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VIA COMPUTER APPLICATIONS

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By

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ABSTRACT

CONSERVATION OF ENERGY IN THE RESIDENTIAL
BUILDING COMMUNITY VIA COMPUTER APPLICATIONS

By

Richard Joseph Patterson

Surveys agree that between 20 to 30 percent of the total United States energy consumption is expended to satisfy the energy needs of human dwellings. Approximately 70 percent of the energy expended in the home is for the purposes of space heating and cooling. This magnitude of consumption, combined with the scarcity in supply of the energy forms used in the home and the increasing costs of available energy supplies, attest to the need for upgrading the energy performance of the residence.

This thesis proposes the energy performance of the residence be improved through: (1) application of computer programs which evaluate the energy performance of residences and (2) establishment of an energy/housing computer capability network which will allow programs addressing building energy performance to be accessed by users in the residential building community.

Three computer programs, IBUC, TRNSYS, and NBSLD, were selected as being representative of existing energy/housing programs which address building energy performance. Each program is applied to a typical residence. Using the application as a common basis, each program is discussed with respect to achieving input and output, heat transfer methodology, aspect of building energy performance addressed, and energy

performance information produced. The three programs range from those utilizing simple simulation techniques employing algebraic equations to those employing sophisticated mathematical models using differential equations. The central processor times and the central memory requirements vary accordingly.

A plan for expanding energy/housing computer capability in the residential building community is proposed. The plan for expanding computer capability involves two key developments. One is the selection of the local governmental unit as the site in the residential building community to serve as an energy/housing computer capability resource center. The local computer capability resource center will provide computer access facilities and user assistance so that a library of energy/housing programs may be accessed and utilized.

The second development is the formation of a group of cooperating agencies. This group is composed of representatives from agencies in the residential building community with energy/housing expertise and this group has the responsibility for the development, implementation, and continued operation of the energy/housing computer capability network.

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1. INTRODUCTION

Of all the energy expended in the United States approximately 23.5 percent (Johnson, 1976a) is consumed for various purposes in the residence. Approximately 87.5 percent of the residential energy expenditure is used for the purposes of comfort space conditioning (73.5%) and domestic water heating (14%) (Johnson, 1977a). These percentages represent consumption conditions of most of the United States' present housing stock which was estimated to be 78 million units in 1975 (Johnson, 1977a).

Most existing dwellings were designed and built at a time when energy was readily available and was comparatively low in price. Consequently, the energy performance of these buildings was not given a high priority. In the present era of increasing energy costs and uncertain availability, building energy performance has become a high priority. Existing homes or new homes built using past design and construction practices are considered wasteful of energy resources and are expensive to maintain at customary comfort levels.

New energy performance criteria for dwellings are evolving that reflect the present energy situation. Shaping the new standards are the factors of potential energy savings (patriotic incentive) and/or potential dollar savings (economic incentive). Through legislation (Act No. 230 of Public Acts of 1972) an energy performance standard, ASHRAE Standard 90-75, was adopted in 1977 to become the initial mandatory energy code for new buildings in the State of Michigan. Discussion of both the Michigan Energy Code, ASHRAE Standard 90-75, and ASHRAE 90A-80 is included in sections 3.3 and 8.3 and Appendix A of this thesis. For dwellings to meet newly developing energy performance criteria and/or comply with energy codes, a re-evaluation of the methods, materials, and systems of construction used in the design and building of new homes and in the retrofitting of existing homes is in order.

The re-evaluation referred to above comprises numerous options for improving the energy performance of both new and existing dwellings. Each option requires the simultaneous consideration of many interrelated factors in order to determine its relative economic and/or thermal merits. A thorough energy performance analysis, involving more than a few energy saving options, quickly becomes too complex for the individual. With the aid of a computer and an appropriate energy/housing computer program the analysis can be performed rapidly and accurately, providing an evaluation of each option considered. Having the information provided by the computer analysis, the individual can proceed to make well informed decisions regarding the improvement of building energy performance.

Petersen (1974) comments on the significant need for making information concerning the various options for improving the energy performance of dwellings available to those who can benefit most by it. One way of accomplishing this is to extend computer capability (computing facilities and library of energy/housing programs) into the residential building community (RBC), making it available to individuals concerned with improving the energy performance of buildings. For an extension effort of this kind to be realized a viable plan is required which addresses and resolves the problems of energy/housing program availability and computing facilities accessibility.

There are many computer programs in existence which address an array of energy/housing problem areas. Many of these programs are written by and for persons with heat transfer and computer backgrounds. With the exception of some energy code officials and home builders who have had exposure to the Michigan Energy Code, most potential program users in the RBC do not have computer or heat transfer knowledge. New energy/housing computer programs need to be developed and/or existing programs modified such that their usage is within the capabilities of potential users in the RBC.

Existing computer programs vary in size as well as in the particular aspect of building energy performance addressed. Large programs require computers having large central memory ($>$ 170 k) and central processor capabilities. Computing facilities of this size are normally associated with academic institutions, corporations, or privately owned companies in the business of providing computing services. Some of the smaller energy/housing programs may operate on microcomputers ($<$ 20 k RAM). Computing facilities of this size are increasing in popularity and decreasing in cost.

Energy/housing computer programs must be accessible to potential users if they are to provide the information needed to aid in making decisions on energy/housing matters. Telecommunication systems have developed to the point that access to powerful computer facilities is possible wherever an ordinary telephone is located. However, providing computer access is complicated by the diverse composition of the RBC.

In addition most potential users presently cannot justify acquiring their own access facilities.

There is presently some computer capability available in the RBC. That computer capability which is presently available does not reach enough of the potential users in the RBC nor does it provide the variety of energy/housing computer programs needed. A network of access sites is required to expand computer capability to those in the diverse RBC who do not now have this service. To establish an energy/housing network a coordinated, cooperative effort is required. This can only be accomplished by an organization having the energy/housing expertise and the willingness to accept the challenge and the responsibility.

2. OBJECTIVES

The primary objective of this study is to propose a plan for improving the energy performance of residences by extending computer capability (a library of energy/housing computer programs and facilities to access these programs) to the residential building community. The primary objective incorporates the following secondary objectives:

a. Assess existing computer programs addressing energy/housing subjects by selecting programs of three different levels of ability to predict the energy performance of residences and comparing their characteristics, capabilities, and limitations.

b. Develop a specific action plan for the residential building community which will facilitate the selection and utilization of computer programs generating information needed to make better informed energy/housing decisions.

3. REVIEW OF LITERATURE

3.1 Building Energy Performance: A New Priority

Energy performance has become a high priority among the characteristics by which buildings are judged. The priority level that a building characteristic attains at any given time is influenced by many factors (costs, availability, style, technology, etc.) associated with the particular characteristic. When something happens that causes the influencing factors of one building characteristic to change, all of the characteristics undergo a reranking of priority.

The shuffling of building characteristic priorities is a normal process that is continuous and gradual. The sudden change in energy costs and availability of some energy sources directly affected building energy performance and caused a sudden reranking of building characteristics with energy performance gaining a much higher priority.

When energy was readily available and relatively inexpensive, there was little incentive for energy conservation in buildings. This was indicated by the fact that many homes built prior to 1960 have less than three inches of ceiling insulation and none in the walls, under floors or over unheated areas. They were also lacking in both heat gain and loss protection for windows. These construction practices were not irrational with respect to energy conservation (Petersen, 1974), since they reflected the level of priority that energy performance held under the circumstances at the time the homes were built.

3.2 Energy Consumption and Potential Savings

Estimates vary as to the amount of energy expended, as well as the potential for reducing this amount, in providing comfort conditioning, lighting, and operating appliances in buildings. Sparks (1977) stated that close to one-third of the nation's energy is used for these purposes. ERDA experts (from Sparks, 1977) indicated that comfort conditioning, lighting, and operation of appliances could be achieved with half as much as is now consumed for these purposes. Roberts in Berry (1975) agreed with the one-third usage figure and estimated that 80 percent of this amount is used for comfort conditioning and water heating. They further indicated that approximately 40 percent of the energy used for comfort conditioning is wasted due to building design, construction practices, and occupant practices. Johnson (1977a) estimated the amount of energy used by each dwelling to be about 200 million btu of primary energy per year. He also indicated that the on-site distribution of energy usage in a single family detached home includes 73.5 percent for comfort conditioning and 14 percent for water heating.

The energy performance of the estimated 78 million residences (Johnson, 1977a) can be improved. Ambrose (1975) referred to the need for developing practical methods for reducing energy consumption in existing dwellings and Landergan (from Berry, 1975) suggested that emphasis on conservation be directed toward existing structures. Energy conservation at the single family residence level was advocated by Swenson (1977) as being just as important and beneficial as is conservation in large buildings with comparatively larger energy budgets. Petersen

(1974) evaluated various combinations of energy conserving techniques to determine if they would be economically optimal for existing residences.

3.3 Emergence of Building Energy Performance Criteria

Individuals seeking relief from increasing utility bills began looking for ways of improving the energy performance of their buildings. This was the beginning of the development of new energy performance criteria to serve as a guide to improve the energy performance of existing homes and in the construction of new buildings. Many publications became available concerning various energy conserving actions applicable to existing buildings (Oviatt, 1975; Petersen, 1974; Federal Energy Administration, 1977).

Formal energy performance standards have been developed pertaining to new building construction. ASHRAE Standard 90-75 (ASHRAE, 1975) began development in 1973 with a joint emergency workshop on energy conservation in buildings (Berry, 1975) and gained final approval in 1975. In 1977, ASHRAE Standard 90-75 was adopted by reference along with several rules to become the Michigan Energy Code (1976). ASHRAE Standard 90-75 has also been used as the technical base for the development of a model energy code (U.S. Dept. Energy, 1977).

New building energy performance criteria continue to be developed and existing ones revised. ASHRAE Standard 90-75 has been revised (ASHRAE/IES, 1980) and a program to develop Building Energy Performance Standards (BEPS) (U.S. Dept. Energy, 1979) is currently underway. In general, these are more complex energy performance criteria than the original ASHRAE 90-75. One reason for this is the consideration being given to the effect, on energy resources, of the form of energy used at the building site (RIF, resource impact factor) and the energy resources consumed in providing that fuel or energy (RUF, resource utilization factor) (ASHRAE/IES, 1980). To illustrate the intent and approach of ASHRAE Standard 90A-80 several sections are included in Appendix A.

The energy resources issue is underscored by comments such as those by Smith and Pease (1973). They compare various building materials in terms of the energy used to produce them and in terms of the costs of their effect on the environment as a result of manufacturing them. Also, Demkin in Berry (1975) discussed a proposed study by Stein to measure the total energy impact of construction materials on the environment. In the case of the ASHRAE Standard (section 12) it was felt that if energy resources were not given consideration the standard would not be addressing the fundamental issue of energy conservation (Coad, 1977).

3.4 New Approach to Building Design and Construction

3.4.1 Sizing of conditioning equipment

A re-evaluation of the approach to the design and construction of buildings and their space conditioning means is needed in view of emerging building energy performance criteria. One of the practices in need of examination is that of selecting space conditioning equipment to satisfy the thermal requirements of buildings. Ideally, the equipment selected will have just enough capacity to maintain the desired comfort conditions during times of the most severe weather conditions (ASHRAE, 1977 and Sherwood & Hans, 1979). If the equipment does not have the capacity to provide the desired conditions it is undersized. The opposite, the selection of equipment that has more capacity to heat or cool than is required by a particular structure, is oversizing.

The practice of oversizing conditioning equipment is more common place than is undersizing. There appear to be three reasons for oversizing. Black (1977) referred to the conservative or "be sure" design philosophy developed over the years with respect to sizing of heating equipment. Since the penality for oversizing has been less severe than the penality for undersizing, oversized equipment was usually selected. Sherwood and Hans (1979) cited the need for oversized equipment in dwellings to compensate, by brute force, for building design deficiencies. Buffington (1975) indicated that oversizing of equipment is due to the use of the traditional steady-state calculation methods in determining the heating and cooling load of the building. For whatever reason the selection of oversized equipment occurs, the result is a waste of resources and a sacrifice in the comfort conditions attainable. Oversized equipment generally operates at reduced efficiency and requires more energy and materials to manufacture than equipment appropriately sized (Kusuda, 1976).

3.4.2 Consideration of factors influencing building energy performance

Proper sizing of conditioning equipment is only one aspect of the overall strategy for the design and construction of buildings with improved energy performance. A much broadened and refined approach to building design and construction is needed if buildings are to reflect the new, developing energy performance criteria. A new strategy must account for as many of the building energy performance factors as possible. Sherwood and Hans (1979) indicate that the building mass, the relationship of the building to its surroundings (including local climate), and human comfort requirements are factors which influence building design and should be considered. According to Coad (1976) the building industry should abandon singular concepts for a universal market and instead return to the practice of designing buildings for a particular region giving consideration to the local climate and to the materials and methods of construction best suited to that region.

The need for a new approach was summarized by Sherwood and Hans (1979) as they pointed out that "the solution to the challenge of more energy-efficient house design obviously lies in more imaginative approaches to this complex problem than in the past. More efficient design will also require more careful engineering, rather than just selection and specification of materials on the basis of outdated rule-of-thumb methods." A similar opinion was expressed by AIA Research Corp., (1976):

> Buildings are constructed to moderate the extremes of external climate to maintain the building interior within the narrow ranges of temperature and humidity that support occupant comfort. Building design can begin to accomplish this role by working with instead of against climatic impacts.

3.5 Evaluating Building Energy Performance With the Aid of a Computer

3.5.1 Computer: an appropriate tool

For reasons of speed, accuracy and convenience the computer is an appropriate tool to use in evaluating various aspects of building energy performance. In instances where the procedure is rigorous, taking into account many factors and using sophisticated techniques, the computer is a necessity. If the program employed is comprehensive and indicates the proper response to the change of the many influencing parameters, the computer can be used to evaluate the sensitivity of various design alternatives (Kusuda, 1976). Burch et al. (1975) indicate that the large memory banks of computers have made it possible to determine the hourly heating and cooling load of buildings as they fluctuate due to varying climatic and building factors. Colliver et al. (1976) stated that a dynamic model enables home owners to evaluate the numerous and complex interactions among occupant living habits, structural characteristics, and weather conditions which are unique from one home owner to another. Chen (1976) pointed out that the engineer, architect, and building owner all have an interest in the energy performance of a building and that the computer can be of assistance in providing relevant information to each of them. The simulation capability of a computer is a necessity, according to Tamblyn (1977) and Chen (1976), when dealing with heating and cooling systems with limited heat sources, such as solar energy, in which thermal storage plays a major role.

3.5.2 Existing energy computer programs

3.5.2.1 energy calculation sequence

Many computer programs are in existence addressing a variety of subjects related to building energy performance. The purposes of such programs include energy auditing, space load calculations, energy consumption, energy code compliance, energy costs analysis, and individual system component simulation. These programs fall within an energy calculation sequence framework with three basic parts: (1) rate of heat loss or gain to the conditioned space (building energy load), (2) energy consumption over a given time period (building energy consumption), and (3) building owning and operating costs. The relationship between each of the sequence parts was described by Stoecker (1976) and discussed in part by Black (1977), Crall (1975), and Black and Coad (1976). Building energy load is needed as input information for the building energy consumption component. Information concerning energy consumption is required input for the economic analysis part of the energy calculation sequence.

Carrying out an energy calculation sequence, or any part of it, can be a very complex or relatively simple task depending on the number of influencing factors accounted for and the methods used to account for them. As stated by Buffington (1975) and Kusuda (1976), determination of the building energy load and building energy requirements may be carried out in a simple manner giving approximate results or they may be carried out in increasing degrees of complexity accounting for more and more of the influencing factors and giving more and more accurate results.

3.5.2.2 code compliance

Computer programs are available to determine the compliance of buildings with energy codes and will be utilized more extensively as codes become more comprehensive. Compliance with section four (exterior envelope) of ASHRAE Standard 90-75 is offered through APEC (undated) services using a program, STD90, containing some optimization (with respect to meeting code requirements) capability. ENERCODE is a computer program addressing the subject of compliance of the exterior envelope component of the Michigan Energy Code (ENERCODE, undated).

Johnson (1976) referred to ASHRAE Standard 90-75 as "a complex technical standard." Even more complexity will be encountered as building energy codes become more performance (vs. specification) (Olin et al. 1975) oriented which is considered desirable (Stein from Berry, 1975). According to comments by Carlson (1980) compliance with the Building Energy Performance Standards being developed (U.S. Dept. Energy, 1979) will be determined by one of three computer programs selected for this purpose. Kusuda (1979a) attempted to develop a computer program with a simplified calculation procedure which still retains the capability to evaluate a building for compliance with sections 10, 11, and 12 of ASHRAE Standard 90-75.

3.5.2.3 load and energy analysis programs

In a series of articles Chen (1975a, 1975b, 1976) discussed 12 computer programs dealing with the calculation of building heating and cooling loads and building energy consumption. His discussion includes not only the overall program capabilities, but also the various methods available for computing heat gain through building exterior walls and for determining cooling loads. He cited the possibility of a spread among loads calculated by various methods of as much as 80 percent.

A compilation of programs undertaken by Crall (1975, 1976) resulted in a bibliography of programs pertaining to the area of heating, refrigerating, air conditioning, and ventilating. Eighty-nine programs are included. Some of these deal with specific subjects outside the scope of this study. Thirty-four programs address the subjects of heating and/or cooling load determination, solar specialty programs, and building energy analysis.

Romine (1976) discussed several programs available through the Automated Procedures for Engineering Consultants, Inc. (APEC) organization. Included, and of particular interest to this study, are a heating and cooling load calculation program (HCC-III) and a program for determining compliance with section 4 of ASHRAE Standard 90-75 (STD90).

3.5.2.4 auditing programs

Several computer programs exist in the general area of energy auditing of buildings. Buffington (1975a) developed computer models for simulating the transient energy requirements for heating and cooling of buildings and applied them to a residential building (Buffington, 1975b). Colliver _et al_. (1976) described the HOUSE program which uses the individual characteristics of a house, its inhabitants, and its location to estimate the total and dynamic energy usage. Another computer program entitled HOUSE was developed by Bodman _et al_. (1979) to assist home owners in evaluating various energy conservation techniques of their own home. This program emphasizes energy conservation through good management.

A home insulation analysis program developed by Hinkle _et al_. (1979a) and Hinkle _et al_. (1979b) estimates winter heating costs for homes in the northern and central parts of the United States. To provide home owners with an evaluation of the economics of additional insulation, program CHEAP was developed by Fehr _et al_. (1979). HACC is a program created by Bowen _et al_. (1979) to provide interested citizens with energy and economic analysis of their home which could help them make well informed energy decisions. The state of Ohio has developed a computerized Home Energy Analysis audit which features a simple questionnaire yet provides a comprehensive and easy to understand analysis report (Ventresca, 1979). One version of the Ohio computerized audit, the mini audit, features an input information form not requiring any dwelling dimensions, as the area of the home is estimated by the computer.

3.5.2.5. the IBUC program

The IBUC (In the Bank or Up the Chimney) computer program, analyzing weather proofing the home, was developed by Harsh _et al_. (1976) and is based on a publication by the U.S. Dept. Housing and Urban Development

(1975). IBUC analyzes six energy conserving actions with respect to their potential savings if implemented, their estimated cost to implement, and the amount of time to pay off the initial investment. The program is available on the Michigan State University Cooperative Extension Service TELPLAN system described by Harsh and Black (1971), Bakker-Arkema and Black (1974), Brook and Bakker-Arkema (1978), and Harsh (1978). IBUC is discussed in detail in a later section.

3.5.2.6 the TRNSYS program

TRNSYS (Transient System Simulation) is a computer program that utilizes a modular structural programming concept enabling it to model a variety of solar and building components. Instructions for the use of TRNSYS has been given by Klein et al. (1974). The user selects from a model library the component models corresponding to the components of the system to be simulated, specifies the manner in which they are interconnected, and supplies the design parameters required by each component subroutine. Available component models include those normally associated with an active solar energy collection system, such as collectors, storage tanks, and controls and those simulating the dynamic heat flow through the walls, roof and floor of a building. System variations are created by adding or rearranging components.

The versatility of the TRNSYS program has been demonstrated by Klein et al. (1975) in the simulation of a home space heating system with both solar and conventional energy inputs. One of the results indicated is that there is little difference in system performance between parallel and series arrangements of the auxiliary and solar heat units with the load. Also, the inclusion of a heat exchanger between the collector and storage tank results in an eight percent reduction in heating by solar energy for the year.

The feasibility of heating water for use in the food processing industry with solar energy was studied by Thomas (1977) using the TRNSYS program. In general, the simulation results indicated that solar water heating was economically feasible for food processing plants especially when electricity was the auxiliary water heating energy source being replaced by solar.

TRNSYS is included in the bibliography of computer programs developed by Crall (1976) in the category of solar programs also described as specialty building energy analysis programs. The TRNSYS program was selected as one of three computer programs suited for de ermining compliance with the Building Energy Performance Standards (Whalon, 1980).

3.5.2.7 the NBSLD program

The NBSLD (National Bureau of Standards Load Determination) program is the third program to be discussed in detail. Kusuda (1976a) described most of the subroutines incorporated into NBSLD and provided instructions for its use.

The approach to load determination used in NBSLD is the most rigorous of the three programs discussed and employs the methodology recommended by the ASHRAE task group on energy requirements discussed by Kusuda (1976b) and reviewed in a series of papers by Chen (1975a, 1975b, 1976).

The capabilities of the NBSLD program have been applied in several instances. NBSLD was used by the National Concrete Masonry Association (1976) to evaluate the effect of heat storage in building components on the building heating and cooling load and thus the capacity of heating and cooling equipment needed. Burch et al. (1975) performed a validation study of NBSLD using an instrumented woodframed four bedroom townhouse operated in a manner simulating occupancy and fluctuating climatic conditions. The test house was located in an environmental laboratory where winter and summer conditions were created like those occurring in Kalamazoo, Michigan and Macon, Georgia. It was found that NBSLD predicted maximum loads averaging 3.2 percent higher than measured and predicted energy requirements averaging 1.5 percent lower than measured values. Jones and Hendrix (1976) employed NBSLD to obtain information on energy conservation opportunities that encourage more energy efficient operation of homes in the Austin, Texas area.

3.5.3 Program sources

There are four sources of computer programs addressing various aspects of energy according to Romine (1976). These include the educational community, computer manufacturers and networks, equipments manufacturers or trade associations, and engineering firms. Programs developed by each of these sources have both positive and negative characteristics in terms of quality and availability. Generally, the programs developed by the education community are more easily obtained than programs developed by other sources.

3.5.4 Computer access networks

The need to provide information on improving the energy performance of homes to individuals in the RBC is supported by several authors. Petersen (1974) pointed out the need for home owners and home buyers to have access to this information for these individuals will be the ones to demand more energy conservation in the housing market. According to Colliver et al. (1976) residential dwellers do not have sufficient information concerning the possibilities of energy conservation in their homes and, therefore, are not utilizing existing technology (energy conservation) to its full potential.

One approach discussed by Black and Coad (1976), that is suitable for extending computer capability to smaller organizations is that of the shared-time computer network. Using a purchased or leased communicating terminal and an ordinary telephone, communication access to high capacity computing equipment can be obtained. A number of world wide shared-time networks are available including TELENET, MERIT and INFONET (Kusuda, 1976). The National Association of Home Builders (NAHB) uses a computer access network to permit home builders, subcontractors, and associated organizations to access NAHB's Automated Management Information System (AMIS) (NAHB, undated). Currently this network does not offer programs addressing energy/housing subjects.

A number of universities have developed computer access networks through their Agricultural Extension Service programs and are currently offering an energy/housing program, among others, to their users. The HOUSE program (Bodman et al., 1979) is available through the University of Nebraska AGNET (AGricultural computer NETwork) system (Kendrick et al., 1976). The Virginia Polytechnic Institute and State University offers the HACC program (Bowen et al., 1979) through the Computer Management Network (CMN). A home insulation analysis program is available on the FACTS (Fast Agricultural Communications Terminal System) network of the Indiana Cooperative Extension Service (Hinkle et al., 1979a and Hinkle et al., 1979b). The IBUC (In the Bank or Up the Chimney) program developed by Harsh et al., (1976) is available on Michigan State University's TELPLAN system.

Another way of making computerized energy/housing programs available is to mail or distribute input forms to potential users. Based on the returned information the computer analysis is performed and the results mail returned to the home owner. The CHEAP (Computerized Home Energy Analysis Program) program is administered in this manner in order to provide the service to more people (Fehr et al., 1977 and Fehr et al., 1979) although it is also available through terminal access. Both postal services and portable computer terminals are used by the Ohio Department of Energy to make their Home Energy Analysis residential audit available to home owners (Ventresca, 1979).

Mail out-return methods of computerized energy audits and analysis have not had good response rates. Ventresca (1979) indicated a return rate of 10 to 20 percent for the 29 question format of Project Conserve. Bowet et al. (1979) indicated a four percent return rate on a free offering of home energy analysis by the Virginia State Energy Office and Virginia Cooperative Extension Service. Bowen et al. (1979) suggested a lack of motivation to complete the input form as the reason for the poor response rate.

3.5.5 Proper application of computer capability

The computer program and the computer program user are both important factors in successfully attaining creditable information to help in making decisions on energy/housing matters. Proper program selection and application can provide beneficial results, but misuse or improper application of programs can also occur. In a comparison of several programs Spielvogel (1977) found that the degree of agreement between programs depended on the interpretive ability of the user and on the suitability of the program for the particular building being studied. Ventresca (1979) referred to the importance of selecting a computer program using methodologies appropriate for home energy auditing purposes as opposed to using a program using complex methodologies for auditing and requiring large amounts of detailed input information. In a discussion on the appropriateness of various programs, Black (1977) commented that the output from a complex program obtained by a user not understanding the purpose or methodology of the program can give the user an impression of knowledge that does not exist.

4. APPROACH TO THIS STUDY

The computer is well established as an appropriate tool for application to tasks involving repetitive, lengthy, time consuming, and inconvenient mathematical and manipulative operations. This makes the computer well suited for application to situations addressing building energy performance.

From the many programs in existence three were selected for this study which represent the range in techniques used to evaluate the various aspects of building energy performance. The three selected are: (1) In the Bank or Up the Chimney (IBUC), (2) TRNsient SYstem Simulation (TRNSYS), and (3) National Bureau of Standards Load Determination (NBSLD) program.

The IBUC program is available on the Michigan State University Cooperative Extension Service TELPLAN system. IBUC employs a steady state load calculation methodology and a degree day energy consumption methodology, applied to the energy auditing of homes.

The TRNSYS program is available on the Michigan State University central computer since it was used previously for the simulation of solar water heating systems for commercial application (Thomas, 1977). This program represents both steady state and dynamic approaches to building energy performance. TRNSYS uses a unique approach to system simulation in that the user creates the system to be simulated from a library of available component simulation subroutines.

