SUMMARY OF RECENT ACTIVITIES ON BUILDING ENERGY SIMULATION ANALYSIS IN NORTH AMERICA

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Abstract - Thermal modeling of building energy performance has played a key role in the development of energy conservation strategies and standards in North America. Background for the development of various building energy simulation computer programs is given in this paper together with current and projected activities in both public and private sectors. The approaches taken by different developers of energy analysis computer programs, such as those of the finite difference network procedures, time and frequency domain thermal response or conduction transfer procedures, and simplified calculation methods are discussed. Needs for a comprehensive and small time scale calculation procedure to study interactions among various components of building, such as envelope heat transfer, thermostat performance, control of air distribution systems and heating and cooling plants are emphasized. Emergence and popular acceptance of microcomputers are likely to have significant impacts on the next generation of building thermal simulation programs. A list of currently avaiable microcomputer based building energy analysis computer

Key Words: building energy consumption, computer simulation, heating and cooling loads, microcomputers, simplified calculations

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Introduction

Thermal modeling has been a central, significant and exciting aspects of building energy conservation activities for the past decade. It has definitely played a key role in the development of various energy conservation standards and guidelines in North America. In fact, energy budget and energy target concepts were unthinkable without advanced energy simulation programs such as, to name a few, NBSLD, DOE2.1, BLAST, TRNSYS, ESP, TRACE, AXCESS, DEROB, PASOLE, SOLPAS, SUNCAT, etc.*/ Those who are interested in a detailed summary of these programs and others developed before 1978 should read a report prepared by S. Feldman and R. Merrium of the Arthur D. Little Co. <1>. This dazzling array of dynamic computer programs to perform detailed and hourly simulation of envelope heat transfer, solar heat gain, system and equipment peformance of heating, ventilating and air-conditioning systems dominated the energy conservation scene of 1970's. It attracted many talented and ambitious analytical minds, and above all, the young and enthusiastic computer happy engineers and architects.

We have come a long way since the early 70's when building science was the domain of relatively conservative engineers and architects. Currently, a surprising number of building scientists are ex-physicists. They were attracted to building thermal analysis not only because that was where the funding and research opportunities were, but because building thermal problems are multibody problems and the computer simulation of intricate interactions among climate, structure, equipment and man can be challenging and exciting as the multi-body problems for atomic physics. It is a multi-parameter science of infinite variations. For some of them it is more challenging and rewarding to solve building problems than to work on astrophysics or the advanced particle physics.

It should be remembered also that the spectacular advances in the building thermal simulation coincided with the revolutionary development of main frame computers for number crunching. The widespread use of programs such as DOE2.1 and BLAST3, solving hourly equations for a large building of many zones and a complex HVAC system, would have been unthinkable without efficient and large memory number crunching machines such as CDC 6400, IBM360, UNIVAC 1108, CYBER and/or CRAY. The next generation of super computers is now making it possible to talk about minute by minute or even second by second calculations for the detailed simulation of mechanical components, such as heat exchangers and control devices as parts of the annual energy calculations. One can not help wondering where all of this is leading to. How far do we go? When do we call it quits and say "enough is enough"?

An ideal simulation program should be able to solve the multitude of simultaneous differential and algebraic (many are non-linear) equations that describe the interrelationships among all the major variables in the building in a small enough time step to simulate the actual dynamics of its thermal performance. One may liken the situation to flight simulators or nuclear reactor simulators,

*/ (Although several commercial names of these computer programs are mentioned in the paper, this does not imply that these programs are either approved or endorsed by the National Bureau of Standards).

which are used extensively for the training of the pilots or the reactor operators in real life. Even better still will be programs that are faster than the real life situation so that the entire annual operation of a multi-room building can be simulated within a few minutes even on a second by second basis. In this way, one can anticipate high peak heating/cooling demands, machine running [illegible] and environmental control operations ahead of real occurrences. It is extremely important to stress here at the outset that the ideal simulation should attempt to solve all the equations for envelope heat and mass transfer, internal surface heat balance, air handling system and heating and cooling plants and their control parameters simultaneously.

I would now like to assess North American modeling activities in the light of this ideal situation to see how far we have come and how much more we have to travel in the next decade.

Traditionally there have been three different ways that building thermal simulations are handled; the finite difference/net work approach (FD/NW), thermal response weighting factor factor approach (RF/WF) (i.e. the Laplace transform method), and the frequency domain or the Fourier transform approach (FT).

It is a well known fact that the North American scene in the late 60's and early 70's was dominated by the discovery and prolific publications on thermal response factors by Stephenson and Mitalas <2,3> of the National Research Council of Canada. It was hailed as a cornerstone of building thermal analysis making it possible to numerically invert the difficult Laplace Transform functions for the [illegible]-layer heat conduction problems, the solution of which theretofore had been found only in the advanced heat conduction text books and only in abstract forms. Thermal response factors are the results of an exact solution of the heat conduction equations, unlike the approximate solutions, such as the finite difference or the finite element approaches. Unlike finite difference calculations, once computed for given sets of multilayer structures, they can be used over and over again to evaluate heat flux and surface temperature by simple algebraic equations applied to the past time history of boundary condition with the same accuracy as the exact solution. They do not have the problems associated with the stability criteria inherent in many of the finite difference approaches that result from the inappropriate selection of increments for the time and space coordinates, which are for structures comprising massive, yet highly conductive layers mixed with thick thermal insulation layers. All one has to have available is sets of thermal response factors for typical envelope configurations, which can readily be generated by the computer program developed by such organizations as the National Bureau of Standards or by the National Research Council of Canada. The response factor technique also made it possible to use smaller memory and slower computer for multi-layer structure heat transfer calculations than that required for the same levels of accuracy using the FD/NW approach. It was a boon to the computerized energy analysis.

ASHRAE Task Group on Energy Requirements adopted the thermal response factor approach for the envelope heat conduction calculation in the early 70's. In addition, and more significantly in retrospect, they extended the basic concept of the thermal response factor approach to the room temperature and cooling load requirement analysis by introducing additional transfer functions called the weighting factors, that are essentially room thermal response factors.

