ANNUAL ENERGY ANALYSIS	PUBLISHED	PROPRIETARY	NON-PROPRIETARY	HAND-HELD CALCULATOR	COMPUTER	DEGREE-DAY	BIN METHOD	DYNAMIC SIMULATION	RESIDENTIAL	NON-RESIDENTIAL	ECONOMIC ANALYSIS
APEC (ESP-1, HCC III)	X	X			X			X	X	X	
ASHRAE (BIN METHOD)	X			X			X			X	
ASHRAE (MANUAL DD)	X			X		X			X	X	X
AXCESS	X	X			X		X	X	X	X	
BLAST	X		X		X			X	X	X	X
CALERDA	X		X		X			X	X	X	X
DOE - 1	X				X			X	X	X	X
DOE - 2	X		X		X			X	X	X	
ECUBE	X	X			X			X	X	X	X
ECP	X				X			X	X	X	X
ENCORE - CANADA	X		X		X			X	X		
ENERGY ANALYST	X	X			X	X			X	X	X
ENERGY PROGRAM	X	X			X			X		X	X
ESA (R.F. MERIWETHER)	X	X			X			X	X	X	X
HOME ENERGY ANALYSIS	X				X			X	X		X
NECAP	X				X			X	X	X	X
OPT TWO		X			X			X		X	X
PROJECT CONSERVE 1		X			X	X			X		X
REAP				X			X			X	X
SCOUT	X				X			X		X	X
SINDA	X				X			X	X	X	
SMEAP	X			X	X				X	X	
TRACE	X	X			X			X	X	X	X
TWO ZONE	X				X			X	X		X
UWENSOL	X				X			X	X	X	

BUILDING HEATING/COOLING LOAD	PUBLISHED	PROPRIETARY	NON-PROPRIETARY.	HAND-HELD CALCULATOR	COMPUTER	DEGREE-DAY	BIN METHOD	DYNAMIC SIMULATION	RESIDENTIAL	NON-RESIDENTIAL	ECONOMIC ANALYSIS
BLESS	X				X	X			X	X	
GAIN		X			X			X	X	X	
HEAT LOSS		X			X			X	X		X
HVAC	X				X	X			X	X	
NBSLD	X		X		X			X	X	X	X
SCOTCH	X	X		X	X	X			X	X	
TEMPMASTER	X				X				X	X	
ACTIVE AND/OR PASSIVE SOLAR											
DIRECT GAIN	X			X				X	X		
F - CHART	X				X	X			X	X	X
FREHEAT	X				X			X	X	X	
H33 & H34			X		X	X			X	X	X
PASOLE	X				X			X	X		
PASSIVE	X				X	X			X	X	X
PDP	X			X			X		X	X	
PEGFLOAT	X			X				X	X	X	
RSVP	X		X		X	X			X		X
SIMSHAC	X		X		X				X	X	X
SOLCOST	X				X			X	X	X	X
TEANET		X		X				X	X	X	
TRNSYS	X				X	X		X	X	X	X

ACTIVE AND/OR PASSIVE SOLAR	PUBLISHED	PROPRIETARY	NON-PROPRIETARY	HAND-HELD CALCULATOR	COMPUTER	DEGREE-DAY	BIN METHOD	DYNAMIC SIMULATION	RESIDENTIAL	NON-RESIDENTIAL	ECONOMIC ANALYSIS
TR8 - 35	X			X		X		X	X	X	
TSD & GLASIM		X			X			X	X	X	
T-33 & T-34			X		X				X	X	X
OTHER											
CALIFORNIA TITLE 24 COMPL	X			X	X	X			X	X	X
UDC PROCEDURE	X			X		X			X	X	

Information on this matrix is based on replies to the survey questionnaire by users of the particular procedure. Where questions arose as to what a particular procedure could do, the questionnaire replies by those with known expertise about the particular procedure were consulted. This information has not been validated and may only be assumed to be correct.

Appendix E

Comparative Analysis of Computer Simulated Energy Calculation and the TC 4.7 Procedure

Attached in this section are tabular results of parallel calculations between the ASHRAE TC 4.7 manual energy calculation procedure and seven comprehensive computer simulation procedures. Parallel calculations were performed by the developer (or his representative) of each of the seven computer-based energy analysis programs. The same building and HVAC system data as well as the same weather data, supplied by the National Bureau of Standards, were used in all of the seven parallel calculations.