The NBSLD computer program was not available at Michigan State University prior to this study. A NBSLD program manual was obtained and from the program listing a punched card deck was created. Some modifications of the program were necessary to make it compatible with the Michigan State University central computer facility. In addition to the modifications, some debugging of NBSLD was required before correct output could be achieved. The NBSLD program offers several options in both steady state and dynamic energy load determinations of buildings.

The discussion which follows is a comparison of the IBUC, TRNSYS, and NBSLD computer programs in terms of: (1) input format and type of information required, (2) heat transfer methodology used, (3) output format and type of information produced, and (4) general operating characteristics of each program.

Neither a validation of the programs nor a comparison of program output values is intended. The intent is that through the discussion, a better understanding of the characteristics of typical energy/housing programs can be gained. With a good understanding of typical programs one can better assess other existing programs and select and use the program appropriate to achieve the desired objective.

Many program runs were made in exploring the characteristics of the three computer programs. Each program was applied to a residential building of single level ranch design with a natural gas forced air heating system. Since the purpose was to explore the characteristics of the programs, input information describing the example house was varied from run to run. Examples of the kind of changes made in the input are: (1) heating and cooling situations, (2) with and without windows, (3) constant and changing weather conditions, (4) flat and sloped roof surfaces, and (5) with and without basements. Because of the variety of input information the examples of program input and output appearing in figures and tables which follow will vary from example to example. The figures and tables were selected to illustrate a program's features rather than to compare output values with a particular residence which had had its energy performance documented.

Following the discussion of the three programs a plan is proposed for making computer programs, addressing building energy performance, accessible to potential users in the residential building community. By doing this the computer becomes a tool which the residential building community can use to easily gain information necessary for making well informed decisions related to building energy performance. The plan is based on an assessment of the composition of the residential building community and of the current state of computer capability in the residential building community. A proposal is made on how the use of computers can be expanded to provide computer capability services to the residential building community.

5. THE IBUC PROGRAM

5.1 The Purpose of IBUC

In the Bank or Up the Chimney (IBUC) (Harsh et al., 1976) is a computer program adopted from a manual of the same title (U.S. Dept. Housing and Urban Development, 1975), prepared for the United States Dept. of Housing and Urban Development (HUD) by Abt Associates, Inc., Cambridge, Massachusetts. The HUD publication is intended for use by a home owner and has two objectives: (1) to assist in making the best choice of energy saving home improvements and (2) to provide step-by-step information on the correct installation of the improvements. The computer program adopted from the HUD manual deals only with the first objective.

Use of the IBUC program enables the home owner to easily gain the economic information needed on which the correct choice of energy saving home improvement decision is based. Through either the HUD manual or the computer program, users are made aware of the potential economic impact of various energy conserving actions. The IBUC program eliminates all manual calculations and simplifies the required input information on the part of the home owner, thus encouraging his participation.

Examples of input and output for the IBUC computer program are shown in Table 5.1 and Figure 5.1 respectively. The information presented is used to illustrate the features of IBUC, discussed in the following sections.

Table 5.1 Input values to the IBUC computer program describing the example residence. See Appendix B for a completed IBUC input form using these same values.

Section I General Information

1a. 3, b. 14, c. 3, d. 1, e. 1620, f. 1, g. 0
2a. *, b. *, c. *, d. *, e. *, f. *

Section II Caulking and Weatherproofing Doors and Windows

3a. 2, b. 14, c. 2
4a. 2, b. 2, c. i4, d. 2

Section III Storm Window Information

5a. 3, b. 12

Section IV Attic Insulation

6a. 1, b. 3, c. 0, d. 1, e. 0, f. 0, g. 0
7. 42, 24
8. 16, 32
9. 10, 10
(10-26 not applicable)

Section V Wall Insulation Information

27a. 164, b. 0, c. 0
28a. 0, b. 0, c. 2

Section VI Crawl Space Walls, Floors, and Basement Wall Information

29. 0
29a. 1, b. 0, c. 1, d. 0
30a. 110
(31-34 not applicable)
35a. 4, b. 58

Section VII Changing Thermostat Setting

36a. 973, b. 4
(37 not applicable)
38. 0 (completes input information)

5.2 Input to IBUC

The input information for the IBUC program describes the physical characteristics of the residence including the basic dimensions, the number of windows and doors, and the style of architecture. Information describing the extent to which some energy saving actions have already been employed and their current physical condition is also requested. Such items as weatherstripping, caulking and amount of insulation are included. Other inputs requested include the type of fuel and the indoor thermostat setting (although not used in determining space load requirements). A complete input form for the IBUC program is included in Appendix B.

Table 5.1 is an example of typical input information needed for the IBUC program. For the house in this example, input information is needed for all six (sections II-VII) of the energy saving options available in the IBUC program. Section I is a general information category. The values in Table 5.1 are the same as the values shown in the IBUC input form included in Appendix B.

The amount of descriptive information required varies depending on the users' choice from among six options pertaining to energy conserving actions. The options are: (1) caulking and weatherstripping, (2) storm windows, (3) attic insulation, (4) wall insulation, (5) crawl space/ basement wall insulation or floor insulation, and (6) thermostat adjustment. Any number of these may be selected depending on the users' needs and interests. Using all six options the example required 51 items of input. As few as 10 input items are needed if only one of the options is desired. Regardless of the options selected, supplying the information is not a demanding task as the input items require responses in the form of either checked choices (section I), numerical quantities, or basic structural dimensions. A number of illustrations are used to aid in the user's understanding of the information requested by particular input items (see input form in Appendix B).

5.3 Output from IBUC

Output from the IBUC program, a result of the input information in Table 5.1, is shown in Figure 5.1. The output consists of economic information on each of the six energy conserving options. Some of the six options are broken down into two energy conserving actions with economic information output for each one. Option one, the caulking and weatherstripping option, is divided into two economic outputs. One regarding caulking doors and windows, the other regarding weather-stripping doors and windows.

The output from each energy conserving action contains three items of economic information: (1) estimated dollar savings realized the first year as a result of implementing the energy saving option, (2) estimated investment to implement the option, and (3) estimated number of years to pay back for the option. The home owner can use this economic information to choose the energy conserving action he wishes to implement. The decision may be based on pay-back period alone or it may be based on the finances available for improving the energy performance of the home.

Estimated dollar savings is simply the change in the thermal performance of the home, expressed in monetary terms, resulting from the energy conserving action. This enables the home owner to compare

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****  IN THE BANK OR UP THE CHIMNEY ****

A COMPUTER PROGRAM TO ANALYZE
WEATHER PROOFING THE HOME

FAMILY LIVING EDUCATION
COOPERATIVE EXTENSION SERVICE
MICHIGAN STATE UNIVERSITY


*** CAULKING AND WEATHERSTRIPPING DOORS AND WINDOWS ***

 1. SAVINGS FROM CAULKING DOORS AND WINDOWS ($/YR) =      4.
    TOTAL INSTALLATION COST = $    20.
    PAY-BACK PERIOD (YRS) =      4.2

 2. SAVINGS FROM WEATHERSTRIPPING DOORS AND WINDOWS ($/YR) =     11.
    TOTAL INSTALLATION COST = $    40.
    PAY-BACK PERIOD (YRS) =      3.2

*** STORM WINDOW INSTALLATION ***

 3. SAVINGS FROM STORM WINDOW INSTALLATION ($/YR) =     57.
    TOTAL INSTALLATION COST = $   420.
    PAY-BACK PERIOD (YRS) =      5.8

*** ATTIC INSULATION ***

 4. SAVINGS FROM INSULATING A UNFINISHED ATTIC

TOTAL   ADDED     ANNUAL     INSTALATION PAYBACK PERDID
INCHES  INCHES   SAVINGS($)    COST($)       YEARS
  4       1.0       26.          121.         4.0
  6       3.0       57.          300.         4.4
  8       5.0       70.          478.         5.4
 10       7.0       78.          656.         6.4
 12       9.0       83.          834.         7.3
 14      11.0       87.         1012.         8.1

*** WALL INSULATION ***

 7. SAVINGS FROM INSULATING WALLS ($/YR) =     111.
    TOTAL INSTALLATION COST = $   656.
    PAY-BACK PERIOD (YRS) =      4.9
          *NOTE* -- A CONTRACTOR WILL NEED TO DO THIS JOB

*** CRAWL SPACE, UNDER FLOORS, AND BASEMENT WALLS INSULATION ***

 8. SAVINGS FROM INSULATING CRAWL SPACE ($/YR) =     49.
    TOTAL INSTALLATION COST = $   205.
    PAY-BACK PERIOD (YRS) =      3.7

10. SAVINGS FROM INSULATING BASEMENT WALLS ($/YR) =     45.
    TOTAL INSTALLATION COST = $   130.
    PAY-BACK PERIOD (YRS) =      3.5

*** THERMOSTAT ADJUSTMENT ***

11. SAVINGS FROM THERMOSTAT TURN-DOWN ($/YR) =    113.
```

Figure 5.1 Output from the IBUC computer program showing the estimated dollar savings for the example residence.

various energy conserving actions, or several stages of implementation of one particular energy conserving action, on the basis of energy saved each year, valued in dollars.

The option indicating the most savings in Figure 5.1 is thermostat set back. One hundred thirteen dollars is expected to be saved as the result of a four degree (input 36 b) lowering in thermostat setting. A savings of one hundred eleven dollars is estimated from insulating the house walls. The least amount of savings expected is from caulking the fourteen doors and windows. Only four dollars a year is expected from this energy saving option. Input information (input 3 a) indicated the present condition of door and window caulking to be fair.

Estimated investment is the second item of economic information output for each energy conserving action. This value is selected by the computer from a stored file of costs assigned to the various thermal improvements. Periodic updating of the cost file is necessary if the economic output is to reflect current construction material prices. Even then improvements costs may not reflect user local conditions because local costs may vary from the average costs in the data file.

The most expensive thermal improvements shown in Figure 5.1 are ceiling and wall insulation. If seven inches are added to the existing three inches (input 6 b), the cost is estimated to be six hundred fifty-six dollars. If nine or 11 more inches are added the costs are expected to be eight hundred thirty-four and one thousand twelve dollars respectively. Wall insulation is estimated to also cost six hundred fifty-six dollars. The least expensive energy conserving action is thermostat turn-down at no cost. Immediate savings are realized from this energy saving action.

Estimated years to pay back is the third output item of economic information. Years to pay back is the estimated investment divided by the estimated savings per year after the estimated yearly savings has been adjusted to reflect its present value.

The years to pay back in Figure 5.1 range from a low of 3.2 years for weatherstripping to a high of 8.1 for 11 additional inches of ceiling insulation.

5.4 IBUC Methodology

In both the HUD manual and IBUC computer program, the output obtained is a result of the selection and mathematical manipulation of predetermined values. The IBUC program alleviates the user's task of making the selection of the appropriate predetermined values, based on user input information, and of performing the necessary arithmatic calculations. In the use of predetermined values in IBUC a sacrifice in accuracy may be made since the predetermined values may collectively represent many factors which vary with the individual dwelling and dwelling location. Any discrepancy between predetermined values in the IBUC program and conditions representing the user's situation can result in output that does not reflect the user's actual situation.

The derivation of the predetermined values used in the IBUC program and their effect on program output is discussed in the sections which follow. The sequence of their use in arriving at the output information, their names as used in the HUD manual, and the parameters contributing to the values are depicted in Figure 5.2.

HEATING FACTOR		SAVINGS FACTOR	ESTIMATED YEARLY SAVINGS
HEATING MULTIPLIER	ENERGY COST		
$\frac{°F\ DAY}{YR} \times \frac{HR.}{DAY} \times \frac{CU.\ FT.}{BTU} \times \frac{\$}{¢} \times \frac{1}{EFF.} \times DDIF$	$\times \frac{¢¢}{CU.\ FT.}$	$\times \frac{BTU}{HR.\ °F}$	$= \frac{\$}{YR.}$

Figure 5.2 IBUC calculation sequence for gas heating.

5.4.1 The heating multiplier

The basis for determining the energy performance of the residence in the IBUC program is the well known degree day procedure (ASHRAE, 1976). The degree day value is not a program input variable nor does a degree day value appear in the computer program itself. Instead, the degree day variable is one of several parameters which are part of a parameter referred to in the HUD manual as a heating multiplier. According to one of the contributors to the HUD manual (Timko, 1977), the heating multiplier is defined as:

$$HM = \frac{HDD \times CF \times DDIF}{BTU \times EFF}$$

where: HM = heating multiplier

HDD = heating degree days

CF = conversion factors

DDIF = degree day interim factor

BTU = energy content of heat source

EFF = equipment efficiency

Heating multiplier values, one for each energy source for the state of Michigan, are adopted from the HUD manual and directly applied in the IBUC computer program. The heating multiplier value for gas fuel is 0.0197. Neither the specific values nor the method used to attain the specific values of the parameters used to calculate the heating multipliers for the state of Michigan are known. The modified degree day method for estimating space heating energy requirements (ASHRAE, 1976) incorporates a degree day interim factor, a part-load correction factor, and the rated efficiency of the heating equipment. The degree day interim factor and the part-load correction factor replaced the need, in previous ASHRAE degree day methods, to estimate seasonal system efficiency. Using the modified 1976 ASHRAE degree day method the heating multiplier is defined as:

$$HM = \frac{HDD \times CF \times DDIF \times PLCF}{BTU \times EFF}$$

where: HM = heating multiplier

HDD = heating degree days

CF = conversion factors

DDIF = degree day interim factor

PLCF = part-load correction factor

BTU = energy content of heat source

EFF = equipment efficiency

When the two degree day procedures, the one used in the HUD manual and the modified 1976 ASHRAE procedure, are compared, the result is heating multiplier values of different magnitude for the same geographic location, Lansing, Michigan. Assuming no oversizing of heating equipment (PLCF = 1.36), 80 percent rated equipment efficiency, six thousand nine hundred nine degree days, and six degrees F. winter design temperature (DDIF = 0.758), the 1976 ASHRAE method results in a heating multiplier value of 0.0214. The calculation is as follows:

$$HM = \frac{6909 \times 0.758 \times 1.36 \times 0.0000024}{0.80} = 0.0214$$

This compares to the HUD and IBUC value of 0.0197. The difference between these two heating multiplier values may be due to variations in the assumed parameter values and/or due to the differences between the two methods.

Use of a single value to represent the result of combining several contributing parameters, as the heating multiplier does, has the advantage of reducing the complexity of manual calculation. For reduced complexity some degree of accuracy is sacrificed if the single value heating multiplier is applied to situations not described by its contributing parameters.

The degree day, one of the parameters in the heating multiplier, is an indication of the ambient temperature conditions of a particular geographic area. Thus, the ability of the heating multiplier to reflect true conditions will decrease when the IBUC program is used in geographical areas with different degree day values from the degree day value used to arrive at the heating multiplier in the IBUC computer program.

The degree day interim factor is another parameter which has an effect on the derived heating multiplier value. The degree day interim factor is selected on the basis of the outdoor winter design temperature of a particular geographic location. It is a correction factor taking into account two aspects of homes constructed today as opposed to homes constructed at the time the degree day method of estimating heating energy requirements was devised. One aspect is the increased amount of insulating material utilized in home construction today. Second is the increase in the amount of internal heat gain, resulting from an increase in the number of heat dissipating appliances, that ultimately contributes toward partial fulfillment of the space heating requirements.

These two aspects mean that in homes built today the envelope heat loss may be compensated for to a lower outdoor temperature than the customary 65 degree fahrenheit degree day base. Since the degree day interim factor is based on the outdoor design temperature and since it is a parameter used to determine the heating multiplier, the calculated heating multiplier value will reflect conditions representative on only the geographical area for which the correction is made.

The effect of these two geographic dependent parameters, the degree day and the degree day interim factor, on the heating multiplier value is illustrated in Table 5.2. Heating multiplier values shown were computed using the 1976 ASHRAE modified degree day procedure assuming 80 percent rated equipment efficiency and zero percent oversizing (PLCF = 1.30). The Benton Harbor and Houghton locations represent extreme winter degree day conditions in Michigan. The percent variation column is a comparison of heating multiplier values for several Michigan locations with the heating multiplier for Lansing, Michigan. The values in the percent variation column show the percent variations that are reflected in the economic output when one heating multiplier value is used in calculations for all Michigan locations.

The last column in Table 5.2 expressed the percent variation in terms of estimated dollar savings. A gas price of 35 cents per hundred cubic feet and a savings factor (defined in section 5.4.4) of 30 BTU/HR °F are assumed. The use of the Lansing heating multiplier value to estimate savings for Benton Harbor results in overestimating the savings by 2.94 dollars, or 13 percent more than if the Benton Harbor heating multiplier value is used. If the Lansing heating multiplier is used to estimate savings in Houghton the savings is underestimated by 4.73

Table 5.2 Effect of geographic location on heating multiplier values and the effect of heating multiplier values on estimated yearly savings from the IBUC program.

Geographic Location in Michigan	97 1/2% Outdoor Design Temp., °F	Degree Day Interim Factor	Degree Days Per Year	Heating Multiplier, 1976 ASHRAE	% Variation Lansing vs. Other Locations	Estimated Dollar Savings
Lansing	6	.758	6909	.0214	0	22.47
Benton Harbor	3	.734	6200	.0186	+13	19.53
Houghton	-4	.682	9325	.0259	-21	27.20
Detroit	8	.774	6258	.0198	+7	20.79
Iron Mt.	-16	.598	8653	.0211	+1	22.16

dollars or 21 percent less than if the Houghton heating multiplier value is used. The estimated savings for Benton Harbor and Houghton differs by 7.67 dollars.

Other parameters contributing to the heating multiplier, when the 1976 ASHRAE procedure is used, include a term for energy content of the energy heat source, a term for the rated efficiency of the heating equipment and a part-load correction factor. All are important to the accuracy of the heating multiplier. Values used for these parameters should be carefully selected to describe the particular situation as accurately as possible. The energy values for various energy sources are well documented. Rated full-load efficiencies of fuel fired equipment are usually in the range of 70 to 80 percent and may be obtained from the manufacturer (ASHRAE, 1976). A part-load correction factor may be selected from ASHRAE based on a comparison of the design heat loss of the structure and the rated output of the fuel fired heating system.

5.4.2 The energy cost value

A single value for the cost of each type of heating energy source is contained within the IBUC program. Any discrepancy between the energy cost value contained in the program and the local energy cost will be reflected in the economic output information. For example, estimated yearly savings will vary 3.21 dollars for each 5-cent variation in gas price, assuming a heating multiplier value of 0.0214 and a savings factor of 30 BTU/HR °F. The type of energy source used in the home heating system is a user input item. From this information both the heating multiplier value and the energy cost value are selected and used in subsequent program calculations.

5.4.3 The heating factor

Multiplication of the heating multiplier and the energy cost results in a value, referred to in the HUD manual and the IBUC program, as the heating factor. This value collectively represents the effect of climate, energy content of the energy source, efficiency of the heating system, and cost of the energy. No separate discussion of the derivation of the heating factor is needed since it is the product of two values discussed previously and no new parameters are introduced.

5.4.4 The savings factor

Each energy conserving action, if implemented, implies an improvement in the thermal performance of the home through a reduction in the rate of heat loss. In both the HUD manual and IBUC computer program, the improvement in the thermal performance of the structure is represented by savings factor values. The magnitude of the improvement, or heat loss reduction, realized from the implementation of any one energy conserving action depends on the rate of heat loss from the structure after having implemented the energy conserving action.

For example, a home presently without attic insulation realizes a greater reduction in heat loss with the addition of six inches of insulation than would a home presently with two inches of insulation with the addition of four more inches of insulation. A savings factor value is the difference between the rate of heat loss prior to the implementation of the energy conserving action and the rate of heat loss after the energy conserving action has been implemented.

Savings factor values, adopted from the HUD manual, corresponding to several potential stages of implementation of each energy conserving action are stored in the computer. Selection of the appropriate value for use in subsequent computation, involving a particular energy conserving action, is made based on user input information that establishes the expected change in the thermal performance of the structure. Multiplication of the selected savings factor value with the calculated heating factor value results in the estimated yearly dollar savings for a particular energy conserving action, Figure 5.2. Estimated dollar savings is one of three items of economic information output from the IBUC program.

5.5 Summary of the IBUC Program

The IBUC computer program is best suited for use by the home owner. The program provides information to assist in making decisions regarding the implementation of various energy conserving actions in the home. The necessary input information is easily obtained and the format of the input form permits the required information to be easily recorded. Drawings aid the user in completing the input form by describing the energy conserving options and explaining the information required.

A limitation of the IBUC program is the use of the steady state method of heat transfer. This method is not capable of accurately describing heat transfer in a constantly changing climate. IBUC is not a comprehensive program. It focuses on the energy consumption of the residence as affected by the components of the building envelope. The energy consumption calculation used in IBUC does not incorporate the 1976 ASHRAE modification to the degree day procedure.

The IBUC program uses one set of degree day, energy cost, and building cost values. If the program is used in geographic areas where the values are not valid, the variation is carried through the calculations and is reflected in the program output.

It must be pointed out that most of the limitations that have been described are characteristics that make the IBUC program uncomplicated and easy for the home owner to use.

6. THE TRNSYS PROGRAM

6.1 Purpose of TRNSYS

TRNSYS (Transient System Simulation) version 7.3, is a simulation system developed at the University of Wisconsin for simulating applications of solar energy to water heating and space heating and cooling systems (Klein et al., 1974). This simulation method is based on a modular concept, whereby, each physical component or closely allied group of components, involved in the flow of energy in a heating/cooling system, is modeled independently of other components. TRNSYS, therefore, is a library of component subroutines and does not consist of a fixed program with the same input and output formats for each simulation. To use the TRNSYS simulation system the user first formulates the system to be simulated using subroutines from the TRNSYS library. The program input is then prepared based on the individual input needs of the TRNSYS modules selected. The system simulated may be simple using only a few of the subroutines available or may be complex using many of the available subroutines in the TRNSYS library.

Information flow between the component modules, or individual subroutines, is controlled through an executive program. Connections, as in a real system, usually include a linkage between the output of one module and the input of another. Each of the component modules has a sequentially numbered input, output, and parameter list that must be satisfied either through component interaction or through specification by the user.

There are several modules in the TRNSYS library that do not represent real system components. They include modules for implementation of input and output for the user developed program and modules for performing certain specific mathematical tasks at the users discretion.

The heat transfer methodology applied in the TRNSYS program is based on hour-by-hour climatic data and on the use of differential and algebraic equations to describe the various time dependent energy processes. Due to the modularity concept of simulation a user of TRNSYS needs to have only a superficial familarity with computer operations and a general comprehension of the factors involved in heat transfer processes. There is a built-in element of flexibility that allows the user to insert mathematical descriptions of processes other than those used in the TRNSYS component simulation modules. To do this requires a thorough knowledge of both programming techniques and heat transfer processes.

Although the TRNSYS system includes modules describing solar system components such as collectors, storages, pumps, etc., the focus of this work deals only with those modules most closely involved with the heat loss or heat gain to the living space of a residence. Application of the TRNSYS program to the simulation of commercial solar hot water heating systems has been performed by Thomas (1977).

The TRNSYS program was applied to the residence described in section 4.0 on an individual subroutine basis. Figures 6.1 and 6.2 refer to a discussion of input to the TRNSYS program. This is followed by a discussion of a simulation of the example home, selecting subroutines employing simple heat transfer methodologies. The block diagram of the formulated program is given in Figure 6.3 with the corresponding input and output shown in Figures 6.4 and 6.5 respectively. Another simulation program is formulated for the same home using subroutines employing sophisticated heat transfer methodologies. The block diagram for this simulation is shown in Figure 6.6 with the corresponding input and output shown in Figures 6.7 and 6.8 respectively.

6.2 Individual TRNSYS Modules

While each component module in the TRNSYS library is different in that they each perform specific simulation functions, all modules are similar from the standpoint of the mechanics of program formulation. Their similarity is in the type and order of presentation of information that is required to be supplied by the user. As many as eight categories of information may be required by a component module with each category representing at least one card of program input. Figure 6.1 identifies the categories of module information in the order required for submission. Figure 6.2 is the corresponding input of actual program information for a single component module. Some modules do not require all eight information categories. Which categories are required is an individual component module characteristic and is discussed in the TRNSYS system users manual on a module-by-module basis.

6.2.1 Module identification

The first information category (Figure 6.1) concerning each TRNSYS module deals with module identification. Module identification serves as

INFORMATION CATEGORY	TYPE OF MODULE INFORMATION
1	UNIT (no.) TYPE (no.) Comment or component name
2	Parameters (no.)
3	Parameter value list for module
4	Inputs (no.)
5	Input source identified (other system modules TYPE and output sequence number)
6	Initial input values if the source is other system modules or constant input values if no source is specified in category five
7	Derivatives (no.)
8	Initial values of dependent variables

Figure 6.1 The type of individual module information required for a TRNSYS program module. See numerical examples in Figure 6.2.

INFORMATION CATEGORY	MODULE INFORMATION
1	UNIT 39 TYPE 17 EAST WALL
2	PARAMETERS 6
3	1.000E+00 2.230E+01 0. 0. 7.830E-01 9.000E-01
4	INPUTS 4
5	0,0 0,0 0,0 19,2
6	-4.9 0.0 0.0 0.0
7	DERIVATIVES 3
8	0.0 1.000E+01 2.000E+01

Figure 6.2 Example input values for a typical TRNSYS program component module. These values correspond to the information categories described in Figure 6.1.

means of informing the TRNSYS executive program which real system components have been selected for simulation by the user. Module identification also serves as a code for the communication of information within the program as simulation proceeds. Each module is identified in two ways, in addition to the name of the component it represents in the corresponding real system. The first means of module identification is a TYPE number. Every module in the TRNSYS library was assigned a permanent, unique TYPE number at the time the TRNSYS simulation system was developed. This number identifies the module with respect to the real system component it models or the specific function it performs. A module with the same TYPE number may be used repeatedly in a simulation. A few modules dealing with input and output are limited in the number of times they can be used in a program. For example, a TYPE 17 wall module may be used to simulate each exterior wall in a home. No matter how many times the wall module is used in a program, the wall module is identified with the TYPE number unique to it.

The second means of module identification is a UNIT number assigned to each module at the time of program formulation by the user. The TYPE 17 wall module in Figure 6.2 was assigned UNIT number 39. Unlike the TYPE number no two modules in a user developed simulation program may be assigned the same UNIT number. If more than one wall module is used in a program, each would have a different UNIT number. Both the TYPE and the UNIT number identification for a wall module are shown in the example input of Figure 6.2.

6.2.2 Module parameters

Information category two and three (Figure 6.1) deal with the parameters required for a particular module. Category two is the number of parameters required and category three is a list of the required parameter values. The number of parameters required varies, depending on the specific component module and, in some cases, the mode option chosen within the component model. The wall module of Figure 6.2 requires six parameters. In order they are: (1) wall type code, (2) area, (3) percent of wall that is window, (4) percent of window that is shaded, (5) absorptance of wall to solar radiation, and (6) infrared emittance of exterior wall. Values of the required parameters must be listed in the order specified in the user's manual. The parameter values describe the characteristics of the real system component.

6.2.3 Individual module inputs

Information categories four, five, and six (Figure 6.1) involve inputs to the individual module. The number of inputs for the particular module are specified in category four. This number varies depending on the need of the particular module and, in some cases, on the user's preferences. Four inputs are needed for the wall module of Figure 6.2.

In information category five the source of the inputs are identified. Input sources may be designated as the outputs of other modules used in the simulation or may be designated as an input to be specified by the user. When the input originates from another module in the system simulation, the UNIT number of the source module is given followed by the position number of the output from the source module. In this way the TRNSYS executive program is able to link the system component modules and provide for the flow of information between them. Indoor temperature, the fourth input to the wall module in Figure 6.2, is designated as 19,2. The source of this input is the second output of UNIT 19. When the input source is not from another system component module, a value of zero is given to both the UNIT number and the output number. Outdoor temperature, solar radiation and wind velocity, the first three inputs to the module of Figure 6.2, are designated by 0,0. This means that either a particular input is not necessary for the current application of the component module or designates the input value is to be specified by the user.

The sixth information category contains initial values for the corresponding input sources indicated in category five. When no system module is identified as the input source in category five (UNIT 0, output position 0), a non zero value for that input may be supplied in category six which then becomes a constant value input to that module throughout the simulation. Outdoor temperature, the first input to the wall module of Figure 6.2, is assigned the value of -4.9. This causes the outdoor temperature input to the wall subroutine to remain constant. Whether a module input value is a constant specified by the user or is obtained as output from another component module is an option available to the user.

6.2.4 Module derivatives

The number of derivatives involved in the component simulation is specified in information category seven (Figure 6.1). This number is predetermined for each mode within the component module. Once the mode option is selected by the user the number of derivatives is known. The wall module of Figure 6.2 employs three derivatives. Category eight contains initial values for the dependent variables used in the corresponding derivatives of information category seven. The three initial temperature values assigned to the dependent variables in category eight are 0.0, 10, and 20 (Figure 6.2).

6.3 Program Formulation Examples

With a simulation objective clearly established the user proceeds with program formulation by identifying all of the real system components involved and noting their interrelationship. Modules are selected from the TRNSYS library that will achieve the desired objectives by modeling the real system components and by performing non-component functions such as input, output, or specialized tasks.

A block diagram can be utilized as a program formulation aid with each block representing a system module. Such a diagram allows the user to better visualize each component in the system with respect to other components. The diagram allows the user to map the flow of information between components, to note the required input and parameter information, and to visualize the potential output information.

Two examples of programs formulated from TRNSYS subroutines are discussed in this section. Both examples are simulations of the example house described in section 4.0. The first program is an application of the space heating energy per degree-hour module (TYPE 12). The entire simulation program in this simple example consists of only four TRNSYS modules. The methodology of the energy per degree-hour subroutine is discussed in section 6.5.1.

The second program example uses more of the TRNSYS modules. A greater number of the appropriate modules provide a more complete description of the energy performance of a building than the TYPE 12 module by itself. The principle modules used in the more complete simulation are TYPE 17 wall, 18 roof, and 19 room and basement. The methodology of these subroutines is discussed individually in section 6.5.2.

6.3.1 TRNSYS program: module TYPE 12

An example of a block diagram for the first example program is shown in figure 6.3. This diagram illustrates an application of the energy per degree-hour module (TYPE 12) of the TRNSYS simulation system to the example home described in section 4.0. The four modules employed are data reader, energy per degree-hour space heating, quantity integrater, and printer. The energy per degree-hour subroutine is discussed in section 6.5.1.

The inputs and outputs of individual component modules are noted on the component block in the diagram (Figure 6.3). Lines of information flow are drawn between modules, linking the outputs of some modules to the inputs of others. In Figure 6.3 T_{amb} (ambient temperature), output position number 7 of UNIT 9 TYPE 9, is linked to the appropriate input position of both UNIT 12 TYPE 12 and UNIT 25 TYPE 25. In this example, T_{amb} is a required input to UNIT 12 TYPE 12, the energy per degree-hour module. To have the T_{amb} value appear in the output record it is input to UNIT 25 TYPE 25, the printer module. It is not necessary

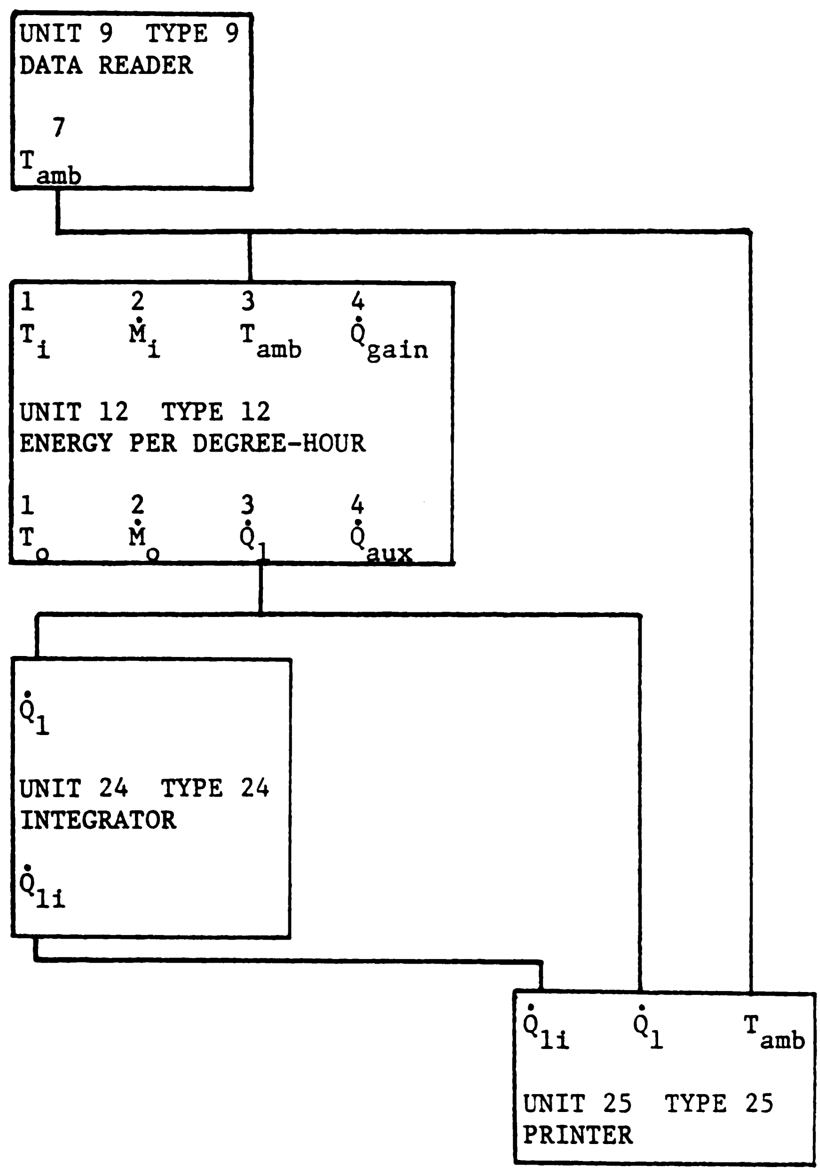

Figure 6.3 An example block diagram of a complete program using the methodology of the Degree-Hour TRNSYS module.

that all of the inputs and outputs of the component modules be utilized. Only the inputs and outputs of interest to the user or those required by the component modules to perform their functions need to be linked appropriately.

A program takes shape as the needed modules are fitted into a diagram, identified, and lines of communication between components established. When all of the components in the system being simulated have been accounted for with appropriate simulation subroutines and provision for the required input and output has been made the program development is complete. At this point, the type and quantity of program input information can be assessed. Since the user tailors the program to suit the needs of the simulation problem, no standard input form is used. With the TRNSYS system input is on a module-by-module basis with each module requiring nearly the same type of information. Using the block diagram (Figure 6.3) as a guide, the user proceeds on a module-by-module basis noting the information required by each of the eight information categories. This information, put into a format acceptable to the users' computer facilities, comprises the input for the program. All of the required input information for the program illustrated in the block diagram of Figure 6.3 is shown in Figure 6.4 as it would be submitted to a computer. This example illustrates the point that not all component modules require input to each of the eight information categories. Differential equations are not a part of the simulation methodology of the modules used in this example, therefore, input to information categories seven and eight does not appear in Figure 6.4.

Output from a user developed simulation program is at the discretion of the user within the provisions of the TRNSYS simulation system.