The term "cooling load" here is frequently used to signify the fact that the analysis is introduced in the cooling mode and to stress that it is not necessarily the same as the heat gain. Equally, one can say that heat loss is not the same as heating load, although these terms are often used interchangeably, thus creating confusions. The heating and cooling loads in the ASHRAE Task Group terminology are the thermal loads imposed upon the heating and cooling coils in the air handling unit. Since the heating and cooling coils exchange heat between the heating and cooling medium such as hot and chilled water and the air in the air-handling unit, the temperature and humidity of the air entering the coils determines the heating and cooling loads together with the air volume flow rate across the coils. Since the inlet air temperature and humidity condition are determined by those of the return or recirculated air and by the outdoor air brought in for the ventilation purpose, it becomes evident that the calculation of the heating and cooling loads is in essence synonymous with the room air temperature calculation. The room air temperature calculation in turn requires a detailed heat transfer calculation among the room air, various room surfaces and outdoor air brought in via infiltration.

The accurate room air temperature calculation requires the precise assessment of the room surface temperatures, which are influenced significantly by the solar incident radiation through the windows as well as by the mutual infra-red radiative heat exchange among surfaces. These involve not only the surfaces of walls, ceiling, floor and windows, but also the lighting fixtures, electric appliances, radiant panel or fintube radiant heaters and most importantly, the room thermostats. It is an extremely difficult mathematical process to account for the multiple reflection process for the direct beam solar radiation and complex convective heat exchange among the complicated room surface geometries encountered in the actual building. It is also a nonlinear process because the convective and radiative surface heat transfer coefficients are functions of the surface temperature itself. Moreover the room air temperature varies from floor to ceiling due to stratification or imperfect mixing.

Several computer programs were developed at the National Bureau of Standards (NBS) and at the National Research Council of Canada (NRC) to approximately deal with this detailed room surface heat transfer, using what is commonly referred to as the detailed heat balance method or the DHB method. The DHB method entails the simultaneous solution of a matrix equation involving the room surface radiative heat exchange, internal heat generation, air infiltration, conductive heat gain and solar heat gain. A typical DHB calculation involves the inversion of a matrix approximately 30 x 30 for each room. For a six room house this means a 180 x 180 matrix must be inverted at every hour of the year, requiring large computer memories and resulting in long computation times even by super number crunching machines. If this is to be done for a smaller time step to include the simulation of thermostat and/or HVAC system performance, it becomes more complex and extremely costly.

The weighting factor, WF, approach was intended to reduce the lengthy calculations required by the DHB procedure. In the WF method, the conduction and infiltration heat gain/loss through the envelope elements and internal heat gains are precalculated on an hourly basis for a given room temperature and stored as a time series. Weighting factors were developed from separate calculations using the NRC's DHB program for typical office building constructions of light, medium and heavy thermal mass. Using an auto regressive technique developed by Mitalas <3> it is possible to determine the fraction of all these heat gains absorbed by the room air and the remaining fraction absorbed by the room interior surfaces and convected into the room air with a certain time delay, the magnitude of which depends upon the thermal mass characteristics of the surfaces. Remember, however that this concept was introduced at the time when the computer speed and memory capacity were still very much limited and the computation cost prohibited the performance of the DHB calculation at each time step.

These weighting factors are used as autoregressive multipliers to the time series of hourly heat gains previously calculated and stored to attain the heat convected into (out of) the air handling system, or the cooling (heating) load. The heating and cooling loads thus determined are considered to be those given off and removed by the heating and cooling coils respectively. Separate simulation calculations are then performed to estimate the electrical and thermal energy requirements of the chillers, fans and reheaters to meet the heating and cooling loads needed to maintain the prescribed room temperature and humidity. The most important thing is that the calculations are done in three separate and sequential steps in lieu of a simultaneous solutions for heating/cooling load calculation, air handling system simulation and the simulation of the operation of the heating/cooling equipment.

The sequential calculation demands at each step the values of certain assumed variables, such as the room temperature and humidity for the load determination, thermostat performance and other control parameters, part load performance data for every pieces of equipment involved (such as inlet temperature to the heat exchangers, output temperature from cooling tower, air humidity ratio and temperature entering and leaving the cooling and dehumidifying coil). In spite of these limitations, stemming in a large part from these simplifying assumptions, the RF/WF approach has been used in many of the existing North American energy simulation computer programs and has served well for modeling most conventional commercial buildings. Their heating and cooling systems are usually oversized, operated on a 24 hour basis under relatively stable indoor temperature and humidity throughout the year, and the time profiles of internal heat gains from occupants and lighting/equipment follow steady set patterns throughout the year. Moreover, many of the commercial buildings are internal heat dominated and the energy impact was significant mostly in the operation of air handling systems and its controls. Thus the emphasis placed by the practicing US engineers, most of who were interested only in large commercial buildings, where the coupling between the envelope heat transfer and HVAC system performance is weak, was not to dwell too much upon the mathematical rigor of DHB or the accuracy of the weighting factors. They rather favored an expansion of the simulation capability of the program to handle the operation and performance of numerous and innovative air handling systems and large heating and cooling plant operation. This general syndrome to place the emphasis on the air handling system simulation was used to justify the adoption of the weighting factor/transfer function approach which became the basis for a series of DOE energy simulation programs (CAL-ERDA, DOE1, DOE2, etc.).

The weighing factor approach, however, is not at all suitable, for evaluating the precise effect of building thermal mass on the effect of indoor temperature fluctuation around the thermostat set point, due to night time setback or intermittent operation of the heating/cooling systems.

Rigorous analysis employing the hourly DHB approach is very much needed for the design and evaluation of passive heating and cooling of residential buildings. With this in mind, the computer program NBSLD <4> was developed in the early 70's at the National Bureau of Standards and its concept was later expanded into the BLAST <5> and TARP <6> programs. The TARP program is currently considered by many to represent the state of the art in DHB calculation methodology. Its uniqueness is in solving the multi-room heat balance equations together with the air pressure balance equations permitting the evaluation of natural air transfer as well as the humidity and contaminant movement among the many rooms in the building. To the best of this author's knowledge, this is, in fact, the only program in the North America that is capable of solving the multi-room heat and mass transfer problem simultaneously, which is difficult for the weighing factor approach employed by DOE2.1 and other programs of similar nature.

e Lawrence Berkeley Laboratory, where DOE's computer simulation activities have been conducted in the past, has recognized the limitation of the ASHRAE Task Group approach and has developed a version where the DHB routine is included to generate Customized Weighing Factors in lieu of the standard ASHRAE Task Group values, thus resolving, at least partially, the difficulties inherent in the ASHRAE Task Group approach <7>.

