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ENERGY UTILIZATION INDEX METHOD FOR PREDICTING BUILDING ENERGY --ETC(U)
MAY 77 L M WINDINGLAND, D C HITTLE DACA23-76-C-0001

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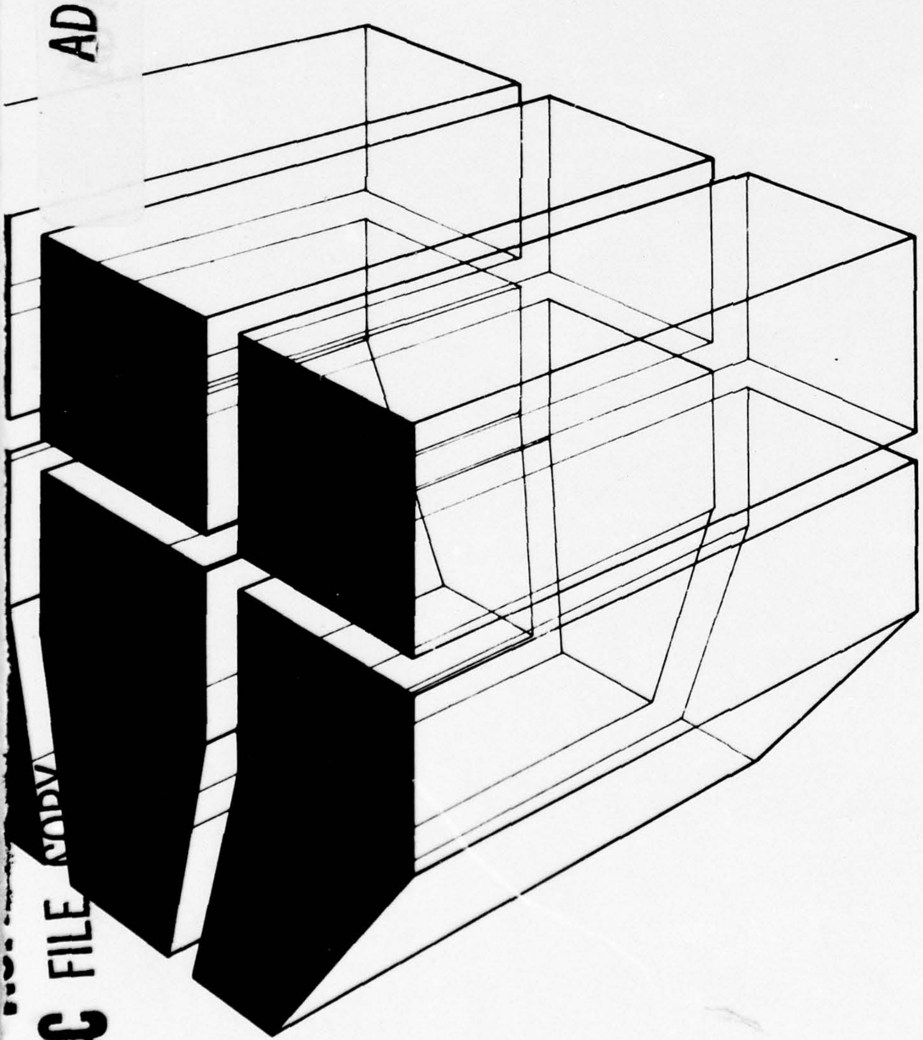
ENERGY UTILIZATION INDEX METHOD FOR PREDICTING BUILDING ENERGY USE VOLUME I: METHOD DEVELOPMENT



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This report describes development of the Energy Utilization Index (EUI) method for manually calculating monthly and annual energy consumption for buildings on military installations. The method uses basic building parameters such as U-factors, dimensions, occupancy, type of HVAC equipment, and average monthly weather conditions to arrive at a prediction for a building's monthly and annual energy use. Procedures for aggregating individual building consumption data into facility and →

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cont

installation consumption predictions are provided. The method for correcting the predictions to account for actual weather conditions is also described.

Volume I describes the development of the EUI method, tells how the method is used, and compares predictions generated by the method with actual consumption data. A comparison of ±4 percent was shown for one building type.

+ or −

Volume II is a proposed supplement to TB ENG 259, *Repairs and Utilities, Utilities Utilization, Targets and Evaluations* (13 Mar 61), based on the EUI method. The information is intended to supplement Chapters 2 and 3 of TB ENG 259 and provides Facilities Engineering personnel with a refined method for predicting energy use in support of budget preparation, command reporting requirements, and the evaluation of energy conservation alternatives.

FOREWORD

This study was performed for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), as part of RDT&E program 6027.19A, Project 4A762719AT41, "Design, Construction, and Operations and Maintenance Technology for Military Facilities"; Task T6, "Energy Systems"; Work Unit 009, "Energy Utilization of Mechanical Systems." The OCE Technical Monitor is Mr. James Walton.

The work was performed under Contract No. DACA-23-76-C-0001 by Hittman Associates, Inc., Columbia, MD, for the Energy Systems Branch, Energy and Power Division of the U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL. Mr. Douglas C. Hittle and Mr. Larry M. Windingland were the CERL Principal Investigators. Dr. Donald J. Leverenz is Chief of the Energy Systems Branch and Mr. Richard G. Donaghy is Chief of the Energy and Power Division.

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ENERGY UTILIZATION INDEX METHOD FOR
PREDICTING BUILDING ENERGY USE
VOLUME I: METHOD DEVELOPMENT

1 INTRODUCTION

Background

Army Facilities Engineers must be able to predict building energy use on their installations in order to satisfy command reporting requirements and support future budget estimates. Energy use predictions have also become increasingly important in considering projects for energy conservation programs such as the Energy Conservation Investment Program (ECIP).

The existing method for predicting energy consumption is contained in TB ENG 259, *Repairs and Utilities, Utilities Utilization, Targets and Evaluation* (13 Mar 61). This method provides for predicting annual building heating energy use and installation electrical use but does not directly consider individual building cooling energy requirements, improvements in modern mechanical equipment, and building designs. In addition, the present method does not allow for monthly energy consumption predictions, nor does it place the proper emphasis on individual building energy usage, which is required to determine each building's potential for contributing to an energy conservation program. The techniques available for eliminating these deficiencies require extensive use of complex computer simulation programs. Although several manual methods have been proposed, none are readily available for use by the Facilities Engineer. Thus, a manual procedure is needed that will allow the Facilities Engineer to predict energy requirements of modern facilities more accurately and to evaluate the impact of various building modifications on energy consumption.

Objective

The objective of this study was to revise current methods of establishing energy consumption targets for buildings, to develop a method for evaluating individual building energy performance, and to develop a supplement to TB ENG 259 that provides Facilities Engineers with improved methods for calculating heating, cooling, electrical, and refrigeration energy consumption.

Approach

The following approach was used in the research effort:

1. Evaluate the existing Army method for predicting energy usage as stated in TB ENG 259 and analyze its ability to predict building heating and cooling energy usage.

2. Define criteria for a new method of predicting building energy usage.

3. Determine the types of data readily available to Facilities Engineers which could be used in a new method for predicting energy consumption.

4. Divide military buildings into characteristic groups and model one building from each group using a building energy analysis computer simulation program to determine a base Energy Utilization Index (EUI) in Btu's per square foot for each characteristic building.

5. Parametrically analyze the effects of building design variations on energy consumption for each of the five characteristic buildings using a building energy analysis simulation program.

6. Based on the parametric studies, develop algorithms to modify the EUI for one of the characteristic buildings to an EUI for a given building based on the differences in design between the given building and the characteristic building.

7. Based on these algorithms, develop the EUI method for predicting energy consumption in military buildings and provide a supplement to TB ENG 259 describing the use of the method.

Scope

This report is in two volumes. Volume I covers the work accomplished to develop the new method for predicting building energy use and includes as an appendix a report prepared by Hittman Associates, Inc., that analyzes TB ENG 259 and details the procedures used to develop the EUI method.

Volume II, a proposed supplement to TB ENG 259, provides instructions for computing monthly heating and cooling fuel consumptions as well as forecasting consumption for lighting, electrical appliances, cooking, hot water, laundry, and cold storage based on the EUI method.

Mode of Technology Transfer

Volume II of this report is a suggested supplement to Army Technical Bulletin TB ENG 259. Information contained in Volume II will also affect the process for targeting installation energy use as it is now outlined in Army Regulation 420-44.

2 DISCUSSION

TB ENG 259 was evaluated for its capability to estimate building heating and cooling energy requirements. It provides a satisfactory method for estimating annual fuel requirements for installations that do not vary their real property significantly from year to year or upgrade comfort conditions such as adding cooling to existing buildings. The major drawback is that the method does not place proper emphasis on individual buildings; thus, it does not properly account for such changes as adding cooling, replacing old barracks with new barracks, replacing wood structures with concrete structures, changing the use and occupancy patterns of a building, and changing mechanical systems and energy conservation measures. The method assumes that similar buildings can be grouped and analyzed together, which is acceptable except that no allowance is made for adjustments to buildings within a group, such as adding insulation, reducing window areas, or changing occupancy patterns.

To alleviate these deficiencies, specific criteria were identified for consideration in the development of a new method:

1. The method must provide for predicting individual building heating and cooling energy use on a monthly basis.

2. It must identify for each building the major energy consumption categories such as heating, cooling, lighting, hot water, cooking, laundry, electrical appliances, and cold storage.

3. It must use data readily available to the Facilities Engineer.

4. It must be reasonably accurate without requiring computer assistance.

5. It must identify areas in which energy conservation measures can be applied and assist in determining the most economical way to modify a building to reduce its energy use.

6. Corrections for actual weather conditions must be made from easily obtainable weather parameters.

To begin development of the new method, the types of data available to a Facilities Engineer were analyzed by reviewing Army posts' real property records, examining as-built engineering drawings, and interviewing key post personnel. One potential problem which surfaced during this analysis was the type and amount of building information required for making reasonable energy estimates. While much of the information is readily available to the Facilities Engineer, some data critical to energy estimates must be obtained through a search of engineering drawings or, in some cases, building surveys. Data that are not readily available include: wall, floor, and roof U values; building envelope area (surface area of building exposed to the weather); equipment capacity; and window area. These data are so critical in energy calculations that it was considered necessary for the Facilities Engineer to obtain them in order to realize reasonable accuracy with a new method.

Five characteristic building groups were selected which typify a large percentage of an Army post's buildings and a major portion of its energy use: single-family houses, townhouses (multifamily houses), barracks, administrative/office buildings, and commissaries. Commissaries were selected because of their unique cold storage requirements and customer-oriented occupancy pattern.

A characteristic building in each of these basic building types was selected for computer modeling and load determination. The characteristic buildings were selected by visits to various Army posts, review of real property records, and visual observation to insure that they were not unique or extraordinary to Army construction. The buildings were then analyzed and their physical parameters reduced to computer input form for calculation of the heating and cooling loads using a building load analysis computer simulation program. These loads became the base-energy load or Energy Utilization Index (EUI) for each characteristic building.

Next came selection of several building parameters that were expected to cause the most significant variation in energy use within the building: wall, floor and roof U values, window area, building envelope area, floor area, inside set-point temperature, infiltration/ventilation rate, type of heating/cooling and distribution system, and occupancy. Using hourly weather data for three different climatic regions, parametric analyses were performed by varying the selected parameters over logical limits and using the building load analysis computer simulation program to calculate variations in the heating or cooling load. The results of this parametric study led to development of a set of equations and curves which could be used to determine the monthly energy use for heating and cooling of different building types based on differences between the characteristics of the computer-coded buildings and the actual building being considered. In addition, energy use equations for lighting, electrical appliances, cooking, domestic hot water, laundry, cold storage, and distribution losses were developed from physical surveys of the characteristic buildings and consolidation of data from previous energy use studies (discussed in the appendix).

The EUI method was developed for the five basic building types based on the studies. The EUI method isolates various load-contributing components within a building, enabling determination of the various loads on a building--for example, loads due to heat conduction through the walls and roof, infiltration/ventilation, solar radiation, and internal heat generation of equipment and occupants. These features make the method extremely versatile in determining the effects of energy conservation alternatives in different buildings.

The method uses readily available weather parameters: heating degree days and cooling degree days. Although the validity of these parameters has been questioned in the past, this study has shown that very good correlations can be obtained (see curves in the appendix), with the exception of transitional months having very few degree days. Since these months represent such a small fraction of the total load, however, the effect is negligible. The use of actual heating degree days and cooling degree days also allows for rapid adjustments to the prediction. Predictions can also be made for anticipated severe or mild weather conditions by using the appropriate number of degree days.

To verify the developed algorithms, an office building having available energy use data was analyzed. The EUI method was used to estimate the heating, cooling, and electrical energy consumption for a full year. Comparison of the actual versus predicted values indicated an accuracy of about 4 percent. A single-family residence analyzed using the EUI method yielded similar results. It therefore appears that the algorithms developed for the EUI method have reasonable validity for predicting energy use in buildings.

The EUI method was specifically designed to predict buildings' energy use on a monthly basis. However, summation of energy consumption for a building can be performed for any time period desired--monthly, annually, etc.--and the individual contributing loads can be converted to represent the fuel type for each load (e.g., gas, electricity, oil, coal). These fuel usages can then be summed for every building on an installation to obtain a prediction of total installation fuel use.

A detailed discussion of the development of the EUI method is contained in the appendix, and Volume II contains the proposed supplement to Chapters 2 and 3 of TB ENG 259 based on the EUI method.

3 CONCLUSIONS

1. The Energy Utilization Index (EUI) prediction method has several advantages over the present method described in TB ENG 259: (a) it provides the capability to predict building energy use based on the physical characteristics of the building; (b) it can differentiate between heating and cooling energy usage; (c) it provides for predicting energy usage on a monthly basis and permits adjustment of the prediction based on actual weather data; (d) it provides a capability to identify areas having energy conservation potential, such as inadequate insulation, excessive infiltration, or excessive distribution losses.

2. The input information required for computing a building's EUI is available to the Facilities Engineer in various forms. Although obtaining this information may require a review of engineering drawings and, in some cases, building surveys, the input information is vital to reasonable energy predictions.

3. The disaggregation of the load-contributing factors makes the EUI method a valuable tool that assists in decisions on application of energy conservation measures by enabling comparison of the loads from different buildings.

4. The EUI method has been initially tested and appears reasonably accurate. While validation on a wide range of buildings is necessary to verify the accuracy of the method, the method could be used in the interim by Facilities Engineers as a tool for determining energy conservation measures to apply to existing buildings.

5. The EUI method can provide District Engineers with a tool to initially predict the energy consumption of proposed new buildings considered under major construction programs.

APPENDIX

Development of a Method to Determine Energy Utilization of Existing Utility Systems

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I. INTRODUCTION

The Technical Bulletin TB ENG 259 has been used by the United States Army in estimating the energy utilization in Army facilities. This study, conducted by Hittman Associates, Inc., under contract to the United States Army Construction Engineering Research Laboratory, presents a new methodology for computing the monthly energy use with reasonable accuracy which could be used as a replacement for Chapters II and III of the TB ENG 259. The procedures employed in the development of this methodology are presented in this document.

A. Background and Scope of Study

The TB ENG 259 manual provides a satisfactory method for predicting gross estimates of fuel requirements on an annual basis, but does not provide the proper emphasis on energy utilization nor does it identify effects of excessive energy use in individual buildings. Presently available methods that can provide such information require computer support in order to obtain a reasonable level of accuracy. Due to these limitations, it was determined that a new procedure was needed that was capable of the following:

- Forecasting heating and cooling energy use in buildings
- Identifying energy use for lighting, hot water, equipment, etc., to compute building total energy use
- Identifying areas in which energy conservation measures can be evaluated
- Assisting in decision making for any improvements to be done for buildings in order to decrease energy use
- Utilizing readily available data
- Obtaining reasonable accuracy without computer assistance

The objective of this study was to develop a set of algorithms that could be applied to each of the five building types studied. The development of the algorithms included a series of computer analyses on heating and cooling energy use in several buildings as well as performing sensitivity analysis of building elements, internal loads, and ambient weather conditions.

The algorithms developed here were also presented in a manual format to be used by the Army and any interested party.

B. Utility of the Study and Its Limitations

The utility of this study is multidimensional. In addition to being used by Army facility engineers, it may be used by analysts, researchers, builders, and maintenance personnel in each of the following:

- Predicting energy use
- Evaluating energy conservation measures
- Identifying the need for maintenance of structures and HVAC systems.