TABLE E-1 SEVEN PARALLEL CALCULATIONS FOR THE ASHRAE TC 4.7 MANUAL PROCEDURE AND COMPUTER SIMULATION PROCEDURES FOR DUAL-DUCT SYSTEM

	Light Equip $kW/yr/ft^2$	Fan $kW/yr/ft^2$	Cooling Plant $kW/yr/ft^2$	Heating Gas $cf/yr/ft^2$
TC 4.7	11.6	3.05	6.68	43.1
E-CUBE	11.6	2.82	5.69	43.8
TC 4.7	11.8	15.1	5.1	22.9
ESAS	11.8	9.8	5.2	22.9
TC 4.7	12.6	8.7	3.3	76.77
BLDSIM	12.6	7.2	4.4	44.25
TC 4.7	11.7	13.7	9.2	62.95
BLAST	11.2	13.9	7.9	53.87
TC 4.7			23.3*	78.76
DOE-2			23.1	82.49
TC 4.7			21.4*	67.0
AXCESS			21.1	90.0
TC 4.7	11.25	8.0	2.62	9.29
TRACE	11.25	11.09	4.14	29.04

* Sum of all the electrical consumption

TABLE E-4 SEVEN PARALLEL CALCULATIONS FOR ASHRAE TC 4.7 MANUAL PROCEDURES AND COMPUTER SIMULATION PROCEDURES FOR VAV AND 4-PIPE FAN COIL HEAT RECLAIM SYSTEMS

	Light Equip $kW/yr/ft^2$	Fan $kW/yr/ft^2$	Cooling Plant $kW/yr/ft^2$	Heating Gas $cf/yr/ft^2$
TC 4.7	11.6	3.0	6.7	21.1
E-CUBE	11.6	2.8	5.7	21.5
TC 4.7	11.8	11.5	9.3	170.2
ESA	11.8	9.2	8.1	140.8
TC 4.7	12.6	1.4	4.3	27.68
BLDSIM	12.6	2.4	2.9	11.22
TC 4.7	11.7	2.4	4.51	12.40
BLAST	11.2	2.6	4.43	10.85
TC 4.7			17.3*	5.1
DOE-2			16.0	9.9
TC 4.7			23.*	4.16
AXCESS			25.1	0
TC 4.7	11.25	4.0	4.45	13.82
TRACE	11.25	2.9	2.65	19.60

* Sum of all the electrical consumption

Appendix F

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
Greg F. Samds	Ferendino/Grafton/Spillis/ Candela 800 Douglas Rd. Coral Gables, FL 33134 305-444-4691	In House- Manual Calculations for Retrofit Systems 1978	+10
Don Deyoe	Southern California Gas Company 810 So. Flower St. Los Angeles, CA 90017 213-689-3056	ECUBE III 1/15/79 (In-House Program)	5
Huber H. Buehrer	Buehrer & Stough 4246 Sylvania Ave. Toledo, Ohio 43623 419-473-2741	In-House 1976	±10
Stephen D. Heath	Mitchell Webb Associates, Inc. 1927 Fifth Ave. Suite 100 San Diego, CA 92101 505-238-1522	ASHRAE 177	Varies but 2% typical
Frank H. Bridgers	Bridgers & Paxton Consulting Engineers 713 Truman Ct., N.E. Albuqueruqe, NM 87108 505-285-8577	In-House Bridgers & Paxton Energy Analysis 1978	±10 5% thermal
Gregory N. Cunniff	Drapes Engineering 202 Eklund Bldg. Great Falls, MT 59401 406-452-9558	In-House	10-50
John P. Lamb	IBM Real Estate Div. 1000 Westchester Ave. White Plains, NY 10604 914-696-6018	In-House- Uses modified version of NBSLD for loads	5-10
Don M. Sutton	Oklahoma Gas Co. Post Office Box 871 Tulsa, OK 74102 583-6161 x918	ECUBE "7.5" (In-house)	+5 +5

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of program	Claimed Validation % error
R. G. Werden, P.E.	Werden Associates P.O. Box 414 Jenkintown, PA 19046 215-885-2500	In-House	2
Bruce Birdsall	The Ohio State Univ. 2003 Millikin Rd. Columbus, OH 43210 614-422-5558	Procedures to Address Retrofit Options for HVAC System 8/77	+10
L. A. Abbatiello	Oak Ridge National Laboratory Box Y, Bldg. 9102-1 Oak Ridge, TN 37830	MAD II 3/79 (In-House Program)	±5-15%
Donald C. Pedreyra	Donald Pedreyra, P.E. Consulting Engineer 8536 E. Lehigh Ave. Denver, CO 80237 330-773-1599	BEACON Dec. 1978	5
Philip L. Frank	Westinghouse Electric Corp. 2040 Ardmore Blvd. Pittsburgh, PA 15221 412-256-3168	Load & Energy Study present version	1-2
John S. Nelson	Affiliated Engrs., Inc. (Affiliated Flud & Assoc.) 625 N. Segoe Road Suite C Madison, Wisconsin 53705 600-238-2616	TRNSYS 9.2 Has Many Substantial In-House Enhancements TRACE 300	±20 ±20-100