```
UNIT  9      TYPE  9      DATA READER
     PARAMETERS  5
     1.000E+01    1.000E+00    7.000E+00    5.556E-01     -1.778E+01

UNIT 12      TYPE 12      SPACE HEAT 3
     PARAMETERS  8
     3.000E+00    2.550E+02    2.110E+01    1.000E+00     1.000E+00    1.000E+00    1.000E+00    0.
     INPUTS  4
      0, 0         0, 0         9, 7         0, 0
     0.           0.           0.           0.

UNIT 24      TYPE 24      INTEGRATOR
     INPUTS  1
     12, 3
     0

UNIT 25      TYPE 25      PRINTER
     PARAMETERS  4
     1.000E+00    1.104E+03    1.128E+03    6.000E+00
     INPUTS  3
      9, 7        12, 3        24, 1
     TAMB         HQLOAD       TQLOAD

END
```

Figure 6.4 Actual input information for the example TRNSYS program depicted in Figure 6.3.

The user needs only to incorporate print and/or plot modules into the program and to identify the source module outputting the desired information. In general, the print and plot modules are utilized in the same manner as other TRNSYS library modules with certain requirements peculiar to the functions they perform.

The form in which the output appears is determined by the printer module. The time interval at which output occurs is user specified. An output for the degree-hour simulation program of Figure 6.3 and 6.4 is shown in Figure 6.5. From Figure 6.3 the desired output sources are identified by noting the UNIT number and the output position number. The output sources the the ambient air temperature (9,7) the heating load (12,3) and the cumulative heating load throughout the simulation period (24,1). These sources become the input to the printer module (UNIT 25, TYPE 25) with the resulting program output shown in Figure 6.5. Automatically included in column one of the output is the time of printout, the printout interval having been specified by the user in the printer module parameter list.

The TRNSYS output of Figure 6.5 is for a simulation period of 24 hours in mid January. The second column is the hourly ambient temperature output directly from the weather data tape. The third and fourth columns are the hourly and cumulative heating loads respectively. The greatest hourly load (6,656 KJ/HR-°C) for the example house occurred the initial hour of the simulation. The smallest load (5,381 KJ/HR-°C) occurred 19 hours into the simulation during the warmest (0°C) hourly outdoor temperature. The methodology of the energy per degree-hour module (TYPE 12) used to simulate the house in this example is discussed in section 6.5.1.

TIME	T_{amb}	HQLOAD	TQLOAD
1104.0000	-5.001E+00	6.656E+03	0.
1105.0000	-4.835E+00	6.613E+03	6.635E+03
1106.0000	-4.612E+00	6.557E+03	1.322E+04
1107.0000	-4.446E+00	6.514E+03	1.975E+04
1108.0000	-4.057E+00	6.415E+03	2.622E+04
1109.0000	-3.723E+00	6.330E+03	3.259E+04
1110.0000	-3.334E+00	6.231E+03	3.887E+04
1111.0000	-3.168E+00	6.188E+03	4.508E+04
1112.0000	-2.945E+00	6.132E+03	5.124E+04
1113.0000	-2.779E+00	6.089E+03	5.735E+04
1114.0000	-2.057E+00	5.905E+03	6.355E+04
1115.0000	-1.279E+00	5.707E+03	6.915E+04
1116.0000	-5.564E+01	6.522E+03	7.477E+04
1117.0000	-3.897E+01	5.480E+03	8.027E+04
1118.0000	-1.675E+01	5.423E+03	8.572E+04
1119.0000	-8.000E+04	5.381E+03	9.112E+04
1120.0000	-5.564E+01	5.522E+03	9.658E+04
1121.0000	-1.112E+00	5.664E+03	1.022E+05
1122.0000	-1.668E+00	5.806E+03	1.079E+05
1123.0000	-1.501E+00	5.763E+03	1.377E+05
1124.0000	-1.279E+00	5.707E+03	1.194E+05
1125.0000	-1.112E+00	5.664E+03	1.251E+05
1126.0000	-1.112E+00	5.664E+03	1.308E+05
1127.0000	-1.112E+00	5.664E+03	1.364E+05
1128.0000	-1.112E+00	5.664E+03	1.421E+05

Figure 6.5 Output from the example TRNSYS program depicted in Figure 6.3.

The general characteristics of the TRNSYS library modules have been discussed and program formulation method has been illustrated using a simple application of the degree-hour (TYPE 12) module. While the example does serve the purpose of illustration, it by no means conveys the full extent to which the TRNSYS simulation system may be utilized.

6.3.2 TRNSYS program: modules TYPE 17, 18, and 19

TRNSYS modules TYPE 17, 18, and 19 account for more of the factors influencing the energy performance of a building than does the TRNSYS TYPE 12 module. The TYPE 12 module accounted for only one influencing factor, temperature difference, as the driving force in the heat transfer process. In addition to the air temperature difference, solar radiation, wind, and thermal capacitance are among the factors considered with respect to their influence on the total energy performance of the residence when TRNSYS modules 17, 18, and 19 are used. Modules TYPE 17, 18, and 19 are incorporated into the program, as it is formulated, in the same manner as any module would be if it represented a real component in a system involving the flow of energy. The simulation methodology used in the TYPE 17, 18, and 19 subroutines is discussed in section 6.5.2.

The second example program, incorporating modules TYPE 17, 18, and 19, is illustrated in the block diagram shown in Figure 6.6. Twenty TRNSYS modules make up the simulation program. Of the 20, only seven carry different TYPE numbers since some are used repeatedly in order to give individual treatment to the building constructions of the home.

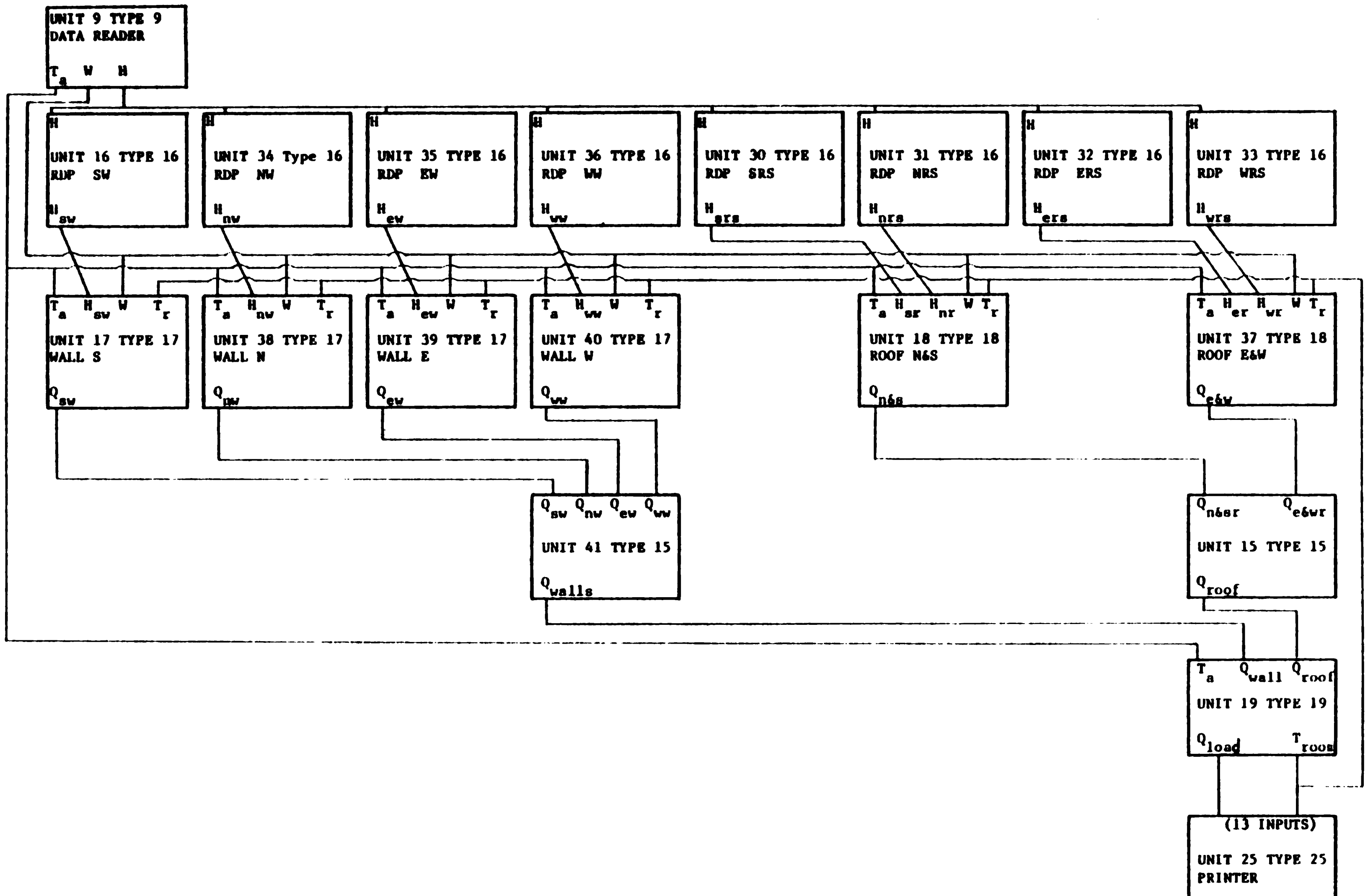

Figure 6.6 An example block diagram of a complete program using the methodology of the TYPE 17, 18, and 19 TRNSYS modules.

The program begins with a TYPE 9 card reader module. This module accesses the weather tape which supplies hourly data on ambient temperature, wind velocity, and solar radiation, the major driving forces considered in the heat transfer processes. The solar radiation information from module TYPE 9 becomes input to eight TYPE 16 modules, the solar radiation processors. The solar radiation modules translate the radiation incident on a horizontal surface, as obtained from the weather data tape, to that incident on a wall or roof surface slope and orientation. The translated solar information output from the solar radiation processors, TYPE 16, is supplied as input to the four TYPE 17 wall modules and the two TYPE 18 roof modules.

A TYPE 17 wall module is used to predict independently the energy flow through each of the four walls of the example house. Each of the four TYPE 17 wall modules receive four inputs. The inputs are translated solar information from the TYPE 16 module, wind velocity and ambient temperature input from module TYPE 9, and room temperature input from the room and basement module TYPE 19. The rate of energy transfer between a wall and the room is the output from each of the TYPE 17 wall modules used in the program. Those four energy flow rates are summed through use of a TYPE 15 algebraic operations module, yielding the total rate of energy flow through the walls of the residence. This quantity then becomes an input to the TYPE 19 module, the room and basement.

Two TYPE 18 roof modules are used to model the rate of energy exchange through the roof/ceiling construction in this example. The example residence described in this program is one with roof ridges running in both the east-west and the north-south directions. This accounts for the roof surfaces facing four different directions. Each of the two TYPE 18 roof modules account for the two opposite facing roof surfaces. Two solar radiation inputs from TYPE 16 modules are required by each of the TYPE 18 modules to account for the two opposite facing roof surfaces. Otherwise inputs to the TYPE 18 roof module are the same as for the TYPE 17 wall modules. The outputs from the two TYPE 18 roof modules are the rate of energy flow between the ceiling and the room. These two outputs are summed through use of a TYPE 15 algebraic operations module before becoming input to the TYPE 19 room and basement module.

TYPE 19, the room and basement subroutine is a major module in the TYPE 17, 18, and 19 method of simulating the thermal performance of a residence in the TRNSYS system. The TYPE 19 module receives the output of TYPE 17 and 18 modules and incorporates this information, along with other inputs and parameters, into an algorithm leading to a determination of the thermal performance of a residence. A provision is made in the TYPE 19 module to account for a variety of user specified sources of heat gains or losses other than through the ceiling/roof and wall building constructions. The example program (Figure 6.6) indicates that three inputs are made to TYPE 19. They are the rate of energy flow between the room and the ceiling, the rate of energy flow between the room and the walls, and the ambient temperature from module TYPE 9.

A TYPE 25 printer module is used to gain output from the example program. This concludes the formulation of the TYPE 17, 18, and 19 program for the simulation of the example house.

All of the input for the TYPE 17, 18, and 19 program is shown in Figure 6.7. The values shown are an accumulation of the information requirements of the eight categories for each of the 20 TRNSYS modules.