Given the broad scope of this study, it was obvious that a number of limits had to be placed on the work to enable the addressing of all areas required. These limits must be recognized by the users of this procedure. The general limitations of this study were as follows:

- The algorithms were developed for five specific building types. Application to other building types may result in a reduced level of accuracy.
- The algorithms were developed based on the climatic range from Chicago to Atlanta. While the algorithms may be applied beyond this range, the accuracy of the results will be somewhat reduced.

Other limitations which may be associated with some particular aspect of the study are presented and discussed in the appropriate sections of the text.

II. ANALYSIS OF TB ENG 259

The current procedures for computing fuel consumption and cost targets for military installations are defined in the Department of the Army Technical Bulletin TB ENG 259, dated 13 March 1961. The portions of this document applicable to space heating and cooling (Section II, Heating, and Section III, Electrical) have been reviewed for their applicability to predict heating and cooling energy use and to evaluate the impact of energy conservation measures. Also, this document and the procedures it defines were analyzed for their ability to identify energy conservation potential. Discussions of the document's procedures and their capabilities and shortcomings follow in two sections.

A. Heating Energy

Section II, Heating, provides a procedure for computing a cost target for all heating services. This procedure has three steps: (1) calculation of the heating load, (2) calculation of the system efficiency and amount of fuel used, and (3) the calculation of the cost of fuel and fuel services. The methodology and the capabilities and the shortcomings of these procedures are discussed below.

The calculation of building heating loads is based on the volume of a building and the heating demand units (HDUs) defined for the category of building type into which this building falls. Buildings are categorized by utilization activity, by the number of floors in the structure (1, 2, 3, or more), and by type; i.e., permanent, temporary, or a tent or hutment. Each category of building has a level of heating demand defined for it by Army publication AR 420-70 in terms of cubic feet of building volume per HDU. Table 1 shows the categories of buildings and the associated heating demand values. The heating load calculation for a building is completed by dividing the heating volume of the building (or portion of a building fitting into one category) by the appropriate building category cubic feet per HDU value in Table 1.

The calculations of fuel consumption for space heating purposes can be completed for an entire facility, group of buildings, or individual building by use of the total HDU requirements of all buildings assigned to the same degree day base, the number of degree days for the location of the building, and the appropriate fuel factor for the facility's

TABLE 1. HEAT DEMAND UNIT (HDU) REQUIREMENTS BY CATEGORY OF BUILDING (Ref. 1)

Permanent Buildings

Category	Allowable inside temp °F.	Degree day base	Cu. ft. per HDU for entire building 1-story Building	2-story Building	3-story Building	Example
A-1	61-72	65	60	65	70	See Note 1.
A-2	61-72	65	45	50	55	See Note 2.
A-3	73 and higher	65	45	50	55	See Note 3.
A-4	55 to 60	50	125	135	140	See Note 4.
A-5	40	50	200	210	220	See Note 5.

Semipermanent and Temporary Buildings (See Note 6)

Category	Allow. inside temp. °F.	Degree day base	Cu. ft. per HDU	Example
B-1	61-72	65	40	See Note 1.
B-2	61-72	65	30	See Note 2.
B-3	73 and higher	65	25	See Note 3.
B-4	55-60	50	85	See Note 4.
B-5	40	50	135	See Note 5.

Hutments and Tents (See Note 7)

Category	Allow. inside temp. °F.	Degree day base	Cu. ft. per HDU	Example
C-1	61-72	65	40	Hutments
C-2	61-72	65	16	Tents

Note 1. Includes those portions of barracks, administration buildings, classrooms, recreation buildings, mess halls, and like buildings which are normally heated 10 to 12 hours daily (such as living quarters, offices, hanger lean-to's, lavatories, showers, wards, hospital corridors where personnel work seated or in a standing position involving little or no exercise.

2. Includes those portions of dwellings, converted quarters, and hospital wards which are normally heated 12 to 24 hours daily (such as those specified in note 1).

3. Includes operating rooms, delivery, and recovery rooms; hydrotherapy, X-ray, special wards, clinics, physical examination, and similar rooms; maternity sections; and special process rooms, such as paint shops, and drying rooms.

4. Space in shops and warehouses (issue and similar rooms; shops, hangers, and other buildings or sections of buildings where many employees work).

5. Spaces in shops and warehouses where heat is required to protect material and stored equipment from freezing or to control condensation.

6. Included are prefabricated buildings, trailers, quonset huts, and jamesways.

7. Multiply square feet areas of hutments and tents by 7 to obtain cubic feet of heated space.

heating plants and systems. Buildings which are heated to 56°F or above have heating system energy requirements calculated using heating degree days of a 65°F base. Those heated to 55°F or below, some warehouses, shops, etc., utilize heating degree days at a 50°F base in heating energy calculations. The appropriate heating degree day base by category of building is also shown in Table 1. The fuel factor is based on the weighted average efficiency of heating plants and boiler plants on the Army facility (or serving a group of buildings being evaluated) determined from the previous year's fuel consumption data, and the heating design zone in which the installation is located. The factor represents the fractional pound of standard fuel (25×10^6 Btu per ton) required to provide space heating for one HDU for one degree day.

The fuel requirement is calculated by:

$$\frac{(\text{No. of HDU}) \times (\text{Fuel Factor}) \times (\text{Heating Degree Days})}{2000} = \text{Standard tons of fuel}$$

Two calculations can be done, one for each degree day base. Target costs for fuels are then determined based on the average cost of fuel for the previous year adjusted for anticipated increases and decreases.

This procedure is an effective one when applied to entire facilities for estimating average fuel consumption. However, being a tool developed well before the energy crisis, it does not serve the purpose of evaluating energy conservation methods and impacts. The primary purpose of this tool has been to predict the energy use of a building or group of buildings, assuming that they will use what buildings of a similar nature have historically. However, in these days of high fuel prices and fuel shortages it has become increasingly important not only to evaluate energy use in terms of an average building, but also to determine the capabilities of each building to contribute to an energy conservation program. From this viewpoint, no longer is the primary concern only to calculate how much heating energy is going to be needed by a building next year but also it must be determined how much energy a building such as this needs in its current condition and what might be done to reduce this requirement of fuel. To address the latter questions, many physical and energy parameters must be considered in the fuel/energy use calculation which have not been included in the existing manual. The current methodology does not clearly consider or account for variations of the following important factors in the heating energy calculation:

- Construction parameters, such as wall, roof, and floor heat transfer coefficients; i.e., levels of insulation are not considered.

- Window area, or the thermal gains and losses associated with solar radiation, heat conduction through the glass, or air infiltration through and around windows.

- Indoor set-point temperature, except in the categorization of buildings by set point greater, or less, than 55°F.

- People, lighting, and other internal loads and their impact on heating energy use.

- Different types of heating and distribution systems with improved efficiencies.

The methodology presented in this report can be used to both identify heating fuel requirements and identify particular areas of energy conservation potential.

B. Air Conditioning Energy

Section III, Electrical, is a tool for predicting total electrical consumption. Targets are calculated using the actual electrical consumption per capita per month for the corresponding period of the previous year and an assumed 100 percent occupancy for the targeted period. Corrected targets are determined using actual occupancy level. Allowances are made for new electricity loads added since the end of the last target period plus any anticipated load additions during the target period. However, it does not provide a methodology to be used in predicting cooling energy consumption.

III. IDENTIFICATION OF ARMY CHARACTERISTIC BUILDINGS

A. Introduction

Characteristic buildings of the five types with which this program was concerned (single-family houses, town houses, barracks, administration/office buildings, and commissaries) were defined primarily on the basis of buildings which could be visited at Fort Belvoir in Virginia and Fort George G. Meade in Maryland. In addition, the Office of the Chief of Engineers (OCE) was consulted to insure that the characteristic buildings selected would be representative of nationwide Army facilities. No attempt was made to select buildings which are "the typical structure" of that building type. Rather, a characteristic building was selected with some assurance that it was not unique or extraordinary. It was not important to select a building which was most typical, but rather, what was needed was a building with parameter values within the range of common occurrence.

The design and structural features considered important in defining these residences included:

(1) Structural parameters such as construction details, dimensions, and materials used;

(2) Energy consumption parameters such as heating and cooling equipment, types of fuels used, appliances, and their energy consumption levels.

Whereas specific life-styles were not prescribed for the occupants of the characteristic buildings, a certain number of life-style parameters were imposed, by necessity, for the analyses. Examples of life-style parameters that were identified include thermostat set point, relative humidity set point, type and number of appliances, daily profile of appliance usage, and usage of ventilation fans. Most of these parameters were defined for average conditions; no attempt was made to modify the parameters to allow for variations caused by weekends or holidays, vacations, entertaining of large groups, difference in age or affluence of the occupants, etc. Occupancy, lighting, and appliance loads were, however, adjusted for weekends. It should also be recognized that the life-style of any given occupant (in a real case) could vary greatly from the average conditions defined for these analyses, and that variations in occupant life-style can affect the building's energy consumption.

With respect to ventilation air, the single-family and town house structures were defined as having no mechanical ventilation equipment. The administration/office building and commissary have ventilation air supplied throughout, while the barrack has air supplied to the hallways and mess areas. The normal rate of air infiltration through the residential structures, augmented by kitchen and bathroom fans, was more than sufficient to meet the physiological and esthetic requirements of both the town house and single-family units. The windows of the respective characteristic buildings were defined as remaining closed during periods of heating and cooling. However, allowances were made for daily opening of entrance doors in accordance with the population of each type of building.

Based on the brief survey of buildings at Fort Belvoir and Fort Meade, and data obtained from personnel on these bases, as well as data collected from OCE, CERL, and outside sources, a characteristic building for each of the five building types was defined. This chapter describes these characteristic buildings along with their relevant structural and energy-use parameters.

B. Single-Family Residence

Although the single-family residence is still the most prevalent form of housing in the U.S., it is not the most predominant structure in the military. Discussions with OCE indicated a very strong trend in Army family housing away from single-family units (Ref. 2). Although in 1970, some 69.4 percent of all year-round civilian dwelling units nationwide were single-family buildings (Ref. 3), a survey of family housing units at Fort Belvoir showed that only eight percent of all permanent family housing units are single-family structures (Ref. 4). In this context, the term "single-family residence" refers to the completely detached single-family house.

The family housing programs in the military of the past two or three decades have not concentrated on single-family dwellings. The "Capehart" program of the late 1950's and early 1960's, the most extensive family housing program in the military since the Second World War, was concentrated in multifamily housing, particularly town houses, duplexes, and low-rise apartments. Subsequent programs have increased the emphasis on town houses. Therefore, it is not too surprising that the last single-family residences built at Fort Belvoir were constructed in 1950. In fact, 123 of the 127 single-family units at Fort Belvoir were built between 1930 and

1935 (Ref. 4). For the purposes of this study, these single-family units are divided into two major categories, officer and NCO housing. It was assumed that throughout the Army, NCO single-family residences outnumber officer single-family residences. Therefore, the structure selected as the characteristic single-family house was an NCO family unit. This structure was selected as a characteristic single-family residence after visits to both Fort Belvoir and Fort George G. Meade, which included examination of Real Property records and building drawings, talks with Real Property department personnel, and a review of a computer listing of Fort Belvoir building inventory, "Installation Inventory of Military Real Property" as of September 30, 1974 (Ref. 4).

The characteristic single-family house which was selected is identical to 41 units at Fort Belvoir and, with minor modifications, this design appears there another 24 times. Sixty-one of these units are NCO family housing, the other four are officers' housing. In addition, about 40 to 50 nearly identical units were observed in a visit to Fort George G. Meade in Maryland, indicating that the design is not unique to one Army base. The internal floor plan is not in itself critical to the energy analysis, since the single-family house has been treated as a unit shell in heat transfer calculations. However, it must be noted here that this design is one which includes a "heated attic," that is, a large portion of the attic is actually conditioned living area. It is a story-and-a-half design with a second floor totalling 660 square feet of living area (two bedrooms, a bath, and storage space) over a first floor of 1,140 square feet (two bedrooms, bath, living room, kitchen, and dining area). Although this type of design seems somewhat unusual, it does represent virtually all NCO family housing, and at least 50 percent of all single-family residences at Fort Belvoir. Tables 2 and 3 show the physical and energy consumption parameters used for the characteristic house. These parameters are based on the actual buildings surveyed at Fort Belvoir, with the exception of appliance use data which was based on statistical analysis of the Baltimore/Washington area by Hittman Associates, Inc. (Ref. 5), and assumes appliance use to be invariant with respect to geographic location.

One point noted during the examination of Real Property records and construction drawings for the characteristic building was that the floor area designated on the Real Property records was not indicative of actual conditioned living space of the building. The Real Property records indicated a floor area of 2,237 square feet as compared to a living area calculated from drawings of approximately 1,800 square feet. Therefore, caution is recommended when using Real Property record floor areas, since similar inaccuracies could have a significant impact on energy use calculations determined on a per square foot basis.

TABLE 2. STRUCTURAL PARAMETERS FOR THE CHARACTERISTIC SINGLE-FAMILY RESIDENCE

Basic Design:	Four Bedroom, Story-and-a-Half
Foundation:	Partial Basement and Crawlspace
Floor Area:	1,800 sq. ft. First Floor - 1,140 sq. ft. Second Floor - 660 sq. ft.
Construction Type:	Masonry and Frame
Exterior Wall Composition:	Wall #1 Brick - 4" Air Space Brick - 4" Air Space Insulation Board - 1/2" Plaster - 1/2"
	Wall #2 Wood Shakes Insulation Board - 1/2" Air Space Insulaton Board - 1/2" Plaster - 1/2"
Exterior Wall Area:	Wall #1 - 1,100 sq. ft. Wall #2 - 640 sq. ft.
Roof Type:	Roof #1 - Gable with four (4) window dormers Roof #2 - Flat
Roof/Ceiling Composition:	Roof #1 Slate Plywood Sheathing - 1/2" Air Space Fiberglass batts - 3 1/2" Insulation board - 1/2" Plaster
	Roof #2 Metal Roofing Plywood Sheathing - 1/2" Air Space Insulation Board - 1/2" Plaster - 1/2"
Windows:	
Type/Material:	Double Hung/Wood Sash
Glazing:	Single
Storm Sash:	No
Area:	326 sq. ft.
Exterior Door(s):	
Type/Material:	Wooden
Number:	Two
Storm Door(s):	No
Total Area:	51 sq. ft.
Patio Door:	None
Dwelling Facing:	North
People:	Two adults, two children
Weather:	St. Louis, 1956

TABLE 3. ENERGY CONSUMPTION PARAMETERS* FOR THE CHARACTERISTIC SINGLE-FAMILY RESIDENCE

Heating System	Oil, 2-Pipe Hot Water	
Cooling System	Electric, Window Units	
Hot Water Heater	Propane	
Cooking Range	Electric	1,200 Kw-hr/year
Clothes Dryer	Electric	990 Kw-hr/year
Refrigerator/Freezer	Electric	1,830 Kw-hr/year
Lights	Electric-Incandescent	2,140 Kw-hr/year
Color TV	Electric	500 Kw-hr/year
Dishwasher	Electric	363 Kw-hr/year
Clothes Washer	Electric	103 Kw-hr/year
Iron	Electric	144 Kw-hr/year
Coffee Maker	Electric	106 Kw-hr/year
Miscellaneous	Electric	900 Kw-hr/year

**Figures Shown Represent Energy Input to Structure For Each Appliance (Based on Data in Ref. 6).*

C. Town House Residences

The town house residence has become the predominant form of family housing structure in the Army. The "Capehart" program of the late 1950's and early 1960's shifted the emphasis in family housing construction from single-family units to duplexes and row structures of four to twelve town house units (Ref. 2). The recent trend in town house construction is towards structures of four to six units each.

At Fort Belvoir, duplexes and town houses totaling 1485 units provide ninety-two percent of the housing for families of officers and NCO's (Ref. 4). Forty-eight percent of these residences are duplexes, twenty-eight percent are town houses with twelve units per structure, and sixteen percent are town houses of four to six units each. The remaining units are town houses in structures of eight, nine, or ten units each.

The Fort Belvoir units were built in three distinct construction periods. More than ninety percent (1364 units) were built between 1956 and 1960 under the Capehart program (Ref. 4). The remainder of the units at Fort Belvoir were built in 1939 (37 units) or during the period 1947 to 1950 (84 units). The three periods show a distinct trend of reducing size in family housing. This trend is demonstrated in the following table by Fort Belvoir average housing unit square footage (Ref. 4):

1939	2312 sq ft
1947-50	1909 sq ft
1956-60	1221 sq ft

The characteristic town house selected for this study is a hypothetical four-unit structure based on a "Capehart" duplex at Fort Belvoir. Each unit has three bedrooms for a total floor area of 1467 square feet on two floors.