During the heyday of solar energy utilization, separate modeling activities were going on in the solar communities independent of the ASHRAE Task Group and its response factor related activities. This was especially true at the University of Wisconsin, Madison, the University of Texas, and the Los Alamos Scientific Laboratory. Most of the thermal simulation programs developed for the solar heating/cooling application used the finite-difference and network approach pioneered in SINDA <8>, MITAS <9>, TRNSYS <10> and DEROB <11>. This was primarily because solar heating systems required an accurate assessment of the strong coupling between the building heating requirement and the available capacity of the solar heating system, which depends upon the heat storage capability of room interior thermal mass, the size and location of fenestration, the available solar energy, and the performance of the solar collector d heat storage devices. All of these elements . to be analyzed simultaneously. Existing solar related programs using the FD/NW approach are, however, limited in the scope of the room heat balance calculation employed and the level of simulation of conventional mechanical systems found in the large commercial buildings.

Silverman et al. <12> and later Sowell et al. <13> developed a network based HVAC system simulation procedure, which is embodied in an IBM program called ENET and makes use of an advanced automatic programming concept. This program, however, is not interfaced with building envelope heat transfer. Jiang <14> gave a very comprehensive theoretical background for the network solution approach, which in an essence provides a bridge between the thermal response factor concept and the network solution approach in the form of state-space formulas.

A MacArthur et.al applied the state-space concept to the program called GEMS <15>, which solves the envelope and control simulation equations simultaneously with very small time steps. The algorithmic details of GEMS are, however, not publicly available because of the proprietary nature of the program. National Bureau of Standards is currently developing the HVACSIM+ program <16> using a FD/NW approach to simulate many of the HVAC systems and equipment. A similar approach has also been reported in Europe under the name of ASTEC. Details of these two programs are expected to be discussed during this conference by Dr. Kelly of NBS and Mr. Sonnay of CSTB, France.

It is becoming clear that the development of supercomputers has encouraged the re-evaluation of DHB with the FD/NW approach instead of the thermal response factors approach to solve building and system interactions problems.

Another approach to building thermal simulation has involved the employment of frequency domain analysis. This requires solving heat conduction equations in the frequency domain instead of the conventional time domain by using the Fourier transforms instead of the Laplace transforms. Although the frequency domain analysis has been widely used in Australia <17>, its use in North America has not been well known until Dr. Subbarao of SERI demonstrated its power in a recent article <18>. The merits of the frequency domain analysis are in its mathematical elegance, its ability to show graphically the effect of thermal mass and its ease of handling the periodic heat transfer problems (such as the annual cycle of earth contact heat transfer). Its ability to handle the interactions between the building HVAC system and its controls has not yet been demonstrated. The method is, however well suited for the microcomputer solution of heat conduction analysis problems in multi-layer structures.

Simplified Methods

Parallel with the development of detailed building system simulation programs, many North American energy analysts have been interested in the development of simplified calculation procedures. This desire comes from the fact that in the recent years the detailed simulation programs have become increasingly unwieldy and are becoming the tools for only a limited number of energy analysis specialists who are familiar with the intricacy of modern large computing systems. This has left many of the practicing engineers and architects disenchanted with the complexity of these programs. In addition many engineers find it difficult to grasp what is actually taking place internally in the large energy simulation programs and are uncomfortable when they do not know the details of what they are analyzing. The advent of microcomputers has opened up possibilities of developing energy simulation calculation procedures suitable for the personal computers in the practicing engineer's offices. Very few of the currently available hourly simulation programs, however, fit in their microcomputers. What is needed is a computational procedure or modeling technique that is simple enough to fit the micro-computer yet comparable in accuracy with the results obtained by the hourly simulation programs of large main frame computers. Within the last two years, several microcomputers based building energy analyses programs have been developed. Some, which have come to the author's attention, are listed in the appendix of this paper. Three notable developments in North America involving microcomputers based methods are discussed below.

Variable Base Degree Day method (VBDD): Kusuda and Allereza <19> examined the age old degree day method against measured data and DOE2 calculated residential energy consumption data. They found that the measured and the DOE2.1 calculated annual energy consumption agree very well with that determined by the simple degree day method, provided that the base or the "balance point" temperature, where the daily total energy consumption becomes zero, is determined by detailed daily heat balance calculations. Traditionally the balance point temperature has been assumed to be constant at 65°F regardless of the type of building and internal load. The good agreement found between the VBDD calculations and the detailed simulation calculation was also replicated for cooling, which surprised many skeptics of the degree day method.

In order that the degree day method be valid, it is necessary to have a linear relationship between the daily total heating and cooling requirements and the daily average outdoor temperature as shown in figure 1. Moreover, the regression line representing this linear relationship must cross the ordinate axis at the balance point temperature. The analysis performed for and the measured data taken from numerous buildings proved this situation to be generally correct except for very light weight buildings with relatively large fenestration area. These exceptions showed significant deviation from the linearity, especially around the balance point temperature. This phenomena was also demonstrated by Burch <20> in his recent experiments involving small NBS test houses where he studied the effect of wall thermal mass on energy consumption and presented the results in the form shown in Figure 2. His finding implied that the variable base degree day method is probably not suitable for the very light weight building with larger solar heat gain. This is contrary or opposite to the intuitive conceptions held by many researchers.

Burch explained that deviation around the balance point from the linear relationship between the daily total heating load and the daily average outdoor temperature is due to the fact that light weight building under large solar heat gain tends to become overheated during the mild temperature days. The day-time overheating of the indoor temperature significantly above the thermostat set point will cause an unnecessary heat loss increase, which could otherwise have been stored in the internal mass to be utilized later during the night time when heating is needed. The degree of the overheating is a function of building interior thermal mass and the total solar heat gain with respect to its envelope heat loss.