```
UNIT 9     TYPE  9       DATA READER
    PARAMETERS 11
    1.000E+01    1.000E+00    7.000E+00    5.560E-01    -1.778E+01    9.000E+00    4.470E-01    0.          1.000E+01
    4.187E+01    0.
UNIT 16    TYPE 16       RDP   S WALL
    PARAMETERS  7
    1.000E+00    1.500E+01    4.200E+01    9.000E+01    0.           4.871E+03    0.
    INPUTS  1
     9.10
    0.
UNIT 35    TYPE 16       RDP   E WALL
    PARAMETERS  7
    1.000E+00    1.500E+01    4.200E+01    9.000E+01    9.000E+01    4.871E+03    0.
    INPUTS  1
     9.10
    0.
UNIT 34    TYPE 16       RDP   N WALL
    PARAMETERS  7
    1.000E+00    1.500E+01    4.200E+01    9.000E+01    1.800E+02    4.871E+03    0.
    INPUTS  1
     9.10
    0.
UNIT 36    TYPE 16       RDP   W WALL
    1.000E+00    1.500E+01    4.200E+01    9.000E+01    2.700E+02    4.871E+03    0.
    INPUTS  1
     9.10
    0.
UNIT 30    TYPE 16       RDP  SR  SURF
    PARAMETERS  7
    1.000E+00    1.500E+01    4.200E+01    2.260E+01    0.           4.871E+03    0.
    INPUTS  1
     9.10
    0.
UNIT 32    TYPE 16       RDP  ER  SURF
    PARAMETERS  7
    1.000E+00    1.500E+01    4.200E+01    1.400E+01    9.000E+01    4.871E+03    0.
    INPUTS  1
     9.10
    0.
UNIT 31    TYPE 16       RDP  NR  SURF
    PARAMETERS  7
    1.000E+00    1.500E+01    4.200E+01    2.260E+01    1.800E+02    4.871E+03    0.
    INPUTS  1
     9.10
    0
UNIT 33    TYPE 16       RDP  WR  SURF
    PARAMETERS  7
    1.000E+00    1.500E+01    4.200E+01    1.400E+01    2.700E+02    4.871E+03    0.
    INPUTS  1
     9.10
    0.
UNIT 17    TYPE 17       S  WALL
    PARAMETERS  6
    1.000E+00    2.973E+01    1.200E-01    0.           8.000E-01    9.000E-01
    INPUTS  4
     9. 7        16. 1         9. 9        19. 2
    0.           0.           0.           0.
    DERIVATIVES  3
    0.           1.000E+01    2.000E+01
UNIT 39    TYPE 17       E  WALL
    PARAMETERS  6
    1.000E+00    3.121E+01    1.500E-01    0.           8.000E-01    9.000E-01
    INPUTS  4
     9. 7        35. 1         9. 9        19. 2
    0.           0.           0.           0.
    DERIVATIVES  3
    0.           1.000E+01    2.000E+01
UNIT 38    TYPE 17       N  WALL
    PARAMETERS  6
    1.000E+00    2.973E+01    1.400E-01    0.           8.000E-01    9.000E-01
    INPUTS  4
     9. 7        34. 1         9. 9        19. 2
    0.           0.           0.           0.
    DERIVATIVES  3
    0.           1.000E+01    2.000E+01
UNIT 40    TYPE 17       W  WALL
    PARAMETERS  6
    1.000E+00    3.121E+01    1.500E-01    5.000E-01    8.000E-01    9.000E-01
     9. 7        36. 1         9. 9        19. 2
    0.           0.           0.           0.
    DERIVATIVES  3
    0.           1.000E+01    2.000E+01
UNIT 18    TYPE 18       N S  ROOF
    PARAMETERS 11
   -2.000E+00    9.360E+01    5.070E+01    2.540E+01    8.000E-01    9.000E-01    0.          1.000E+00 -2.000E+00
    2.000E+00    0.
    INPUTS  6
     9. 7        30. 1        31. 1         9. 9         0. 0        19. 2
    0.           0.           0.           0.           0.           0.
UNIT 37    TYPE 18       E W  ROOF
    PARAMETERS 11
   -2.000E+00    6.240E+01    4.400E+01    4.400E+01    8.000E-01    9.000E-01    0.          1.000E+00 -2.000E+00
    2.000E+00    0.
    INPUTS  6
     9. 7        32. 1        33. 1         9. 9         0. 0        19. 2
    0.           0.           0.           0.           0.           0.
    DERIVATIVES  2
    0.           1.000E+01
UNIT 15    TYPE 15       ALGEB
    PARAMETERS  1
    3.000E+00
    INPUTS  2
    18. 1        37. 1
    0.           0.
UNIT 41    TYPE 15       ALGEB
    PARAMETERS  7
    0.           0.           3.000E+00    0.           3.000E+00    0.           3.000E+00
    17. 1        38. 1        39. 1        40. 1
    0.           0.           0.           0.
UNIT 19    TYPE 19       ROOM BASEMENT
    PARAMETERS 13
    1.000E+00    2.500E-01    5.000E+00    0.           5.000E+01    1.000E+01    1.560E+02    2.440E+00  1.000E+01
    4.000E+04    3.800E+02    1.830E+01    2.388E+01
    INPUTS  3
     9. 7        15. 1        41. 1
    0.           0.           0.
UNIT 25    TYPE 25       PRINTER
    PARAMETERS  4
    1.000E+00    1.104E+03    1.128E+03    6.000E+00
    INPUTS 10
     9. 7        18. 1        18. 2        37. 1        37. 2        15. 1        17. 1        38. 1        39. 1
    40. 1
    TAMB         QNSR         TANS         QEWR         TAEW         TQROOF       QSW          QNW          QEW
    QWW
UNIT 42    TYPE 25       PRINTER
    PARAMETERS  4
    1.000E+00    1.104E+03    1.128E+03    6.000E+00
    INPUTS  3
    41. 1        19. 1        19. 2
    TQW          QLOAD        RTEMP
END
```

Figure 6.7 Input information for the TRNSYS program depicted in Figure 6.6.

Output from the TYPE 17, 18, and 19 program is shown in Figure 6.8. The user may obtain output from any TRNSYS subroutine by specifying the output source in the TYPE 25 printer module. The output of Figure 6.8 is for a simulation of the example house for a period of 24 hours in mid-January. The six outputs in Figure 6.8 are (first row) ambient temperature, heat loss through the north-south roof, attic temperature of the north-south roof, (second roof) hourly heat loss through the house walls, hourly house heating load and indoor temperature.

In this simulation the indoor temperature is allowed to drift between maximum and minimum specified values. As long as the calculated indoor temperature is within the specified limits there is no heating load. This situation can be seen (Figure 6.8) during the first six hours of the simulation. At the start of the simulation indoor temperature was 21 degrees, midway between the maximum and minimum specified values. Since the minimum temperature is satisfied for the first six hours of simulation there is no need for any heating. Gradually the indoor temperature falls to the minimum value specified (18.3 degrees) and heating of the house is necessary beginning the seventh hour of the simulation. The minimum indoor temperature is maintained throughout the rest of the simulation period.

The maximum house heating load (15,880 KJ/HR) is during the eighth hour of the simulation. At this time the heat loss through the walls of the house was 7,328 KJ/HR or 46 percent of the total heating load.

TIME	TAMB	QNSR	TANS
TIME	TQW	QLOAD	RTEMP
1104.0000	-4.992E+00	-3.422E+04	-8.836E-01
1104.0000	-8.917E+03	0.	2.109E+01
1105.0000	-4.825E+00	-2.877E+03	-1.008E+00
1105.0000	-8.397E+03	0.	2.036E+01
1106.0000	-4.603E+00	-2.032E+03	-1.001E+00
1106.0000	-8.276E+03	0.	1.991E+01
1107.0000	-4.436E+00	-1.968E+03	-9.835E-01
1107.0000	-8.122E+03	0.	1.947E+01
1108.0000	-4.047E+00	-1.927E+03	-9.131E-01
1108.0000	-7.918E+03	0.	1.905E+01
1109.0000	-3.713E+00	-1.984E+03	-8.222E-01
1109.0000	-7.719E+03	0.	1.864E+01
1110.0000	-3.324E+00	-1.877E+03	-6.920E-01
1110.0000	-7.542E+03	-1.569E+04	1.830E+01
1111.0000	-3.157E+00	-2.140E+03	-5.873E-01
1111.0000	-7.328E+03	-1.588E+04	1.830E+01
1112.0000	-2.935E+00	-2.135E+03	-3.736E-01
1112.0000	-4.266E+03	-1.276E+04	1.830E+01
1113.0000	-2.758E+00	-2.112E+03	-9.235E-02
1113.0000	-3.650E+03	-1.207E+04	1.830E+01
1114.0000	-2.045E+00	-2.075E+03	4.743E-01
1114.0000	-2.760E+03	-1.095E+04	1.830E+01
1115.0000	-1.267E+00	-2.022E+03	9.566E-01
1115.0000	-4.512E+03	-1.243E+04	1.830E+01
1116.0000	-5.440E-01	-1.960E+03	1.754E+00
1116.0000	-3.658E+03	-1.129E+04	1.830E+01
1117.0000	-3.772E-01	-1.894E+03	1.961E+00
1117.0000	-4.877E+03	-1.233E+04	1.830E+01
1118.0000	-1.548E-01	-1.857E+03	2.129E+00
1118.0000	-5.228E+03	-1.258E+04	1.830E+01
1119.0000	1.200E-02	-1.836E+03	2.210E+00
1119.0000	-5.928E+03	-1.323E+04	1.830E+01
1120.0000	-5.440E-01	-1.828E+03	2.086E+00
1120.0000	-6.660E+03	-1.431E+04	1.830E+01
1121.0000	-1.100E+00	-1.836E+03	1.911E+00
1121.0000	-7.001E+03	-1.459E+04	1.830E+01
1122.0000	-1.656E+00	-1.854E+03	1.686E+00
1122.0000	-7.147E+03	-1.491E+04	1.830E+01
1123.0000	-1.469E+00	-1.874E+03	1.576E+00
1123.0000	-7.155E+03	-1.493E+04	1.830E+01
1124.0000	-1.267E+00	-1.888E+03	1.532E+00
1124.0000	-7.148E+03	-1.492E+04	1.830E+01
1125.0000	-1.100E+00	-1.894E+03	1.522E+00
1125.0000	-7.139E+03	-1.489E+04	1.830E+01
1126.0000	-1.100E+00	-1.897E+03	1.503E+00
1126.0000	-7.153E+03	-1.491E+04	1.830E+01
1127.0000	-1.100E+00	-1.899E+03	1.486E+00
1127.0000	-7.160E+03	-1.492E+04	1.830E+01
1128.0000	-1.100E+00	-1.901E+03	1.472E+00
1128.0000	-7.165E+03	-1.493E+04	1.830E+01

Figure 6.8 Output from the TRNSYS program depicted in Figure 6.6.

6.4 TRNSYS Methodology

The discussion of heat transfer methodology is limited to those TRNSYS library modules that pertain specifically to the simulation of the thermal performance of a building. Basically, there are two methods a TRNSYS system user may employ to simulate the energy performance of a residence. One method is relatively simple while the other method is more complex. The more complex method describes the heat transfer processes in greater detail, thus more closely representing the actual heat transfer situation in a building. Both are available through the flexible programming provision of the TRNSYS simulation system. The method employed depends on the needs, priorities and objectives of the TRNSYS system user.

6.4.1 TRNSYS module TYPE 12

The primary module from the TRNSYS library that achieves the degree-hour simulation of the heating load of a residence is the TYPE 12 subroutine. This module utilizes an approach similar to the degree-day concept for estimating the heating load of a residence. Degree-day values are not used by TRNSYS. Instead, an energy per degree-hour method is used. The equation for the instantaneous heat load, as used in TRNSYS module TYPE 12 is:

$$\dot{Q}L = UA\ (T_r - T_{amb}) = \dot{Q}_{gen} - \dot{Q}_{gain}$$

where $\dot{Q}L$ = instantaneous residence heating load, energy/hour

UA = user determined residence heating requirements, energy/degree-hour

T_r = residence room temperature, degrees

T_{amb} = outdoor ambient temperature, degrees

$\dot{Q}_{gen}$ = constant heat gains (appliances, lighting, people), energy/hour

$\dot{Q}_{gain}$ = time variant heat gains to the residence, energy/hour

The most significant aspect of the TRNSYS degree-hour method is the basis for obtaining the driving force temperature differential, $T_r - T_{amb}$. T_r is user specified, T_{amb} is taken from hourly climatic records for the geographic location in which the residence is located. This provides an hourly accounting of the required energy load rather than a monthly or yearly estimate as when the degree-day concept is used. With the degree-day concept the driving force is based on an accumulation of degrees of temperature difference between the mean daily temperature and 65 degrees F..

Four mode options are available to the user within the TYPE 12 module. These options provide programming flexibility in that one of the options will describe the users existing system. If no real system exists, there are four system options available for experimentation.

Two of the options deal with situations where two sources, auxiliary and solar for example, may both contribute to satisfy the space heating load. In one case the auxiliary source supplies the entire load when the solar supply is inadequate to satisfy the entire load. In the other option the auxiliary source makes up only that part of the total load that the solar source is unable to fulfill. In both of these cases the space load is a function of the user specified room temperature and the heating requirements of the residence.

No auxiliary energy source is included in either the third or fourth mode option of TRNSYS module TYPE 12. The third option is strictly a space load determination on the basis of the user specified room temperature and the residence energy requirements. Application of the mode three option of TYPE 12 to the example residence is illustrated in Figure 6.3, 6.4, and 6.5 in the discussion of program formulation. In the fourth option of module TYPE 12 no room temperature is specified. Instead the thermal capacitance of the residence is specified. The residence capacitance and the residence energy requirements then become the basis for determining the residence room temperature.

6.4.2 TRNSYS modules TYPE 17, 18, and 19

6.4.2.1 TYPE 17 wall

Each exterior wall of a dwelling may be modeled independently using module TYPE 17 of the TRNSYS library. Variations in each wall building construction may be described and, thereby, taken into account with respect to their effect on the thermal performance of the building. Typical information required to describe each wall includes the wall area, the percent of wall area that is window, the percent of window that is shaded, the absorptance of the wall to solar radiation and the infrared emittance of the wall. Weather factors such as solar radiation, wind velocity and ambient air temperature are inputs to TYPE 17 from weather data.

The user has the option of choosing between one of three standard wall constructions or specifying a wall construction composed of his own selection of materials. The latter option requires a thorough understanding of the principles of heat transfer by the TRNSYS user. The three standard wall construction options are an insulated wood frame construction, an uninsulated masonry construction, and a combination wood frame with face masonry insulated construction. All of the material dimensions and thermal properties of the walls have been included in the TYPE 17 subroutine.

Both differential and algebraic equations are used to describe the flow of heat through a wall construction in the TRNSYS TYPE 17 module. Algebraic equations are used to describe the flow at the outside surface node since this node is assumed to have no thermal capacitance. Three additional nodes within the opaque portion of the standard wall constructions are described with differential equations. These equations account for the thermal capacitance of the wall construction materials. Since derivatives are used the user must provide the TYPE 17 module with an approximate value for the initial temperature of each of the three internal wall nodes. The number of derivatives and the approximate initial temperature values are specified in information category seven and eight of the input for a TYPE 17 wall module.

Conduction and radiation are the two means of heat transfer considered in the TYPE 17 module. Conduction through the opaque portion of the wall and conduction through the windows are both considered, but are accounted for through separate calculations. Heat gain as a result of solar radiation through window glass is the other source of heat flow considered. Total heat flow through the wall construction is the sum of the heat flow by the way of the two conduction paths and the heat flow by the way of the radiation path through the window portion of the wall.

6.4.2.2 TYPE 18 roof

The TYPE 18 roof subroutine serves the same purpose in a TRNSYS program as the TYPE 17 wall module except the roof subroutine deals with heat flow through the roof/ceiling constructions. In the case of both the TYPE 17 and the TYPE 18 modules the total heat exchange between the room and the building constructions becomes input to the TYPE 19 room and basement module. The TYPE 19 module uses this information to describe the total thermal performance of the building under study.

The user may select from several standard roof constructions available in the TYPE 18 module. The properties of the standard construction are completely specified within the module. The user also has the option to specify a construction composed of his own selections of building materials. The standard options include a flat roof, with a two or three node option, and a pitched roof with or without solar collectors mounted on it.

Some of the parameters that are provided by the user to the TYPE 18 module that are used to describe a typical roof/ceiling construction include the ceiling area, the areas of the roof surfaces facing different directions roof absorptance to solar radiation, and infrared emittance of the roof surface. The flow of heat through the roof/ceiling assembly is described using both algebraic and differential equations.

6.4.2.3 TYPE 19 room and basement

TYPE 19, the room and basement subroutine, incorporates the inputs from the TYPE 17 and the TYPE 18 modules and other sources into an overall dwelling space heating or cooling load simulation. In addition to the load contributions from the heat flow through the ceiling and walls the contributions due to infiltration, basement construction and internal heat sources are taken into account through parameters specified by the user. Other user specifications include option code numbers, indicating the user's preferences, and the physical dimensions describing the dwelling under study. The TYPE 19 subroutine uses the same methods to describe the heat transfer processes as the TYPE 17 and 18 subroutines employed.

A significant aspect of the TYPE 19 room and basement subroutine is the two options available to the user regarding the simulated control over the heating or cooling system. The two control options are referred to as the energy rate control (mode 1) and the temperature level control (mode 2).

With mode 1, energy rate control, the room temperature is determined based on all of the heat losses or gains considered in the TYPE 17, 18, and 19 modules. The calculated room temperature is compared with user specified upper and lower room temperature limits. If the calculated room temperature is above the upper acceptable limit a cooling load occurs. If the calculated room temperature is below the specified lower room temperature limit, a heating load occurs. When the calculated room temperature is between the upper and lower user specified limits a no load situation is assumed. When the latter situation exists no load is output for that time step.

The heating or cooling load that is calculated for a particular time step, when the mode 1 option is being used, is assumed to be fully satisfied, instantaneously, by an unspecified source. In a real situation the space load demand is not met instantaneously. Both the heating or cooling system has inherent start-up and shut-down characteristics affecting its output over time. However, fewer TRNSYS components are needed to simulate the thermal performance of a residence when the mode 1 option is selected and the resulting load determination is suitable for many purposes.

The mode 2 option of the TYPE 19 subroutine is called the room temperature level control. In this option TYPE 19 determines the dwelling space load as in mode 1. In addition it considers the energy transferred into the room from sources such as a furnace or solar heat supply. In this way the user can simulate various space conditioning systems in order to study their effectiveness in satisfying the space load demand. The output of the modules simulating the energy supply becomes input to the TYPE 19 module and is considered along with other energy sources in attempting to satisfy the space load of the dwelling. The energy source may or may not have the capability to satisfy the space load demand. This will be reflected by the room temperature output form TYPE 19.

The performance characteristics of the energy source and any related components are taken into account in the mode 2 option. As more factors are accounted for the situation becomes more realistic and accurate. Energy source system components can include modules from the TRNSYS library representing solar system devices, heat exchangers, temperature controllers and others.

6.5 Summary of the TRNSYS Program

The unique feature of the TRNSYS program is the modular simulation technique. This feature allows the user to create programs to simulate a variety of systems addressing building energy performance. There is no set input form for a TRNSYS program because the input depends on the subroutines selected for use in the simulation. Each subroutine requires the same TYPE of information. The total input for a TRNSYS program is an accumulation of the inputs for each of the subroutines used to make up the program.

To make use of the TRNSYS simulation system the user needs to perform two tasks. First, the desired program has to be developed from TRNSYS modules. Second, the required input information has to be specified. To complete the first task the user should have knowledge of the relationship between the physical components of the system to be simulated. To complete the second task the user should have knowledge of the factors affecting the performance of the system's components. For the components used in this study the user should have knowledge of the factors affecting the heat transfer in buildings. A knowledge of computer programming is not required by the user in order to use the TRNSYS simulation system.

Both algebraic and differential equations are used in TRNSYS. Differential equations are used to describe the heat transfer situations taking place under transient conditions. The only way the user is involved with differential equations is in specifying the initial values of the dependent variables when required.

7. THE NBSLD PROGRAM

7.1 Purpose of NBSLD

The National Bureau of Standards Load Determination (NBSLD) program was developed at the National Bureau of Standards by Kusuda (1976a). The purpose of NBSLD is to aid in the thermal design of buildings by providing a means of accurately determining heating and cooling loads. The organization of NBSLD consists of an executive program and numerous subroutines. Some of the subroutines may be used individually as main programs when only the information provided by that subroutine is of particular interest.

The NBSLD program is flexible with provision for several modes in which it may be used. It can be used to determine the design heating and cooling load for a structure based on summer and winter design conditions or it can be used for a determination of the instantaneous heating and cooling loads based on hourly weather data for a particular location. Within both of these modes there are additional options available to the user. This flexibility permits the user to thoroughly evaluate each aspect of a structure that may affect its thermal performance. In addition to its thoroughness and accuracy the NBSLD program incorporates several unique features of thermal analysis not available in other heating and cooling load calculation programs.

The NBSLD program was applied to the residence described in section 4.0. The input and the various outputs are discussed in the following sections. Figure 7.1 is the input for the NBSLD simulation of the example residence. The input data of Figure 7.1 is included in Appendix C in a completed NBSLD input form. Figure 7.2 shows that two types of output are obtained from NBSLD when the design day option is selected. Each is produced by different NBSLD subroutines. Figures 7.3 and 7.4 are examples of the design day outputs obtained. Figure 7.5 illustrates a third output can be obtained when the hour-by-hour method of simulation is selected. This simulation method employs an hourly weather record to simulate actual climate conditions. Figure 7.6 is an example of an hour-by-hour simulation.

7.2 Input to NBSLD

Most of the input information to the NBSLD program falls into one of three categories: (1) building operating data, (2) building physical data, and (3) climatic data.

The building operating data category of input consists of information regarding potential sources of heat generation within the building and information regarding ventilation air characteristics. The operating schedules of lighting, equipment, and appliances which may add to the cooling load or alleviate the building heating load are input on an hour-by-hour basis. Acceptable limits of ventilation air temperature and ventilation air rates are also inputs in this category.

A description of the physical aspects of the building that influence its thermal performance are inputs in the category on building physical data. Room dimensions, constant heat transfer coefficients, building material properties, infiltration rates, type of heat transfer exposures, exposure areas, and exposure orientations are typical of the input data in this category. The building physical data category requires the greatest amount of input information to the NBSLD program.

The climatic data category of input includes information on the geographic location of the particular building, summer and winter design conditions, and the time of year in which the simulation is being done. Some of the information in this category is used by the program to select the appropriate weather data from a weather data tape used when the program is run in the hour-by-hour simulation mode.

Information in the first two categories may be used to describe the specific characteristics of a particular space within a structure such as a single office in a large office building. In a like manner this information may also be used to describe a single room within a residence when such a detailed thermal analysis of the structure is desired. For the discussion in this study the entire house is considered to be a single room since most residences strive to have nearly uniform thermal conditions throughout the inhabited space. However, should it be desired to investigate the effect of isolating certain rooms or functional areas from the heating system the NBSLD program has the capability to do so. Considering the entire house as a single room in no way alters the running of the NBSLD program other than to reduce the amount of input information and to shorten the computation time.

Input to the NBSLD program is achieved by completing the input data form in Appendix C. The NBSLD input form contains 34 data fields, each requiring a varying amount of numerical or alphanumeric information. The total amount of input data required to complete the 34 input fields depends on the complexity of the various building constructions and/or the complexity of the building configuration. The input fields that are not self-explanatory are described in the following discussion.

There are five inputs in field one. RUNID is an index for the calculation of conduction transfer functions with a 1 indicating a calculation of transfer functions is desired. For the RUNTYP variable, the user must input either the value 1 or the value 2. A 1 indicates a desire to have an hour-by-hour determination of the heating and cooling load using hourly weather information. A value 2 indicates an interest in the design heating and cooling load for which hourly weather information is not required. The input for the ASHRAE variable is 0. This signifies the use of the exact calculation procedure to convert the heat gains and losses to loads. The other option, the weighting factor method, is incomplete. The variable IDETAL controls the amount of NBSLD output. If a 0 is used, the output is the heating and cooling loads. If a 1 is used, the output will include the input data, the heating and cooling loads, and details of intermediate calculations. The input to the METHOD variable is 0 signifying the radiation exchange among the room surfaces is to be treated on a room-by-room basis (in this study the residence was assumed to be a single room). No other option is currently available.

Input fields three through 11 are daily schedules for lighting, appliance and equipment operation, and building occupancy for weekdays, weekends, and holidays respectively. Values between 0 and 1 are input to these nine fields. These are normalized values with the maximums specified elsewhere in the input. Input fields 12 and 13 are 24-hour profiles of thermostat settings during cooling and heating situations. Input field 14 contains maximum and minimum limits for indoor temperature and humidity. Input field 15 specifies the simulation starting time and duration. Input field 16 is data pertaining to design conditions used when no weather tape is available.

Input fields 19-21 describe the various building constructions. They are used as input into the NBSLD program as many times as there are different types of constructions in the building. The exterior walls of a typical woodframed residence, for example, may be described using two different constructions since the rate of heat transfer through the wall at the framing is likely to differ from the heat transfer rate through the wall between the framing members. The construction at the stud framing might consist of four layers of materials. In a typical construction they would be (from the inside out): gypsum board, wood stud, sheathing material and siding. Through the stud cavity construction there are four layers of materials, typically: gypsum board, insulation, sheathing and siding.

Using the construction at the stud framing as an example, input into field 19 would have the value 4, indicating the number of layers of materials. Information input into field 20 consists of five items: material thickness, thermal conductivity, density, specific heat and thermal resistance. This information is input as many times for each construction as there are different material layers in that construction (i.e., four times in this example). Field 21 is a provision for an alphanumeric description of each of the corresponding material layers input into field 20. Information is input into field 21 as many times for each construction as there are different material layers. This alphanumeric information does not enter into the calculations with the program, but appears in the output for clarity purposes.

The total amount of input into fields 19-21 required to describe the wall construction at the stud framing is nine punch cards or lines depending on mode of input. This is an accumulation of one entry in field 19, the number of layers of materials in the construction, and four entries for each of the fields 20 and 21.

It is the input information of fields 20 and 21 that is required for a determination of the conduction transfer functions (discussed in section 7.4.4), one of the features of the NBSLD program. Specifying input information of this detail may require more effort than is required for obtaining the input for most other heating and cooling load determination programs. However, unless the user is doing research involving many unusual materials or building constructions, the conventional materials of construction are not so numerous nor the typical building constructions so varied that the specifying of input for fields 19-21 becomes a difficult, time consuming task. The NBSLD program has the capability to store the conduction transfer functions once they have been computed for a particular construction and recalled whenever that same construction is again encountered. The storage mode is selected through input of the RUNID variable in input field one. By having to calculate the conduction transfer functions only once for each construction the amount of input and computer computation time is reduced.

The information input into fields 29-31 pertains to a description of the configuration of a building. In field 29 there are eight items of input. They are an identification of the type of exposure (i.e., wall, roof, etc.), a code relating this exposure to one of the constructions described in fields 19-21, the area of the exposure, and the orientation angle of the exposure in degrees clockwise from the south. The four remaining inputs to field 29 include the overall heat transfer coefficient of the exposure, a shading coefficient, and a shadow parameter indicating whether or not external shading of the exposure occurs.

Fields 30 and 31 provide for input having to do with external shading devices such as overhangs and window fins. All the input in fields 30 and 31 are in the form of dimensions locating the shading device with respect to the shaded window or wall.

Fields 29-31 are input as a unit into the NBSLD program as many times as there are different exposures. There may be only one input each for the roof-ceiling and for the floor constructions. Simply shaded structures may be described with a small amount of input. The NBSLD program has the capability to accomodate very complex configurations when necessary.

Only in fields 19-21 and fields 29-31 is the amount of input information variable from one computer run to the next. The input into the remainder of the 34 input fields is independent of the various constructions and differing configurations of the building. Once the input form is completed the information may be input into a computer by way of the punched card mode or interactively depending on the desire of the user and the available computer input facilities.

The NBSLD program was applied to the example house described in section 4.0. Figure 7.1 is the input data to NBSLD for the example home. This same input is included in the NBSLD input form in Appendix C.

7.3 Output from NBSLD

Due to the nature of the input information and the structure of the NBSLD program there are two design load outputs produced when the design day mode (RUNTYP = 2) is used. To illustrate how the NBSLD program functions in the RUNTYP = 2 mode a schematic representation of the relationship between the type of input, the program structure, and the output is shown in Figure 7.2. The two outputs (Figure 7.3 and Figure 7.4) are design day loads calculated on the basis of the input of design day conditions. Each of the outputs is produced by a separate segment of the NBSLD program using a different heat transfer calculation methodology.

The design load output in Figure 7.3 was produced mainly by the NBSLD subroutine, winter. This subroutine employs steady state heat transfer methodology. The three items appearing in this output are the sensible heating load (11,017 BTU/HR), the latent heating load (0), and the total design heating load for the residence (11,017 BTU/HR). Subroutine winter is used only when the NBSLD program is run in the RUNTYP = 2 mode.

As illustrated in Figure 7.2 there is a second design day output from the NBSLD program. The subroutines that produce this output have

```
1.2.0.1.0
  MSU HOUSE
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
78..78..78..78..78..78..78..78..78..78..78..78..78..78..78..78..78..78..78..78.
78..78..78..78.
68..68..68..68..68..68..68..68..68..68..68..68..68..68..68..68..68..68..68..68.
68..68..68..68.
68..78..25..60.
3.0.0
1..16..15..23..00..20..23..41..41....64.67.42.43.5..0..20.
  NO ATTIC NO CEL
0.0.1
4
.03937..42.50...2.0
.383  ..025.2...2.0
.03937..07.37...3.0
.03937..07.37...3.0
GYPSUM BOARD
FIBR INSULATION
SHEATHING /DECKING
SIDING/ROOFING
4
.03937..42.50...2.0
.29528..07.27...3.0
.03937..07.37...3.0
.03937..07.37...3.0
GYPSUM BOARD
STUD
SHEATHING
SIDING
2
.333.1..140...2.0
1...2.95...19.0
CONCRETE SLAB
FOOT EARTH
5
0..0..0..0..21.
.03937..42.50...2.0
.29528..025.2...2.0
.03937..07.37...3.0
.03937..07.37...3.0
CEILING/AIR SPACE
GYPSUM BOARD
SHEATHING/DECKING
SIDING/ROOFING
4
.03937..42.50...2.0
.511  ..025.2...2.0
.03937..07.37...3.0
.03937..07.37...3.0
GYPSUM BOARD
FIBR INSULATION
SHEATHING /DECKING
SIDING/ROOFING
0
1..0..0..0..0..0..0..0..0..0...02.1.
3.0.8.17
78..68..99000..99000..68..50.
0.0
2.2.2.2
50..30..8.
1.5.1500..0..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
2.1.360..0..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
2.2.40..0..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
2.1.216..90..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
2.2.24..90..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
2.1.360..180..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
2.2.40..180..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
2.1.216..-90..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
2.2.24..-90..0..0...78.0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
5.3.1500..0..0..0..0..0
0.0.0.0.0.0.0
0.0.0.0.0.0.0.0.0
0..0..0..0..0..1.
0.0.0.0.0
```

Figure 7.1 Input values to the NBSLD program describing the example residence.

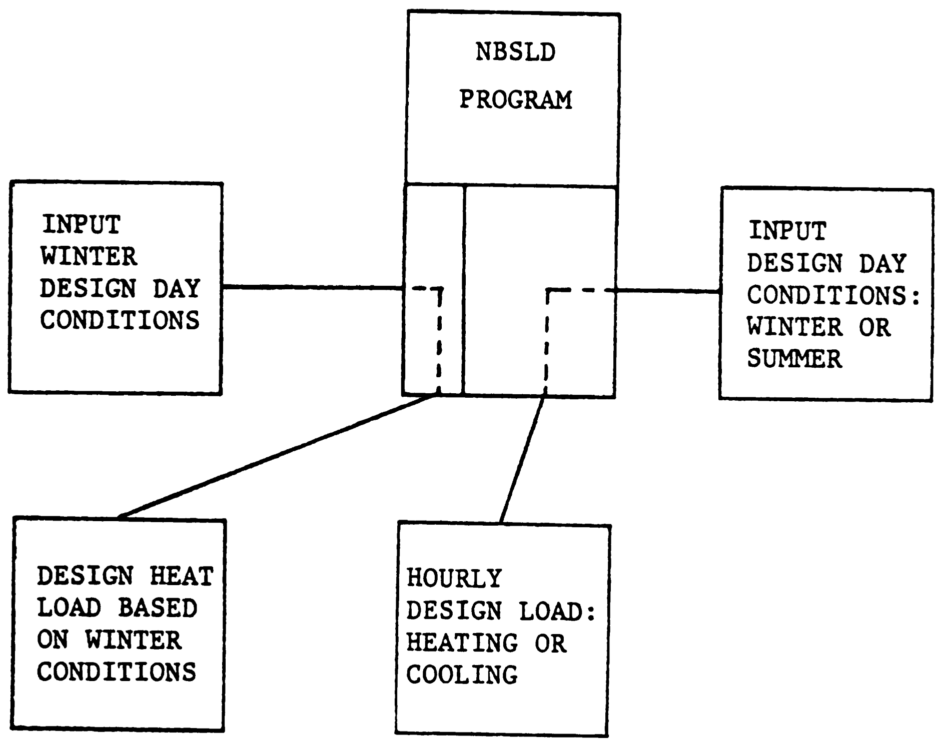

Figure 7.2 Type of output produced when the NBSLD program is run in the Design Day mode (RUNTYP = 2).