Tables 4 and 5 show the physical and energy consumption parameters for the characteristic town house structure. These parameters are based on the actual buildings observed at Fort Belvoir, with the exception that appliance use data was based on HAI's statistical analysis of the Baltimore/Washington area civilian housing (Ref. 5), assuming appliance use to be invariant with respect to geographic location.

Special notice must be made that while the actual building used as a model for this structure was not air conditioned, the characteristic unit has been air conditioned to permit evaluation of cooling energy requirements. The Army has not in the past had a general policy of air conditioning

TABLE 4. STRUCTURAL PARAMETERS FOR THE CHARACTERISTIC TOWN HOUSE RESIDENCE

Arrangement:	Rectangular building, 4 town house units in a row
Basic Design:	Three bedrooms, two stories
Foundation:	Slab-on-Grade
Floor Area (per unit):	1,467 sq ft (each floor 733.5 sq ft)
Construction Type:	Wood frame with brick veneer
Exterior Wall Composition:	Brick Air space Felt Plywood sheathing-5/16 inch Air space Wallboard-1/2 inch
Exterior Wall Area:	
Interior Unit:	761 sq ft
End Unit:	1,186 sq ft
Roof Type:	Gable
Roof/Ceiling Composition:	Asphalt shingles Felt Plywood-5/8 inch Air space Fiberglass loose fill insulation-4 inches
Windows:	
Type/Material:	Double hung/wood sash
Glazing:	Single
Storm sash:	No
Area:	
Interior Unit:	129 sq ft
End Units:	150 sq ft
Exterior Door(s):	
Type/Material:	Wood
Number:	Two per unit
Storm Door(s):	No
Total Area:	41 sq ft/unit
Patio Door:	No
Dwelling Facing:	North
People:	Two adults, two children
Weather:	St. Louis, 1956

TABLE 5. ENERGY CONSUMPTION PARAMETERS* FOR THE CHARACTERISTIC TOWN HOUSE RESIDENCE

Heating System	Gas, Forced Air		
Cooling System	Central, Electric, Forced Air		
Hot Water Heater	Gas	270	Therms/year
Cooking Range	Gas	105	Therms/year
Clothes Dryer	Electric	990	Kw-hr/year
Refrigerator/Freezer	Electric	1,830	Kw-hr/year
Lights	Electric-Incandescent	1,740	Kw-hr/year
Color TV	Electric	500	Kw-hr/year
Furnace Fan	Electric	394	Kw-hr/year
Clothes Washer	Electric	103	Kw-hr/year
Iron	Electric	144	Kw-hr/year
Coffee Maker	Electric	106	Kw-hr/year
Miscellaneous	Electric	900	Kw-hr/year

*Figures shown represent energy input to structure for each appliance (based on data in Ref. 6).

family housing. However, within the last five years it has begun a program of installing central cooling systems on a limited basis in some locations (Ref. 2).

D. Barracks

At Fort Belvoir there are 175 barracks, of which 156 are "temporary" wooden frame structures built between 1940 and 1943 (Ref. 4). Five of the sixteen permanent barracks have been built since 1956, and three were built between 1928 and 1934 (Ref. 4). However, none of these barracks is of the type most characteristic of permanent Army barracks as defined by the Office of the Chief of Engineers (Ref. 2).

The most prominent permanent barracks are those built between 1952 and 1960 (Ref. 2). Originally designed for a 260-man capacity, many of these barracks have been renovated and now have a reduced capacity of 150 to 160. One such renovated barrack at Fort Meade was used as the characteristic barrack structure. It is a concrete block structure, similar to most built between 1952 and 1960 (Ref. 2) and includes a mess hall/kitchen in a one-floor structure attached at one end of the three-story main building. Other types of barracks built through 1971 are somewhat similar in construction to the modeled building, although many do not include mess halls. Newer style barracks built since 1971 have a brick veneer on the exterior of the concrete block walls however, other features of the barracks are very similar to older ones. Heating and domestic hot water in the modeled building are supplied from a central steam plant, although it is common to have such facilities located in a partial basement in similar units. New barracks, as well as some renovated barracks, have had central air-conditioning systems installed in recent years (Ref. 2).

Only permanent structures were included as candidates for characteristic buildings. This does not mean that the algorithm developed in this report may not be applied to "temporary" buildings as well. Rather, it is believed that the algorithm should be most applicable to (and most accurate for) Army buildings which will remain in existence in the foreseeable future; therefore, only permanent buildings were used for algorithm development.

Tables 6 and 7 show the physical and energy consumption parameters for the characteristic barrack selected for this study. These parameters are based on the actual buildings seen at Fort Meade. Equipment energy use data is based on observed levels of appliances in living areas of several

TABLE 6. STRUCTURAL PARAMETERS FOR THE CHARACTERISTIC ENLISTED MEN'S BARRACKS

Basic Design:	Three story rectangular barracks with one story kitchen and mess-hall attached at one end
Foundation:	Partial basement (unconditioned) and crawlspace
Floor Area:	36,000 sq ft
Construction Type:	Masonry
Exterior Wall Composition:	Wall No. 1 Concrete block-8 inches Air space Gypsum board-1/2 inch Wall No. 2 Concrete block-8 inches
Exterior Wall Area:	Wall No. 1 - 12,838 sq ft Wall No. 2 - 3,006 sq ft
Roof Type:	Built-up
Roof/Ceiling Composition:	Roof No. 1 Built-up roofing Loose fill insulation-6 inches Concrete slab-2 inches Roof No. 2 Built-up roofing Loose fill insulation-6 inches Concrete slab-2 inches Air space Acoustical tile-1/2 inch
Roof Area:	Roof No. 1 - 13,794 sq ft Roof No. 2 - 1,590 sq ft
Windows:	
Type/Material:	Casement/steel sash
Glazing:	Single
Storm Sash:	No
Area:	4,928 sq ft
Exterior Door(s):	
Type/Material:	Steel doors
Number:	7
Storm Door(s):	No
Total Area:	300 sq ft
Dwelling Facing:	North
People:	160
Weather:	St. Louis, 1956

TABLE 7. ENERGY CONSUMPTION PARAMETERS FOR THE CHARACTERISTIC BARRACKS

Heating System	Low pressure steam from central steam plant On-site steam to hot water converter Air handler and fan coil distribution	
Cooling System	On-site electric reciprocating chiller Fan coil distribution	
Hot Water Heat	On-site steam to hot water converter	
Living and Dayroom Areas		
Lights	Incandescent	67,000 Kw-hr/year
Miscellaneous Appliances (radios, TVs, phonographs, etc.)	Electric	12,679 Kw-hr/year
Mess Hall and Kitchen Areas		
Lighting		19,000 Kw-hr/year
Kitchen Appliances		2,800 therms/year
Laundry		
Lighting		1,900 Kw-hr/year
Washers	Electric	41,400 Kw-hr/year
Dryers	Gas	
Office		
Lighting		3,500 Kw-hr/year
Miscellaneous Appliances		1,900 Kw-hr/year

barracks at Fort Belvoir and Fort Meade, and on mess hall and laundry equipment information supplied by the Environment and Energy Control Office at Fort Meade (Ref. 7).

E. Administrative/Office Buildings

The Army has not had a major construction program for office type buildings since World War II. The result is that administrative and office functions are housed in a wide variety of structures. Expanding administrative staffs have been forced to utilize any available space, including former barracks and warehouses. Nearly every type of Army structure has been converted into an office building on one base or another. Frequently, these converted buildings are temporary structures, having been abandoned by their original users for a new permanent structure. Therefore, a majority of the permanent administrative/office buildings are of the pre-1940 variety.

In keeping with the assertion that characteristic buildings should be based upon permanent structures, the characteristic administrative/office building selected for this study is a three-story, brick and concrete office building built in 1934. It is rectangular with the first floor approximately 4.5 feet below grade level. This building has a total floor area of 12,600 square feet, and is occupied by approximately 65 personnel of the civil engineering staff of Fort Belvoir. Internally, about one-half of the building is in an open bay type arrangement, while the other half is segregated into offices by temporary-type partitions. Tables 8 and 9 show additional physical and energy-use parameters of the characteristic administrative/office building. This data is based on the structure observed at Fort Belvoir.

F. Commissary

The characteristic commissary selected for this study is the one at Fort Belvoir. It is a modern one-story, brick and concrete block structure that resembles a typical "civilian" supermarket. The layout of the building, with a huge store area (15,000 sq ft), a cool (55°F) meat packing room, large refrigerator and freezer rooms, and a large dry storage area, etc., is not unlike the supermarkets of the large chain operators. The lighting level and the amount of refrigeration within the store, the construction style and the type of equipment and materials used is also similar. One variation from the typical supermarket operation worthy of notice is in the number of customers who are in the building at any one time. The Fort Belvoir commissary receives about 2,400

TABLE 8. STRUCTURAL PARAMETERS FOR THE CHARACTERISTIC ADMINISTRATION BUILDING

Basic Design:	Three-story, rectangular building, central entrance and stairways, first floor 4 ft - 4 inch below grade.
Foundation:	Concrete slab
Floor Area:	12,600 sq ft
Construction Type:	Masonry
Exterior Wall Composition:	Wall No. 1 Concrete block-8 inches Air Concrete block-8 inches Wall No. 2 Brick Air Brick Air Brick
Exterior Wall Area:	Wall No. 1 - 1,119 sq ft Wall No. 2 - 5,353 sq ft
Underground Wall Composition:	Concrete block-8 inches Air Concrete block-8 inches
Underground Wall Area:	1,305 sq ft
Roof Type:	Gable
Roof/Ceiling Composition:	Slate Plywood sheathing-3/4 inch Air Concrete slab-3-1/2 inches
Windows:	
Type/Material:	Double hung/steel sash
Glazing:	Single
Storm Sash:	No
Area:	990 sq ft
Exterior Door(s):	
Type/Material:	Wood
Number:	4
Storm Door(s):	No
Total Area:	186 sq ft
Dwelling Facing:	North
People:	65
Weather:	St. Louis, 1956

TABLE 9. ENERGY CONSUMPTION PARAMETERS FOR THE CHARACTERISTIC ADMINISTRATIVE OFFICE BUILDING

Heating System	On-site hot water boiler (No. 2 fuel oil) Fan coil distribution
Cooling System	On-site electric reciprocating chiller Fan coil distribution
Hot Water Heat	On-site steam to hot water converter
Lighting	99,000 Kw-hr/year
Electric Equipment and Appliances (Office equipment, vending machines, mechanical drawing copier, etc.)	58,000 Kw-hr/year

customers per day, or 267 per hour for every hour the store is open; up to 300 are in the store at the same time. This provides a very large internal cooling load during store hours. By comparison, a limited survey of Baltimore metropolitan area major chain supermarkets indicates that the number of customers per hour of operation varies from about 65 to 120.

The evaluation of heating and cooling energy usage performed by the computer models and the algorithm developed in this study represent energy usage only in the store, office, and meat packing areas. Refrigerated and freezer rooms were not included in this analysis, except that their effect on heating and air conditioning requirements in adjacent areas was considered. Energy usage for refrigeration has been considered an equipment usage. Function and design variations make it inaccurate to include refrigeration system energy usage in the same category as air-conditioning energy.

Tables 10 and 11 show the physical and energy-use parameters of the characteristic commissary. This data is based on the actual structure as observed at Fort Belvoir.

TABLE 10. STRUCTURAL PARAMETERS OF CHARACTERISTIC COMMISSARY

Basic Design:	One story, rectangular structure
Foundation:	Slab-on-grade
Floor Area:	Total area-25,160 sq ft Conditioned space, excluding refrigerators and freezers-16,812 sq ft
Construction Type:	Masonry and steel frame
Exterior Wall Composition (of conditioned space):	Brick Air Concrete Block 4 inches
Exterior Wall Area (of conditioned space):	4,155 sq ft
Roof Type:	Built-up
Roof/Ceiling Composition:	Built-up roofing Concrete slab-3 inches
Roof Area:	16,892 sq ft
Windows:	
Type/Material:	Casement and fixed/metal sash
Glazing:	Single
Storm Sash:	No
Area:	555 sq ft
Arrangement:	All on south face and shading by overhanging roof
Exterior Door(s):	
Type/Material:	Steel
Number:	3 (4 glass doors included in window area)
Storm Door(s):	No
Total Area:	94 sq ft
Dwelling Facing:	South
People:	Up to 300 customers and 80 employees
Weather:	St. Louis, 1956

TABLE 11. ENERGY CONSUMPTION PARAMETERS FOR THE CHARACTERISTIC COMMISSARY

Heating System	On-site hot water boiler (No. 2 fuel oil)
	Forced-air and hot water finned tube radiation distribution systems
Cooling System	On-site electric reciprocating chiller
	Forced air distribution
Hot Water Heater	Electric, 120-gallon capacity
Lighting (in the store and meat packing areas only)	263,000 Kw-hr/year
Electric Equipment Appliances (in the store and meat packing areas only)	370,000 Kw-hr/year

IV. COMPUTATION OF HEATING AND COOLING ENERGY USE

Heating and cooling loads and resultant energy requirements were calculated for each of the five characteristic buildings defined in Chapter III. These loads and their corresponding energy use were disaggregated to all buildings' load contributing elements, positive and negative. The computer program used in determination of the loads considers factors such as building architecture, building structure, the building surroundings, weather, and the pertinent astronomy of the sun. The energy use in each building was computed by use of an equipment and distribution system simulation program. The description of the computer programs, computation procedures, and the results of these computations are discussed below.

A. Description of the Computer Programs Used For Load and Energy Use Computation

The load calculation program is a revised form of the original U.S. Postal Service Program with its capabilities being expanded to include disaggregation of heating and cooling loads into load contributing elements. The elemental loads include loads due to walls and roof, windows, infiltration, and internal loads. The load calculating program, being a composite of heat transfer, environmental, and geometric models, computes the loads, both heating and cooling, imposed upon the building space conditioning system on an hourly basis.

The program consists of a set of subroutines, small programs (each of which performs an engineering calculation), and a main program which reads the required data, directs the flow of information from one subroutine to another, and writes the output on paper and magnetic tapes. Loads are computed on the basis of actual recorded weather data using the Convolution Principle. Weather data, for a selected year, is taken from magnetic tapes available from the U.S. National Climatic Center.

1. Hourly Weather Data

Weather tapes of past years are available for enough weather stations throughout the United States so that a tape is likely to be available for a station near the site of any building being considered. The load subprogram uses weather tapes to realistically simulate the changing meteorological conditions to which the building is continuously exposed.

The data read from the weather tape and a brief summary of the uses to which they are put are listed below:

(a) Dry-bulb temperature (used in computing heat transfer and sensible loads)

(b) Wet-bulb temperature (used in computing humidity ratio and latent loads)

(c) Wind velocity (used in computing outside surface heat transfer film coefficient and infiltration)

(d) Wind direction (used in computing infiltration)

(e) Barometric pressure (used in computing heat gain and heat loss by radiation between the building and the sky).

2. <u>Hourly Solar Radiation Data</u>

The amount of heat gained by the building through an exterior surface (roof, exterior wall, or window) depends upon the radiant environment to which the surface is exposed. This radiant environment may be simulated more accurately by a computer than by hand calculations because the computer can evaluate the components of radiant environment on an hourly basis. The program makes hourly calculations of the following components of the radiant environment for each exterior surface:

(a) Angle of incidence of the sun's rays

(b) Direct normal intensity

(c) Brightness of sky and ground

(d) Re-radiation to sky

(e) Shadows cast upon the surface.

By combining these data with such constants of the surface as emissivity, shape factor between surface and sky, and shape factor between surface and ground, the program arrives at hourly radiation fluxes.

The System Simulation Program simulates the action of the control system in order to realistically determine the heating and/or cooling requirement that the thermal distribution system is demanding from the heating and cooling plant for the hour under consideration. Furthermore, it also simulates the part load performance characteristics of

HVAC equipment so that an accurate estimate of the unit's energy consumption can be made. Three major tasks performed by the systems simulation program are:

(a) Sizing energy-consuming heating and cooling equipment (chillers, boilers, pumps, cooling towers, etc.) and fan systems using peak zone and peak building heating and cooling loads determined by the Load Calculation Program.

(b) For each hour of the analysis, summing together space thermal loads and ventilation air loads through use of the characteristics of each thermal distribution system to obtain the hourly output requirements that must be provided by the heating and cooling plants.

(c) Through the use of part load performance data from typical systems, converting the thermal requirements into energy requirements.