In order to correctly account for this non-linearity around the balance point temperature for annual energy analysis, Burch devised a daily bin method. The number of days that fall into a given outdoor temperature bin were multiplied by the heating requirement at that temperature and summed to yield the total annual heating energy requirement.

Sander and Barakat <21> developed a method to account for the overheating problem by using a solar utilization factor (SUF) concept, which depends upon two factors such as:

$$\text{Gain Load Ratio (GLR)} = \frac{\text{Daily total solar heat gain}}{\text{Daily total envelope heat loss}}$$

$$\text{Mass Gain Ratio (MGR)} = \frac{\text{Total thermal mass of interior surfaces}}{\text{Mean hourly solar heat gain of the day}}$$

The SUF is a fraction of solar heat gain that is effectively utilized for the reduction of space heating requirement. If the space is overheated beyond the thermostat set point, the value of SUF becomes less than unity.

Figure 3 illustrates the chart developed by Sander/ Barakat depicting the relationship among SUF, GLR and MGR, which was a result of a multitude of comprehensive DHB calculations.

If all the solar heat gain during the daytime is utilized effectively to reduce the daily heating requirement, the SUF will be unity and the linearity between the load and outdoor temperature holds. In other words the building with a large internal thermal mass will have the SUF of unity as long as the GLR is less than unity.

Even for the massless building the SUF is close to unity as long as the solar heat gain does not exceed the envelope heat loss at no time during the day. The solar utilization factors are also affected by the amount of allowable room temperature swing associated with the night setback operation. The more the night setback is, the more the utilization of the daytime solar heat gain. Barakat and Sander prepared several charts similar to Figure 3 relating the solar utilization factors to GLR, MGR and to the daily room temperature swings. These charts were later embodied into a microcomputer based home energy estimate calculation program called the HOTCAN <22>; also developed by the National Research Council of Canada. This program includes a new calculation methodology developed by Mitalas to account for the heat loss from basements and slab-on-grade floors <23> and is considered one of the most comprehensive microcomputer programs for home heating energy analysis

The important thing is that light buildings with large windows have the anomalies from the degree day analysis while the heavy buildings with small windows follow the good linear relationship even near the balance point temperature. Thus the effect of thermal mass must now be thought as the effect of not having enough mass. Again this scenario is only valid for the typical household eration where one thermostat is controlling the heating plant and room temperature is allowed to exceed the setpoint and the heating plant is shut down by the thermostat during the mild temperature hours.

The Sander/Barakat charts are very significant in that it is the first time that the effect of building thermal mass is clearly presented linking it to the solar heat gain and to the envelope heat loss in a way understandable to building designers. It is possible now for any building designer to evaluate tradeoffs among the thermal insulation, fenestration design and internal thermal mass without resorting to numerous and expensive analyses by detailed hourly simulation computer programs. An interesting fact is that this simplified procedure was brought into light only through the detailed simulation analyses. The VBDD concept should also be applicable to the cooling operation if overcooling is permitted during the cool night by bringing cool outdoor air into the house and letting the room mass absorb the coolness to reduce the daytime air-conditioning requirement the next day. More research is needed, however, to develop similar charts such as the Sander/Barakat applicable for cooling problems. Another major accomplishment in the United States in recent years is the publication of the ASHRAE TC4.7 procedures for simplified energy analysis itable for conventional commercial buildings with complex mechanical and air handling systems <24>. This method relies upon the so called "bin" method which had been previously developed and widely used in heat pump application. Instead of carrying out the hourly sequential simulation throughout the year, the bin method requires calculations only at a few selected temperature points to arrive at the energy consumption estimate. Profiles of hourly energy consumption are plotted against outdoor temperature both for the occupied and unoccupied periods of the building. These hourly profile values are then multiplied by the hourly frequencies of outdoor temperature that fall into selected number of temperature bins and summed up to yield the annual energy consumption. These temperature bins are usually made in 5°F intervals and annual frequencies of outdoor temperature in each of the designated bins are available in US Air Force Manual 88-29 <25> and in a recent ASHRAE publication <26>. Although the energy analysis at each temperature bin is done on an hourly basis, there is no time element that goes into the bin method analysis. Thus the value of the method becomes questionable for the building whose thermal performance depends strongly upon the time sequence of the temperature, as is the case for passive solar buildings. As mentioned before, the hourly energy consumption performance of most conventional commercial buildings are, however, not overly dependent upon the hourly history of the outdoor temperature, rather it is strongly dependent upon the lighting, occupany, its HVAC system and control operation within the given hour. Thus, the bin method calculations can often yield good agreements with detailed hourly simulation calculations. This raises an interesting prospect of combining the small time step calculations, such as done by GEMS and HVACSIM+, with the hourly bin method for the annual energy analysis. The large commercial buildings performance is strongly influenced by the control of their HVAC systems and equipment, which have very small time constants. Precise short time step calculation can be performed for a period of one hour at a given set of outdoor temperatures and the hourly integrated result can then be used as imput to the hourly bin calculations for the annual energy consumption analysis.

Summary

I have described the historical development and the current state of the art building energy performance simulation activities in North America, strictly from the heat and mass transfer algorithmic point of view. There are numerous and equally exciting developments in implementation aspects of building simulations such as input and output procedures including computer graphics, the use of vector algebra, innovative ideas to shorten the computer time, and modularization of subroutine structures, etc. I am sure some of these aspects will be discussed during this conference by other authors.

The most exciting happening is the introduction of powerful micro-computers and their advanced softwares into the building energy analysis. This too will be discussed extensively during this conference and will bring many more diversified and effective approaches to the building energy calculations. I am confident that within a few years we will have very comprehensive and small time step FD/NW programs in conjunction with the hourly bin method on microcomputers. These programs will be connected with the expert systems, graphic routines, word processing and database management systems for input and output handling. The challenge is eternal and the dream continues.