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
Gene A. Donaldson	(916) Union Electric Co. P.O. Box 149 St. Louis, MO 63166 314-621-3222 (Sta. 2048)	AXCESS V6 ESP-1 V1-L3 Also 001 RESML Long Form CBDP Ventilation Boiler	±10-±2 ±10-±2 Long Form Heating Pump ±10-±2
Michael Mark	American Energy Service 727 Massachusetts Ave. Cambridge, MA 02139 617-547-1845	Energy Analyst	20
Ronald N. Jensen	NASA Langley Research Ct. Hampton, VA 23665 804-627-4641	 NECHP Oct. 1976	1-10
Donald L. Fenton	New Mexico Solar Energy Institute Box 3-Sol, NMSU Las Cruces, NM 88003	No name: passive solar energy program utilizing hand calculations.	~ 10 (one house)
Allan J. Thomson	Yoneda Assoc. Ltd. 1905 7th Avenue Regina, Saskatchewan Canada, S4R1C1 1-306-525-5267	 Meriwether ESA P.W.C. Version	< 5
J.M. Galbreath	Sverdrup & Parcel 311 Plus Park Blvd. Nashville, TN 37217 615-244-7584	 EP	5-10
Robert D. Busch	Bickle/CM 2403 San Mateo, N.E. Suite S-8 Albuquerque, NM 87110 505-265-3751	 Home Energy Analysis	15

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
James J. Hirsch	Lawrence Berkeley Laboratory Univ. of California Berkeley, CA 94720 415-486-5711	DoE-2 2.0 2/1/79	Under Study
Michael L. Gaudy	GARD, Inc. 7449 N. Natchez Niles, Ill 60648	Scout 3	2-5
Douglas A. Laubach	Galson Consulting Engineers 6601 Kirkville Rd. E. Syracuse, NY 13057 315-437-7181		20
H. M. Lau	Park & Djwa Eng. Co. 1107 Seymour St. Vancouver BC Canada V6B3177 604-682-6796	R. Meriwether, ESA CDN	10-15
Albert W. Black	MEDSI (Mechanical Engineering Data Service, Inc.) 2016 Big Bend St. Louis, MO 63117 314-645-6232	In-House MEDSI	
William L. Glennie	Princeton Energy Group 729 Alexander Road Princeton, NJ 08540 609-452-8235	PEGFLOAT Sept. 1978	5
J.L. Hughart	Okla. Nat. Gas Co. P.O. Box 871 Tulsa, OK 74102 918-583-6161	E-CUBE III Refers to Don Sutton's	±5
Patrick J. Hughes	Science Applications Inc. 8400 Westpark Dr. McLean, VA 22102 703-827-4917	TRNSYS	9.2 but with personal improvement

Name of Respondee	Address	Name Program	Claimed Validation % error
Bob Wesen	Sullivan & Nessen 725 W. McDowell Rd. Phoenix, AZ 85007 602-257-8525	ANNALS In-House	5
Richard Shipman, P.E.	Data Systems, Inc. 290 Winchester St. Newton, MA 02161 617-744-3454	AXCESS 6 Have used E^3, TRACE ESP-I, EP, etc.	< 10
Robert E. Hamilton	Robert Hamilton & Co. 1441 Kapiolani Blvd. Honolulu, Hawaii 96814 808-946-3650	ESP-1, 1, 2 09-29-78	5-10
E. I. Mackie, P.Eng.	Reid Crowther & Partners 1033 Davie St. Vancouver BC V6E-1M7 604-688-2451	EE SERIES	5-8
R. G. Alvine	Raymond G. Alvine & Assoc., Inc. 360 Aquila Court Omaha, NE 68102 402-346-7006	APEC ESP-1 1978	
E. B. Miller	Miller & Weaver 2720 3rd Ave. S. Birmingham, AL 35233 205-252-0246	In-House	10
Dr. Gideon Shavit	Honeywell 1500 W. Dundee Rd. Arlington Heights, IL 60004 312-294-4000 x 629	In-House BLDSIM 9-78	Function of Building Systems & Control 2.3%
Paul L. Goodman	Vansant & Gusler Suit 400 6330 Newton Rd. Norfolk, VA 23502 804-461-6757	TRACE 301	10
Carl W. Glaser	Engineered Energy Management, Inc. J.R. Tennill & Assoc. 1023 Executive Parkway Dr. St. Louis, MO 63141 314-576-1030	APEC ESP-2 (Version) VIL 2	±5