B. Calculation of Heating and Cooling Loads and Energy Requirements

The monthly and annual heating and cooling loads and subsequent energy requirements for the five characteristic buildings were calculated using weather data for three locations with diverse climatical characteristics; Atlanta, Chicago, and St. Louis. The weather years 1956, 1957, and 1959 were used for the three locations, respectively. These weather years were selected to be typical to the respective locations. The monthly and annual energy requirements were calculated by a two-step process. First, the hourly heating and cooling loads were calculated for each conditioned space in the characteristic buildings using the "Load Program" described above with appropriate structural properties and design data for the respective buildings as well as daily internal load profiles for lights, appliances, and occupants. The hourly weather data were obtained from the U.S. National Climatic Center. In the second step, the energy required to heat and cool the characteristic buildings was calculated using these "Systems Programs"described above. For these calculations, the heating, cooling, and mechanical ventilation systems were defined in Table IV-1 for each characteristic building type.

The structural parameters defined for each characteristic building in Chapter III were used in formulating inputs to the load calculating computer program. Detailed performance

TABLE 12. SYSTEM PARAMETERS OF THE CHARACTERISTIC BUILDINGS

Building Type	Heating	Cooling	Ventilation
Single-family	Oil-fired boiler, hot water radiator	Window units	Not existing
Town house	Gas-fired furnace, forced air	Electric, central forced air	Not existing
Administration	Oil-fired boiler, multi-zone fan system	Electric reciprocating chiller, multi-zone fan system	Existing
Barracks	Steam/hot water convertor, multi-zone fan system and fan coil units	Electric reciprocating chiller, multi-zone fan system and fan coil units	Existing
Commissary	Oil-fired boiler, multi-zone fan system, and hot water baseboard radiation	Electric reciprocating chiller, multi-zone fan system	Existing

parameters were defined as shown in Tables 13, 14, 15, 16, and 17, including U values of the total wall, roof, densities, specific heats, and R values as appropriate.

Equipment and lighting levels included were those observed in the characteristic buildings visited at Fort Meade and Fort Belvoir. The equipment included in each of these buildings is as listed in Tables 3, 5, 7, 9, and 11. Occupancy schedules and equipment and lighting operating schedules were given by post personnel for the various buildings. Internal load profiles for lights, equipment/appliances, and occupants were developed from Ref. 5 for the single-family residence, and from observed equipment usage for the other building types. These profiles were varied for week days and weekends throughout the year. A constant thermostat set point of 72°F was established for both the heating and cooling season. All loads tending to decrease the set-point temperature are defined as heating loads, and those loads tending to increase the set point are cooling loads. For example, cold air infiltrating from outside the heating space would contribute as a heating load, whereas an internal load would always contribute as a cooling load. In calculating the loads, it was assumed that all windows in the buildings were closed throughout the year.

In order to disaggregate the contribution of each building element to the hourly heating and cooling loads, the load affecting items were broken down into ten major categories. Then the hourly heating/cooling contributions, depending on the conditioning mode of the space (heating or cooling mode) were calculated and summed monthly to determine the heating and cooling loads for each characteristic building using Atlanta, Chicago, and St. Louis weather data. The reason for this load disaggregation was to show that the flow of heat flux during each of the two modes (heating and cooling) is primarily in one direction. This finding gives the clue that a correlation procedure utilizing degree days could be employed in the development of the algorithm. The monthly and annual results of this load disaggregation for the Army characteristic single-family building using St. Louis weather data are presented in Tables 18 and 19. Table 18 presents the sensible heating and cooling effect of each of the ten selected categories respectively when the conditioning space is in the heating mode; Table 19 presents the same effects for the cooling mode. In order to study the secondary effect of each individual building's load contributing element on the total heating and cooling loads, a series of parametric studies was performed. These parameters were selected based on their significance of impact on the building conditioning load and energy requirements. The parameters selected for the Army characteristic buildings are presented in Tables 20 and 21. The parametric study was performed using the St. Louis weather data and the above described methodology.

TABLE 13. STRUCTURAL PARAMETERS OF ARMY CHARACTERISTIC SINGLE-FAMILY BUILDING

Component	U Value Btu/hr-ft^2-°F	Thickness ft	Conductivity Btu/hr-ft-°F	Density Lb/ft^3	Specific Heat Btu/Lb °F	R Value Hr-ft^2-°F/Btu
Wall No. 1						
Brick		0.333	0.757	130.0	0.22	
Air Space						1.01
Brick		0.333	0.416	120.0	0.22	
Air Space	0.237					1.01
Insulation Board		0.042	0.065	32.0	0.31	
Plaster		0.042	0.130	34.0	0.26	
Wall No. 2						
Woodsiding		0.042	0.052	32.0	0.31	
Insulation Board		0.042	0.065	32.0	0.31	
Air	0.291					1.01
Insulation Board		0.42	0.065	32.0	0.31	
Plaster		0.42	0.130	45.0	0.26	
Roof No. 1						
Slate		0.42	0.830	175.0	0.20	
Plywood Sheathing		0.42	0.064	34.0	0.29	
Air Space	0.072					0.98
Batt Insulation		0.292	0.026	3.0	0.18	
Insulation Board		0.042	0.065	32.0	0.31	
Plaster		0.042	0.130	45.0	0.26	
Roof No. 2						
Metal Roofing		0.020		455.0	0.06	
Plywood Sheathing		0.042	0.065	34.0	0.29	
Air Space	0.387					0.96
Insulation Board		0.042	0.065	32.0	0.31	
Plaster		0.042	0.130	45.0	0.26	
Floor						
Subfloor	0.60	0.062	0.064	34.0	0.29	
Finish Floor		0.062	0.091	45.0	0.30	
Door						
Solid Wood	0.67					

TABLE 14. ARMY CHARACTERISTIC TOWN HOUSE STRUCTURAL PARAMETERS

Component	U Value Btu/hr-ft²-°F	Thickness ft	Conductivity Btu/hr-ft-°F	Density Lb/ft³	Specific Heat Btu/Lb °F	R Value Hr-ft2-°F/Btu
Wall						
Brick		0.333	0.757	130.0	0.22	
Air Space						1.01
Plywood Sheathing	0.295	0.031	0.065	34.0	0.29	
Air Space						1.01
Wallboard		0.042	0.093	50.0	0.26	
Roof						
Asphalt Shingles		0.042	0.096	99.0	0.26	
Plywood Sheathing		0.052	0.065	34.0	0.29	
Air Space	0.067					0.96
Loose Fill Insulation		0.333	0.027	10.0	0.18	
Wall Board		0.042	0.093	50.0	0.26	
Floor						
Slab-on-grade	0.10					
Door						
Solid Wood	0.67					

TABLE 15. ARMY CHARACTERISTIC ADMINISTRATION BUILDING STRUCTURAL PARAMETERS

Component	U Value Btu / hr-ft^2-°F	Thickness ft	Conductivity Btu / hr-ft-°F	Density Lb/ft^3	Specific Heat Btu/Lb °F	R Value Hr-ft^2-°F / Btu
Wall No. 1						
Concrete Block		0.670	0.600	82.0	0.20	
Air Space	0.308					1.01
Concrete Block		0.670	0.600	82.0	0.20	
Wall No. 2						
Brick		0.333	0.757	130.0	0.22	
Air Space						1.01
Brick	0.270	0.333	0.416	120.0	0.22	
Air Space						1.01
Brick		0.333	0.757	130.0	0.22	
Underground Wall	0.20					
Roof						
Slate		0.042	0.830	175.0	0.20	
Plywood Sheating	0.396	0.063	0.064	34.0	0.29	
Air Space						0.96
Concrete Slab		0.290	0.540	144.0	0.16	
Door						
Solid Wood	0.67					

TABLE 16. ARMY CHARACTERISTIC BARRACKS STRUCTURAL PARAMETERS

Component	U Value Btu/hr-ft^2-°F	Thickness ft	Conductivity Btu/hr-ft-°F	Density Lb/ft^3	Specific Heat Btu/Lb °F	R Value Hr-ft^2-°F/Btu
Wall No. 1						
Concrete Block		0.667	0.600	82.0	0.20	
Air Space	0.388					1.01
Gypsum Board		0.420	0.093	50.0	0.26	
Wall No. 2						
Concrete Block	0.899	0.667	0.600	82.0	0.20	
Roof No. 1						
Built-up Roofing		0.031	0.094	70.0	0.35	
Loose Fill Insulation	0.060	0.500	0.031	6.0	0.20	
Concrete Slab		0.167	0.540	144.0	0.16	
Roof No. 2						
Built-up Roofing		0.031	0.094	70.0	0.35	
Loose Fill Insulation		0.500	0.031	6.0	0.20	
Concrete Slab	0.052	0.167	0.540	144.0	0.16	
Air Space						0.96
Acoustical Tile		0.420	0.033	18.0	0.32	
Floor						
Concrete Slab	1.47	0.380	0.613	144.0	0.16	
Vinyl Tile		0.007	0.116	70.0	0.30	
Door						
Steel	0.50					

TABLE 17. ARMY CHARACTERISTIC COMMISSARY STRUCTURAL PARAMETERS

Component	U Value Btu / $hr\text{-}ft^2\text{-}^\circ F$	Thickness ft	Conductivity Btu / $hr\text{-}ft\text{-}^\circ F$	Density Lb/ft^3	Specific Heat Btu/Lb °F	R Value $Hr\text{-}ft^2\text{-}^\circ F$ / Btu
Wall						
Brick		0.333	0.757	130.0	0.22	
Air Space	0.498					1.01
Concrete Block		0.333	0.600	82.0	0.20	
Roof						
Built-up Roofing		0.031	0.094	70.0	0.35	
Concrete Slab	1.26	0.250	0.540	144.0	0.16	
Door						
Steel	0.50					

TABLE 18. LOAD DISAGGREGATION IN HEATING MODE FOR ARMY SINGLE-FAMILY RESIDENCE

(Btu)

MONTH	TOTAL RADIATION THROUGH WINDOWS	GAIN FROM APPLIANCES	CONDUCTION THROUGH DOORS	CONDUCTION THROUGH WALLS AND ROOF	CONDUCTION THROUGH UNDERGROUND WALLS AND FLOORS	CONDUCTION THROUGH INTERNAL WALLS	GAIN FROM OCCUPANTS	CONDUCTION THROUGH WINDOWS	GAIN FROM LIGHTS	CONVECTION BY INFILTRATION
				Cooling Loads In Heating Mode						
January	1767181.	1401088.	10.	0.	0.	0.	663700.	0.	768087.	0.
February	1950610.	1294242.	1404.	0.	0.	0.	614007.	0.	710432.	0.
March	2685964.	1294703.	1771.	0.	0.	0.	625103.	0.	713573.	0.
April	1936184.	1062160.	3704.	0.	0.	0.	519989.	0.	579620.	0.
May	653492.	472541.	7068.	529.	0.	0.	263220.	0.	265667.	0.
June	92963.	75905.	3101.	951.	0.	0.	46686.	0.	42768.	0.
July	13873.	14504.	379.	1159.	0.	0.	12168.	0.	7685.	0.
August	34967.	42549.	365.	195.	0.	0.	32043.	0.	24185.	0.
September	293664.	281863.	2924.	2391.	0.	0.	185529.	0.	150151.	0.
October	806091.	659543.	4224.	1650.	0.	0.	385609.	0.	373114.	0.
November	1900552.	1236549.	3660.	0.	0.	0.	601503.	0.	683220.	0.
December	1332903.	1374488.	99.	0.	0.	0.	654568.	0.	756533.	0.
TOTAL (Annual)	13468445.	9200134.	28707.	6874.	0.	0.	4604124.	0.	5075033.	0.
				Heating Loads In Heating Mode						
January	0.	0.	-627780.	-22884878.	0.	0.	0.	-10595472.	0.	-9708210.
February	0.	0.	-454866.	-17215644.	0.	0.	0.	-8241626.	0.	-7329500.
March	0.	0.	-347303.	-13006535.	0.	0.	0.	-6851522.	0.	-5909323.
April	0.	0.	-217621.	-8264171	0.	0.	0.	-4656353.	0.	-3834930.
May	0.	0.	-54570.	-1922317.	0.	0.	0.	-1299543.	0.	-1139695.
June	0.	0.	-9209.	-245632.	0.	0.	0.	-198184.	0.	-204847.
July	0.	0.	-1522.	-15690.	0.	0.	0.	-31510.	0.	-31204.
August	0.	0.	-5067.	-94729.	0.	0.	0.	-97550	0.	-96442.
September	0.	0.	-35416.	-721269.	0.	0.	0.	-675536	0.	-706346
October	0.	0.	-87699.	-2384861.	0.	0.	0.	-1673454.	0.	-1637912.
November	0.	0.	-366052.	-12982188.	0.	0.	0.	-6469848.	0.	-5767410.
December	0.	0.	-479443.	-17634089.	0.	0.	0.	-8024297.	0.	-7370863.
TOTAL (Annual)	0.	0.	-2687453.	-97372003.	0.	0.	0.	-48814901.	0.	-43736683.

TABLE 19. LOAD DISAGGREGATION IN COOLING MODE IN ARMY SINGLE-FAMILY RESIDENCE

(Btu)

MONTH	TOTAL RADIATION THROUGH WINDOWS	GAIN FROM APPLIANCES	CONDUCTION THROUGH DOORS	CONDUCTION THROUGH WALLS AND ROOF	CONDUCTION THROUGH UNDERGROUND WALLS AND FLOORS	CONDUCTION THROUGH INTERNAL WALLS	GAIN FROM OCCUPANTS	CONDUCTION THROUGH WINDOW	GAIN FROM LIGHTS	CONVECTION BY INFILTRATION
					Cooling Loads In Cooling Mode					
January	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
February	35740.	17699.	593.	0.	0.	0.	6728.	0.	10595.	2396.
March	401892.	107716.	8401.	99029.	0.	0.	38649	40859.	57180.	39657.
April	747152.	304795.	25661	354228.	0.	0.	122152.	102747.	165586.	105338.
May	2257694.	929878.	118927.	2475988.	0.	0.	400401.	612430.	505076.	510071.
June	3029826.	1281274.	238149.	6342520.	0.	0.	595606.	1436345.	703121.	1181101.
July	3338594.	1387915.	286524.	7630480.	0.	0.	651215.	1536780.	763068.	1306893.
August	3200985.	1359870.	277082.	8073805.	0.	0.	631706.	1876492.	746568.	1537126.
September	3214583.	1075317.	127855.	3630495.	0.	0.	456512.	808730.	595749	721523.
October	2495997.	743100.	72098	1373042.	0.	0.	277809.	199139.	398322.	251070.
November	321534.	120630.	5988.	32456.	0.	0.	40676.	4600.	62670.	12835.
December	108862.	27931.	332.	0.	0.	0.	8804.	0.	14220.	0.
TOTAL (Annual)	19152859.	7356124.	1161611.	30012043.	0.	0.	3230258.	6618120.	4022155.	5668010.
					Heating Loads In Cooling Mode					
January	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
February	0.	0.	-264.	-28634.	0.	0.	0.	-8871.	0.	-4349.
March	0.	0.	-1971.	-132960.	0.	0.	0.	-84589.	0.	-46884.
April	0.	0.	-3513.	-145170.	0.	0.	0.	-145100.	0.	-104856.
May	0.	0.	-5690.	-141720.	0.	0.	0.	-330812	0.	-281208.
June	0.	0.	-3118.	-19522.	0.	0.	0.	-138321.	0.	-171742.
July	0.	0.	-3668.	-1917.	0.	0.	0.	-133921.	0.	-175381.
August	0.	0.	-2797.	-12567.	0.	0.	0.	-116547.	0.	-135662.
September	0.	0.	-10466.	-85008.	0.	0.	0.	-345792.	0.	-350948.
October	0.	0.	10606.	-245315.	0.	0.	0.	-398975.	0.	-349676.
November	0.	0.	2185.	-112934.	0.	0.	0.	-93129.	0.	-63245.
December	0.	0.	941.	-41276.	0.	0.	0.	-29385.	0.	-18867.
TOTAL (Annual)	0.	0.	-45220.	-967023.	0.	0.	0.	-1825443.	0.	-1702818.