```
HEATING LOAD IN BTU PER HOUR
        SENSIBLE LOAD =     10955.
        LATENT   LOAD =         0.
        ------------------------------
        TOTAL    LOAD =     10955.
```

Figure 7.3 Design day heating load output from the NBSLD program.

the capability of determining the heat flow through the constructions of a building under unsteady state conditions in either a heating or cooling situation. Thus, the resulting output is the design heating load for the structure if winter design conditions are input into the program; or the design cooling load for the building if summer design conditions are input. A design day heating load output is shown in Figure 7.4. The format of the output is the same whether the output is a heating or cooling load. In the cooling load output a negative sign preceeds the load values indicating cooling. The output is displayed in hourly printouts for a 24-hour period with each hourly printout consisting of seven items of information. In order of appearance in the printout they are: (1) the hour of the day, (2) the outdoor drybulb temperature, (3) the outdoor wetbulb temperature, (4) the indoor drybulb temperature, (5) the indoor relative humidity, (6) the sensible heat load (QLS), and (7) the latent heat load (QLL). In addition to the 24 hourly printouts there is output information on the total load (269,098 BTU), the maximum hourly load (11,810 BTU), and the time that the maximum hourly load occurred (8th hour).

To this point the discussion concerning ouptut from the NBSLD program has considered only the case when the design day mode (RUNTYP = 2) is utilized. Figure 7.5 illustrates that a third heating or cooling load output may be obtained from the NBSLD program. This output is achieved by assigning the value 1 to the RUNTYP variable resulting in an hour-by-hour simulation of the thermal performance of the structure. The resulting output is produced by the same group of subroutines in the NBSLD program that produced the hourly design day outputs discussed

TIME	DBOUT	WBOUT	DBIN	RHIN	QLS	QLL
1	23.0	20.2	68.0	25.0	12073.	39.
2	23.0	20.2	68.0	25.0	12074.	39.
3	23.0	20.2	68.0	25.0	12074.	39.
4	23.0	20.2	68.0	25.0	12075.	39.
5	23.0	20.2	68.0	25.0	12076.	39.
6	23.0	20.2	68.0	25.0	12077.	39.
7	23.0	20.2	68.0	25.0	12078.	39.
8	23.0	20.2	68.0	25.0	12078.	39.
9	23.0	20.2	68.0	25.0	12079.	39.
10	23.0	20.2	68.0	25.0	12080.	39.
11	23.0	20.2	68.0	25.0	12080.	39.
12	23.0	20.2	68.0	25.0	12081.	39.
13	23.0	20.2	68.0	25.0	12081.	39.
14	23.0	20.2	68.0	25.0	12082.	39.
15	23.0	20.2	68.0	25.0	12083.	39.
16	23.0	20.2	68.0	25.0	12083.	39.
17	23.0	20.2	68.0	25.0	12083.	39.
18	23.0	20.2	68.0	25.0	12084.	39.
19	23.0	20.2	68.0	25.0	12084.	39.
20	23.0	20.2	68.0	25.0	12085.	39.
21	23.0	20.2	68.0	25.0	12085.	39.
22	23.0	20.2	68.0	25.0	12086.	39.
23	23.0	20.2	68.0	25.0	12086.	39.
24	23.0	20.2	68.0	25.0	12086.	39.

TOTAL COOLING CONSUMPTION PER DAY = 0. BTU
TOTAL HEATING CONSUMPTION PER DAY = 290877. BTU
MAX COOLING LOAD = 0. MONTH = 0 DAY = 0 HOUR = 0
MAX COOLING LOAD = 12126. MONTH = 1 DAY = 16 HOUR = 24

Figure 7.4 Hourly Design Day heating load output from the NBSLD program.

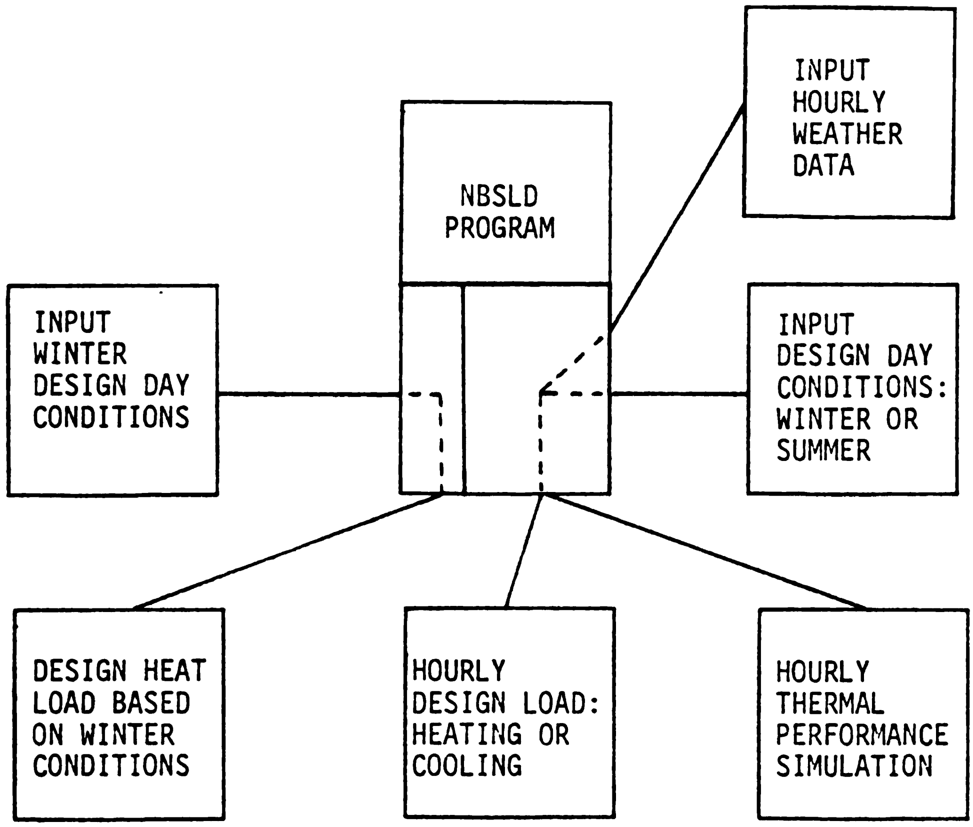

Figure 7.5 Type of output produced when the NBSLD program is run in the simulation mode (RUNTYP = 1).

previously. The difference between the design day output and the hour-by-hour simulation is that the design day output is based on a single set of conditions likely to occur only at one time during the year. The hour-by-hour simulation is based on a continuous hourly record of weather information.

No weather tape compatible with the NBSLD program was available for hour-by-hour simulations. Since NBSLD could not be run in the hour-by-hour simulation mode an example output from the NBSLD program manual (Kusuda, 1976) is shown in Figure 7.6. This output is for the simulation of an office building during January. The maximum hour heating load was for the eighth hour of day two at 74,977 BTU when the average outdoor temperature was 24 degrees. The maximum day heating load was the 17th day at 1,768,679 BTU when the available outdoor temperature was 13.8 degrees.

7.4 NBSLD Methodology

In simulating the thermal performance of a building the NBSLD program takes a comprehensive approach. First, provision is made to account for the factors, both climatic and building related, that influence the energy exchange process. Secondly, NBSLD uses an energy exchange scheme that represents the complex energy exchange processes that take place simultaneously within the room and between the indoor air and the outside environment. Thirdly, the NBSLD program translates the energy exchange scheme into a simulation procedure that captures the realistic effects of the energy exchange process and estimates the thermal performance of a building. Following is a discussion of some of the

	DAY	MHR	QLMAX	CLDAY	HLDAY	DBA
1	1	24	67266.	0.	833917.	33.4
1	2	8	74977.	0.	1557859.	24.0
1	3	8	69210.	0.	1339045.	28.8
1	4	8	51673.	0.	767721.	41.8
1	5	24	46525.	0.	829164.	36.1
1	6	6	54181.	0.	1099831.	31.3
1	7	8	49389.	0.	982197.	35.5
1	8	4	43912.	0.	923993.	35.5
1	9	4	44824.	0.	851840.	36.7
1	10	24	49385.	0.	871738.	37.6
1	11	9	64347.	0.	1239178.	28.5
1	12	4	54753.	0.	1079643.	32.6
1	13	24	46914.	0.	855627.	37.5
1	14	24	71760.	0.	1394308.	24.4
1	15	17	72942.	0.	1742967.	17.4
1	16	7	72919.	0.	1588378.	22.8
1	17	15	74586.	0.	1768679.	13.8
1	18	11	73647.	0.	1680665.	18.2
1	19	4	74156.	0.	1430075.	25.0
1	20	5	63771.	0.	1141373.	32.5
1	21	8	46194.	0.	765276.	40.3
1	22	5	31852.	0.	436868.	48.6
1	23	24	48898.	0.	335641.	49.1
1	24	8	68003.	0.	1301764.	25.4
1	25	6	56741.	0.	1157575.	30.0
1	26	6	48566.	0.	826622.	38.5
1	27	1	37008.	0.	707440.	40.8
1	28	8	40155.	0.	797525.	37.2
1	29	8	43283.	0.	789407.	38.5
1	30	8	42105.	0.	789377.	38.0
1	31	8	43971.	0.	875430.	35.2

MONTHLY COOLING LOAD= .00000000 BTU

MONTHLY HEATING LOAD= .32761124+08 BTU

MAX COOLING LOAD = 0. MONTH = 0 DAY = 0 HOUR = 0
MAX HEATING LOAD = 74977. MONTH = 1 DAY = 2 HOUR = 8
TOTAL COOLING CONSUMPTION FOR 1 ROOMS = .00000 BTU
TOTAL HEATING CONSUMPTION FOR 1 ROOMS = .32761+08 BTU

Figure 7.6 Example of hour-by-hour simulation output from the NBSLD program (Kusuda, 1976a).

specific features of the NBSLD program methodology that makes it comprehensive in nature.

7.4.1 Factors describing heat loss and heat gain

Numerous factors have influence on the processes of energy transfer into or out of a building. To totally describe these exchange processes the factors in the categories of climate, building operations, and building constructions must all be considered. In the NBSLD program climatic conditions and building operating characteristics are accounted for on an hourly basis. By accounting for the various factors on an hourly basis the realistic effects of the factors on building energy performance are considered (Black, 1977). Using time periods longer than an hour may cause the critical peak maximum or minimum values of some factors to be missed and result in the actual situation not being accurately represented. Climatic factors considered on an hourly basis in the NBSLD program are air temperature, solar radiation, and wind velocity. Ground temperature is a climatic factor, but it does not fluctuate enough to warrant an hourly accounting. Instead ground temperature values for summer and winter are separate inputs to the NBSLD program. Building operating factors that are considered include hourly load contributions from lighting, appliances or equipment, and occupants. Also considered is the daily schedules for ventilation and room thermostat adjustment.

In addition to the hourly factors, the characteristics of the building constructions are taken into account. The building constructions are considered with respect to the properties of the individual materials of which they are composed. Individual material properties that are taken into account include density, thermal conductivity, and specific heat. Entire building constructions are evaluated for their thermal behavior under changing environmental conditions. The thermal behavior of a building construction depends on the individual material properties and on the position of individual materials with respect to one another in the building construction. Two building constructions with equal U values may not exhibit equal thermal performance when exposed to fluctuating temperature situations (Kusuda, 1976b). Infiltration air is another factor that has to be taken into account since it contributes to the heating and cooling load of the residence. Infiltration is not so much a property of individual building materials, but more a function of workmanship and the proper assembly of construction components into the building envelope. In the NBSLD program infiltration is handled through a single input value representing the room air changes per hour.

The factors in the categories of climate, building operation, and building constructions represent a large amount of information on which the NBSLD program bases its comprehensive approach for simulating the thermal performance of a building. The comprehensive approach enables the energy transfer processes to be more realistically described than when only one or two parameters are used.

7.4.2 Energy exchange scheme

When two dissimilar environments are separated by the building constructions of a dwelling, a network of dynamic energy flow is formed. The comprehensive approach taken by the NBSLD program enables this heat flow network to be thoroughly represented. At any instant in time the energy exchange process (either heating or cooling) simultaneously involves each of the basic methods of heat transfer; conduction, convection, and radiation.

In a typical residential situation several energy sources may be imparting energy simultaneously to the furnishings, to the building constructions and to the air. The masses and the air, in turn, exchange energy between one another. Figure 7.7 illustrates the energy exchange processes between the indoor air and outdoor environment. This illustration is simplified since it depicts the energy flow through only one building construction and considers all the internal energy sources as one. In reality the energy exchange processes involving an entire room would be depicted by repeating the diagram in Figure 7.7 for each building construction having a different orientation. Also, it would include a separate consideration for each internal source of energy generation. To simulate the energy exchange process each conduction, convection, and radiation transfer of energy is represented in a mathematical equation in the NBSLD program. Once described in mathematical terms the solution of these equations leads to the energy load for a particular structure.

7.4.3 Heat balance equations

In the NBSLD program heat balance equations are used to account for the energy flow at the interior room surfaces by taking into account the energy sources and exchanges within the room (Figure 7.7). The sources and exchange processes include: (1) solar energy absorbed directly by

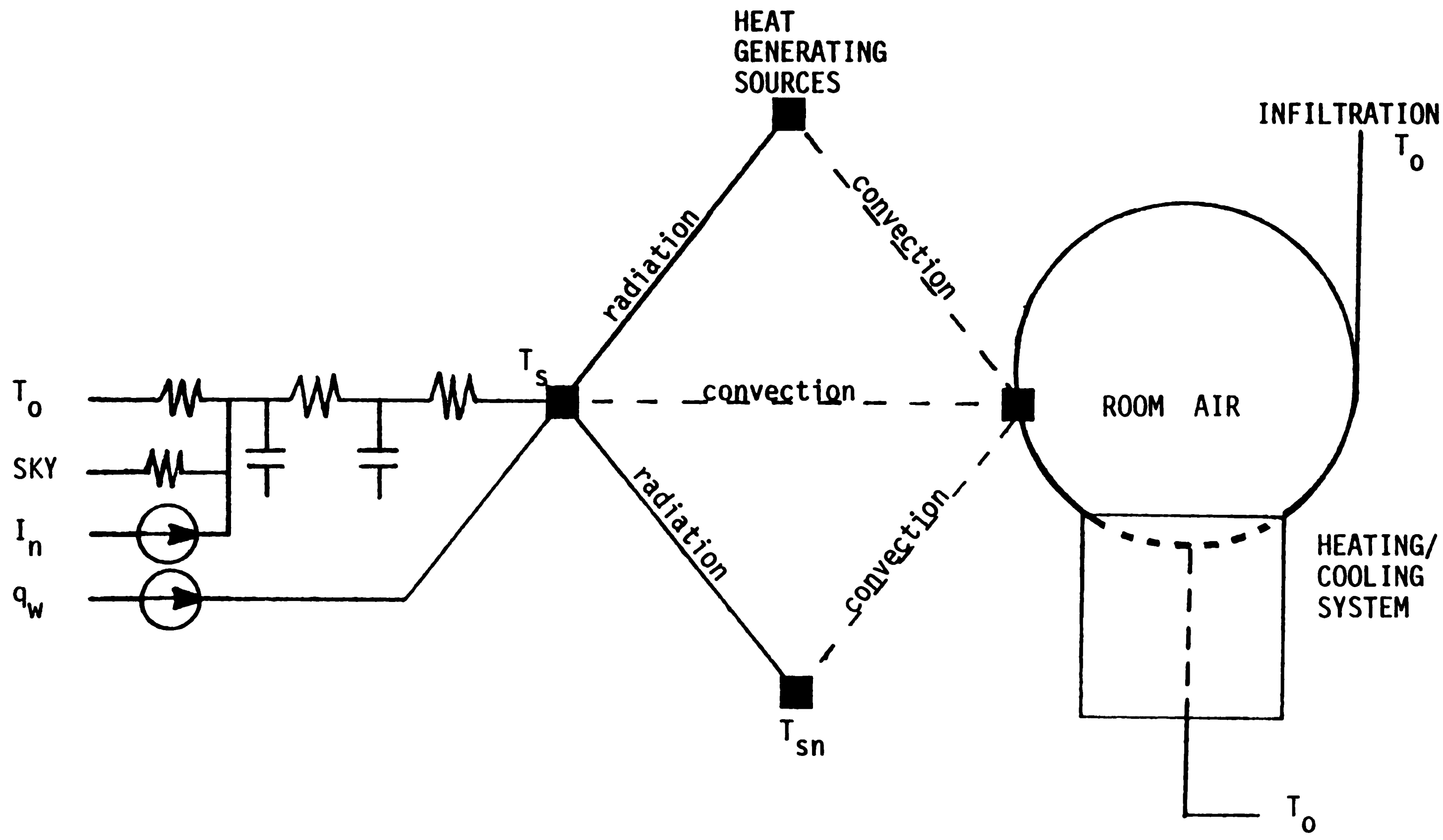

Figure 7.7 Simplified illustration of the energy exchange process simulated by the NBSLD program.

interior room surfaces, (2) radiative exchange of energy between internal heat generating sources (lights, equipment or appliances, and occupants) and room surfaces, (3) convective exchange or energy between the internal heat generating sources and room air, (4) radiative exchange between the various room surfaces, and (5) convective exchange between room surfaces and room air. In addition to these radiative and convective exchanges the contributions of ventilation air and infiltration air are taken into account.

Energy flow at the room surface is influenced by the heat transfer process taking place simultaneously on both sides of the surface. On the room side the exchange processes discussed above influence the energy flow. On the opposite side (within the building constructions) conduction through the materials of construction influences the energy flow at the room surfaces. One heat balance equation is necessary to account for the energy flow at the room surface of every building construction enclosing the room and having dissimilar parallel paths of heat flow. At the very least six heat balance equations are required to represent the surface heat flow in a room consisting of four walls, a floor, and ceiling. Additional heat balance equations are required if there are dissimilar parallel paths of heat flow through any wall and if the user chooses to account for this construction variation. For example, in a stud framed wall the NBSLD program has the capability to account for the heat flow at the surface of the framed area of the wall and the parallel heat flow at the surface of the stud cavity area of the wall.

7.4.4 Conduction transfer functions

In the NBSLD program the conduction energy flow through a building construction is mathematically described using conduction transfer functions. Transfer functions are a set of coefficients that relate an output function to the value of a driving function, such as temperature. In NBSLD conduction transfer functions are calculated through the solution of the standard transient heat conduction differential equation.

The number of transfer function coefficients determined for a specific building construction is related to its massiveness. Heavy concrete or brick constructions may require the calculation of 40 to 50 coefficient terms. Lighter weight wood frame constructions, with less potential for thermal storage or damping, may require fewer than 10 terms to represent its energy transfer characteristics. As each transfer function is calculated, it is subjected to a test procedure within the transfer function subroutines of NBSLD. This test is to determine its significance in terms of its contribution to the description of the heat transfer characteristics of the construction. Calculation of the transfer function coefficients continues as long as they are significant, based on the test criteria specified in the NBSLD subroutines.

Once they have been calculated, the transfer function coefficients are used by other subroutines of the NBSLD program to determine the energy flow through the various building constructions. The rate of energy flow into or out of a construction surface results from a summation of the products of the transfer function coefficients and the driving function (construction surface temperatures). Building construction surface temperatures are derived from hourly records of indoor and outside environmental conditions. Outside environmental conditions come from the hourly history of climatic factors. Inside environmental conditions are either calculated from the energy exchange processes taking place within the room or they are prescribed, depending on the mode the NBSLD program is functioning in. In either case a history of surface temperatures is generated which is used as the driving functions for the calculation of the conduction transfer functions. The multiplication and summation procedure is carried out over as many preceeding hourly time intervals as there are significant transfer function coefficient terms for the particular construction.

Use of the conduction transfer functions enables the NBSLD program to simulate the thermal performance of a building construction under changing thermal conditions. Under steady state conditions two building constructions with equal U values, but with unequal masses will transfer heat at the same rate. When the same two building constructions are subjected to a randomly fluctuating environment, they may not transfer energy at the same rate. The more massive building construction will tend to dampen the effects of the extreme maximum and minimum environmental conditions on the heat transfer rate. Lighter weight constructions will exhibit a heat transfer rate more closely dictated by the fluctuating environmental conditions. The benefit of damping the effects of extreme environmental conditions is that lower heating and cooling loads may result and smaller capacity heating and cooling equipment can be utilized.

7.4.5 NBSLD simulation formats

Four different variations of energy load and room temperature determinations are possible through the NBSLD program. These variations are controlled by the two variables, ITHST and ITK, in input field 26. ITHST and ITK can be assigned values of either 1 or 0. Four numerical combinations result which direct NBSLD to follow one of four formats in the simulation. The four simulation formats demonstrate the effect that room temperature and/or heating and cooling system characteristics have on the predicted heating/cooling load and room temperature. Each of the four simulation formats are discussed below.

In the first format the desired hourly house temperature profile is prescribed. The prescribed temperature profile can reflect night time thermostat setback or some other temperature configuration. From the desired temperature format the resulting heating and/or cooling load is determined without limits on the heating and cooling load system capacities. If the period of simulation falls entirely within the heating season the effects of various hourly house temperature profiles on the heating load can be demonstrated. If the simulation period is during the summer months, necessitating cooling, the effect of the desired temperature profiles on the cooling load can be demonstrated. During a transition season both heating and cooling loads may result from some house temperature profiles. Experimentation can establish the room temperature profile that results in the lowest heating and cooling load and still maintains acceptable comfort levels.

The second format lets the user explore how a building reacts thermally when it is neither heated nor cooled mechanically. In the second format the heating/cooling load remains at zero. The room air temperature is allowed to assume whatever value it may as a result of all energy gains and losses except the gain or loss caused by the heating or cooling system. Solar heat gains and the effect of internal mass are two of the factors which can be examined for the effects they have on the computed floating room temperature.

The third and fourth formats are combinations of the first and second formats with some additional features. In the third format upper and lower hourly room temperature profiles are prescribed that represent acceptable occupant comfort levels in both heating and cooling situations. These profiles establish a band through which the room temperature can drift without any heating or cooling load being computed. The room temperature is maintained within the prescribed comfort band by the heating and cooling systems without any capacity limits placed on them. The capacities of the heating and cooling equipment are determined which will satisfy the specified temperature boundaries.

The fourth format is the same as the third with one significant exception. In the fourth NBSLD program format maximum capacities are specified for the heating and cooling systems. Maximum and minimum hourly room temperature limits are also specified. The heating and cooling systems attempt to maintain the room temperature within the prescribed limits. If the equipment capacities are sufficient, the desired conditions will be maintained. If the equipment is unable to maintain the temperature within the desired limits the room temperature will drift outside of the specified limits. This simulation capability permits the evaluation of heating and cooling system capacities relative to the equipment's ability to maintain acceptable room temperature levels. If a heating or cooling system is not able to completely satisfy the specified temperature levels, other factors influencing building energy performance can be modified to make up for the deficiency rather than using a large capacity mechanical heating or cooling system.

The four NBSLD simulation formats provide flexibility that can be used to evaluate various aspects of the energy performance of a building. Many variations in climate, building, and heating/cooling system interactions can be investigated.

7.5 Summary of the NBSLD Program

The NBSLD program is for the thorough investigation of the heating and cooling load of a building. The thoroughness of the NBSLD simulation can be attributed to three program characteristics. They are: (1) the capability to account for the many factors that influence building energy performance, (2) the techniques used to duplicate the actual heat transfer processes, and (3) the options available for evaluating various ways of satisfying the heating and cooling requirements of the building.

To account for the many factors that influence building energy performance requires an extensive program input. The input for the NBSLD program is extensive and of a type that requires a knowledge of heat transfer. It is the extensiveness and type of input that enables the NBSLD simulation to be thorough.

The NBSLD program uses conduction transfer functions to simulate heat flow through building constructions and uses heat balance equations to simulate the energy exchange processes within the building. These mathematical techniques enable the NBSLD program to account for the dynamic nature of the energy exchanges occurring simultaneously within the building and through the building envelope.

There are several outputs produced by the NBSLD program depending on the simulation options selected. Both steady state and dynamic design day heating load simulations can be obtained. A dynamic design day cooling load can also be obtained. The option that uses the most powerful aspects of the NBSLD program is the hour-by-hour simulation of a building using hourly climatic data. In the hour-by-hour mode seven methods of satisfying the building's heating and cooling requirement can be evaluated.

With all of the required input, the complex simulation subroutines, and the options available the NBSLD program remains easy to use. No knowledge of computer programming is necessary in order to use this powerful simulation tool.

8. CAPABILITIES AND LIMITATIONS OF IBUC, TRNSYS, AND NBSLD

IBUC, TRNSYS, and NBSLD each have advantageous and disadvantageous characteristics as energy/housing computer programs. This section is a discussion of these characteristics in comparison to the most desirable characteristics of an energy/housing program.

8.1 IBUC, TRNSYS, and NBSLD vs. Ideal Energy/Housing Program

An ideal energy/housing computer program should have the following general characteristics. To provide a complete evaluation of options to improve building energy performance the ideal program should include a thorough treatment of each of three phases of the energy calculation sequence (building space load, building energy load, and building energy economics). Without sacrificing thoroughness the amount and complexity of input should be minimized. The output should be displayed in an easily readable format and contain only information compatible with the user's interests and ability to understand. Finally, the program should be inexpensive to run.

Neither the IBUC, TRNSYS, or NBSLD program attain the ideal state. This is illustrated in Table 8.1. Listed in Table 8.1 are a number of characteristics of energy/housing computer programs. The check marks in the columns headed IBUC, TRNSYS, and NBSLD indicate the presence of the particular characteristic in the programs.

Table 8.1 Characteristics of the IBUC, TRNSYS, and NBSLD computer programs.

Program Characteristics	IBUC	TRNSYS	NBSLD
Steady state heat transfer	x	x	x
Dynamic heat transfer		x	x
Hourly meteorological data		x	x
Internal heat gain		x	x
Programmed internal heat gain			x
Programmed internal temperature control			x
Heating/cooling equipment simulation		x	
Latent heat load			x
Sensible heat load	x	x	x
Evaluate inside-out constructions			x
Attic ventilation			x
Room ventilation		x	x
Shading		x	x
Room surface energy exchange			x
Infiltration	x	x	x
Energy economics	x		

Table 8.1 shows that the IBUC program does consider at least one characteristic from each of the three phases of the energy calculation sequence. However, IBUC does not treat the space load or energy consumption phase as thoroughly as either TRNSYS or NBSLD. Steady state algebraic equations and degree day energy consumption are the basis of the energy calculations performed in the IBUC program. The treatment of building energy economics by IBUC is limited. There is no provision in IBUC to allow input of economic parameters.

It is evident from Table 8.1 that TRNSYS includes more of the energy/housing program characteristics than IBUC. The TRNSYS program has the capability to address the space load and the energy consumption phases of the energy calculation sequence. These two phases of the energy calculation sequence are more thoroughly treated by the TRNSYS program than by the IBUC program. The thorough treatment by TRNSYS is possible since TRNSYS uses unsteady state simulation techniques and accounts for more of the factors that affect building energy performance than does IBUC. The TRNSYS program has no capability in the building energy economics phase of the energy calculation sequence.

The NBSLD program addresses only the building space load phase of the energy calculation sequence. Although space load is the only phase of the energy calculation sequence addressed by NBSLD, it is addressed in great detail. The thoroughness of NBSLD is indicated by the number of characteristics checked in Table 8.1.

There are two features of NBSLD which are responsible for its thoroughness. First is its capability to consider numerous options and variations among options pertinent to building energy performance. Second is its capability to use sophisticated simulation techniques to describe heat flow through the building envelope and to describe heat exchanges within the building itself. The NBSLD program does not simulate heating/cooling equipment or address building energy economics.

8.2 Major Deficiencies of IBUC, TRNSYS, and NBSLD