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APPENDIX

MICROCOMPUTER PROGRAMS FOR BUILDING ENERGY ANALYSIS

PROGRAM NAME :	CIRA	TRAKLOAD	PEAR
AUTHOR'S NAME :	ROBERT SONDEREGGER	ROBERT SONDEREGGER	RONALD RITSCHARD
AUTHOR'S ADDRESS :	MORGAN SYSTEMS CORP. BERKELEY, CA 94720	MORGAN SYSTEMS CORPORATION BERKELEY, CA 94707	LAWRENCE BERKELEY LABORATORY BUILDING 90, ROOM 3124 BERKELEY, CA 94720
TYPE OF ANALYSIS :	VBDD	TC4.7	DOE 2.1B EMPIRICAL
SOLUTION TECHNIQUE:	STEADY STATE	STEADY STATE	
BUILDING TYPE :	RESIDENTIAL	COMMERCIAL	RESIDENTIAL
SPECIAL PURPOSE :	PASSIVE SOLAR,NATURAL COOLING ECONOMIC ANALYSIS	NEW & EXISTING BUILDINGS ENERGY AUDIT OPTION	
HVAC SYSTEMS :	EQUIPMENT SELECTION	14 SYSTEMS, 10 MTG & CLG PLANTS	
OPERATING SYSTEM :	CP/M 80, PCDOS	IBM/PC XT, AT	PC DOS
RUN TIME (HOURS) :	80 MINUTES	1 MINUTE/ZONE (1 MINUTE/ZONE 8087)	
PROGRAM LANGUAGE :	COMPILER BASIC	PASCAL	PASCAL
CORE EQUIPMENT :	64K	256K	192K
PRICE :	$240	$795	
UNIQUE FEATURES :	USER FRIENDLY INPUT DYNAMIC DEFAULT ECONOMIC OPTIMIZATION GRAPHICS	LOADS AND SYSTEMS EASE OF USE GRAPHICS, SPEED INTELLIGENT INPUT EDITOR	VALIDATION AGAINST DOE 2.1B GOOD THERMAL MASS AND EARTH CONTACT HEAT TRANSFER ANALYSIS
SUPPORT SYSTEM :	DR. MAX SHERMAN LAWRENCE BERKELEY LABORATORY BLDG. 90, ROOM 3026 BERKELEY, CA 94720 415-486-6651	R. C. SONDEREGGER MORGAN SYSTEMS CORPORATION 1654 SOLANO AVENUE, SUITE C BERKELEY, CA 94707 415-525-4736	RONALD RITSCHARD LAWRENCE BERKELEY LABORATORY BUILDING 90, ROOM 3124 BERKELEY, CA 94720 415-486-6328

APPENDIX (CONTINUED)

MICROCOMPUTER PROGRAMS FOR BUILDING ENERGY ANALYSIS

PROGRAM NAME :	HOTCAN	CMHC2	ECAP	EN4M	ENERGY
AUTHOR'S NAME : AUTHOR'S ADDRESS :	M. E. LUX, NATIONAL RESEARCH COUNCIL OF CANADA	WYNE WEBSTER, CANADA MORTGAGE AND HOUSING CORPORATION	JAMES N. WEST TVA 320 CREDIT UNION BLDG CHATTANOOGA, TN 37401	MC2 ENGINEERING 8107 SW 72 AVE BOX 430980 MIAMI, FLA 33143	WILLIAM SMITH (ELITE) P.O. DRAWER 1194 BRYAN, TX 77806
TYPE OF ANALYSIS :	MONTHLY NORMAL	VBDD BY MONTH	BIN	BIN	CLTD
SOLUTION TECHNIQUE:	SOLAR UTILIZATION FACTOR	SOLAR UTILIZATION FACTOR	CLTD METHOD	TC4.7 HIGHLY ENHANCED	ASHRE HANDBOOK
BUILDING TYPE :	RESIDENTIAL	RESIDENTIAL	COMMERCIAL	RESIDENTIAL/COMMERCIAL	COMMERCIAL
SPECIAL PURPOSE :	PASSIVE SOLAR ECONOMIC ANALYSIS	SUPPORT DELIVERY OF AFFORDABLE ENERGY SENSITIVE HOUSING	ECONOMIC ANALYSIS DAYLIGHTING ANALYSIS	ECONOMIC ANALYSIS	CONTROL EVAPORATIVE COOLING ECONOMIC ANALYSIS
HVAC SYSTEMS :					
OPERATING SYSTEM :	CP/M, APPLE, TRS80 IBM PC - DOS	QNX-(UNIX) FOR MICROCOMPUTERS	PCDOS, CPM	MSDOS, TRSDOS, CPM, PCDOS	PCOS, MSDOS, CPM
RUN TIME (HOURS) :	30 MINUTES	30 MINUTES		5 MIN (PC)	10 MINUTES PER ZONE
PROGRAM LANGUAGE :	MBASIC	C	BASIC	COMPILER BASIC	CB80 FOR 8 BITS, CB86 FOR 16 BITS
CORE REQUIREMENT :	64K	256K MINIMUM 512K RECOMMENDED	64K	64K	56K FOR CP/M 128K FOR MSDOS
PRICE :	$55			$995	$695
UNIQUE FEATURES :	GOOD INFILTRATION SLAB-ON-GRADE HEAT TRANS. BASEMENT WALL/FLOOR ANAL. SOLAR UTILIZATION FACTOR	USER FRIENDLY INPUT COMPREHENSIVE DATA BASE ON CONSTRUCTION ASSEMBLIES & HVAC EQUIPMENT COMPREHENSIVE THERMAL, INFILTRATION & LCC ANALYSIS	SEMI-AUTOMATIC DATA TAKEOFF DAYLIGHTING EFFECT MONTHLY PEAK DEMAND	RUNS 12 MONTHLY TYPICAL DAYS ON 24 HOUR BASIS EXTENSIVE SYSTEM SIMULATION, ECONOMIC ANALYSIS	HOURLY SIMULATION UNLIMITED NUMBER OF ZONES INTERACTIVE INPUT EXTENSIVE SYSTEM SIMULATION MENU-DRIVEN
SUPPORT SYSTEM :	MICHAEL LUBAN R-2000 ENER. ANAL. PROG. P.O. BOX 7081 POSTAL STATION J OTTAWA, ONTARIO CANADA K2A36 613-722-5091	D. WAYNE WEBSTER RESEARCH DIVISION NATIONAL OFFICE MONTREAL, CANADA K1A OP7 613-748-2308	SAME AS THE AUTHOR CRAIG STRANGE C/O ASB ENERGY GROUP W4 C156 TVA 400 SUMMIT HILL DRIVE KNOXVILLE, TN 37902 615-632-6750	R. S. MCCLINTOCK 305-665-6100	SAME AS THE AUTHOR 409-775-1782