TABLE 20. LOAD PARAMETERS USED IN THE PARAMETRIC ANALYSIS OF THE FIVE ARMY BUILDINGS

Load Parameter	Single-Family	Town House	Administration	Barracks	Commissary
Building Envelope Equivalent U Value, Btu/hr-ft^2-°F	0.131; 0.167; 0.256; 0.273	0.126; 0.136; 0.230; 0.246	0.140; 0.310; 0.326	0.193; 0.384; 0.398	0.099; 0.145; 0.493
Window Area, sq ft	245; 326	209; 279	670; 893	3,696; 4,928	----
Occupancy, percent	----	----	50; 100	50; 100	50; 100
Air Change Rate, cfm	196; 254	----	----	----	----
Set-Point Temperature, °F	68; 72; 76	68; 72	68; 72	68; 72	68; 72
Climate Variations	Chicago, St. Louis, Atlanta	Chicago, St. Louis, Atlanta	Chicago, St. Louis, Atlanta	Chicago, St. Louis, Atlanta	Chicago, St. Louis, Atlanta

TABLE 21. SYSTEM PARAMETERS USED IN THE PARAMETRIC ANALYSIS OF THE FIVE ARMY BUILDINGS

Building		Systems
Administration	-	1. Multizone fan system; central cooling coil, hot deck with bypass, and fixed damper.
		2. Multizone fan system; central cooling coil, hot deck with bypass, and enthalpy control economizer.
		3. Reheat fan system; blow-through with face and bypass control.
		4. Variable volume fan system; blow-through and baseboard radiation controlled by outside temperature.
		5. Variable volume fan system; blow-through and baseboard radiation by controlled outside temperature, and system shutdown betwen 6 PM and 6 AM.
Barracks	-	1. Two pipe fan coil, and multizone fan system with central cooling coil, hot deck with bypass, and fixed damper.
		2. Variable volume fan system; blow-through and baseboard radiation.
Commissary	-	1. Multizone fan system; central cooling coil, hot deck with bypass, fixed damper, and baseboard radiation.
		2. Variable volume fan system; blow-through and baseboard radiation controlled by inside temperature.
		3. Variable volume fan system; blow-through, baseboard radiation, and enthalpy controller economizer.
		4. Variable volume fan system; blow-through, and baseboard radiation, with enthalpy control economizer, and shutdown between the hours of 6 PM and 6 AM.

V. HEATING AND COOLING ENERGY ALGORITHM DEVELOPMENT

A. Introduction

The algorithms developed here for the five characteristic buildings are based on equations of thermal conduction, convection, radiation, and mass transfer. For each building type, the algorithms utilize the heating and cooling loads computed for the St. Louis weather conditions as characteristic, then each component load is corrected for those parameters which differ from those of the characteristic structure. The parameters to which the algorithms are sensitive and correction can be applied are:

- Building envelope conductance, or U value
- Building envelope area
- Inside set-point temperature
- Air change rate, or rate of infiltration
- Underground wall and floor conductance
- Underground wall and floor area
- Ground temperature
- Window area
- Level of incident solar radiation
- Latitude
- Number of occupants in building
- Level of lighting energy use
- Level of equipment and appliance energy use
- Climatic variables (including heating degree days cooling degree days, and discomfort index cooling degree days)
- HVAC system efficiencies.

The components of heating and cooling loads are those referred to in Chapter IV: conduction through walls and roofs, floors, doors and windows, solar radiation gain through windows, the internal loads due to people [latent (during cooling) and sensible], lighting, equipment (latent and sensible), and infiltration (latent and sensible). Each of these component loads is significantly impacted by variation of one or more of the above parametric values. The degree of variation is dependent on building type. The development of each building type algorithm is discussed individually below, with specific emphasis on heating loads, cooling loads, and energy use calculations.

Heating degree days are used in calculating each of the following heating load components:

- Building envelope

- Infiltration
- Underground floors and walls
- Internal heat generation.

Cooling degree days are used in calculating the same component loads during cooling with the exception of the infiltration cooling load. For this load, the discomfort index cooling degree day is used to provide a correlation with relative humidity as well as dry bulb temperature.

All figures for this report are included at the end for convenience. Figures are sub-numbered according to the building type in the following manner:

A - Single-family residence
B - Town house
C - Barracks
D - Administration/office
E - Commissary

Figures without a sub-number refer to all building types.

B. Heating

1. Building Envelope Heating Load. The heating load due to conductive heat transfer through the building envelope is primarily a function of: the envelope area, the conductance of envelope materials, the inside temperature, and the outside temperature.

Figure 1 demonstrates the relationship between the monthly envelope heat loss, calculated by the computer model, and heating degree days. This figure covers every month in which heating load occurs for the characteristic structures for each of three climatical conditions: St. Louis, Chicago, and Atlanta. The correlation between heating degree days and heating load is very strong, except in months where the number of heating degree days is very small, indicating a small fraction of the heating load. The result obtained from Figure 1, when entering the graph with the number of heating degree days in a month, will yield the building envelope heating load, QH_1, for a characteristic building with a specific building equivalent U value and envelope area, and an indoor set-point temperature of 72°F.

To compensate for deviations in the U value of exterior surfaces and their corresponding areas, an "equivalent conductance" is needed for the entire building envelope. This "equivalent conductance" or "equivalent envelope U value" is determined from the sum of the products of all envelope component U values and envelope component areas divided by the total envelope area. That is:

$$U_{Eq} = \frac{\sum_{i=1}^{n} U_i A_i}{\sum_{i=1}^{n} A_i} = \frac{1}{A_T} \sum_{i=1}^{n} U_i A_i$$

By use of an equivalent envelope U value, the skin load becomes directly proportional to the area of the envelope. This area is equal to the total area of all surfaces (walls, roofs, windows, and doors) which are exposed to the outside air. This envelope will include floors over crawl spaces (assumed to be at outside air temperature), but does not include floors over basements or slabs-on-grade; nor does it include walls and floors below ground level.

The skin load determined in Figure 1 can be adjusted for a building of different equivalent U values by use of Figure 2. The value of CH_1, a correlation factor based on building skin load variation with envelope equivalent conductance, when multiplied by the envelope heating load, corrects for any building envelope U value. In addition, correction for variation in envelope area can be made by using the ratio of building envelope area to the characteristic building envelope area. This correction is achieved by selecting the proper constant value, CON, which is the inverse of the area for the characteristic structure.

The envelope heat loss variation due to other inside set-point temperatures is shown in Figure 3. This figure, which is derived from analyses of the same building at three different indoor set-point temperatures (68, 72, and 76°F), shows the fractional variations in skin load due to each degree (Fahrenheit) of set-point temperature variation from 72°F. For months with many heating degree days, the fraction becomes a constant. But for months with fewer heating degree days the fractional deviation increases. The accuracy of this correlation is also weak in months with few heating days, but then the heating load in these months is small. Therefore, the error becomes significant only with small portions of heating load.

The U value correlation factor from Figure 2 and the set-point temperature correlation factor from Figure 3 can be used to adjust the building envelope skin load in the following manner:

$$QH_{env} = (CON)(QH_1)(HDD)(CH_1)(A_{total})[(1+FH_1(T-72)]$$

where,

$$CON = 2.246x10^{-4} \text{ for a single-family residence, sq ft}^{-1}$$
$$= 5.296x10^{-4} \text{ for a town house, sq ft}^{-1}$$
$$= 0.209x10^{-4} \text{ for a barracks, sq ft}^{-1}$$
$$= 0.850x10^{-4} \text{ for an administration building, sq ft}^{-1}$$
$$= 0.425x10^{-4} \text{ for a commissary, sq ft}^{-1}.$$

QH_1, CH_1, and FH_1 are determined from Figures 1, 2, and 3 using the known variables for the subject building and the characteristic building: equivalent envelope U value, equivalent envelope area, inside set-point temperature, and monthly heating degree days for the location. If the calculated value for QH_{env} is negative, then there is no envelope heating load and QH_{env} is zero.

2. Infiltration/Mechanical Ventilation Heating Load. The infiltration load is a function of the air change rate, outside weather conditions, and the inside set-point temperature. The infiltration rate for the characteristic single-family structure was estimated to be 0.9 air changes per hour. The heating load due to this air change rate was calculated and compared with that at 0.65. The findings showed a direct one-to-one correlation between the two infiltration rates and their associated heating loads indicating the secondary effects were very small. The variation of infiltration heating load due to the climatical effects and inside set-point temperature are presented in Figures 4 and 5, respectively. Figure 4 presents the correlation between the infiltration heating load and monthly heating degree days. This correlation would not be altered by secondary effects such as solar gain and building mass. Figure 5 presents the infiltration heating load as a function of inside set-point temperature.

In the single-family and town house residences, the infiltration is dominated mainly by wind velocity and other factors such as door openings, furnace exhaust, and bathroom fan operation (stack effect being minor due to the small building height). The following equation presents a reasonable estimate of the variation in the rate of infiltration as a function of window area, the number of doors, and the presence of storm doors/windows.

$$A = 0.25(N_D)(S_1) + 7.7x10^{-3} (Aw)(S_2)$$

where,

A = Infiltration coefficient

N_D = Number of doors

S_1 = 0.67 with storm doors

= 1.00 without storm doors

Aw = Total window area including sliding glass doors, sq ft

S_2 = 0.67 with storm windows

= 1.00 without storm windows.

The infiltration rate, I, is then calculated from the following equation:

$$I = [0.25 + (0.05)\ (A)(V)]\ \frac{VOLUME}{60}$$

where,

I = Infiltration rate, cfm

V = Average wind velocity, mph

VOLUME = Building volume, cu ft.

The barracks and the administration building are assumed to be pressurized and therefore have no infiltration rate. If the buildings do not use outside air and therefore are not pressurized, the infiltration rates are assumed to be 0.30 x 10^{-6} cfm/sq ft floor area for the barracks and 0.66 x 10^{-6} cfm/sq ft floor area for the administration building. The commissary is assumed to be pressurized, but it is also assumed that door openings as customers enter and leave result in an equivalent infiltration rate of 1.25 cfm per customer. This is based on an infiltration rate of 900 cu ft of air per door opening (Ref. 5).

It was assumed that the characteristic single-family and town house residences have no mechanical ventilation while the characteristic barracks, administration, and commissary have mechanical ventilation. The infiltration/mechanical ventilation heating load may then be calculated from the following equation:

$$QH_{inf} = (I+Vr)(QH_2)[1+FH_2\ (T-72)]$$

where,

I = Infiltration rate, cfm;

Vr = Mechanical ventilation rate, cfm

T = Inside set-point temperature, °F.

QH_2 and FH_2 are determined from Figures 4 and 5 using the weather data for the location.

For the buildings (barracks, administration, and commissary) in which the distribution system operates without outside air between certain hours, the infiltration/mechanical ventilation heating load can be adjusted to reflect this system control factor. Since this outside air shutdown normally occurs at night when the temperature range is lower than the daily average temperature, the mechanical ventilation heating load is reduced. At the same time, there will be heating load due to infiltration, since mechanical ventilation is not present and the building is not pressurized. Assuming that these two items cancel each other's effects, the adjusted infiltration can be calculated by the following expression:

$$QH_{inf} = (QH_{inf})_{24\ hr}\left[1 - \frac{X}{24}\right]$$

where,

$(QH_{inf})_{24\ hr}$ = Infiltration heating load

X = Number of hours per day that the system operates without using outside air.

3. Solar Radiation. Solar radiation heat gain through the windows of the building is dependent on three primary variables: the total area of windows, the incident solar radiation available at any location, and the solar angle (the angle between the line of the sun's rays and the horizontal plane). Radiation gain through the window is directly proportional to window area, as was proven by reducing the window area of the characteristic house by 25 percent. The result was a 25 percent reduction in solar radiation heat gain. The incident solar radiation on a horizontal plane varies greatly by location and follows no simple patterns, since it is dependent on latitude, time of year, elevation above sea level, weather, and atmospheric pollution conditions. However, this variable has been measured and tabulated for over 100 locations in the contiguous United States. Table 22A presents the average daily incident radiation (in langleys per day) for each month of the year by location. Monthly total radiation values (in Btu) can be determined by multiplying the average daily value by 3.687 Btu per square foot-langley and the number of days in the month.

Table 22-A. AVERAGE DAILY TERRESTRIAL SOLAR ENERGY RECEIVED ON A HORIZONTAL SURFACE (ly/day)

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Annette, Ak	63	113	231	360	457	466	481	352	266	122	59	40	251
Barrow, Ak	0	38	180	380	513	528	429	255	115	41	0	0	206
Bethel, Ak	38	108	282	444	457	454	376	252	202	115	44	22	233
Fairbanks, Ak	16	71	213	376	461	504	434	317	180	82	26	6	224
Matanuska, Ak	32	92	242	356	436	462	409	314	198	100	38	15	224
Little Rock, Ar	188	260	353	446	523	559	556	518	439	343	244	187	385
Page, Az	294	367	516	618	695	707	680	596	516	402	310	243	495
Phoenix, Az	301	409	526	638	724	739	658	613	566	449	344	281	520
Tucson, Az	315	391	540	655	729	699	626	588	570	442	356	305	518
Yuma, Az	305	401	517	633	703	705	652	587	530	442	330	271	506
Davis, Ca	158	256	402	528	636	702	690	611	498	348	216	148	433
Eureka, Ca	146	194	306	399	471	494	462	406	342	249	159	131	313
Fresno, Ca	186	296	438	545	637	697	668	606	503	375	241	160	446
Inyokern, Ca	312	419	578	701	789	836	784	738	648	484	366	295	579
La Jolla, Ca	244	302	397	457	506	487	497	464	389	320	277	221	380
Los Angeles-WBAS, Ca	248	331	470	515	572	596	641	581	503	373	289	241	447
Los Angeles-WBO, Ca	243	327	436	483	555	584	651	581	500	362	281	234	436
Pasadena, Ca	251	333	439	509	569	580	634	599	482	366	271	236	439
Riverside, Ca	271	362	468	526	608	666	652	603	521	400	309	260	470
San Mateo, Ca	195	282	409	512	577	598	540	477	425	332	229	176	396
Santa Maria, Ca	263	346	482	552	635	694	680	613	524	419	313	252	481
Soda Springs, Ca	223	316	374	551	615	691	760	681	510	357	248	182	459
Boulder, Co	201	268	401	460	460	525	520	439	412	310	222	182	367
Grand Junction, Co	227	324	434	546	615	708	676	595	514	373	260	212	457
Grand Lake, Co	212	313	423	512	552	632	600	505	476	361	234	184	416
Washington, DC	158	231	322	398	467	510	496	440	364	278	192	141	333
Aplachicola, Fl	298	367	441	535	603	578	529	511	456	413	332	262	444
Belle Isle, Fl	297	330	412	463	483	464	488	461	400	366	313	291	397
Gainesville, Fl	278	367	445	539	586	544	520	508	444	368	318	254	431
Jacksonville, Fl	267	346	423	514	556	525	522	476	383	331	274	230	404
Key West. Fl	327	410	490	572	579	543	534	501	445	394	332	292	452
Miami, Fl	343	416	491	544	552	531	537	508	447	389	354	319	453
Pensacola, Fl	250	321	405	509	562	568	537	509	430	394	278	224	416
Tallahassee, Fl	274	311	423	483	548	476	544	537	424	353	364	260	416
Tampa, Fl	327	391	474	539	596	574	534	494	454	400	356	300	453
Atlanta, Ga	228	284	377	484	535	554	538	502	412	350	265	201	394
Griffin, Ga	238	302	388	519	577	580	559	523	437	372	288	210	416
Honolulu, Hi	363	422	516	559	617	615	615	612	573	507	426	371	516
Pearl Harbor, Hi	355	404	438	536	577	562	610	575	536	466	393	349	483
Boise, Id	138	236	342	485	585	636	670	576	460	301	182	124	395
Twin Falls, Id	163	240	355	462	552	592	602	540	432	286	176	131	378

Source: Determining the Availability of Solar Energy Within the Contiguous United States, EI&I Associates, 1975

Table 22-A. (Cont'd) AVERAGE DAILY TERRESTRIAL SOLAR ENERGY RECEIVED ON A HORIZONTAL SURFACE (1y/day)