There are two important areas in which each of the three computer programs are deficient. First is the absence of a way to adequately account for quality of workmanship as a factor contributing to building energy performance. Second is the absence of a thorough treatment of building energy economics, the third phase of the energy calculation sequence.

8.2.1 Quality of workmanship

Quality of workmanship is a contributing factor to building energy performance. Building materials and equipment having good energy performance characteristics can not perform well if they are assembled or installed improperly. Improperly assembled or installed materials and equipment result in an overall low building energy performance. Low building energy performance, a result of poor workmanship, can be attributed to energy losses through conduction, convection, and radiation heat transfer, infiltration, and inefficient equipment operation.

The only way quality of workmanship is accounted for in the IBUC, TRNSYS, and NBSLD programs is through the relationship between workmanship and infiltration. Two methods are used to incorporate infiltration into the computer programs. One method is a judgement of the condition of the building. Given this judgement a corresponding infiltration value is selected by the computer and used in the energy performance calculations. Another method is to estimate the building infiltration rate directly and input this value into the program. IBUC uses the judgement of condition method and TRNSYS and NBSLD require an estimate of the infiltration rate.

8.2.2 Building energy economics

Building energy economics is not addressed by TRNSYS or NBSLD and is only addressed in a limited way by the IBUC program. Economic information is important for selecting options to improve building energy performance.

Various options which affect building energy performance can be evaluated through the life cycle cost method (Johnson, 1977b; Beckman *et al*., 1977). The life cycle cost method takes into account the time value of money. The time value of money concept is that a dollar presently in hand is worth more than the likelihood of receiving a dollar some time in the future (Nelson *et al*., 1973).

To perform a life cycle cost analysis on various options to improve building energy performance, consideration of economic parameters in the areas of (1) option cost, (2) finance and tax data, and (3) energy cost and price increase information is required. Some of the specific economic parameters required are listed in Table 8.2. Specific parameter values used in an analysis should be carefully selected since they reflect future economic conditions.

Table 8.2 Economic parameters required for a life cycle cost analysis of building energy performance options.

- Term of economic analysis
- Loan term
- Loan interest rate
- Down payment
- Property tax rate
- Personal income tax rate
- General inflation rate
- Fuel inflation rate
- Discount rate
- Cost of energy conserving option
- Energy costs
- Maintenance cost
- Insurance cost

Using economic parameters pertaining to a specific building energy performance option, the life cycle cost of that option can be determined. Similarly, the life cycle cost of other options for improving building energy performance can be determined. The option which shows the lowest life cycle cost is the economic optimum.

9. EXPANSION OF COMPUTER CAPABILITY IN THE RBC

Technology in the manufacture of computers and telecommunications has progressed to the point where it is possible for essentially anyone having a telephone to gain access to powerful computing facilities. In addition, the availability of small computers ($<$ 20 k RAM) is rapidly increasing. However, even with the present level of computer-associated technology there is not adequate computer capability in the RBC.

Computer capability is a term which describes an individual's or an organization's potential to access and utilize a computer and a library of energy/housing programs. There are two aspects to computer capability. One is the library of computer programs which address a variety of subjects related to building energy performance. This aspect was addressed in the first part of this study with discussion of the specific features of three computer programs (IBUC, TRNSYS, and NBSLD) representing the range of existing energy/housing program capabilities. The second aspect of computer capability is the access to computing facilities which will allow the library of programs to be utilized. At present some parts of the RBC do not have access to computing facilities. Therefore, some parts of the RBC do not have the opportunity to take advantage of the kind of information that can be gained from existing energy/housing computer programs. The discussion in the second part of this study centers around the development of a plan which will bring about expanded computer capability in the RBC. With expanded computer capability a source of energy/housing information not presently available to all parts of the RBC will be available.

9.1 The Residential Building Community

Any community that has the capability to regulate, supply, and consume housing is considered a Residential Building Community (RBC). In this context the RBC consists of individuals and organizations which have diverse specific interests, but which have in common the capability to influence the energy performance of buildings. Among the regulators, suppliers, and consumers of housing in the RBC there is presently a wide range of computer capability. Presently available to the RBC are the resources necessary to bring about an expansion of computer capability and thus supply the type of energy/housing information needed to improve the energy performance of buildings.

9.1.1 Consumers in the RBC

The consumer group in the RBC consists of those persons who utilize residences. From this consumer point of view utilization of a residence includes owning a residence or being in the market for a residence. In either situation the consumer has an opportunity to take action that will lead to an improvement in the energy performance of his residence.

The specific action taken to influence the energy performance of a residence depends on whether the consumer is in the market for a residence or presently owns a residence. Consumers who are in the market for a residence may obtain one through the custom built housing market, through the existing housing market, or through the rental housing market. Consumers in these situations may influence the energy performance of a residence by making energy performance a condition on which a construction, purchasing, or renting agreement is reached. Consumers owning residences may upgrade its energy performance through a variety of retrofitting actions.

9.1.2 Suppliers in the RBC

Suppliers are the part of the RBC that provide the consumer segment with housing stock. Included in the supplier group are the home builders/contractors, architects, realtors, materials suppliers, and utility contractors. The individual enterprises within the supplier group perform dissimilar business functions. However, when the RBC is considered from an overall point of view, it is the collective goods and services provided by this group that results in the stock of residential housing available to the consumer.

Suppliers exert their influence over the energy performance of housing through the materials, methods, and systems contributing to the physical assembly of a residence. The amount of influence the supplier enterprises have varies. Architects and home builders have the most direct control over thermal performance through the materials, methods, and systems they specify or utilize. Materials suppliers and utility contractors are likely to have less control since they may only be dealing with individual materials and systems rather than the entire building assembly. Realtors can influence the energy performance of a residence by emphasizing its energy conserving features. Emphasizing energy conserving features enhances the marketability of the residence and causes energy performance to become a point of negotiation.

9.1.3 Regulators in the RBC

The remaining group making up the RBC, along with consumers and suppliers, is the regulators of housing. In the context of this study regulators are individuals or organizations that influence the energy performance of housing through the imposition of energy related regulations and restrictions. Included in this group are power suppliers, lending institutions, and code enforcing agencies on either the local or state level.

The regulations and restrictions imposed are intended to upgrade the thermal performance of the residence to a level deemed appropriate by the particular regulator. Usually the restrictions imposed apply to the thermal envelope of the building. Such restrictions may include provisions pertaining to the heating, ventilating, cooling, water heating, and electrical systems and equipment. A thermal performance level, implying a maximum expenditure of energy, is usually specified in each case.

9.2 Existing Computer Capability in the RBC

Among the consumers, suppliers, and regulators of housing that make up the RBC, there are individuals and there are organizations ranging in size from small one-man, one-crew operations to large corporations. Individuals, either home owners or persons in the market for a residence, comprise the consumers of housing. Both small and large organizations comprise the suppliers and regulators of housing. For the individuals and the small organizations in the RBC, whether consumer, supplier, or regulator, there is little existing computer capability. By contrast, the larger organizations have adequate computer capability.

9.2.1 Computer capability - large organizations

The typical computer capability of a large organization in the RBC consists of in-house computer facilities with an accompanying library of programs. A computer program library of a large organization might include programs addressing various business functions (i.e., accounting, billing), trade related programs, and energy/housing programs. If an organization is nonpublic, their programs are proprietary. Being proprietory the programs are generally available for in-house use or are available to outside users (small organizations or individuals) with a product or service affiliation with the larger organization. A product or service affiliation might exist between a large building insulation manufacturer or space conditioning equipment manufacturer and the dealers who handle their products. As a result of this affiliation the large organization makes computer programs addressing insulation or equipment selection available to the smaller organizations selling their product. The small organizations use the energy/housing program (accessed according to arrangements made with the large sponsoring organization) to generate information relative to the customer's situation. Information generated is used as an aid in making sales recommendations to customers who might be other small organizations (home builders) or individuals (home owners) in the RBC.

In addition to their in-house computer capability, the large organization is likely to have the terminal equipment which enables time share computer networks to be accessed. Access to time share networks expands the large organization's computer capability in the way of expanded program resources that can be used as needed. The large organizations in the RBC, with their well developed in-house capability combined with remote access capability, are not in need of further computer capability development.

9.2.2 Computer capability - small organizations and individuals

The small organizations and the individuals in the RBC have limited computer capability. Some energy/housing computer capability is extended to small organizations and individuals through the product or service affiliation relationship discussed in the previous section.

Another source of computer capability, available to home builders in particular, is the service offered by the National Association of Home Builders (NAHB, undated). At the present time the NAHB service includes only payroll and accounting program modules. While limited to payroll and accounting services at the present, the potential to provide home builders, and possibly other allied organizations in the RBC, with energy/housing programs exists with the NAHB.

The Cooperative Extension Service of Michigan State University currently provides County Extension personnel with computer capability.

Through its TELPLAN System (Harsh & Black, 1971) the Cooperative Extension Service personnel have access to computer terminal equipment and a library of programs to select from.

The plan proposed in this study (Section 8.4) and the TELPLAN System are similar. The difference between the two computer capability systems is the audiences which are served. The TELPLAN System is directed towards service to the agricultural community, whereas, the proposed plan for expanding computer capability is directed towards service to the RBC. The TELPLAN System currently offers the IBUC home energy saving computer program discussed previously in this study. If the TELPLAN System were expanded, placing access facilities in more locations and including more programs which address building energy performance, the Cooperative Extension Service could provide adequate computer capability to the RBC. As it now exists the TELPLAN System does not reach a major portion of the RBC that is in need of energy/housing computer capability and the current library of programs does not include the variety of energy related programs needed.

The energy/housing computer capability available to individuals and to small organizations in the RBC is inadequate despite the three sources of computer capability discussed. The computer capability available through product or service affiliations reaches too few of the potential users in the RBC. Also, it is likely that the program used will generate information which stresses only the features of the sponsoring company's product. Payroll and accounting are currently the only programs offered by the NAHB. In addition users of the NAHB service must have their own access facilities or use the postal service as the means of program input and output. The cost of access facilities limits the NAHB service to larger home builders. The TELPLAN System presently has too few access sites and offers too few programs addressing building energy performance to adequately provide the Michigan RBC with energy/housing computer capability.

To summarize the existing state of energy/housing computer capability in the RBC, the following points can be made.

1. To justify energy/housing computer capability, the benefit derived must offset the expense of acquiring either a computer access facility or an in-house computer with a library of programs.
2. Organizations, ranging in size from several individuals to corporations, make up the suppliers and regulators of housing. Individuals make up the consumers of housing.
3. Individuals and small organizations do not have adequate energy/housing computer capability.
4. Large organizations have adequate computer capability.

9.3 Energy/Housing Information Needs of the RBC

The Energy Calculation Sequence (Section 3.5.2.1) framework encompasses all computer programs dealing with building energy performance. Programs dealing with building energy performance may use simple or complex simulation techniques to address a single aspect of building energy performance or to address many aspects of building energy performance. Program output may express energy performance in terms of economic or energy evaluations of materials, equipment, systems, structures, etc., depending on the specific purpose for which the program was developed. As computer capability services are established and their benefits become known the entire array of energy/housing programs will have application among the consumers, suppliers, and regulators of housing in the RBC. In the initial stages of computer capability establishment in the RBC there are two aspects of building energy performance for which computer programs will likely be utilized first.

One of the first areas of application of energy/housing computer capability will be that of building energy "auditing." The IBUC Program (Section 5.0) and similar programs (Section 3.5.2.4) should have wide initial appeal among consumers and some of the enterprises in the supplier part of the RBC. Basic "auditing" programs will provide individuals and small organizations, who now have limited computer capability, with a broad base of information useful for energy/housing decision making. Individual materials, methods, and systems that go into the construction or retrofitting of a residence can be evaluated.

The advantages of the "auditing" type of programs are that they are currently available, require simple, easily obtained input information, do not require large computing facilities, and are relatively inexpensive to run. These program attributes, plus the situation that individuals and small organizations in the RBC now have limited computer capability, will enhance the popularity of programs of the "auditing" type. From this "auditing" program, users can progress to programs which address other aspects of building energy performance and/or which use more thorough simulation techniques.

The second aspect of building energy performance for which computer programs will likely be utilized first is that of determining energy code compliance. Currently all new residential buildings constructed in the State of Michigan must satisfy the requirements of the Michigan Energy Code (1976). This code is based on ASHRAE Standard 90-75 (ASHRAE, 1975). The most prominent restrictions included in the Michigan Energy Code are maximum thermal transmittance values for various parts of the building envelope. The allowable levels for the transmittance values are based on local degree-day values. Compliance is determined in the pre-construction stage prior to issuance of a building permit.

Administration and enforcement of the Michigan Energy Code requires a basic understanding of the factors affecting the energy performance of a building. Computer programs are currently available (Section 3.5.2.2) to make the task of determining compliance with the envelope restrictions faster, easier, and more accurate than manual methods.

If building energy performance standards similar to the ones being developed (Section 3.3) are adopted, determining code compliance will be more complicated than determining compliance with existing codes. The tendency is for the newer standards to be more comprehensive, accounting for more of the factors which affect building energy performance than existing codes do. The detail involved in accounting for the numerous factors affecting building energy performance along with the mathematical calculation techniques used to determine building energy performance would make manual determination of compliance an unachievable task for building code officials. As standards are adopted that account for more and more of the factors which affect building energy performance, computer assistance becomes the only realistic means of determining code compliance. The TRNSYS Program (Section 6.0) has been selected as one of the computer programs suitable for determining compliance with the BEPS energy standard, one of the newer energy standards being developed.

9.4 Plan for Expanding Computer Capability in the RBC

Having assessed the composition, existing computer capability, and energy/housing information needs of the RBC, a plan is proposed for expanding computer capability in the RBC. The proposed plan incorporates two basic concepts. The first concept is (1) an expanded public service role on the part of the local governmental unit in the RBC. The second concept is (2) the formation of a group of cooperating agencies responsible for the development, implementation, and continued operation of the computer capability network.

9.4.1 Expanded public service role of the local governmental unit

The concept of expanded public service consists of the local governmental unit serving as a computer capability resource center for the RBC. In this capacity the municipality would provide computer access facilities and guidance for potential users in the selection and utilization of the appropriate energy/housing computer programs. By the local governmental unit providing those services a source of energy/housing information will be available and in close proximity to individuals and small organizations in the RBC.

By having the local municipality the site offering computer capability many RBCs are created over a statewide area. When fully implemented a network of computer capability resource centers involving approximately 1400 sites (Duley, 1979) would be established through the state of Michigan.

The local governmental unit exists for the purpose of providing service to the public within its jurisdiction. Typical services currently provided by the municipality include planning, zoning, taxation, assessing, utilities, regulation, etc. These services are directly related to housing. Since the purpose of the municipality is to provide service and since the services typically provided are directly related to housing, offering the energy/housing computer capability services represents only an expansion in scope of the services typically provided.

By carrying out the responsibilities associated with the services normally provided, a common awareness has developed between the municipality and the public it serves. The established awareness will enhance the acceptance of the computer capability service by the RBC. Acceptance will be enhanced because the service will be offered by an organization known to the community.

One of the services currently provided by the municipality is the enforcement of building energy codes. Computer assisted building energy code compliance is now possible (Section 8.3) and will likely be one of the first services made available through the energy/housing computer capability network. Access to an energy code compliance program would benefit not only the individuals and small organizations in the RBC, but would also directly benefit the code enforcement department of the local governmental unit.

To serve as a computer capability resource center, the municipality must have equipment that allows access to computing facilities and a library of energy/housing programs. Larger municipalities, who have computerized record keeping and accounting, may currently have computer access capability. The smaller municipalities will need to acquire appropriate access facilities. Smaller governmental units can help justify the costs of computer access facilities by utilizing them for other typical municipal services as well as for energy/housing program usage.

In addition to making equipment available to access computing facilities, the computer capability resource center must also provide assistance to program users from the RBC. User assistance is an important and essential function of the computer capability resource center. Assistance will be required with energy/housing program selection and with entering and retrieving information.

Individuals presently employed in the code enforcement departments of municipalities could provide the assistance required. These people have acquired experience in the interpretation and enforcement of various codes, most importantly the Michigan Energy Code. However, many of these individuals will not have had experience with the use of energy/housing computer programs or with computer facilities. Therefore, it will be necessary to provide instruction to the personnel who will be providing assistance to users of the computer capability resource center. Personnel in the code department of municipalities will be able to see direct benefit from learning to use the computer capability network, since one of the first programs likely to be available on it will address building energy code compliance. Educational assistance was provided to code enforcement personnel when the Michigan Energy Code was being introduced in the state.

9.4.2 Group of cooperating agencies

The second basic concept of the proposed plan for expanding energy/housing computer capability in the RBC is the formation of a group of cooperating energy/housing agencies. This group will have responsibility for the development, implementation, and continued operation of the computer capability network. Total responsibility for the computer capability network could be placed with the energy and code agencies of the state. Within these organizations there is extensive experience with building and energy code administration and enforcement on a state-wide basis. However, the reception, effectiveness, and continued success of the computer capability network will be enhanced by combining the expertise of other energy/housing organizations in the RBC with the expertise of the state agencies. In this way the total energy/housing resources of the RBC will be incorporated into the policies affecting the energy/housing computer capability network.

The proposed group of cooperating energy/housing agencies will consist of representation from the state energy and code agencies, academic institutions, Michigan Home Builders Association, Michigan Association of Building Inspectors, and Michigan State University Cooperative Extension Service. As a group, the representatives from these agencies will establish and carry out the policies necessary to achieve the development, implementation, and continued operation of the computer capability network. Specifically, the group of cooperating agencies will need to address the topics of network funding, network computer facilities, energy/housing computer program library, and user assistance programs.

Each agency will bring to the energy/housing group of cooperating agencies a resource of unique expertise. The state energy and code agencies will contribute a background of experience in energy and building code administration and enforcement. Being state agencies, administration and enforcement has been carried out on a state-wide basis setting up channels of communication with municipalities through the state.