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Program	Claimed Validation % error
John F. Germ	Geo. S. Campbell & Assoc., Inc. Chattanooga, TN 37403 615-267-9718	TRACE	
Arthur Abbood	Shooshanian Engineering Assoc. 129 Malden St. Boston, Mass. 02118 617-426-0110	TRACE E.P.	10± 5-10
Roger Wadsworth	Personius-Wadsworth P.O. Box 166 Horseheads, NY 14845 607-739-3847	ESP-1 1978	(by others) 5
C. J. Allen R. J. Mauck	Albert Kahn Associates, Inc. 700 New Center Building Detroit, Michigan 48202 313-871-8500	MA33 In-House, uses APEC HCC 111 for the LOADS portion of its input	±5
James H. Stewart	Paul Sprehe and Assoc. 5926 N. Main Suite 511 Oklahoma City, OK 73112 405-840-1901	TRACE 301	-10
Thomas C. Chen,	Daverman Assoc., Inc. 200 Monroe Ave., N.W. Grand Rapids, MI 49506 616-456-3500	BLESS	Load at design conditions +7
S. A. Klein J. W. Mitchell	Univ. of Wisconsin Solar Energy Lab. Madison, WI 53706 608-263-5626	TRNSYS 9.1	

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
Edward Brady	Pacific Gas and Electric Company 77 Beale Street San Francisco, CA 94106 781-4211	1.3	State Certified Program
Larry Palmiter	Nat. Ctr. for App. Tech Box 3838 Butte, MT 59701 406-723-5477	SUNCAT In-House	RMS-2°F measured test cell temps.
Douglas C. Hittle	U.S. Army Construction Engineering Research Laboratory, (CERL) P.O. Box 4005 Champaign, IL 61820 217-352-6511	BLAST 2.0	∽ 5%
Bob England	Yoneda & Associates 1305 7th Ave. Regina, Saskatchewan S4R 1C1 306-525-5267	R. F. Meriwether ESA DPW CANADA	6% Monthly
Alfred Greenberg	Alfred Greenberg Assoc. RD Box 235 Port Jervis, NY 12771 212-832-3100	MANUAL	±20
Alfred Greenberg	Geo-Energy Ltd. Suite 2555 299 Park Ave. New York, NY 10017 212-673-1829	ACCESS/ Version VI	±10
Laheri Mehta	S&H Information Systems, Inc. 110 W. 50th St. New York, NY 10020 212-489-9212	SHIS-MODIFIED AXCESS 1979	5-15
Robert Hadden	Ross F. Meriwether & Assoc. 1600 NE Loop 410 San Antonio, TX 78209 512-824-5302	ESA Series	3-9

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
G. K. Yuill	UNIES Ltd. 1666 Dublin Ave. Winnipeg, Canada R3HOH1 204-633-6363	BLAST 1.2	10
Kasim Sihnamohideen	Johnson Controls, Inc. 507 E. Mich. St. Milwaukee, WI 53201 414-276-9200	OPT TWO 1978	5-10
Philip W. B. Niles	Calif. State Polytechnic Univ. San Luis Obispo, CA 93407 805-546-2613	"Direct Gain Admittance Model" Validated against data on 100% solar heat test module (i.e. floating temp.)	
George W. Kimball	GK Associates 157 Stanton Ave. Auburndale, MA 02166 617-965-3291	TSD & GLASIM	±3°
Edwin S. Douglas	Edison Elec. Inst. 90 Park Ave. New York, NY 10016 212-573-8773	AXCESS VI	"Close"
Philip S. Alongi	Walter R. Ratai, Inc. 6659 N. Sidney Pl. Milwaukee, WI 53209 414-352-7850	TRACE 400	±10
C. B. Winn	CSU Ft. Collins Co. Ft. Collins, CO 80523 303-491-5166	SIMSHAC 1974	±10
C. B. Winn	SEEC 2524 E. Vine Dr. Ft. Collins, CO 80523 303-221-5166	SEEC I 1978	±10 Based on FCHART