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Chicago, Il	96	147	227	331	424	458	473	403	313	207	120	76	273
Lemont, Il	171	232	326	390	497	553	527	486	384	265	157	131	343
Moline, Il	159	220	317	402	493	558	565	498	407	290	176	134	352
Indianapolis, In	147	214	312	393	491	547	542	486	405	293	176	130	345
Ames, Ia	174	253	326	403	480	541	436	460	367	274	187	143	345
Dodge City, Ks	255	316	418	528	568	650	642	592	493	380	285	234	447
Kansas City, Ks	182	251	342	441	522	589	579	525	426	327	215	164	380
Manhattan, Ks	192	264	345	433	527	551	531	526	410	292	227	156	371
Topeka, Ks	192	249	337	430	505	554	552	512	424	320	214	165	371
Lexington, Ky	172	263	357	480	581	628	617	563	494	357	245	175	411
Louisville, Ky	164	231	325	420	515	560	550	498	408	303	190	150	360
Lake Charles, La	239	304	396	483	554	582	521	506	448	402	296	232	414
New Orleans, La	237	296	393	479	539	549	502	491	418	389	269	220	399
Shreveport, La	232	292	384	446	558	557	578	528	414	354	254	205	400
Blue Hill, Ma	153	228	319	389	469	510	502	449	354	266	162	135	328
Boston, Ma	139	198	293	364	472	499	496	425	341	238	145	119	311
Cambridge, Ma	153	235	323	400	420	476	482	464	367	253	164	124	322
East Wareham, Ma	140	218	305	385	452	508	495	436	365	258	163	140	322
Lynn, Ma	118	209	300	394	454	549	528	432	341	241	135	107	317
Annapolis, Md	175	243	340	419	488	557	542	469	383	294	189	155	355
Silver Hill, Md	182	244	340	438	513	555	516	459	397	295	202	163	359
Caribou, Me	133	231	364	400	476	470	508	448	336	212	111	107	316
Portland, Me	157	237	359	406	513	541	561	482	383	273	157	138	351
East Lansing, Mi	121	210	309	359	483	547	540	466	373	255	136	108	311
Sault Ste Marie, Mi	130	225	356	416	523	557	573	472	322	216	105	96	333
St. Cloud, Mn	170	251	366	423	499	541	555	491	360	241	146	123	348
Columbia, Mo	173	251	340	434	530	574	574	522	453	322	225	158	380
Glasgow, Mt	154	258	385	466	568	605	645	531	410	267	154	116	388
Great Falls, Mt	140	232	366	434	528	583	639	532	407	264	154	112	366
Summit, Mt	122	162	268	414	462	493	560	510	354	216	102	76	312
Lincoln, Ne	188	259	350	416	494	544	568	484	396	296	199	159	363
North Omaha, Ne	193	229	365	463	516	546	568	519	410	298	204	170	379
North Platte, Ne	200	266	358	475	523	599	598	540	432	322	220	178	393
Bismarck, N.D.	157	250	356	447	550	590	617	516	390	272	161	124	369
Cape Hatteras, NC	244	317	432	571	635	645	629	557	472	361	284	216	447
Greensboro, NC	200	276	354	469	531	564	544	485	406	322	243	197	383
Sea Brook, NJ	157	227	318	403	478	522	518	457	385	285	192	139	340
Trenton, NJ	173	214	343	424	491	546	540	469	389	294	195	155	355
Albuquerque, NM	303	386	511	618	686	726	683	626	554	438	334	276	512
Ely, Nv	238	333	464	564	624	708	648	608	519	393	287	220	467
Las Vegas, Nv	277	384	519	621	702	748	675	627	551	429	318	258	509
Reno, Nv	234	324	449	592	664	714	707	646	532	395	277	209	479
Ithaca, NY	116	194	272	334	440	501	515	453	346	231	120	96	302

Table 22-A. (Cont'd). AVERAGE DAILY TERRESTRIAL SOLAR ENERGY RECEIVED ON A HORIZONTAL SURFACE (ly/day)

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
New York, NY	146	210	312	378	455	526	518	492	361	262	160	128	324
Sayville, NY	160	249	335	415	494	565	543	462	385	289	186	142	352
Schenectady, NY	130	200	273	338	413	448	441	397	299	218	128	104	282
Upton, NY	155	232	339	428	502	573	543	475	391	293	182	146	355
Cleveland, Oh	125	183	303	286	502	562	562	494	278	289	141	115	320
Columbus, Oh	128	200	297	391	471	562	542	477	422	286	176	129	340
Put in Bay, Oh	126	204	302	386	468	544	561	487	382	275	144	109	332
Oklahoma City, Ok	255	317	407	498	540	623	610	588	484	379	284	237	435
Stillwater, Ok	205	289	390	454	504	600	596	545	455	354	269	209	405
Astoria, Or	90	162	270	375	492	469	539	461	354	209	111	79	301
Medford, Or	116	169	216	317	429	491	497	409	339	207	118	77	282
Philadelphia, Pa	175	242	347	425	493	554	538	465	388	293	191	152	355
State College, Pa	139	202	297	373	467	544	528	454	361	275	155	120	335
Newport, RI	115	231	330	395	489	538	517	449	380	273	175	141	339
Charleston, SC	250	308	393	517	553	556	523	495	417	349	281	228	406
Rapid City, SD	183	277	400	482	532	585	590	541	435	315	204	158	392
Oak Ridge, Tn	161	239	331	450	518	551	526	478	416	318	213	163	364
Memphis, Tn	192	267	359	470	554	589	583	535	442	354	238	184	397
Nashville, Tn	163	240	329	450	517	567	553	494	428	327	217	161	370
Brownsville, Tx	287	336	402	458	556	604	619	555	465	406	284	253	435
Corpus Cristi, Tx	262	330	413	474	561	604	629	558	470	408	285	240	436
Dallas, Tx	231	307	394	454	521	595	588	538	458	363	261	221	411
El Paso, Tx	331	432	549	655	715	730	670	639	575	462	367	313	536
Fort Worth, Tx	250	320	427	488	562	651	613	593	503	403	306	245	477
Midland, Tx	283	258	476	550	611	617	608	574	552	396	325	275	466
San Antonio, Tx	279	347	417	455	541	612	639	585	493	398	295	256	442
Flaming Gorge, Ut	238	298	443	522	565	650	599	538	425	352	262	215	426
Salt Lake City, Ut	163	256	354	479	570	621	620	551	446	316	204	146	394
Norfolk, Va	208	270	372	477	540	572	550	481	398	310	223	184	382
Burlington, Vt	129	198	300	367	495	530	532	455	343	231	124	103	317
Friday Harbor, Wa	87	157	274	418	514	578	586	507	351	194	102	75	320
Pullman, Wa	111	205	304	462	558	653	699	562	410	245	146	96	372
Prosser, Wa	117	222	351	521	616	680	707	604	458	274	136	100	399
Seattle, Wa	70	124	244	360	446	471	501	431	310	174	90	59	273
Spokane, Wa	119	204	321	474	563	596	665	556	404	225	131	75	361
Tacoma, Wa	75	139	265	403	503	511	566	452	324	188	104	64	300
Greenbay, Wi	137	210	312	385	490	542	539	462	353	240	139	110	327
Madison, Wi	148	220	313	394	466	514	531	452	318	241	145	115	324
Milwaukee, Wi	149	210	312	403	509	565	562	485	392	267	161	120	345
Lander, Wy	226	324	452	548	587	678	651	586	472	354	239	196	443
Laramie, Wy	216	295	424	508	554	643	606	536	438	324	229	186	408

The solar angle varies with latitude and time of year. The correlation of solar radiation gain through the windows with latitude can best be defined when season of the year is also included. In Figure 6, the CR_2 curve represents the correlation of latitude with radiation heat gain during the winter months of November, December, January, and February. The CR_4 curve gives the correlation of latitude with radiation heat gain for the Spring and Fall months of March, April, May, September, and October for periods of heating only.

Therefore, the monthly solar radiation heat gain during heating periods for any month can be determined by use of incident solar radiation data, the curves in Figure 6, and the following equation:

$$QH_{rad} = 3.687 \times N_{days} \times IR \times A_w \times CR$$

where,

N_{days} = Number of days in the month

IR = Incident solar radiation on a horizontal plane, in langleys per day

A_w = Total glass area in building

CR = Value of CR_2 or CR_4 (depending on month) obtained from Figure 6, using latitude of location of study.

The only factor significantly affecting solar radiation heat gain which was not considered here is building and glass orientation. However, in the Army buildings which have been observed during the course of this program, the distribution of glass around the buildings studied was close to being even or the total glass area was small with respect to the total envelope area. When the glass distribution is even, orientation of the building becomes less important.

4. <u>Heating Load Due to Floors and Underground Walls.</u> The heat flux through floors and underground walls normally is treated as a steady state conduction heat transfer, with temperature difference being the difference between inside set-point temperature and monthly average ground temperature. The heat flux for the period during each month that the building stays in the heating mode will be the heating load component due to the floor and underground walls. This is due to that fact that during the heating season, the ground temperature stays below the inside set-point temperature. In Figure 7, the

correlation between heating degree days and number of hours, CH_F, during which the building will be in the heating mode is given. Secondary effects such as the effect of changes in building equivalent U value and infiltration rates on the duration of heating mode have not been investigated, but they are expected to be minor.

Ground temperature is primarily a function of outside temperature averaged for a given month. Table 22-B gives the average monthly temperature for various cities. Use the temperature given for the city listed that is closest to the Army facility. Figure 19 shows the correlation between ground temperature and average monthly temperature.

Utilizing Figure 7, the monthly heating load due to the floor and underground walls could be calculated from the following equation:

$$QH_{floor} = (CH_F)(A_f U_f + A_w U_w)(T_{sp} - T_g)$$

where,

CH_F = From Figure 7

A_f = Floor area

A_w = Underground wall area

U_f = Floor U value

U_w = Underground wall U value

T_{sp} = Inside set-point temperature

T_g = Monthly ground temperature, from Figure 19

5. Internal Loads. The internal heat generation due to occupants, lighting, appliances, and equipment is a function of the level of occupancy, lighting, and equipment operation and the number of hours during which the building is in the heating mode. In addition, the schedules, or daily profiles, of occupancy, lighting, and equipment which define the load factors for the different hours of the day, will also affect the amount of internal load generation which occurs during the heating mode. The correlation of monthly heating degree days (actually a good indicator of heating mode duration) with internal heat load is shown in Figure 8. Deviations from this relationship could most easily and significantly be affected by variations in occupant life-style. However, only average life-style characteristics can be considered in this procedure.

TABLE 22-B. AVERAGE MONTHLY TEMPERATURE (°F)

City	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	ANNUAL
Albany	22.7°	23.7°	33.0°	46.2°	57.9°	67.3°	72.1°	70.0°	61.6°	50.8°	39.1°	26.5°	47.6°
Albuquerque	35.0	39.9	45.8	55.7	65.1	74.9	78.5	76.2	70.0	58.0	43.6	37.0	56.6
Atlanta	44.7	46.1	51.4	60.2	69.1	76.6	78.9	78.2	73.1	62.4	51.2	44.8	61.4
Baltimore	34.8	35.7	43.1	54.2	64.4	72.5	76.8	75.0	68.1	57.0	45.5	35.8	55.2
Bismarck	9.9	13.5	26.2	43.5	55.9	64.5	71.7	69.3	58.7	46.7	28.9	17.8	42.2
Boise	29.1	34.5	41.7	50.4	58.2	65.8	75.2	72.1	62.7	51.6	38.6	32.2	51.0
Boston	29.9	30.3	37.7	47.9	58.8	67.8	73.7	71.7	65.3	55.0	44.9	33.3	51.4
Buffalo	24.5	24.1	31.5	43.5	54.8	64.8	69.8	68.4	61.4	50.8	39.1	27.7	46.7
Burlington, Vt.	16.2	17.4	26.7	41.2	53.8	64.2	69.0	66.7	58.4	47.6	35.3	21.5	43.2
Charleston, W. Va.	36.6	37.5	44.4	55.3	64.8	72.0	74.9	73.8	68.2	57.3	45.3	37.1	55.6
Charlotte	42.7	44.2	50.0	60.3	69.0	77.1	79.2	78.7	72.9	62.5	50.4	42.7	60.8
Cheyenne	25.4	27.3	32.4	42.6	52.9	63.0	70.0	67.7	58.6	47.5	34.2	29.5	45.9
Chicago	26.0	27.7	36.3	49.0	60.0	70.5	75.6	74.2	66.1	55.1	39.9	29.1	50.8
Cincinnati	33.7	35.1	42.7	54.2	64.2	73.4	76.9	75.7	69.0	57.9	44.6	35.3	55.2
Cleveland	28.4	28.5	35.1	47.0	58.0	67.8	71.9	70.4	64.2	53.4	41.3	30.5	49.7
Columbia, S.C.	46.9	48.4	54.4	63.6	72.2	79.7	81.6	80.5	75.3	64.7	53.7	46.4	64.0
Columbus	29.9	31.1	38.9	50.8	61.5	70.8	74.8	73.2	65.9	54.2	41.2	31.5	52.0
Concord, N.H	21.2	22.7	31.7	43.8	55.5	64.5	69.6	67.4	59.3	48.7	37.6	25.0	45.6
Dallas	45.9	49.5	56.1	65.0	72.9	81.3	84.9	85.0	77.9	67.8	54.9	48.1	65.8
Denver	28.5	31.5	36.4	46.4	56.2	66.5	72.9	71.5	63.0	51.4	37.7	31.6	49.5
Des Moines	19.9	23.4	33.8	48.7	60.6	71.0	76.3	74.1	65.4	54.2	37.1	25.3	49.2
Detroit	26.9	27.2	34.8	47.6	59.0	69.7	74.4	72.8	65.1	53.8	40.4	29.9	50.1
El Paso	42.9	49.1	54.9	63.4	71.9	81.0	81.9	80.4	74.5	64.4	51.2	44.1	63.3
Great Falls	22.1	23.8	30.7	43.6	53.0	59.9	69.4	66.8	57.4	47.5	34.3	27.3	44.7
Hartford	26.0	27.1	36.0	48.5	59.9	68.7	73.4	71.2	63.3	53.0	41.3	28.9	49.8
Honolulu	72.5	72.4	72.8	74.2	75.9	77.9	78.8	79.4	79.2	78.2	75.9	73.6	75.9
Houston	53.6	55.8	61.3	68.5	76.0	81.6	83.0	83.2	79.2	71.4	60.8	55.7	69.2
Indianapolis	29.1	31.1	38.9	50.8	61.4	71.1	75.2	73.7	66.5	55.4	40.9	31.1	52.1
Jackson, Miss	47.9	50.5	56.5	64.9	73.1	79.8	82.3	82.0	76.5	67.0	55.5	49.4	65.5
Jacksonville	55.9	57.5	62.2	68.7	75.8	80.8	82.6	82.3	79.4	71.0	61.7	56.1	69.5
Juneau	25.1	26.8	30.4	38.0	45.6	52.3	55.3	54.1	48.9	41.6	34.3	28.4	40.1
Kansas City, Mo	31.7	35.8	43.3	55.7	65.6	75.9	81.5	79.8	71.3	60.2	44.6	35.8	56.8
Little Rock	40.6	44.4	51.8	62.4	70.5	78.9	81.9	81.3	74.3	63.1	49.5	41.9	61.7
Los Angeles	55.8	57.1	59.4	61.8	64.8	68.0	73.0	73.1	71.9	67.4	62.7	58.2	64.4
Louisville	35.0	35.8	43.3	54.8	64.4	73.4	77.6	76.2	69.5	57.9	44.7	36.3	55.7
Memphis	41.5	44.1	51.1	61.4	70.3	78.5	81.3	80.5	73.9	63.1	50.1	42.5	61.5
Miami	66.9	67.9	70.5	74.2	77.6	80.8	81.8	82.3	81.3	77.8	72.4	68.1	75.1
Milwaukee	20.6	22.4	31.0	43.6	53.4	63.3	68.7	67.8	60.3	50.0	35.8	24.6	45.1
Minneapolis	12.4	15.7	27.4	44.3	57.3	66.8	72.3	70.0	60.4	48.9	31.2	18.1	43.7
Mobile	53.0	55.2	60.3	67.6	75.6	81.5	82.6	82.1	77.9	69.9	58.9	54.1	68.2
Nashville	39.9	42.0	49.1	59.6	68.6	77.4	80.2	79.2	72.8	61.5	48.5	41.4	60.0
New Orleans	54.6	57.1	61.4	67.9	74.4	80.1	81.6	81.9	78.3	70.4	60.0	55.4	68.6
New York City	33.2	33.4	40.5	51.4	62.4	71.4	76.8	75.1	68.5	58.3	47.0	35.9	54.5
Norfolk	41.2	41.6	48.0	58.0	67.5	75.6	78.8	77.5	72.6	62.0	51.4	42.5	59.7
Oklahoma City	37.0	41.3	48.5	59.9	68.4	78.0	82.5	82.8	73.8	62.9	48.4	40.3	60.3
Omaha	22.3	26.5	36.9	51.7	63.0	73.1	78.5	76.2	66.9	55.7	38.9	28.2	51.5
Philadelphia	32.3	33.2	41.0	52.0	62.6	71.0	75.6	73.6	66.7	55.7	44.3	33.9	53.5
Phoenix	49.7	53.5	59.0	67.2	75.0	83.6	89.8	87.5	82.8	70.7	58.1	51.6	69.0
Pittsburgh	28.9	29.2	36.8	49.0	59.8	68.4	72.1	70.8	64.2	53.1	40.8	30.7	50.3
Portland, Me	21.8	22.8	31.4	42.5	53.0	62.1	68.1	66.8	58.7	48.6	38.1	25.8	45.0
Portland, Ore	38.4	42.0	46.1	51.8	57.4	62.0	67.2	66.6	62.2	54.2	45.1	41.3	52.9
Providence	29.2	29.7	37.0	47.2	57.5	66.2	72.1	70.5	63.2	53.2	43.0	32.0	50.1
Reno	30.4	35.6	41.5	48.0	53.9	60.1	67.7	65.5	58.8	49.2	38.3	31.9	48.4
Richmond	38.7	39.9	47.7	58.1	67.0	75.1	78.1	76.0	70.2	58.7	48.5	39.7	58.1
Sacramento	45.2	49.2	53.4	58.4	64.0	70.5	75.4	74.1	71.6	63.5	52.9	46.4	60.4
St. Louis	31.9	34.7	42.6	54.9	64.2	74.1	78.1	76.8	69.5	58.4	44.1	34.8	55.3
Salt Lake City	27.2	32.5	40.4	49.9	58.9	67.4	76.9	74.5	64.4	51.7	36.7	30.1	50.9
San Francisco	50.7	53.0	54.7	55.7	57.4	59.1	58.8	59.4	62.0	61.4	57.4	52.5	56.8
Seattle	38.3	40.8	43.8	49.2	55.5	59.8	64.9	64.1	59.9	52.4	43.9	40.8	51.1
Sioux Falls	15.2	19.1	30.1	45.9	58.3	68.1	74.3	71.8	61.8	50.3	32.6	21.1	45.7
Spokane	25.3	30.0	38.1	47.3	56.2	61.9	70.5	68.0	60.9	49.1	35.7	30.1	47.8
Washington, D C	36.9	37.8	44.8	55.7	65.8	74.2	78.2	76.5	69.7	59.0	47.7	38.1	57.0
Wichita	32.0	36.3	44.5	56.7	66.0	76.5	80.9	80.8	71.1	59.9	44.4	35.8	57.1
Wilmington	33.4	33.8	41.3	52.1	62.7	71.4	76.0	74.3	67.6	56.6	45.4	35.1	54.1

Though the internal load varies depending on the level of occupancy in the single-family and the town house residences, the life-style effect of the occupants tends to minimize the occupancy effect. This is due to the appliance and lighting usage habits of occupants. Figure 8-A,B gives the total internal load for these two structures.