APPENDIX (CONTINUED)

MICROCOMPUTER PROGRAMS FOR BUILDING ENERGY ANALYSIS

PROGRAM NAME :	SEA	SASEAD	ASEAM	LASER	LASPE
AUTHOR'S NAME :	CHARLES KALASINSKY FERREIRA & KALASINSKY ASS.	ISH SUD SUD ASSOCIATES	M. GOODMAN FLEMINGS ASSOC.	M. GOODMAN FLEMINGS ASSOC.	D. KNEBEL/R. LINTON
AUTHOR'S ADDRESS :	P.O. BOX L-6 NEW BEDFORD, MA 02745	DUHRAM, NC			P.O. BOX 1028 4820 WESTGROVE DRIVE SUITE 102, ADDISON, TX 75001
TYPE OF ANALYSIS :	MODIFIED BIN METHOD	MODIFIED BIN METHOD			STEADY STATE
SOLUTION TECHNIQUE:	TC4.7 PROCEDURE WITH ENHANCEMENT	TC4.7 PROCEDURES	"	"	MODIFIED TC4 7
BUILDING TYPE :	COMMERCIAL	COMMERCIAL/RESIDENTIAL	COMMERCIAL/RESIDENTIAL	COMMERCIAL/RESIDENTIAL	COMMERCIAL/RESIDENTIAL
SPECIAL PURPOSE :	SYSTEM ANALYSIS, ECONOMICS, GRAPHICS	CONTROL, EQUIPMENT, ECONOMICS	"	"	MONTHLY ENERGY/DEMAND ECONOMICS, CONTROLS, EVAP COOLING
HVAC SYSTEMS :	SECONDARY, UNITARY, HEAT PUMPS, PRIMARY PLANTS				
OPERATING SYSTEM :	PC-DOS, MS-DOS, CPM/80 TRS-DOS		APPLE DOS	IBM PC-DOS	IBM PC-DOS OR MS-DOS
RUN TIME	10 MIN./ALTERNATIVE				3 MIN./ZONE
PROGRAM LANGUAGE :	COMPILER BASIC	BASIC	BASIC	BASIC	FORTRAN 77
CORE REQUIREMENT :	64K	48K	48K		265K
PRICE :	495	$1,000	$50		$395
UNIQUE FEATURES :	UNLIMITED NUMBER OF ZONES & SYSTEMS, SCREEN INPUT WITH DEFAULTS, COLOR GRAPHIC OUTPUT				EXTENSIVE HVAC SYSTEM/EQUIPMENT SIMULATION UNLIMITED ZONE
SUPPORT SYSTEM :	FERREIRA & KALASINSKY ASS. 13 WELBY ROAD P.O. BOX L-6 NEW BEDFORD, MA 02745 (617) 996-4499	SUD ASSOCIATES P.O. BOX 3593 DUHRAM, NC 27702 919-493-5277	W. S. FLEMINGS & ASSOC. 5802 COURT ST RD SYRACUSE, NY 13206 315-437-1780	W. S. FLEMINGS & ASSOC. 5802 COURT ST RD SYRACUSE, NY 13206 315-437-1780	RICHARD LINTON ENGINEERING SOFTWARE, INC. P.O. BOX 1028 4820 WESTGROVE DR. SUITE 102 ADDISON, TX 75001 214-380-0048

APPENDIX (CONTINUED)

MICROCOMPUTER PROGRAMS FOR BUILDING ENERGY ANALYSIS

PROGRAM NAME :	CALPAS3	ESPRE	ADM-2
AUTHOR'S NAME :	BERKELEY SOLAR GROUP	RICHARD MERRIUM ARTHUR D. LITTLE	ADM ASSOCIATES, INC. TAGHI ALEREZA
AUTHOR'S ADDRESS :	3140 MARTIN LUTHER KING BERKELEY, CA 94703	ACORN PARK CAMBRIDGE, MA 02140	3299 RAMOS CIRCLE SACRAMENTO, CA 95827
TYPE OF ANALYSIS :	HOUR BY HOUR 8760	HOUR BY HOUR 8760	HOUR BY HOUR 8760
SOLUTION TECHNIQUE:	RC-NETWORK METHOD	RC-NETWORK	RESPONSE FACTOR/WEIGHTING FACTOR
BUILDING TYPE :	RESIDENTIAL	RESIDENTIAL (2-ZONES)	RESIDENTIAL COMMERCIAL (10 ZONE)
SPECIAL PURPOSE :	PASSIVE HOUSE NATURAL COOLING	CONTROL SIMULATION NATURAL COOLING	COMPLETE LOAD, SYSTEM AND PLANT SIMULATION
HVAC SYSTEMS :	EVAPORATIVE COOLING	ECONOMIC ANALYSIS EQUIPMENT SELECTION	OVER 30 HVAC SYSTEMS AND EQUIPMENT
OPERATING SYSTEM :	MSDOS PCDOS	MSDOS IBM PC	PCDOS/MSDOS/CPM 86 VICTOR 9000 (IBMPC OR EQUIVALENT)
RUN TIME (HOURS) :	20 MIN PER ZONE	3 MIN ON IBM PC	18 MIN PER ZONE
PROGRAM LANGUAGE :	FORTRAN	FORTRAN	INPUT : BASIC FILE MANAGEMENT : PASCAL CALCULATIONS : FORTRAN
CORE EQUIPMENT :	256K	128K	256K
PRICE :	$795		$2,500
UNIQUE FEATURES :	8760 DYNAMIC SIMULATION CALIFORNIA ENERGY CODE COMPLI	COIL MODEL SLAB/ATTIC ROUTINES 2 ZONE SIMULTANEOUS ADD ON HEAT PUMP LOTUS COMPATIBLE OUTPUT	8760 DYNAMIC SIMULATION ITEMIZED COMPONENT BASED ENERGY OUTPUT
SUPPORT SYSTEM :	CHARLES S. BARNABY BERKELEY SOLAR GROUP 3140 MARTIN LUTHER KING, JR. WAY BERKELEY, CA 94703 415-843-7600	E. BEARDSWORTH EPRI 3412 HILLVIEW AVENUE PALO ALTO, CA 94303 415-855-2470	ADM ASSOCIATES, INC. 3299 RAMOS CIRCLE SACRAMENTO, CA 95827 (916) 363-8383