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
Bruce T. Maeda	Davis Alternative Technology Assoc. P.O. Box 503 Davis, CA 95616 916-756-9300	TPSIM currently In- House	w/temp. monitoring over short time periods
Dwayne Murphy	The Trane Co. 3600 Pammel Creek Rd. (17-2) LaCrosse, WI 54601 608-787-3858	TRACE VERSION 400	
Robert Romancheck	PA Power & Light Co. 2 N. 9th St. Allentown, PA 18101 215-821-4462	In-House	±10-15
Ralph M. Lebens	Arcaed 8 Paddington St. London W1, U.K. 01-487-2641	PDP (+ heating load & cost benefit) Aug. 77	2°F difference in max. room air temp.
Paul Sullivan	Total Environmental Action Inc. Church Hill Harrisville, NH 03450 603-827-3374	TEANET	<1° test cell date
Louis A. Trama	Hovem-Basso Assoc. 25 W. Long Lake Rd. Bimeld Hills, MI 48013 313-645-0400	ECUBE 75	
G. M. Kaler, Jr.	Lennox Industries Inc. P.O. Box 400450 Dallas, TX 75240 214-783-5405	CALERDA 1.4L	7.5
Dr. Firky L. Lansing	Jet Propulsion Lab. 4800 Oak Grove Dr. Pasadena, CA 91103 Mail 79-5 213-354-2936	ECP Sept. 78	±10 max on-going activity

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Valiation % error
E. F. Sowell	Cal. State Fullerton Div. of Engr., E 100 Fullerton, CA 92634 714-773-2261	BLAST 1.2	
Richard E. Lampe	WTA/CSI 2357 59th Street St. Louis, MO 63110	HACE	5
Irwin Herbst	Meyer Strong & Jones 230 Park Ave. New York, NY 10017 212-867-2010	In-House	estimate was slightly high
Rodney L. Oonk	Solaron Corp. 720 S. Colorado Blvd. Denver, CO 80222 303-759-0101	FChart	(whenever possible)
Glyn Beesley	Herman Blum C.E., Inc. 1015 Elm Dallas, TX 75202 214-741-7701	TRACE	
Roger T. Liellis	Martin Marietta P.O. Box 179 Denver, CO 80209 303-973-3853 FTS-329-3853	MITAS FTN	< 1
Edward C. Brohl	Ames Laboratory Iowa State University Ames, Iowa 50011 515-294-6844	FCHART 3.0	5-10
R.D. Ulrich	Brigham Young Univ. 242 JB Provo, Utah 84602 801-374-1211 x2625	In-House	±20
John Morgan	AECON, Inc. 217 Suffield Village Suffield, CT 06078 203-668-0288	In-House	Varies
Charles S. Barnaby	Berkeley Solar Group 3026 Shattuck Ave. Berkeley, CA 94705 415-843-7600	NBSGLD In-House enhanced NBSLD	NBSLD

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
George Lauger	George Lauger C.E. 114 East 32nd St. New York, NY 10016 212-689-9393	ASHRAE	3-5
Zulfikar Cumali	CCB/Cumali Assoc. 2930 Lakeshore Ave. Oakland, CA 94610 415-465-0511	CCB/CALERDA	3-8
Peter Willings	H. H. Angus & Assoc. Ltd. 1127 Lescue St. Don Mills Ontario Canada 449-5056 (416)	ESA Canadian	Term requires more precise definition
The Haskell Co.	Gary L. Wingfield 720 Gilmore St. Jax, FL 32204 904-358-1601	ESP-1 12/78	10
Mark D. Levine Dave Goldstein	Lawrence Berkeley Lab. Berkeley, CA 94720 415-486-5328	TWOZONE	Compared with average data ±20% or better
Edgar C. Jones	Ferebee, Walters & Assoc. 5672 International Drive Charlotte, NC 28211 704-364-8220	ECAL In-House	2%±
David O. Northrup	Univ. of Texas, School of Architecture Austin, TX 70712 512-471-4911	DEROB 1979	5-10
Jack A. Foster	Gorman Design Inc. 2176 Whitehaven Rd. New York, NY		±8
Frank S. Wang	The Dow Chemical Co. Larkin Lab. Midland, MI 48640 517-636-4478	Version 1 Sept. 1977 01 In-House FINITE ELEMENT THERMAL ANALYSIS 1978	Analytic solution, field test 10-15%
George Bush	Lawrence Livermore Lab. Box 808, L-46 Livermore, CA 94550 415-422-1463	TRNSYS	