The internal load in the barracks is directly related to the level of occupancy since occupancy variations result in changes in the occupant load as well as equipment and lighting loads. Figure 8-C gives the internal sensible heat generation per square foot of floor area based on full occupancy. At occupancy levels other than full capacity, the usage per occupant changes, since some lighting and equipment loads are independent of occupancy level. To correct for these variations, an occupancy correction factor, OCF, must be applied from Table 23. The total internal load may be calculated from the following equation:

$$QH_I = (QH_o)(FOL)(AREA)[1+1.334(OCF)]$$

where,

QH_o = Occupant heat generation from Figure 8-C

FOL = Fractional occupancy level

AREA = Floor area of barracks, sq ft

OCF = Occupancy correction factor from Table 23.

In the administration and commissary structures, the equipment and lighting loads remain constant, regardless of building occupancy. The total internal load then is determined by the equation:

$$QH_I = (QH_o)(AREA)(FOL + A)$$

where,

QH_o = Occupant heat generation from Figure 8

FOL = Fractional occupancy level

AREA = Floor area, sq ft

A = 10.3 for the administration building

= 3.89 for the commissary.

TABLE 23. OCCUPANCY CORRECTION FACTORS

Percent Occupancy	Correction Factor	Percent Occupancy	Correction Factor	Percent Occupancy	Correction Factor
150	0.78	75	1.23	25	2.04
140	0.80	70	1.28	20	2.20
130	0.83	65	1.34	15	2.53
120	0.87	60	1.39	10	2.86
110	0.93	55	1.46	8	3.13
100	1.00	50	1.52	6	3.57
95	1.04	45	1.60	4	4.30
90	1.08	40	1.67	2	5.93
85	1.13	35	1.78	Inactive	0.0
80	1.18	30	1.88		

SOURCE: Repairs and Utilities Utilization Targets and Evaluation, Department of the Army Technical Bulletin, TB ENG 259, 13 March 1961.

6. Heating Load Due to Interior Walls. Only the commissary has a heating load from interior walls. While the other buildings have a uniform interior temperature, the commissary has refrigerated and frozen storage rooms. Heat transfer through the walls between these storage rooms and the main store area causes a heating load that is primarily a function of the wall area, the conductance of the wall materials, the store temperature, and the storage room temperature.

Figure 7 shows the correlation between heating degree days and the number of hours per month, CH_F, that the building is in the heating mode. Utilizing Figure 7, the monthly heating load due to the interior walls can be calculated from the following equation:

$$QH_{iw} = CH_F[(EA_r)(EU_r)(T_i-T_r)+(EA_f)(EU_f)(T_i-T_f)]$$

where,

CH_F = Correlation factor from Figure 7-E

EA_r = Equivalent wall area between the store and the refrigerated storage room, sq ft

EU_r = Equivalent U value of the wall between the store and the refrigerated storage room, Btu/hr-ft^2-°F

T_i = Store set-point temperature, °F

T_r = Refrigerated storage temperature, °F

EA_f = Equivalent wall area between the store and the frozen storage room

EU_f = Equivalent U value of the wall between the store and the frozen storage room, Btu/hr-ft^2-°F

T_f = Frozen storage temperature.

7. Heating Energy Use. Algebraic addition of all the loads calculated in the previous steps will result in the total building heating load which has to be met by the heating system. The equation expressing this heating load is:

$$QH_{total} = QH_{env} + QH_{inf} - QH_{rad} + QH_{floor} + QH_{iw} - QH_I$$

The heating system energy usage deviates from the heating load due to the heating system inefficiencies. For the single-family and town house residences there are two system inefficiencies: (1) losses due to the furnace (incomplete combustion and flue gas); (2) losses due to the distribution system. Accounting for these two losses, the monthly heating energy usage for the single-family and town house residences can be calculated from the following equation.

$$Q_{heat} = \frac{QH_{total}}{(E_f)(E_{dist})}$$

where,

E_f = Furnace efficiency, E_f = 1.0 if served by a central plant

E_{dist} = Distribution efficiency

The inefficiencies of the heating systems in the barracks, administration, and commissary buildings are due to three factors: (1) boiler efficiency at full load; (2) distribution system; (3) part load characteristics of the boiler. Items (1) and (3) are equal to 1.0 for buildings served by central plants.

The part load efficiencies of the boiler are determined by adjusting the boiler efficiency by the boiler load factor. Figure 17 gives the boiler load factor as a function of the load ratio, LR, where the load ratio is determined by the following equation.

$$LR = \frac{QH_{total}}{(\text{Boiler rating, Btu/hr})(720 \text{ hr/month})}$$

For central plants, $LR > 0.3$ for the cold season and $LR < 0.3$ for the mild season.

The distribution efficiency, $(\frac{1}{LCF})$, is defined as the ratio of the building heating load to the total heating load which is imposed on the heating equipment by the distribution system. This efficiency depends on several factors such as type of distribution system, controls, and climatical considerations. Considering that the role of control systems can be applied in the load calculation section, the distribution system efficiencies for five basic systems are presented in Table 24 for two periods of operation: (1) the period during which the system operates near its full capacity (greater than 30 percent), which also indicates the cold season; (2) the period during which the system operates at a small fraction of its capacity (less than 30 percent), which also indicates the mild season.

Table 24. LOAD CORRECTION FACTORS AND AUXILIARY ELECTRIC CONSUMPTION FOR HEATING SYSTEMS

System Type	LCF		C Kw-hr/cfm month	
	LR > 0.30	LR ≤ 0.30	LR > 0.30	LR ≤ 0.30
Multizone Fan System	1.2	2.6	0.81	0.7
Multizone Fan System with Two-pipe Fan Coil System	1.0	1.1	0.46	0.3
Reheat Fan System	1.0	1.0	0.86	0.66
Variable Volume Fan System With Baseboard Radiation Controlled by Outside Temperature	1.0	1.3	0.42	0.26
Variable Volume Fan System with Baseboard Radiation Controlled by Inside Temperature	1.2	1.6	0.42	0.26

Then the heating energy usage is given by the following equation.

$$Q_{heat} = \frac{(QH_{total})(LCF)}{(BE)(BLF)}$$

where,

QH_{total} = Total heating load, Btu/month

LCF = Load correction factor, from Table 24

BE = Boiler efficiency

BLF = Boiler load factor, from Figure 17

The electric consumption due to the operation of the fans, pumps, and other auxiliary equipment can be estimated as a function of supply fan flow rate. This is a reasonable assumption since the energy consumption by the fans is the governing factor, and there is a direct relationship between the supply fan flow rate and return and exhaust fan flow rates. Therefore, the monthly electric consumption for the accessories can be calculated, depending on the system load ratio, from the following equation:

$$E_a = (C)(R)$$

where,

C = Fan and pump consumption rate from Table 24, Kw-hr/cfm-month

R = Fan flow rate, cfm

In order to include the effect of system shutdown at night for buildings with baseboard heating, the heating load can be adjusted to reflect the number of hours during which the system is shut down. The effects of temperature drop during the shutdown period and the energy needed to bring the building up to the set-point temperature have been included in the analysis. The reduced heating load is determined from the following equation:

$$QH_{total} = (QH_{total})_{24\ hr}[1 - (0.0292)(x)]$$

where,

$(QH_{total})_{24\ hr}$ = Total heating load for 24-hour operation, Btu/month

X = Hours per day that the system is shut down

Night shutdown of the system would also affect the electric consumption due to the fan and pump operations. To account for this effect, the electric consumption is altered to reflect the number of hours the system is shut down. The electrical consumption due to the operation of the fans and pumps is then calculated from the following equation:

$$Q_a = (E_a)_{24\ hr} \left(1 - \frac{X}{24}\right)$$

where,

$(E_a)_{24\ hr}$ = Auxiliary electric consumption based on 24-hour operation, Kw-hr/month

X = Hours per day that the system is shut down

C. Cooling

1. Building Envelope Cooling Load. The methodology of development for the cooling skin load calculation is identical to that used for heating skin load with the exception that cooling degree days are used instead of heating degree days. Figure 9 demonstrates the relationship between the monthly envelope heat gain and outside temperature.

The skin load determined in Figure 9 may be adjusted for a building of different equivalent U values by use of Figure 10. In addition, correction for variation in envelope area can be made by using the ratio of building envelope area to that of the characteristic building. This correction is made by the use of the proper constant, K, for each building type.

The envelope heat gain variation due to other inside set-point temperatures is shown in Figure 11. For months with many cooling degree days, the fractional variations in skin load due to set-point temperature variation from 72°F become nearly a constant. But for months with fewer cooling degree days, the fractional deviation increases. As it is with heating, the correlation is weak in months with few cooling days, but then the cooling load in these months is small and the error is significant only with small portions of the heating load.

The U value correction factor and the set-point temperature correlation factor can be used to adjust the building envelope cooling load in the following manner:

$$QC_{env} = (K)(QC_1)(CDD)(CC_1)(A_{total})[1-FC_1(T-72)]$$

where,

$K = 2.246 \times 10^{-4}$ for a single-family residence, sq ft^{-1}

$= 5.296 \times 10^{-4}$ for a town house, sq ft^{-1}

$= 0.209 \times 10^{-4}$ for a barracks, sq ft^{-1}

$= 0.850 \times 10^{-4}$ for an administration building, sq ft^{-1}

$= 0.425 \times 10^{-4}$ for a commissary, sq ft^{-1}

A_{total}= Total envelope area of the building, sq ft.

QC_1, CC_1, and FC_1 are determined from Figures 9, 10, and 11 using the known variables for the subject building and the characteristic building: equivalent envelope U value, equivalent envelope area, inside set-point temperature, and monthly cooling degree days for the locations. If the calculated value for QC_{env} is negative, set QC_{env} equal to zero.

2. Infiltration/Mechanical Ventilation Cooling Load. The infiltration cooling load is a function of the air change rate, outside weather conditions, and the inside set-point temperature. The procedures for determination of infiltration cooling load are similar to those used for heating, except that the cooling load is correlated with the discomfort index cooling degree days to account for the latent component of the cooling load. The discomfort index is a function of dry bulb and wet bulb temperatures of the outside air; therefore, it correlates very well with latent, as well as sensible load components. Table 25 presents the monthly and annual number of discomfort index cooling degree days by location.

The variation of infiltration cooling load due to the climatical effects and inside set-point temperature are presented in Figures 12 and 13, respectively. Figure 12 presents the correlation between the infiltration cooling load and monthly discomfort index cooling degree days. Figure 13 presents a factor which corrects the infiltration cooling load for any inside set-point temperature.

Table 25. MONTHLY AND ANNUAL DISCOMFORT INDEX COOLING DEGREE DAYS

Station and Region	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Eastern Seaboard													
Rochester, NY	0	0	0	0	58	167	225	217	82	0	0	0	749
Boston, MA	0	0	0	0	20	214	279	271	91	13	0	0	888
New York City, NY	0	0	0	0	48	270	326	349	135	36	0	0	1164
Washington, DC	0	0	0	33	109	315	388	372	175	52	11	0	1455
Raleigh, NC	0	0	15	57	204	345	442	419	218	88	24	20	1832
Hatteras, NC	0	0	11	71	185	428	504	481	353	233	57	57	2380
Charleston, SC	0	47	50	119	326	413	512	481	285	178	43	64	2518
Tallahassee, FL	0	78	76	120	364	403	481	496	338	233	59	85	2733
Jacksonville, FL	0	125	99	165	411	443	543	535	383	305	97	107	3213
Tampa, FL	32	166	157	218	450	473	519	527	420	341	154	178	3635
Miami, FL	124	261	256	323	481	488	548	558	495	457	233	146	4370
Southern Section													
Atlanta, GA	0	12	28	77	289	368	465	450	263	121	19	39	2131
Montgomery, AL	0	48	44	106	372	420	496	519	308	171	27	68	2579
Jackson, MS	0	50	50	107	372	413	512	481	300	302	60	47	2694
Shreveport, LA	22	54	57	137	395	450	566	550	360	198	49	47	2885
New Orleans, LA	28	103	118	200	349	450	543	527	420	310	121	119	3288
Dallas, TX	0	25	68	101	419	533	605	574	413	251	21	22	3032
Abilene, TX	0	16	46	114	310	465	504	481	330	172	12	0	2450
San Antonio, TX	25	70	90	185	403	503	535	481	405	271	50	48	3066
Houston, TX	39	99	113	158	419	413	550	550	428	295	105	85	3254
Laredo, TX	45	164	217	293	473	548	589	597	488	403	97	73	3987
Brownsville, TX	129	200	238	360	457	488	535	558	465	411	142	150	4133
North Central and Mid-west													
Sault Saint Marie, MI	0	0	0	0	0	49	64	119	12	0	0	0	244
Fargo, ND	0	0	0	0	22	248	209	211	27	0	0	0	717
Minneapolis, MN	0	0	0	0	59	279	240	266	52	27	0	0	923
North Platte, NB	0	0	0	0	79	285	318	264	91	0	0	0	1037
Chicago, IL	0	0	0	18	95	300	302	326	97	37	0	0	1175
Columbus, OH	0	0	0	21	109	276	341	318	110	35	0	0	1210

Source: Thom, E.C., "A New Concept for Cooling Degree Days," Air Conditioning, Heating and Ventilating, June 1957.