With the enactment of a state residential energy code, state energy and code agencies have gained experience with designing and providing programs familiarizing local government code personnel with energy code provisions and code compliance procedures. Similar familiarization programs will need to accompany the establishment of the energy/housing computer capability network. The personnel selected to serve as computer user assistants may require training in the use of computer access facilities, basic heat transfer, and input-output requirements of the various energy/housing computer programs. The better prepared the assistance personnel are the more willing they will be to accept the assistance responsibilities and the more successful they will be in aiding program users from the RBC.

Academic institutions will contribute expertise towards the task of energy/housing computer program development and evaluation. One of the greatest needs is that of making the entering and retrieval of energy/housing program information easily understood and achievable by users with limited heat transfer, building, and computer usage backgrounds. The challenge is to minimize the amount of input information and still describe the problem in enough detail that the output information carries the creditability expected by the program user.

The Home Builders Association and the Association of Building Inspectors will bring to the group of cooperating agencies a background of practical energy/housing experience. This practical energy/housing experience has been gained as the result of the day-to-day working relationship with the various individuals and enterprises in the RBC. When the experience that has been gained is reflected in the policies developed by the group of cooperating agencies the reception and continued success of the energy/housing network will be enhanced.

Extensive experience in the use of a computer network (TELPLAN) for addressing problems in the agricultural community has been achieved by the Michigan State University Cooperative Extension Service. The TELPLAN system was discussed in Section 8.2. Because of the similarities of the energy/housing network and the TELPLAN system the Cooperative Extension Service will contribute valuable expertise to the group of cooperating agencies.

9.4.3 Funding the energy/housing computer capability network

The need for funding for the energy/housing computer capability network will occur in two phases. Initially funding will be needed for the establishment of the computer capability network. Following establishment of the network, funding will be needed for its continued operation and maintenance.

Establishment of the energy/housing computer capability network will include the costs of computing facilities, access site input-output equipment, energy/housing computer program library, and familiarization programs for the personnel who will assist program users at the local access site. Operation and maintenance of the energy/housing network will include costs for computer use, wages for assisting personnel at the access site, and costs associated with expanding and updating of the energy/housing computer program library.

The magnitude of each of the costs associated with the establishment and the operation and maintenance of the energy/housing network will vary. Some of the factors which will affect the costs are: (1) the size and number of computer programs included in the library of energy/housing programs, (2) the costs of computer program acquisition, and (3) the existing computer capability of the local governmental unit (local access site).

Funding for the energy/housing network will be derived from federal, state, and local governments. During the establishment phase of the network, expenses for developing an energy/housing computer program library, arranging for computing facilities, and development and implementation of a familiarization program for user assistants will be obtained from federal and state levels of government and from philanthropic organizations. The availability fo federal funding will depend upon governmental energy policies at the time. State funding may be obtained through the state energy and code agencies. The expense of acquiring input-output equipment for a network access site in the RBC will be shared by the state and the local municipality. Sharing of the input-output equipment expense may be through a matching funds arrangement and/or based on the existing computer capability of the local municipality. It is probable that the input-output facilities at the municipality will be utilized for purposes other than access to the energy/housing network.

The costs of operation and maintenance of the energy/housing network will be met through funding from the state and local government. Funding to retain the required network computer facilities will be provided by the state. Part of this expense will be passed on to the local government, based on the accumulated computer use time and on the particular program used. At the discretion of the local government their expense for network computer facilities may be offset through the establishment of a user fee. The state will provide funding for maintenance and expansion of the energy/housing program library when indicated by the group of cooperating agencies. Where access sites are established the local government will provide funding for network user assistance personnel. If existing employees of the building and code departments of municipalities are selected as user assistance personnel, their wages may be shared between code enforcement and user assistance responsibilities.

10. CONCLUDING DISCUSSION

10.1 Energy/Housing Computer Programs

IBUC, TRNSYS, and NBSLD are typical of existing energy/housing computer programs. Together, they illustrate the range of variation among existing programs in the simulation techniques utilized to evaluate the energy performance of buildings. They are examples of the type of resource available to the residential building community which can be used to improve the energy performance of buildings if they are accessible. The plan proposed for expanding energy/housing computer capability in the residential building community is intended to achieve the required program accessibility.

Both simple and complex techniques describing building energy performance are employed by the three programs. Steady state load calculation and degree day energy consumption constitute the simple techniques. Unsteady state, dynamic, hour-by-hour load and energy consumption is the complex approach.

IBUC uses simple techniques to address the building load, the energy consumption, and the economic aspects of building energy performance. Through the options available in the NBSLD program either very complex or simple techniques may be utilized in addressing the building load aspect of building energy performance. TRNSYS is the most versatile of the three programs. It uses simulation techniques similar to those used in the NBSLD program. Another feature of TRNSYS is the use of system component simulation in addressing the building load and the energy consumption aspects of building energy performance.

Both the simplified techniques and the refined, rigorous techniques of building energy performance simulation have their advantages and disadvantages. Programs utilizing simple techniques require a small amount of basic, easily obtained input information. Programs utilizing the rigorous approaches require a greater amount of information and more detailed information. It could be a difficult task for individuals not having knowledge of basic heat transfer or building construction to understand and obtain the information needed for complex simulation techniques. Both the complex and the simple technique programs benefit from well-planned program input formats.

The steady state heat transfer techniques are often utilized to estimate the heat loss of buildings at design temperature conditions. The design heat loss has traditionally been utilized for sizing conditioning equipment and for obtaining building energy consumption estimates based on the degree day energy consumption methodology.

Simple simulation techniques yield less accurate results than the refined, rigorous techniques. This is because the simple techniques do not include heat transfer equations which closely describe the actual heat transfer processes taking place in buildings or consider all the factors influencing building energy performance. In particular, steady state heat transfer does not account for the ability of building materials to store heat. Thus, when outdoor temperatures fluctuate the capability of steady state techniques to accurately describe heat transfer through the building envelope is decreased.

Dynamic hour-by-hour calculations, used by TRNSYS and by some subroutines in NBSLD, employ mathematical techniques (differential equations in TRNSYS and conduction transfer functions in NBSLD) to account for the response of the building mass to fluctuating outdoor temperatures. When the effect of building mass is realistically accounted for, peak thermal loads of buildings estimated with dynamic methods tend to be lower than peak thermal loads (design loads) estimated using steady state techniques. Conditioning equipment can be more accurately sized when based on dynamic load determination.

The simple simulation methodologies are easy to computerize and inexpensive to operate and maintain in a ready access state on a computer system. This is because there are fewer calculations required, the calculations required are simple, and there are fewer influencing factors considered in simple building energy performance methodologies in comparison to complex methodologies. Computing costs are less for programs requiring the least system storage space, the least computer memory space, and the least computer time to complete the required calculations.

For whatever specific purpose the programs in the energy/housing program library are selected or developed, they should be as easy as possible to use without sacrificing the simulation accuracy required. Ideally an energy/housing program would require a small amount of easily obtained input, would perform calculations which accurately represent the actual heat transfer and/or energy consumption processes, and would provide output organized and expressed in terms easily comprehended by the program user. Simulation algorithms exist which enable the energy performance of a building to be accurately evaluated. However, these sophisticated simulation techniques require a large amount of complex input data.

There are two alternatives to using an energy/housing program based on sophisticated simulation techniques. One is to use a program having less complex algorithms, realizing the sacrifices in accuracy of simulation. The second alternative is to seek ways of reducing the amount and complexity of the program input information. Nall et al. (1977) describes an effort to simplify the input information required for the NBSLD program. Simplification of input is achieved, as well as other advantages, through the use of computer graphic techniques. From a pictorial display the computer determines much of the input information needed to describe the building being evaluated for energy performance. As progress continues to be made with making sophisticated programs, such as NBSLD, easier to use their utilization will be more readily accepted in the RBC.

10.2 Expansion of Computer Capability

Existing computer capability in the RBC does not adequately provide many individuals and organizations in the RBC with easy access to a library of energy/housing programs. The diverse make-up of the RBC, consisting of consumers, suppliers, and regulators which in turn may be either individuals, small organizations, or large organizations, complicates the task of expanding energy/housing computer capability. The plan proposed to achieve expanded energy/housing computer capability in the RBC calls for the establishment of a network of computer access sites. Increasing the number of access sites will bring potential users in the RBC within closer proximity to an access facility than now exists.

The local governmental unit is the site selected for the RBC computer capability resource center. The municipality was chosen because of its role in public service and because of its existing ties with the RBC established through the services performed.

At each computer capability resource center users will have the opportunity to receive assistance with the selection of an appropriate program from a library of energy/housing programs and to receive assistance with accessing computing facilities. It is proposed that personnel presently employed in local code administration and enforcement positions are the best qualified to assume the additional responsibilities of providing the required assistance.

Overall responsibility for the computer capability network is placed with a group of cooperating energy/housing agencies. Forming this group are representatives form state code and energy agencies, academic institutions, Michigan Home Builders Association, Michigan Association of Building Inspectors, and Michigan State University Cooperative Extension Service. As a group, responsibilities include the formulation and the carrying out of policies addressing funding, network computer facilities, energy/housing computer program library, and user assistance programs.

Contributions of expertise from all the cooperating agencies will help insure the success of the energy/housing computer capability network. However, the state energy and code agencies are key participants. Their state-wide jurisdiction in addressing code and energy matters coincides with the state-wide scope of the proposed energy/housing network. A commitment from the state energy and code agencies is needed in order for the energy/housing network to become a successful reality.

Funding for the energy/housing computer capability network will be derived from local, state, and federal levels of government. Expenses for the access facilities, computer programs, and computing facilities will depend on the policies developed by the group of cooperating agencies. For example, the size of required computing facilities and thus the cost of establishing the energy/housing network will depend on the number of programs in the energy/housing library, the size or complexity of the programs selected, and the cost of acquiring or developing the required energy/housing programs.

The expansion of computer capability in the RBC will take place over a period of time rather than occurring in one single step. The rate of development of the energy/housing network will depend on several factors. One factor is the establishment of new regulations calling for higher levels of thermal performance for the residence. Another factor is the economic picture of energy supplied to the residence including the development and demonstrated success of nontraditional energy sources. Finally, the rate of development will depend on the commitment from the group of cooperating agencies to its responsibility for developing, implementing, and maintaining the proposed energy/housing network.

11. CONCLUSIONS

The following are conclusions from this work:

1. There are in existence computer programs which address a variety of aspects of building energy performance.
2. Both simple and sophisticated simulation techniques are used to evaluate building energy performance by the existing energy/housing programs.
3. The characteristics of energy/housing computer programs employing simple and sophisticated simulation techniques may be compared as follows:

simple techniques	sophisticated techniques
a. yield results which are approximations.	a. capable of closely simulating the actual energy performance of a building.
b. tend to be comprehensive, including more parts of the energy calculation sequence.	b. tend to be narrow in focus, concentrating on one part of the energy calculation sequence.
c. require a small amount of input information.	c. require extensive input.
d. the input required is not complicated and is easy to obtain.	d. some of the input required is complex and difficult to obtain.
e. can operate on small computing facilities and running time is of short duration.	e. require large computing facilities and long running time.

4. Two important building energy performance factors, quality or workmanship and building energy economics, are not adequately addressed by IBUC, TRNSYS, or NBSLD.

5. Although the RBC is diverse, residential energy conservation is an area of common interest among consumers, suppliers, and regulators of housing.
6. The present energy/housing computer capability in the RBC is inadequate.
7. The local governmental unit, a public service organization, is a logical site to establish a computer capability resource center.
8. A group of cooperating agencies will enable the computer capability network to reflect the energy/housing expertise present in the RBC.

12. SUGGESTIONS FOR FUTURE WORK

Future work towards bringing about the use of computer programs for improving the energy performance of residences should include the following:

1. Improve input and output functions of energy/housing programs.
   A. Work needs to be done to minimize the amount and complexity of required program input information without sacrificing the accuracy of the heat transfer algorithms used.
   B. Output of programs evaluating building energy performance should be displayed in a format and in terms compatible with the user's capability to understand and utilize.
2. Organize a nucleus group of energy/housing cooperating agencies. This group will:
   A. Set up channels of communication between participants in the group of cooperating agencies.
   B. Establish the committment, contribution, and responsibility of each agency towards the development, implementation, and operation and maintenance of the energy/housing computer capability network.

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APPENDICES

APPENDIX A

EXCERPTS FROM ASHRAE STANDARD 90-75 AND MICHIGAN ENERGY CODE

1.0 PURPOSE

1.1 The purpose of this Standard is to provide design requirements which will improve utilization of energy in new buildings and to provide a means of determining the anticipated impact of that energy utilization on the depletion of energy resources.

1.2 The requirements of this Standard are directed toward the design of building envelopes with adequate thermal resistance and low air leakage; toward the design and selection of mechanical, electrical, service water heating, and illumination systems and equipment; and toward the prudent selection of fuel and energy sources; all of which will promote effective use of depletable energy resources and encourage increasing use of nondepletable energy resources.

1.3 It is intended that this Standard be flexible in order that designers be encouraged to use innovative approaches and techniques to achieve effective utilization of energy. More effective use of energy may be achieved by the use of alternate design solutions, which follow the specific requirements of Sections 10 and/or 11. Section 12 provides a method for calculating the quantities of energy resources required and the impact of on-site energy use on those resources.

1.4 It is intended that this Standard be used in the design of new buildings and that compliance with its requirements should be determinable in the preconstruction stage, by evaluation and analysis of the design.

1.5 This Standard shall not be used to abridge any safety, health or environmental requirements.

1.6 Where more stringent requirements exist in building and construction codes, those requirements shall prevail.

2.0 SCOPE

2.1 This Standard sets forth requirements for the design of new buildings for human occupancy, as enumerated below, covering their exterior envelopes and selection of their HVAC, service water heating, energy distribution and illuminating systems and equipment for effective use of energy.

2.1.1 This Standard covers new buildings that provide facilities or shelter for public assembly, educational, business, mercantile, institutional, and residential occupancies, as well as those portions of warehouse, factory and industrial occupancies which are used primarily for human occupancy. Office space is an example of a human occupancy area where energy is used primarily to provide human comfort. Unless otherwise stipulated, the term buildings, as used in this Standard, includes mobile homes and manufactured buildings.

2.1.2 Buildings or portions thereof whose peak design rate of energy usage is less than 11 W/m^2 (3.5 $Btu/h \cdot ft^2$) of gross floor area for all purposes and those which are neither heated nor cooled are excluded from the scope of this Standard.

2.1.3 Where specifically noted in the sections of this Standard, certain other buildings or elements thereof may be exempt when design data are not available or not applicable.

2.2 This Standard does not cover specific procedures for the operation, maintenance, and use of buildings.

2.3 For certain consumer products and industrial equipment, governmental standards for energy efficiency and energy use may supersede or be incorporated in voluntary standards referenced in this standard.

4.0 EXTERIOR ENVELOPE REQUIREMENTS

4.1 Scope

The criteria of this section establish the minimum thermal requirements of the exterior envelope of new buildings. The equations, charts and tables in this section are intended only for use in defining these criteria. In cases where a system analysis approach to building design is desired, the requirements of Section 10 and/or 11 of this Standard shall apply.

4.2 General

4.2.1 The intent of this section is to provide minimum requirements for building envelope construction in the interest of energy conservation. These requirements are not intended nor should they be construed as the optimization of energy-conserving practices.

Paragraph 4.3 applies to one- and two-family residential buildings, hotels and motels, not exceeding three stories above grade (Type A Buildings). Paragraph 4.4 applies to all other buildings not covered by 4.3 (Type B Buildings). Paragraph 4.5 applies to all buildings (Type A and Type B Buildings).

4.2.1.1 In addition to the criteria set forth in this section, the proposed design should consider energy conservation in determining the orientation of the building on its site; the geometric shape of the building; the building aspect ratio (ratio of length to width); the number of stories for a given floor area requirement; the thermal mass of the building; the exterior surface color; shading or reflections from adjacent structures, surrounding surfaces or vegetation; opportunities for natural ventilation; and wind direction and speed. For a national standard the above considerations are difficult if not impossible to quantify. However, particularly on a local basis, many of these items including the effects of mass, passive solar and daylight utilization can be quantified and therefore should be included.

4.2.1.2 To comply with the requirements of Section 4.0, calculation procedures and information contained in Chapters 19-26[5-10] of the 1977 ASHRAE HANDBOOK & Product Directory, Fundamentals Volume, shall be used. Other available measured thermal performance data for envelope sections, either from laboratory or field data or from engineering analyses may be considered either in addition to, or in place of, the criteria set forth in this section provided equal and repeatable results can be proven.

4.2.2 The gross area of exterior walls measured on the exterior consists of all opaque wall areas (including foundation walls, between floor spandrels, peripheral edges of floors, etc.), window areas (including sash), and door areas, which enclose a heated and/or mechanically cooled space (including interstitial areas).

4.2.3 A roof assembly shall be considered as all components of the roof/ceiling envelope through which heat flows, thus creating a building transmission heat loss or gain, where such assembly is exposed to outdoor air and encloses a heated and/or mechanically cooled space.

4.2.3.1 The gross area of a roof assembly consists of the total interior surface of such assembly, including skylights exposed to the heated and/or mechanically cooled space.

4.2.3.2 Where return air ceiling plenums are employed, the roof/ceiling assembly shall:

a. for thermal transmittance purposes, not include the ceiling proper nor the plenum space as part of the assembly, and

b. for gross area purposes, be based upon the interior face of the upper plenum surface.

4.2.4 All buildings that are heated and/or mechanically cooled shall be constructed to provide the required thermal performance of the various components.

4.2.4.1 The stated U_o value of any one assembly, such as roof/ceiling, wall or floor, may be increased and the U_o value for other components decreased provided that the overall heat gain and/or loss for the entire building envelope does not exceed the total resulting from conformance to the stated U_o values.

4.2.4.2 The following dry bulb temperatures shall be used for calculations in this section:

	Indoor		Outdoor[13]
	°C	F	
Winter	22.0	72	97½%
Summer	25.5	78	2½%

4.2.5 A building designed to be both heated and/or cooled shall meet the more stringent of the heating or cooling requirements of the exterior envelope as provided in this section when requirements differ.

4.2.6 The design of buildings for energy conservation may increase the water vapor pressure differentials between the interior and exterior environments. Vapor retarders, air infiltration and operating interior relative humidity should be considered to maintain the thermal and moisture integrity of the envelope.

4.3 Criteria for Type "A" Buildings

4.3.1 Type "A" Buildings shall include:

A-1 Detached one- and two-family dwellings