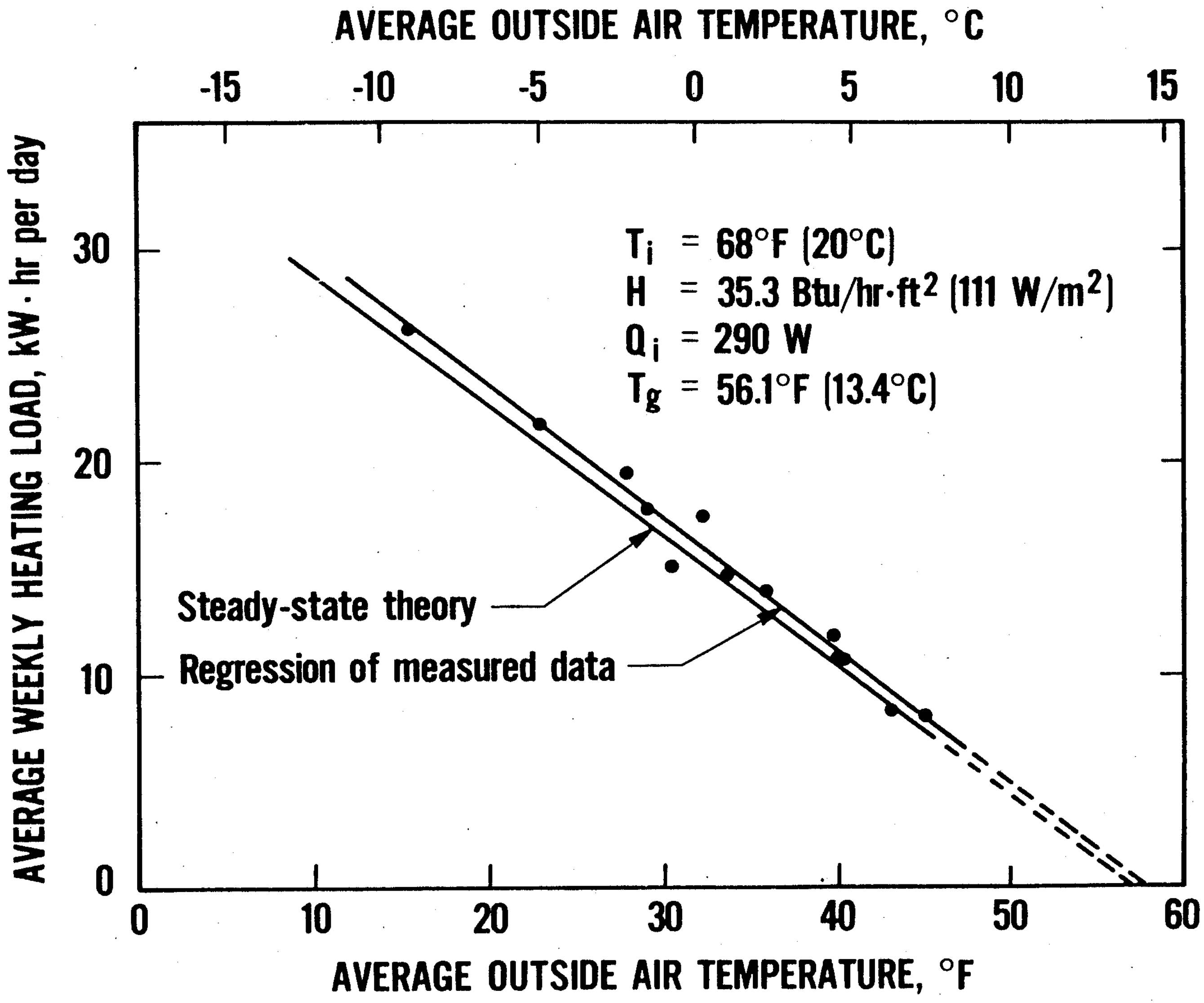

Figure 1. Relationship between daily total heating loads vs. daily average outdoor temperature.