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
Ed Hoover	Energy Systems Center Desert Research Inst. 1500 Buchanan Blvd. Boulder City, NV 89005 702-293-4217	TRNSYS 9-1	In some cases
Joseph Reitblatt	Singer 502 Sunnyvale Wilmington, NC 28401 919-791-8510	Engr. 63 Engr. 64 1-1-79	23 In-House
Stuart Fauna	Inst. Energy Conversion Univ. of Delaware Wilmington, DE 19808 302-955-7155	TRNSYS	
Margaret Stallings	Institute of Energy Conversion University of Delaware One Pike Creek Center Wilmington, DE 19808	Project Conserve I Sept. 1977	±10
Chaney	Texas Electric Service Co. Box 97A Ft. Worth, TX 817-856-1411	AXCESS VI 10/1/78	EEI has validation data
Leonard J. Hayward	Acco Air Conditioning 6265 San Fernando Rd. Glendale, CA 91201 1-213-244-6571	TRACE 1978	20
Robert M. Helm	Energy Management Service 0435 S.W. Iowa Portland, OR 97201 503-244-3613	EP Jan. 79	±10 on from pt. of matching existing bldg. consumption
Eugene A. Carter	Univ. of Alabama Huntsville P.O. Box 1247 Huntsville, AL 35805 205-895-6331	Liv & Jordon Temps & Coulson Becker & Boyd	Jan. 79
Mitchell A. Woodward	Bernard Johnson Inc. 5050 Westheimer Houston, TX 77056 713-622-1400	TRACE 300-400	10

Energy Analysis Calculation Procedure Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
Virgil E. Carrier	Energy Management Consultants 7456 West 5th Ave. Denver, CO 80226 303-232-0522	ESP-1 also several others	±5
William E. Schultz	Wyle Laboratories 7800 Governors Dr. Huntsville, AL 35807 205-453-3240	SINDA See note on questionnaire	0
Charles H. Patterson	Tenn. Valley Authority DB-PSC-5C Chattanooga, TN 37401 615-755-3841		1
T. Kusuda	National Bureau of Standards Rm. 104 B Bldg. 226 Washington, D.C. 20234 301-921-3501	NBSLD NBSWHF	±10
Umesh K. Bhargava	Mueller Assoc., Inc. 1900 Sulphur Spring Rd. Baltimore, MD 21227 301-247-566	ECUBE 75	10-20
R.D. McFarland	LASL MS/571 Los Alamos, NM 87545 505-667-2620	PASOLE 1978	room temperature calculation validated
Robert B. Kinney	Univ. of Arizona Aerospace and Mech. Engineering Tucson, AZ 85721 602-795-8388	In-House	13 (Partially completed)
Flemming H. Nielsen	D.W. Thomson Consultants 1690 W. Broadway Vancouver, BC V7C1T7 Canada 604-731-4921	TRACE 300	

Energy Analysis Calculation Procedures Validation

Name of Respondee	Address	Name of Program	Claimed Validation % error
W. Spiegel	Walter F. Spiegel, Inc. Consulting Engineers 321 York Road Jenkintown, PA 19046	THERML 1. THERML-LOAD CALL 2. MERIWETHER-ENERGY 3. TRACE-ENERGY	3-20
	Energy only	TRACE	
Richard J. Slichta	Xerox Corp. - W304 Xerox Square Rochester, NY 14644 716-422-3684	HCC-111 LEVEL 03	5

NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 80-2068	2. Gov't. Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE	5. Publication Date
REVIEW OF CURRENT CALCULATION PROCEDURES FOR BUILDING ENERGY ANALYSIS	July 1980
	6. Performing Organization Code 742.01
7. AUTHOR(S) Tamami Kusuda	8. Performing Organ. Report No. NBSIR 80-2068
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, DC 20234	10. Project/Task/Work Unit No. 742 9504 11. Contract/Grant No.
12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP) Office of Building and Community Systems Department of Energy Washington, DC 20585	13. Type of Report & Period Covered 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

Existing calculation procedures for building energy analysis, both computer-based and manual, were surveyed by questionnaires to determine the extent to which they were used and their technical content. It was found that most of the Nation's building energy consumption analyses are done by computerized simulation of HVAC system and equipment performance. This report provides brief descriptions of some energy analysis procedures which merit further study. It also identifies items not covered in the existing procedures which need to be developed for the improvement of energy calculation technology.

17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)

Calculation procedures; computer simulation; energy analysis; energy conservation

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