A-2 All other residential buildings, 3 stories or less, including but not limited to multi-family dwellings and hotels and motels

4.3.2 Heating and Cooling Criteria

4.3.2.1 **Walls.** Any building that is heated and/or mechanically cooled shall have a combined thermal transmittance value (U_o value) for the gross area of exterior walls not exceeding the values shown in Fig. 1, using Table 1, Heating Degree Days as given in the 1976 ASHRAE HANDBOOK & Product Directory, Systems Volume, Chapter 43.[17]

4.3.2.1.1 Eq 1 shall be used to determine acceptable combinations to meet the requirements of Fig. 1.

Equation 1 Formula for Determining Combinations
(See Fig. 1 and Section 4.3.2.1, and/or Fig. 4 and Section 4.4.2.1)

$$U_o = \frac{[U_{wall} \times A_{wall}] + [U_{fenestration} \times A_{fenestration}] + [U_{door} \times A_{door}]}{A_o}$$

(See note below.)

where

U_o*	= the average thermal transmittance of the gross wall area, W/m²·°C(Btu/ft²·h·F)
A_o	= the gross area of exterior walls, m² (ft²) (see 4.2.2)
U_{wall}	= the thermal transmittance of all elements of the opaque wall area, W/m²·°C(Btu/ft²·h·F)
A_{wall}	opaque wall area, m²(ft²)
$U_{fenestration}$	= the thermal transmittance of the window area, W/m²·°C(Btu/ft²·h·F)
$A_{fenestration}$	= window area (including sash) m² (ft²)
U_{door}	= the thermal transmittance of the door area, W/m²·°C(Btu/ft²·h·F)
A_{door}	= door area, m² (ft²)

*Fig. 1 for Type "A" Buildings; Fig. 4 for Type "B" Buildings

Note: Where more than one type of wall, window and/or door is used, the U × A term for that exposure shall be expanded into its sub-elements, as:

$$[U_{wall_1} \times A_{wall_1}] + [U_{wall_2} \times A_{wall_2}] + \ldots\ldots, \text{etc.}$$

For U values and temperature differences for below grade walls see Chapter 24 of the 1977 ASHRAE HANDBOOK & Product Directory, Fundamentals Volume.[14]

4.3.2.1.2 The requirements for locations with less than 278 Celsius Heating Degree Days (500 Fahrenheit Heating Degree Days) shall be:

a. If only heating is provided, there is no U_o requirement.

b. If the building is to be mechanically cooled when built or if provision is made for the future addition of mechanical cooling, the U_o shall be 1.70W/m²·°C (0.30 Btu/ft²·h·F) maximum for Type A-1 and 2.15W/m²·°C (0.38 Btu/ft²·h·F) maximum for Type A-2.

4.3.2.2 **Roof/Ceiling.** Any building that is heated and/or mechanically cooled shall have a combined thermal transmittance value (U_o value) for the gross area of the roof assembly not to exceed the values shown in Fig.

2, using heating degree days as given in the 1976 ASHRAE HANDBOOK & Product Directory, Systems Volume, Chapter 43."

Exception: Roof/Ceiling assemblies in which the finished interior surface is essentially the under side of the roof deck, such as a wooden cathedral ceiling, shall have a U_o value not to exceed 0.45W/m²·°C (0.08 Btu/ft²·h·F) for any Heating Degree Day area.

4.3.2.2.1 Eq 2 shall be used to determine acceptable combinations to meet the required U_o values of Fig. 2.

Equation 2 Formula for Determining Roof/Ceiling Combinations **(See Fig. 2 and Section 4.3.2.2 and/or Fig. 5 and Section 4.4.2.2)**

$$U_o = \frac{[U_{roof} \times A_{roof}] + [U_{skylight} \times A_{skylight}]}{A_o}$$

(See note below.)

where

U_o = the average thermal transmittance of the gross roof/ceiling area, W/m²·°C (Btu/ft²·h·F)

A_o = the gross area of a roof/ceiling assembly, m²(ft²) (see 4.2)

U_{roof} = the thermal transmittance of all elements of the opaque roof/ceiling area, W/m²·°C (Btu/ft²·h·F)

A_{roof} = opaque roof/ceiling assembly, m²(ft²)

$U_{skylight}$ = the thermal transmittance of all skylight elements in the roof/ceiling assembly, W/m²·°C (Btu/ft²·h·F)

$A_{skylight}$ = skylight area (including frame) m²(ft²)

Note: Where more than one type of roof/ceiling and/or skylight is used, the U × A term for that exposure shall be expanded into its sub-elements, as:

$[U_{roof_1} \times A_{roof_1}] + [U_{roof_2} \times A_{roof_2}], + \ldots\ldots$, etc.

4.3.2.3 **Floors over Unheated Spaces.** For floors of heated and/or mechanically cooled spaces over unheated spaces, the U_o value shall not exceed the values shown in Fig. 6. For floors over outdoor air (example: overhangs) U_o value for heating shall meet the same requirements as for roofs shown in Fig. 2.

4.3.2.4 **Slab-on-Grade Floors.** For slab-on-grade floors, the thermal resistance of the insulation around the perimeter of the floor shall be as shown in Fig. 3. The insulation shall extend downward from the top of the slab for a minimum distance of 0.6m (24 in.) or downward to the bottom of the slab then horizontally beneath the slab for a minimum total distance of 0.6m (24 in.). There are no insulation requirements for heated slabs in locations having less than 278 Celsius degree days (500 Fahrenheit degree days), or for unheated slabs in locations having less than 1390 Celsius degree days (2500 Fahrenheit degree days).

4.3.2.5 **Crawl Space Plenum.** The exterior walls of crawl spaces used as plenums (see 5.12) for supply or return air shall be insulated to provide a thermal resistance, excluding film resistances of

$$R = \frac{\Delta t}{47.3}\ m^2 \cdot °C/W \left(R = \frac{\Delta t}{15}\ ft^2 \cdot h \cdot F/Btu\right)$$

where:

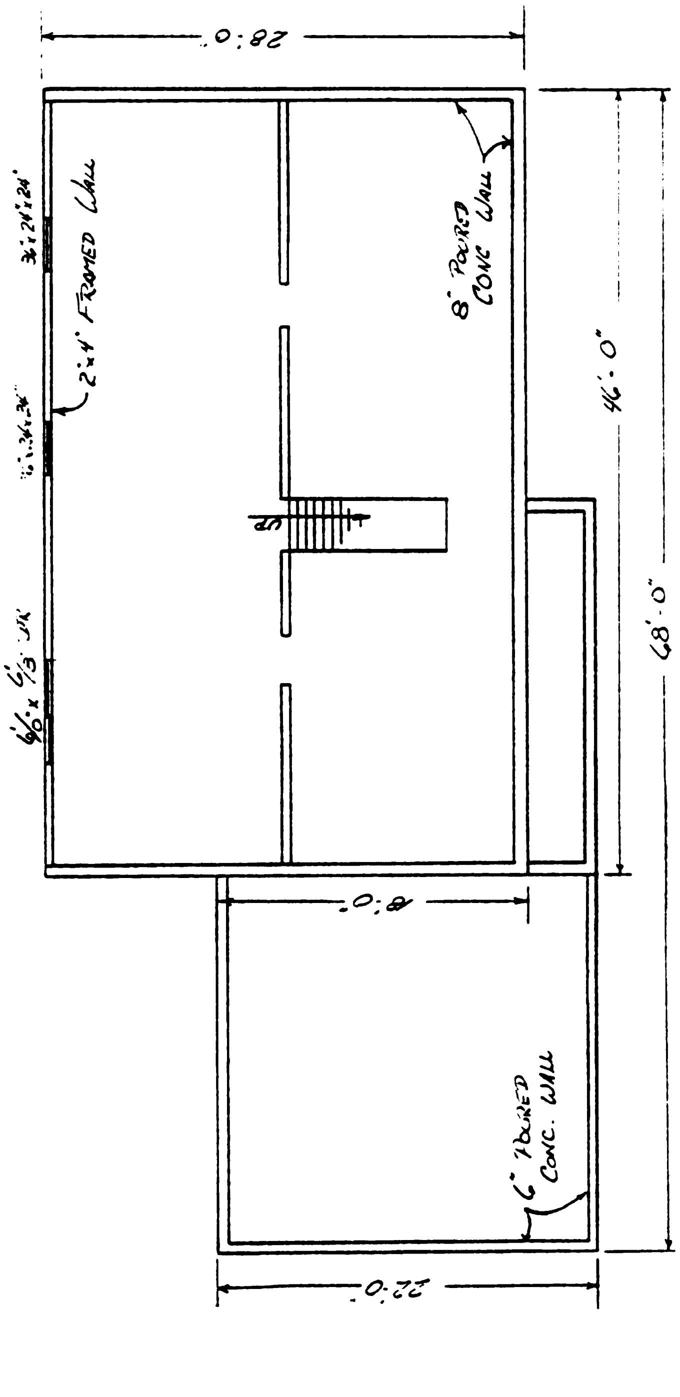
Δt = the design temperature differential between the air in the plenum and the outdoor air in °C(F)

EXTERIOR ENVELOPE COMPLIANCE

Example One

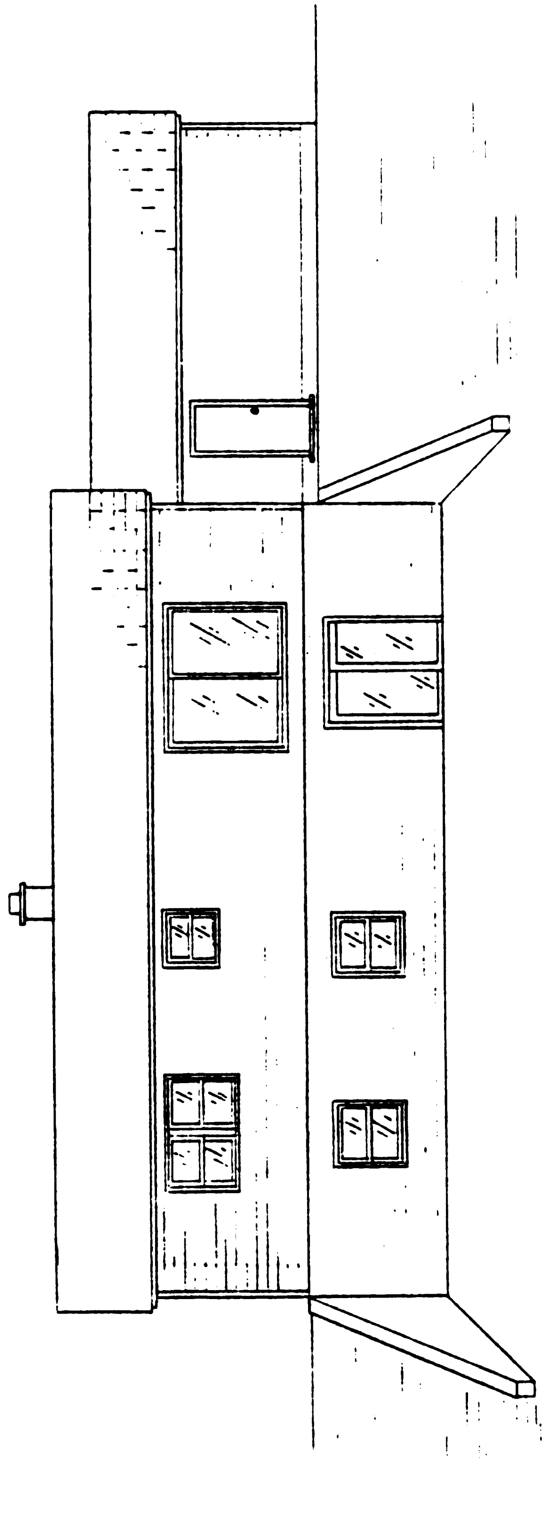
Example House:

- See drawings 1, 2, 3 and 4 for plans, evaluation, and construction of roof/ceiling, wall, and floor assemblies.
- Single story, three bedroom ranch
- Located in Grand Rapids
- Heated walk-out basement
- Unheated garage
- Walls have 16" O.C. framing (including walk-out)
- Roof/ceiling has 24" O.C. framing
- One foot of exposed concrete foundation wall on three sides of house
- Both sliding glass patio doors are double glazed (1/4" air space)
- All windows are single glazed without storm windows



BASEMENT PLAN

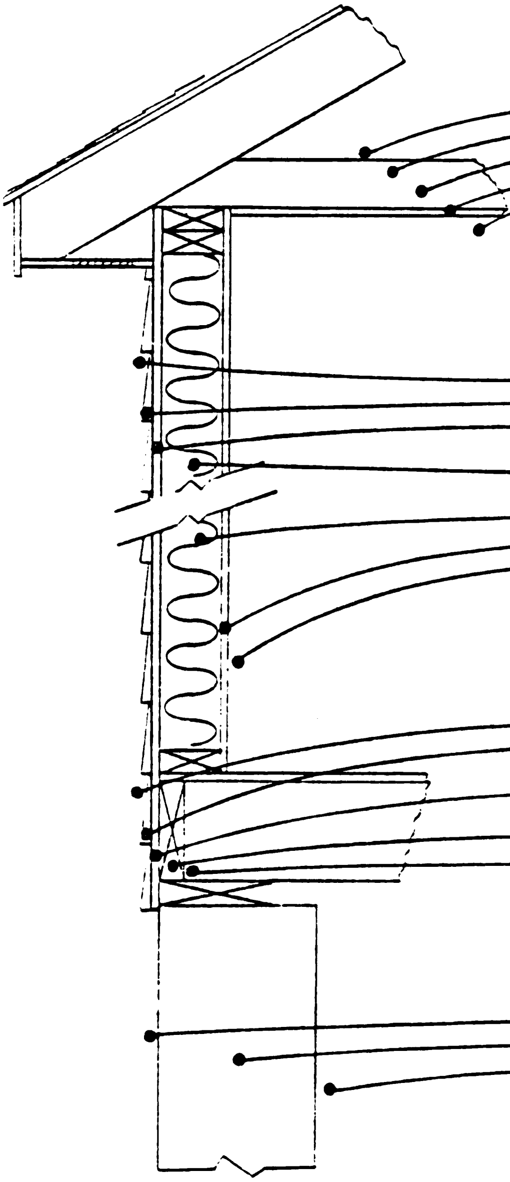
DRAWING NO. 2



REAR ELEVATION

DRAWING NO. 3

SECTIONS AND R VALUE CALCULATIONS



CEILING	CAVITY R	JOIST R
Top Surface	.61	.61
6" R-19 Insulation	19.00	--
3 1/2" Soft Wood	--	4.35
1/2" Gyp Board	.45	.45
Bottom Surface	.61	.61
R_t =	20.67	6.02

WALL	CAVITY R	STUD R
Outside Surface	.17	.17
Wood Siding, 1/2"x8"	.81	.81
1/2" Asphalt Impreg. Sheathing	1.32	1.32
3 1/2" R-11 Insulation	11.00	--
3 1/2" Wood Stud	--	4.35
1/2" Gyp Wall Board	.45	.45
Inside Surface	.68	.68
R_t =	14.43 ,	7.78

RIM JOIST	R
Outside Surface	.17
Wood Siding, 1/2" x 8"	.81
1/2" Asphalt Impreg. Sheathing	1.32
1 1/2" Soft Wood	1.89
Inside Surface	.68
R_t =	4.87

FOUNDATION WALL	R
Outside Surface	.17
8" Conc. 8x.08	.64
Inside Surface	.68
R_t =	1.49

DRAWING NO. 4

Basic Calculations

House Perimeter

28' + 28' + 46' + 46' = 148 ft.

Gross Assembly Areas

Gross roof/ceiling area (interior surface, 4" walls):

45'-4" X 27'-4" = 1239 ft^2

Gross wall area:

Framed wall (with siding exterior)

First floor	130' X 8' =	1040 ft^2
Basement	46' X 8' =	368 ft^2
		1408 ft^2

Framed wall area (with dry wall exterior)

First floor (garage)	18' X 8' =	144 ft^2
Rim joist area	1' X 148'=	148 ft^2
Exposed foundation wall area	1' X 102'=	102 ft^2
Gross Wall Area		1802 ft^2

Floor area over unheated space:

None, therefore, the floor is not considered in the determination for compliance in this example.

Note: 1) Since the basement floor is an unheated slab-on-grade perimeter, insulation is required on the walk-out side.

Note: 2) Wall framing is estimated to be 20% of the gross wall area.

Note: 3) Ceiling framing:

2' X s spaced 24" oc = 6.25% wood framing area
2' X s spaced 16" oc = 9.37% wood framing area

ROOF/CEILING HEAT FLOW REGIONS

Framing 1239 ft^2 x 0.0625 77 ft^2	Top Surface	0.61	
	3½" Soft Wood	4.35	
	½" Gypsum Board	0.45	
	Bottom Surface	0.61	
A = 77 ft^2	TOTAL R =	6.02	A/R= 12.8
Cavity 1239 ft^2 - 77 ft^2 framing 1162 ft^2	Top Surface	0.61	
	6" R-19 Insulation	19.00	
	½" Gypsum Board	0.45	
	Inside Surface	0.61	
A = 1162 ft^2	TOTAL R =	20.62	A/R= 56.2
A =	TOTAL R =		A/R=
A =	TOTAL R =		A/R=
	TOTAL Roof/Ceiling A/R =		69.0

WALL HEAT FLOW REGIONS

Single Glazed Windows

3 - 70" x 54" = 79 ft^2
1 - 38" x 38" = 10 ft^2
1 - 46" x 42" = 13 ft^2
2 - 42" x 54" = 32 ft^2
134 ft^2

	R
U = 1.10	
R = 1/U	
R = 1/1.10	0.91
TOTAL R =	0.91

A = 134 ft^2 A/R= 147.3

Double Glazed Windows

Doors: 1 - 102" x 84" = 60 ft^2
1 - 78" x 84" = 46 ft^2
106 ft^2

	R
U = 0.58	
R = 1/U	
R = 1/0.58	1.72
TOTAL R =	1.72

A = 106 ft^2 A/R= 61.5

Wood Slab Doors (Metal Storm)

2 - 42" x 84" = 49 ft^2

	R
U = 0.33	
R = 1/U	
R = 1/0.33	3.03
TOTAL R =	3.03

A = 49 ft^2 A/R= 16.2

Framing (With Siding Exterior)

1408 ft^2
x 0.20
282 ft^2

	R
Outside Surface	0.17
Wood Siding ½" x 8"	0.81
½" Asphalt Impreg. Sheathing	1.32
3½" Soft Wood	4.35
½" Gypsum Board	0.45
Inside Surface	0.68
TOTAL R =	7.78

A = A/R= 36.3

TOTAL CONTINUE WALLS ON NEXT PAGE A/R =

WALL HEAT FLOW REGIONS

Framing (With Dry Wall Exterior)

144 ft^2
x 0.20
29 ft^2

Outside Surface	0.17
½" Gypsum Board	0.45
3½" Soft Wood	4.35
½" Gypsum Board	0.45
Inside Surface	0.68

A = 29 ft^2 TOTAL R = 6.10 A/R= 4.8

Cavity (With Siding Exterior)

1408 ft^2 - Gross
-134 ft^2 - Single Glazed Windows
-106 ft^2 - Double Glazed Windows
- 25 ft^2 - Wood Slab Door
-282 ft^2 - Wood Framing
861 ft^2 - Cavity

Outside Surface	0.17
Wood Siding ½" x 8"	0.81
½" Asphalt Impreg. Sheathing	1.32
3½" R-11 Insulation	11.00
½" Gypsum Board	0.45
Inside Surface	0.68

A = 861 ft^2 TOTAL R = 14.43 A/R= 59.7

Cavity (With Dry Wall Exterior)

144 ft^2 - Gross
-29 ft^2 - Wood Framing
-24 ft^2 - Wood Slab Door
91 ft^2 - Cavity

Outside Surface	0.17
½" Gypsum Board	0.45
3½" R-11 Insulation	11.00
½" Gypsum Board	0.45
Inside Surface	0.68

A = 91 ft^2 TOTAL R = 12.75 A/R= 7.1

Rim Joist (With Siding Exterior)

130 ft^2
x 1 ft^2
130 ft^2

Outside Surface	0.75
½" Gypsum Board	0.45
1½" Soft Wood	1.89
Inside Surface	4.87

A = 130 ft^2 TOTAL R = A/R= 26.7

TOTAL CONTINUE WALL ON NEXT PAGE A/R =

WALL HEAT FLOW REGIONS

Region	Component	R	
Rim Joist (With Dry Wall Exterior)	Outside Surface	0.17	
18 ft^2	¼" Gypsum Board	0.45	
x1 ft^2	1½" Soft Wood	1.89	
18 ft^2	Inside Surface	0.68	
A = 18 ft^2	TOTAL R =	3.19	A/R= 5.6
Exposed Concrete Foundation	Outside Surface	0.17	
102 ft^2	8" Concrete (8 x 0.08) = 0.64	0.64	
x 1 ft^2	Inside Surface	0.68	
102 ft^2			
A = 102 ft^2	TOTAL R =	1.49	A/R= 68.5
A =	TOTAL R =		A/R=
A =	TOTAL R =		A/R=
	TOTAL WALL A/R =		433.7

CODE REQUIREMENT AND COMPLIANCE TABLE

Assembly 1	Code Requirements of Assembly BTU/HR ft^2 °F 2		Gross Area of Assembly, ft^2 3		Code Requirements Expressed as UA Values BTU/HR°F 4		Dwelling A/R Values, BTU/HR°F 5
Roof/Ceiling	U_o (Code Maximum) = 0.05	×	A Roof/Ceiling = 1239	=	UA Roof/Ceiling Code = 62.0	↔	A/R Roof/Ceiling = 69.0
Roof/Ceiling (Cathedral)	U_o (Code Maximum) =	×	A Roof/Ceiling Cathedral =	=	UA Roof/Ceiling Code Cathedral =	↔	A/R Roof/Ceiling Cathedral =
Wall	U_o (Code Maximum) = 0.205	×	A Wall = 1802	=	UA Wall Code = 369.4	↔	A/R Wall = 433.7
Floor (over unheated space)	U_o (Code Maximum) =	×	A Floor =	=	UA Floor Code =	↔	A/R Floor =
Floor (heated slab on grade)	R (Code Minimum) =		No Test For Compliance				
Floor (unheated slab on grade)	R (Code Minimum) - 5.45		No Test For Compliance				
					↓ = UA Envelope Code = 431.4		↓ = A/R Envelope Calculated = 502.7

Meets Code	Does Not Meet Code
☐	☒

Owner John Q. Layman

Site Address 624 Citizen Street, NW, Grand Rapids

Contractor I. Warmum, Inc

Date ______ Phone 451-0002

Annual Heating Degree Days 6894

IS THIS NUMBER GREATER THAN THIS NUMBER?

****

IF THE $UA_{ENVELOPE}$ CODE VALUE (COL.4) EQUALS OR EXCEEDS $A/R_{ENVELOPE}$ VALUE (COL.5) THE DWELLING COMPLIES!

APPENDIX B

COMPLETED INPUT FORM FOR THE IBUC PROGRAM

IN THE BANK or UP THE CHIMNEY

- ENERGY SAVINGS

A TELPLAN PROGRAM*

Name____________________

Address____________________

City____________________ Zip__________

There are many ways to make houses more energy efficient and prevent the escape of heat for which you have paid. Some of the most important steps are: caulking and weatherstripping around doors and windows; adding storm windows; insulating attics, walls, and floors or basement and crawl space walls. Some steps cost more than others. This program is designed to help you figure out what it might cost to add these energy-savers to your house, how much each might save on heating costs, and how long it would take to pay off your initial investment.

The information you provide about your house on this questionnaire will be put into a computer which will do the calculating for you, using a program developed at M.S.U. The information you get back from the computer will help you determine where you can get greatest energy savings for your investment. In order to get the most helpful information back, be sure you are as accurate as possible in filling out the form. Measure wherever you can instead of guessing. The information you receive is based on average prices for Michigan; exact prices may vary somewhat in your area. The computer does figure in the rate of inflation for "one-shot" investments lasting several years.

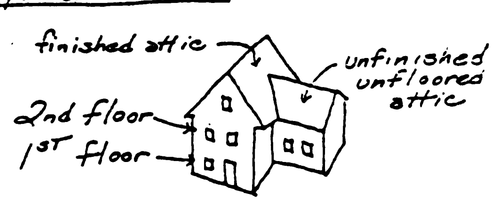
First: Draw a rough plan of each floor in your house on the enclosed graph paper. Show which areas are heated, basement, and crawl spaces. Draw the attic area. (See example -- your house may be different than the examples in this form but show what it is like as closely as possible.) You may draw to scale. Show the outside dimensions of each area to the nearest foot you can; then use these to calculate the square foot areas and total length of walls requested in the form.

Second: Fill out Section I, "General Information". Each of the other Sections, II through VII, refers to a different weatherproofing step. Fill out each one you are interested in considering.

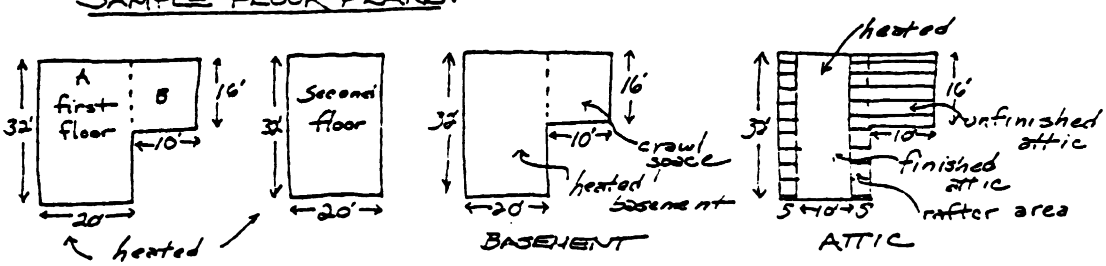
Square foot area:
1st floor - 32'x20'= 640
16'x10'= 160
800 sq. ft.

2nd floor - 32'x20'= 640 sq. ft.

Example of a House:



SAMPLE FLOOR PLANS:



*This computer program was developed by Steve Harsh, Agricultural Economics Department; James Boyd and Leslie Mack, Agricultural Engineering Department, Cooperative Extension Service, Michigan State University, East Lansing, MI 48824.

SECTION I. General information

House information

3 1a. What kind of fuel is used by your heating system?
1 = Electric
2 = Oil
3 = Gas
4 = Coal

14 b. How many windows are on your house regardless of size (include basement windows)?

3 c. How many doors are on your house including sliding glass doors?

1 d. How many stories do you have? (Do not include finished attic or basements).

1620 e. What is the square foot area of the floors of your house (Do not include finished attic or basements).

1 f. Does your house have
1 = crawl space
2 = exposed basement walls
0 = no crawl space or exposed basement walls?

0 g. Does your home have central air conditioning (0=no, 1=yes)

Check all of the following weatherproofing steps you would like to consider: Now, read each of the following sections to see if you want to make added choices.

✓ 2a. Caulking and weatherstripping (Sec. II)

✓ b. Installing storm windows (Sec. III)

✓ c. Attic insulation (sec. IV)

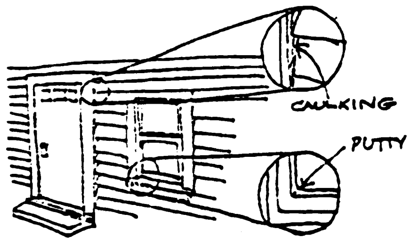
✓ d. Wall insulation (sec. V)

✓ e. Crawl space walls, floor or basement walls (sec. VI)

✓ f. Thermostat adjustment (sec. VII)

EACH OF THE FOLLOWING SECTIONS REFERS IN DETAIL TO ONE OF THE WEATHERPROOFING STEPS YOU HAVE JUST CHECKED.

SECTION II. Caulking and Weatherproofing Doors and Windows



If you are interested in this step, answer the following questions:

Which of the following best describes the condition of the caulking around the windows and doors:

2 3a. 1=OK - Cracks completely filled-window putty good.
2=Fair - Caulking and putty cracked or missing in places.
3=Poor - No caulking, noticeable drafts.

14 b. Number of windows needing caulking.

2 c. How many doors need caulking?

Which of the following best describes the condition of weatherstripping on your doors and windows?

2 4a. Condition of window wea[illegible]
1=OK - Unbroken weatherstripping, no drafts.
2=Fair - Some weatherstripping damaged
3=Poor - No weatherstripping

2 b. Condition of door weatherstripping
1=OK - Unbroken weatherstripping, no drafts.
2=Fair - Some missing
3=Poor - No weatherstripping

14 c. How many windows need weatherstripping?

2 d. How many doors need weatherstripping?

SECTION III Storm Window Information

If you are interested in this step, answer the following questions:

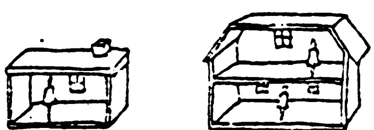
__3__ 5a. What kind of storm windows would you consider installing?
1=Plastic sheeting over windows
2=Regular single glass
3=Combination self storing storm windows

__12__ b. How many storm windows will you install?

SECTION IV Attic Insulation

If you are interested in this step, answer the following questions:

__1__ 6a. What type of roof do you have?
0=Flat or mansard (see drawing below)
1=Other types of roofs



flat mansard

If flat or mansard roof, skip to Section V.

Flat roofs or mansard roofs are uncommon in houses, especially older houses. Insulating them should be done by a contractor and costs will vary.

__3__ b. How many inches of insulation do you have in your attic?

However, if old insulation is packed down or missing in spots enter 0 for thickness.

__0__ c. Will you have a contractor install the insulation or do it yourself?
0=do it yourself
1=use contractor

SECTION IV Attic Insulation (Continued)

Do you have one or more of the following types of attics? (0=no; 1=yes)

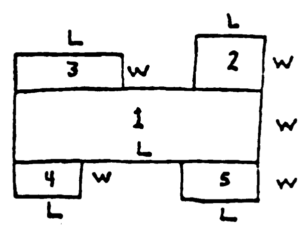
__1__ 6d. Unfinished attic (with the floor joists exposed)

__0__ e. Unfinished attic (with a floor but no plans to finish attic)

__0__ f. Unfinished attic (with a floor and you plan to finish it into rooms in the future)

__0__ g. A finished attic.

If you answered yes on line 6d or 6e, give the length (l) and width (W) in feet of each area of your home with an unfinished attic above it. If you have more than one of these areas, report each as a separate area. The diagram below is an example of a home with five separate unfinished attic areas. Areas may be numbered in any order as long as you report all such areas.



7. Size of Area 1 __42__ long, __24__ wide

8. Size of Area 2 __16__ long, __32__ wide

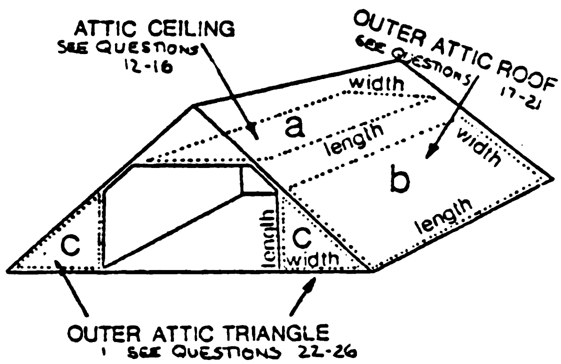
9. Size of Area 3 __10__ long, __10__ wide

10. Size of Area 4 __ __ long, __ __ __ wide

11. Size of Area 5 __ __ long, __ __ __ wide

SECTION IV Attic Insulation (Cont.)

If you answered yes on line 6f or 6g, give the length and width of the areas shown; if you answered no, skip to Section V. Numbers on the diagram refer to the questions which follow.



Attic Ceiling Areas

These are the flat areas which form the ceiling and you could have more than one so list the size of as many of these areas as you have.

12. Attic Ceiling 1 __ long, ___wide

13. Attic Ceiling 2 __ long, ___wide

14. Attic Ceiling 3 __ long, ___wide

15. Attic Ceiling 4 __ long, ___wide

16. Attic Ceiling 5 __ long, ___wide

Outer Attic Areas

List as many as you have.

17. Outer Attic Area 1 __ long, ___wide

18. Outer Attic Area 2 __ long, ___wide

19. Outer Attic Area 3 __ long, ___wide

20. Outer Attic Area 4 __ long, ___wide

21. Outer Attic Area 5 __ long, ___wide

Outer Attic Gable Areas

List the dimensions of outer attic gable areas (Outer Attic G.A.) which you have.

22. Outer Attic G.A. 1 __ long, ___wide

23. Outer Attic G.A. 2 __ long, ___wide

24. Outer Attic G.A. 3 __ long, ___wide

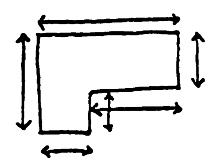
25. Outer Attic G.A. 4 __ long, ___wide

26. Outer Attic G.A. 5 __ long, ___wide

SECTION V Wall Insulation Information

If you are interested in this step, answer the following questions:

Measure the distance around each story of your house in feet. These would be the walls you insulate.



164 27a. Length of outside walls on first floor.

0 b. Length of outside walls on second floor.

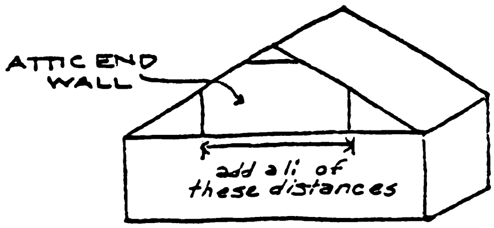
0 c. Length of outside walls on third floor (if you have one).

0 28a. If you have other walls to insulate, what is the length of these walls in feet?

0 b. What is the length of the finished attic end walls? These are the ends of rooms on the outside including dormers that should be insulated. Add all of these lengths together.

(See example next page)

SECTION V Wall Insulation Information (Cont.)



__2__ c. Choose which of the following types of insulation you would like to consider:
1=Mineral Fibers (fiberglass or rock wool)
2=Cellulose fibers
3=Urea Formaldehyde foam

SECTION VI Crawl Space Walls, Floors, and Basement Wall Information

If you are interested in this step, answer the following questions:

__0__ 29. Do you have a concrete slab on the ground? (0=no; 1=yes)
If yes,
skip rest of this section, and go to Section VII.

Which of the following types of crawl spaces or basement walls do you have? You could have one or more of these types of spaces. (see below)
(0=no; 1=yes)

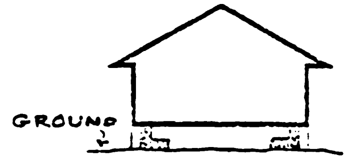
__/__ 29a. Crawl space with walls around it

__0__ b. Floor over garage, porch, or open crawl space.

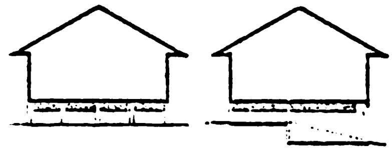
__/__ c. Heated basement that sticks out of the ground.

__0__ d. Will contractor install insulation?
0=no; 1=yes

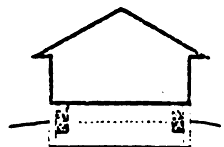
SECTION VI Crawl Space Walls, Floors, and Basement Wall Information (Cont.)



a. Crawl space with walls around it



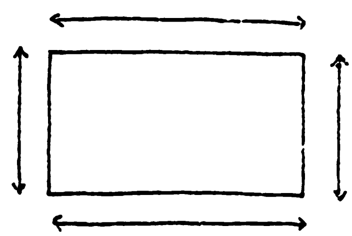
b. Floor over garage, porch, or open crawl space



c. Heated basement walls that stick (wholly or partially) out of the ground:

Crawl Space to Insulate

__152__ 30a. What is the distance in feet around the crawl space under your floor?



SECTION VI Crawl Space Walls, Floors, Basement Wall Information, cont.

Floors to insulate

What is the width and length of the floors over cold unheated areas that should be insulated?

31. Area of Floor 1 _ _ wide,_ _ _ long

32. Area of Floor 2 _ _ wide,_ _ _ long

33. Area of Floor 3 _ _ wide,_ _ _ long

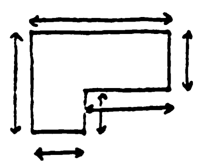
34. Area of Floor 4 _ _ wide,_ _ _ long

Basement Walls to Insulate

The basement of a house usually sticks out of the ground and this band of wall, usually concrete, should be insulated.

4 35a. Average height of exposed wall from the ground line to the first floor (feet). (Measure height of greatest exposed area and add this to height of least exposed area and divide the total by two).

58 b. What is the distance around the heated part of the basement (feet).



SECTION VII Changing Thermostat Setting

Considerable amounts of fuel can be saved by turning heating thermostat... and cooling (air conditioning) therm...ats up. For each degree the thermostat is turned up or down we can estimate the fuel savings.

If you are interested in this step, answer the following questions:

973 36a. What is your best estimate of your total heating fuel cost for the last 12 months (dollars)?

4 b. How many degrees will you turn down your thermostat?

Answer line 37 only if you have home central air conditioning.

______ 37a. If you have central air conditioning what is the best estimate of your cooling costs for one season (dollars)?

______ b. If you have central air conditioning, how many degrees will you turn up your therm stat?

0 38. This completes the form.

Thank you.

If there are comments you would like to add, please do so below:

APPENDIX C

COMPLETED INPUT FORM FOR THE NBSLD PROGRAM

Input
Field

INPUT VARIABLES AND ARRAYS

1

RUNID	RUNTYP	ASHRAE	IDETAL	METHOD
1	2	0	1	0

(Integer)

2 NAMEBD (Col. 3-36, Alphanumeric)

X	X	M	S	U		H	O	U	S	E																									

3 QLITX (24,3)

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

4 QEQUX (24,3)

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

5 QOCUP (24,3)

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

6 QLITX'

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

7 QEQUX'

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

8 QOCUP'

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

9 QLITX"

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

10 QEQUX"

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

11 QOCUP"

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0						

12 RMDBS (24)

78	78	78	78	78	78	78	78	78	78
78	78	78	78	78	78	78	78	78	78
78	78	78	78						

13 RMDBW (24)

68	68	68	68	68	68	68	68	68	68
68	68	68	68	68	68	68	68	68	68
68	68	68	68						

14

RMDBWD	RMDBSO	RHW	RHS
68	78	25	60

15

NDAY	NSKIP	TAPE 2
0	0	0

(INTEGER)

16 ZBLDG (15)

MONTH	DAY	ELAPS	DBMAX	RANGE	WBMAX	DBMWT	TGS	TGW	UG
1	16	15	23	0	20	23	41	41	.1

LONG	LAT	TZN	ZLF	RHOW
84.67	42.83	5	0	20

17 NAMERM (Col. 3-36, Alphanumeric)

X	X	N	O		A	T	T	I	C		N	O		C	E	L																			

18

IROT	ISKIP	INCLUD
0	0	1

(INTEGER)

19

NLAYR
4

(INTEGER)

(NOT INPUT)

IRF

20

	L	K	D	C	RES	
	.03937	.42	50	.2	0	1st LAYER-innermost
20A	.383	.025	2	.2	0	2nd LAYER
20B	.03937	.070	37	.3	0	3rd LAYER
20C	.03937	.070	37	.3	0	4th LAYER
...						
...						
...						
...						
...						
20N						Nth LAYER

21 LAYER DESCRIPTION (24 Col.max. Alphanumeric)

	GYPSUM BOARD	1st LAYER-INNERMOST
21A	FIBR INSULATION	2nd LAYER
21B	SHEATHING/DECKING	3rd LAYER
21C	SIDING/ROOFING	4th LAYER
...		
...		
...		
...		
21N		Nth LAYER

22

NLAYR
0

(NLAYR = ZERO CARD INDICATING END OF WALL/ROOF/FLOOR DATA)

23 ZROOM (12)

ROOMNO	QLITY	QEQPX	QCU	FLCO	FRAS	TS	CFMS	ARCHGS	ARCHGW
1	0	0	0	0	0	0	0	0	0

ARCHGM	ZNORM
.02	1

24

IW	IL	ISTART	ILEAVE
3	0	8	17

25

TUL	TIL	QCMAX	QHMAX	DBVMAX	DBVMIN
78	68	99,000	99,000	68	50

26

ITHST	ITK
0	0

(INTEGER)

27 NNEXP (4)

NS	NW	NN	NE
2	2	2	2

(INTEGER)

28

L	W	H
50	30	8

29

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHD
1	5	1500	0	0	0	.78	0

(INTEGER: ITYPE AND IRF)

30 SHADW (30,15)

FL	HT	FP	AW	BWL	BWR	D
0	0	0	0	0	0	0

31

FP1	A1	B1	C1	FP2	A2	B2	C2
0	0	0	0	0	0	0	0

29A

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHD
2	1	360	0	0	0	.78	0

(INTEGER: ITYPE AND IRF)

30A SHADW (30,15)

FL	HT	FP	AW	BWL	BWR	D
0	0	0	0	0	0	0

31A

FP1	A1	B1	C1	FP2	A2	B2	C2
0	0	0	0	0	0	0	0

32

UENDW	UCELNG	AENDW	ATCHT	ARCHGA	AIRNT
0	0	0	0	0	1

33

IEXTED	IEXMS	IEXME	NTVNT	NVENT
0	0	0	0	0

(INTEGER)

34 (BLANK DATA CARD INDICATING END OF DATA)