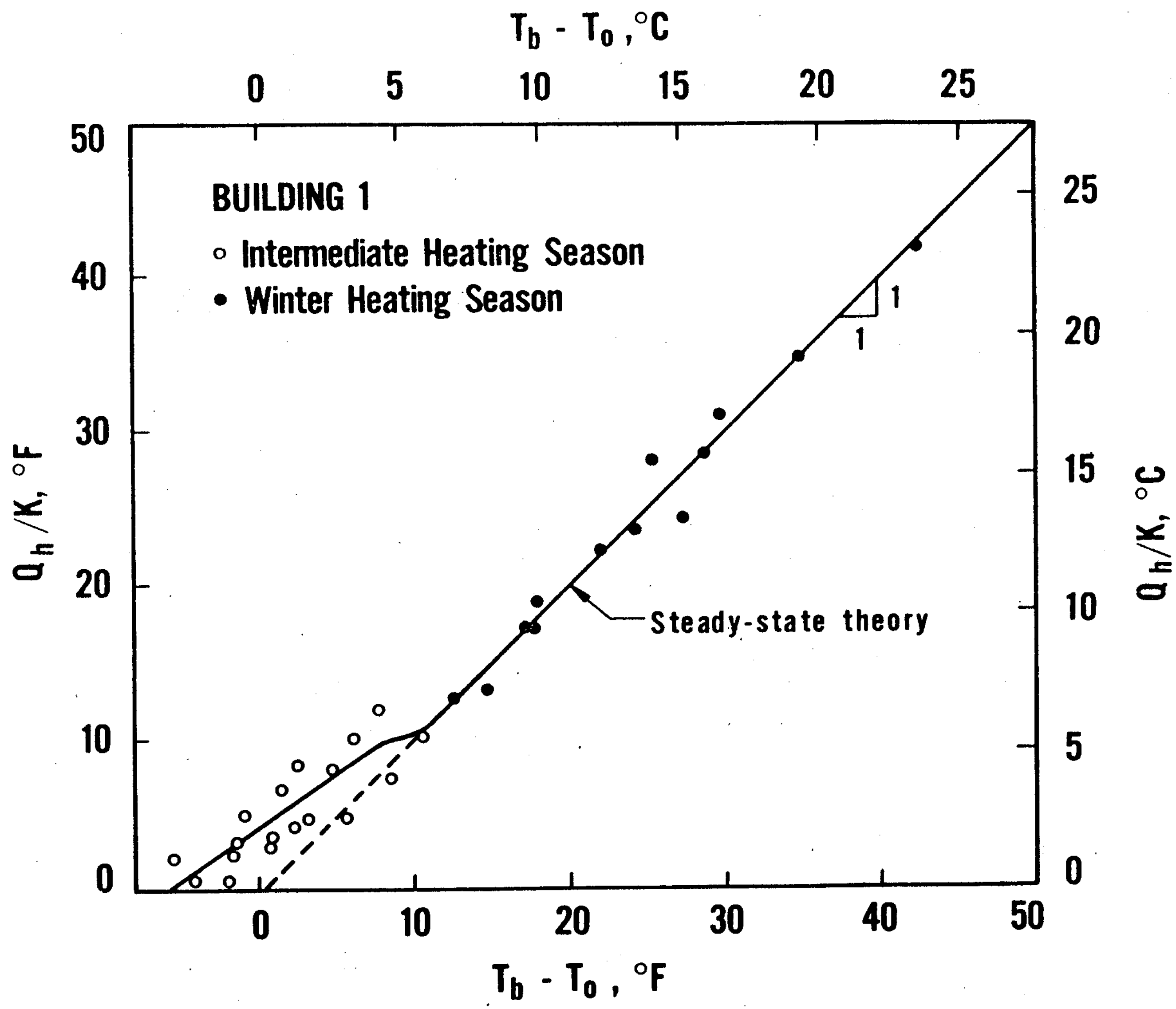

Figure 2. Burch plot of heating load vs outdoor temperature for NBS Test Building.

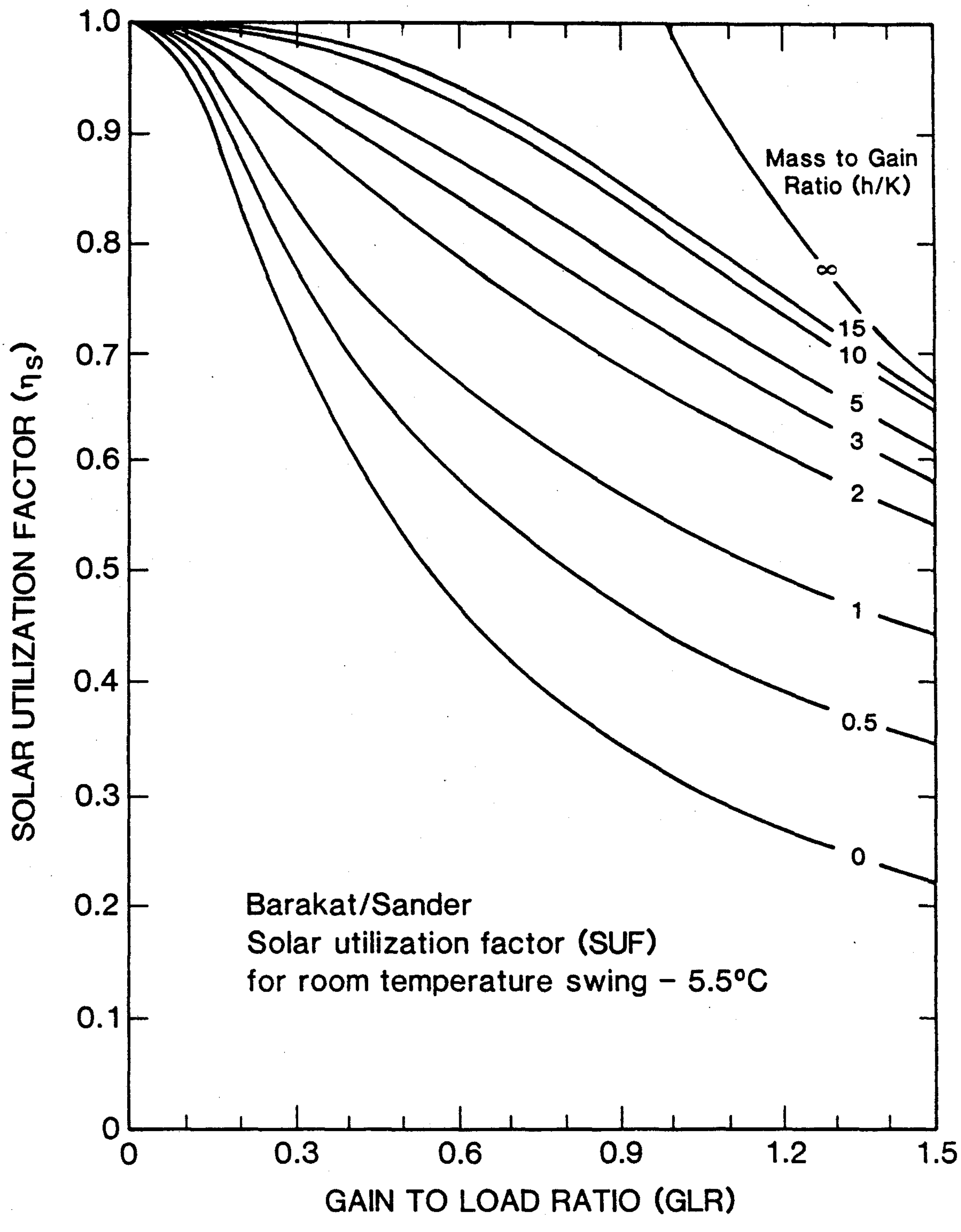

Figure 3. Barakat/Sander Chart for Solar Utilization Factors (SUF).