Table 25 (Cont'd.) MONTHLY AND ANNUAL DISCOMFORT INDEX COOLING DEGREE DAYS

Station and Region	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Annual
Kansas City, MO	0	0	0	41	232	390	473	457	198	114	0	1905
St. Louis, MO	0	0	12	41	200	370	434	434	202	87	13	1793
Amarillo, TX	0	0	0	0	154	354	364	318	203	77	0	1470
Oklahoma City, OK	0	0	25	61	104	405	481	457	300	136	0	1969
Ft. Smith, AR	0	0	31	56	333	413	527	519	278	145	0	2302
Memphis, TN	0	13	18	82	326	413	527	504	248	126	28	2309
Nashville, TN	0	0	20	64	258	368	488	457	225	92	0	1972
Knoxville, TN	0	0	23	50	241	335	419	411	210	90	0	1779
Mountains and Southwest												
Billings, MT	0	0	0	0	56	178	240	168	48	0	0	690
Casper, WY	0	0	0	0	0	87	147	75	24	0	0	333
Reno, NV	0	0	0	0	15	36	132	62	21	0	0	266
Salt Lake City, UT	0	0	0	0	54	68	271	178	84	0	0	655
Denver, CO	0	0	0	0	21	188	194	145	54	0	0	602
Las Vegas, NV	0	0	0	31	163	338	457	380	323	68	0	1760
Winslow, AZ	0	0	0	0	34	180	287	209	135	0	0	845
Albuquerque, NM	0	0	0	0	54	270	287	247	173	34	0	1065
Yuma, AZ	0	0	56	123	147	480	615	581	570	244	27	2843
Phoenix, AZ	0	0	29	96	279	450	543	496	443	163	0	2499
Tucson, AZ	0	0	0	41	225	420	465	434	390	197	0	2172
El Paso, TX	0	0	0	21	279	383	388	364	330	87	0	1852
Pacific Coastal Area												
Seattle, WA	0	0	0	0	30	0	119	98	17	0	0	264
Red Bluff, CA	0	0	0	41	138	278	426	318	225	56	0	1492
Sacramento, CA	0	0	0	20	85	203	264	217	188	62	0	1039
San Francisco, CA	0	0	0	0	11	31	43	48	75	10	0	218
Fresno, CA	0	0	0	54	102	248	372	295	270	96	0	1437
Bakersfield, CA	0	0	14	74	183	300	427	349	308	108	0	1763
Los Angeles, CA	0	0	0	11	46	203	202	235	218	109	42	1066

The cooling infiltration rates for the various buildings are determined using the same methodology as for heating. The infiltration cooling load is then determined from the following equation:

$$QC_{inf} = (I+V_r)(QC_2)[1-FC_2(T-72)]$$

where,

I = Infiltration rate, cfm

V_r = Mechanical ventilation rate, cfm

T = Indoor set point temperature, °F

QC_2 and FC_2 are determined from Figures 12 and 13 using the weather data for the subject location.

For the buildings (barracks, administration, and commissary) in which the distribution system operates without outside air between certain hours, the infiltration load can be adjusted to reflect this system control factor using the same methodology as described in the heating section. By considering that the outside air shutdown normally occurs at night (having a lower temperature range and a higher relative humidity when compared with the daily average values), the fact that some natural infiltration takes place without mechanical ventilation, and assuming that these two items cancel each other's effect, the adjusted infiltration load can be calculated by the following equation:

$$QC_{inf} = (QC_{inf})_{24\ hr}\left[1 - \frac{X}{24}\right]$$

where,

$(QH_{inf})_{24\ hr}$ = Infiltration heating load

X = Number of hours per day that the system operates without using outside air.

3. Solar Radiation. The radiation heat gain through windows during the cooling months can be determined using methods similar to those used for the heating mode. However, the correlation factors are different. From Figure 14, the CR_1 curve represents the correlation of latitude with radiation heat gain during the summer months of May, June, July, and August. The CR_3 curve gives the correlation of latitude with radiation heat gain for the Spring and Fall months of March, April, September, and October. The heat gain during cooling, or the radiation component of cooling load for each

month can then be calculated using the equation:

$$QC_{rad} = 3.687 \times N_{days} \times IR \times A_w \times CR$$

where,

N_{days} = Number of days in the month

IR = Monthly incident solar radiation from Table 22

A_w = Total glass area in building

CR = Value of CR_1 or CR_3 (depending on the month) obtained from Figure 14, using latitude of location of study.

4. Cooling Load Due to Floors and Underground Walls. Floors and underground walls could have a net heat gain or heat loss depending on the time of year and location. This effect can be seen by assigning ground temperatures higher/lower than 72°F (the inside house temperature). Similar to the heating section, Figure 15 presents the correlation between cooling degree days and number of hours, CC_F, during which the building will be in the cooling mode. Following the discussion made on this topic in the heating section, the floor and underground walls cooling load could be calculated by using the following equation:

$$QC_{floor} = (CC_F)(A_f U_f + A_w U_w)(T_{sp} - T_g)$$

where,

A_f = Floor area, sq ft

A_w = Underground wall area, sq ft

U_f = Floor U value, Btu/hr-ft^2-°F

U_w = Underground wall U value, Btu/hr-ft^2-°F

T_{sp} = Inside set-point temperature

T_g = Monthly ground temperature, from Reference 8.

CC_F is determined from Figure 15 using the number of monthly cooling degree days.

5. Internal Loads. The methodology used to develop the internal load contributions to the cooling load is similar to that used in the heating section. For the single-family and town house residences, the total internal load is determined from Figure 16-A,B.

The internal load for cooling in the barracks is determined similarly to the component for heating with the exception that latent as well as sensible loads are taken into account. Figure 16-C gives the sensible component of the occupant load per square foot of building area. The total internal cooling load may then be calculated from the following equation:

$$QC_I = (QC_o)(AREA)(FOL)[1.61+1.43(OCF)]$$

where,

QC_o = Occupant heat generation

FOL = Fractional occupancy level

OCF = Occupancy correction factor

AREA = Area of barracks, sq ft.

The internal load for the administration and commissary buildings is determined similarly to the component for heating with the exception that latent as well as sensible loads are taken into account. Figures 16-D and 16-E give the sensible components of the occupant load per square foot of building area. The total internal cooling load may then be calculated from the following equation:

$$QC_I = (QC_o)(AREA)[(FOL)\ A+B]$$

where,

A = 1.613 for the administration building

A = 1.626 for the commissary

B = 13.4 for the administration building

B = 5.06 for the commissary.

6. Cooling Load Due to Interior Walls. Only the commissary has a cooling load due to interior walls. This cooling load is a heat flow out of the store area into the refrigerated and frozen storage rooms. The cooling load is determined in a similar manner to the heating load.

Figure 15 shows the correlation between cooling degree days and the number of hours, CC_F, that the building is in the cooling mode. Utilizing Figure 15, the monthly cooling load due to the interior walls can be calculated from the following equation:

$$QC_{iw} = CC_F[(EA_r)(EU_r)(T_i-T_r)+(EA_f)(EU_f)(T_i-T_f)]$$

where,

CC_f = Correlation factor from Figure 15-E

EA_r = Equivalent wall area between the store and the refrigerated storage room, sq ft

EU_r = Equivalent U value of the wall between the store and the refrigerated storage room, Btu/hr-ft^2-°F

T_i = Store set-point temperature, °F

T_r = Refrigerated storage temperature, °F

EA_f = Equivalent wall area between the store and the frozen storage room

EU_f = Equivalent U value of the wall between the store and the frozen storage room Btu/hr-ft^2-°F

T_f = Frozen storage temperature.

7. <u>Cooling Energy Use</u>. Algebraic addition of all the loads calculated in the previous steps will result in the total building cooling load which has to be met by the cooling system. The equation expressing this cooling load is:

$$QC_{total} = QC_{env}+QC_{inf}+QC_{rad}-QC_{floor}-QC_{iw}+QC_I.$$

The cooling system energy usage deviates from the cooling load due to the cooling system inefficiencies. For the single-family and town house residences there are two system inefficiencies: (1) losses due to the operation of the cooling unit; (2) losses due to the distribution system. Accounting for these two losses, the monthly cooling energy usage for the single-family and town house residences can be calculated from the following equation.

$$Q_{cool} = \frac{QC_{total}}{(1000)(EER)(E_{dist})}$$

where,

Q_{cool} = Cooling energy use, Kw-hr/month

QC_{total} = Total cooling load, Btu/month

EER = Energy efficiency rating, Btu/Watt-hr

E_{dist} = Efficiency of the distribution system.

The above equation will reduce to the following for residences served by central plants.

$$Q_{cool} = \frac{QC}{E_{dist}}$$

where,

Q_{cool} = Cooling energy use, Btu/month.

The inefficiencies of the cooling systems in the barracks, administration, and commissary buildings are due to three factors: (1) chiller efficiency at full load; (2) distribution system; (3) part load characteristics of the chiller.

The part load efficiencies of the chiller are determined by adjusting the chiller efficiency by the chiller load factor, CLF. Figure 18 gives the chiller load factor as a function of the load ratio, LR, where the load ratio is determined by the following equation.

$$LR = \frac{QC_{total}}{(\text{Chiller rating, Btu/hr})(720\ \text{hr/month})}$$

For central cooling systems, $LR > 0.3$ for the hot season, and $LR < 0.3$ for the mild season.

The distribution efficiency, $(\frac{1}{LCR})$, is determined from Table 26 using the same methodology as was used in the heating section.

The cooling energy use may then be determined from the following equation.

$$Q_{cool} = \frac{(CC)(LCF)(CLF)}{(1000)(EER)}$$

where,

Q_{cool} = Cooling energy use, Kw-hr/month

CC = Chiller capacity, Btu/month

Table 26. LOAD CORRECTION FACTORS AND AUXILIARY ELECTRIC CONSUMPTION FOR COOLING SYSTEMS

System Type	LCF		RF		C Kw-hr/cfm month	
	LR > 0.30	LR ≤ 0.30	LR > 0.30	LR ≤ 0.30	LR > 0.30	LR ≤ 0.30
Multizone Fan System	2.0	2.8	--	--	1.1	0.86
Multizone Fan System with Two-Pipe Fan Coil System	1.2	2.5	--	--	0.69	0.37
Reheat Fan System	4.6	7.1	0.4	0.8	1.2	0.83
Variable Volume Fan System with Baseboard Radiation	1.1	1.9	--	--	0.62	0.31

LCF = Load correction factor from Table 26

CLF = Chiller load factor from Figure 18

EER = Energy efficiency rating, Btu/Watt-hr

The above equation will reduce to the following for buildings served by central plants.

$$Q_{cool} = (QC_{cool})(LCF)$$

Reheat systems impose a load on the building's heating system that is directly proportional to the total cooling load. From the analysis it was determined that this reheat heating load, Q_{rh}, is given by the following equation.

$$Q_{rh} = (QC_{total})(RF)(LCF)$$

where,

RF = Reheat factor from Table 26

LCF = Load correction factor from Table 26.

The reheating energy requirements, Q_{heat}, may be determined by the same methodology as used in the heating section.

The electric consumption due to the operation of the fans, pumps, and other auxiliary equipment, Ea, can be estimated using the same methodology as was used in the heating section. The monthly electric consumption for the accessories can be calculated from the following equation.

$$Ea = (C)(R)$$

where,

C = Fan and pump consumption rate from Table 26, Kw-hr/cfm-month

R = Fan flow rate, cfm.

In order to include the effect of system shutdown at night, the cooling load can be adjusted to reflect the number of hours during which the system is shut down. The effects of temperature rise during the shutdown period and the energy needed to cool the building down to the set-point temperature have been included in the analysis. The reduced cooling load is determined from the following equation.

$$QC_{total} = (QC_{total})_{24\ hr}\ [1-0.0283(X)]$$

where,

$(QC_{total})_{24\ hr}$ = Total cooling load for 24-hour operation, Btu/month

X = Hours per day the system is shut down.

The effect of night shutdown on the electric consumption due to the fan and pump operations is determined using the same methodology as was used in the heating section. The electric consumption of the fans and pumps is then determined from the following equation.

$$Ea = (Ea)_{24\ hr}\left(1 - \frac{X}{24}\right)$$

where,

$(Ea)_{24\ hr}$ = Auxiliary electric consumption based on 24-hour operation, Kw-hr/month

X = Hours per day that the system is shut down.

VI. DEVELOPMENT OF ADDITIONAL ENERGY USE ALGORITHMS

In each of the five building types, energy use due to lighting, cooking, hot water heating, laundry, cold storage, and other appliances and equipment can be estimated using the algorithms contained in this chapter. Single-family and town house residences have been treated alike for these energy use calculations and are identified as family housing. The development procedures for each of the energy use activities is discussed in a separate section below with respect to all building types.

A. Lighting

For the family housing units, lighting energy use was based on a lighting level typical to residential housing in the Baltimore-Washington area. The power associated with this lighting level is 0.39 watts per square foot of floor area, and the daily load factor* for this equipment is 8.35 hours (Refs. 5 and 6). The typical resultant energy use is 1.19 Kw-hr/sq ft of floor area/yr, or 3.25 x 10^{-3} Kw-hr/sq ft/day. These values have been developed for housing units in a range from 1000 to 1800 square feet of living area and for an average family of four. Residences occupied by fewer than three residents are anticipated to have a lower load factor, and it was estimated that they use only about two-thirds of the lighting energy of a family of four in a similar residence.

Lighting use in barracks can be separated into two categories: bunking areas and non-bunking areas. Installed lighting fixtures in bunking areas have a rating of about 0.9 watts/sq ft, and the load factor for such lighting is 4.4 hours per day. This lighting level is based on observations at Fort Belvoir and Fort Meade. Similarly the lighting level of non-bunking areas in observed barracks is about 0.7 watts per square foot, with a load factor of 14.9 hours per day. The resultant lighting energy usage in barracks is: 0.0040 Kw-hr/square foot/day for bunking areas, 0.0104 Kw-hr/square foot/day for non-bunking areas, and 0.007 Kw-hr/square foot/day for the entire barracks, assuming the barracks is 53 percent bunking area as was the observed characteristic barracks at Fort Meade.

The preceding energy use factors for lighting in a barracks are based on an assumed 100 percent occupancy level. Adjustments for other occupancy levels can be made by use of the

**Equivalent number of hours during which all lights are on at the indicated rate.*

occupancy correction factors presented in Table 23, from Section III, Electrical of TB ENG 259 (Ref. 1). These occupancy correction factors make the adjustments on lighting use to account for the fact that lighting energy usage and occupancy do not vary proportionately; i.e., half of the occupants will use more than half the lighting energy that 100 percent occupancy level would use. The correction is made by multiplying the full occupancy energy use level by the fractional occupancy and the corresponding occupancy correction factor.

Lighting energy use in administration/office buildings is a function of the lighting level and the work schedule of the people in the building. Typically, the levels of lighting vary from 2 to 4 watts per square foot. An average of three watts/sq ft is commonly used for commercial office space. However, the military offices observed indicated a somewhat lower level of 2.5 watts/sq ft should be used if actual levels are unknown. For buildings in which one working shift is scheduled, the number of hours that all lights are on was estimated to be 10.5 hours. In addition, a minimum number of lights will remain on all the time (estimated at ten percent for 13.5 hours per/day). This results in a load factor of 12 hours per day for an office building with one working shift. A multiplier of 1.5 was established for increasing the number of working hours to represent equivalent full load lighting hours for one shift operation. Similar multipliers, developed for two and three shift operations, are 1.2 and 1.0, respectively.

Lighting use in commissaries was determined in the same fashion as it is for the administration/office building. However, there was no question about the number of shifts; workers and customers are in the building almost 24 hours a day on weekdays, Saturdays have shorter hours, and there are no people in at all on Sundays. Table 27 shows the approximate number of people who are in the Fort Belvoir commissary during the day. Over a week-long period, the average load factor for lighting is about 18 hours per day. The average lighting rate for the commissaries is 2 watts per square foot. This includes refrigerated/freezer rooms and storage areas (where lighting levels are considerably lower than in the store or working areas).

Table 27. Number of People in Fort Belvoir Commissary on a Typical Weekday

Time	Number of People			
	Employees	Vendors	Customers	Total
6:00 - 8:00 AM	13	15		28
8:00 - 8:30 AM	33	15	100	148
8:30 - 9:00 AM	25	15	200	240
9:00 - 6:30 PM	84		30	384
6:30 - 12:00 PM	20			20
12:00 - 3:00 AM	28			28
3:00 - 6:00 AM	16			16

Source: R.A. King, Manager, Fort Belvoir Commissary

B. Cooking

The cooking energy use in family housing units (both single-family and town house) was estimated based on average range and oven energy usage (Refs. 9, 10, and 11). Annual average consumption for electric range/oven combinations is about 1200 Kw-hr. Comparable gas consumption is about 105 therms for both natural gas and propane appliances. However, gas ranges without pilots would use considerably less gas--about 70 therms (Ref. 10). These values convert to the following average daily energy use levels:

Electric range/oven	3.3 Kw-hr/day
Gas range/oven w/pilots	0.29 therms/day
w/o pilots	0.19 therms/day.

The barracks' mess hall cooking energy use was based on that of a cafeteria located in an office building (Ref. 12). This cafeteria used 3.38 therms per day to prepare 210 lunches, or 1600 Btu/lunch. Because cooking energy requirements are somewhat higher to prepare dinners, the total energy use to prepare three meals a day was estimated to be 3.2 times the energy use at lunch. Typical eating habits of residents of enlisted men's barracks indicate that an average of about 2.15 meals/day/resident are eaten at the barracks. Therefore, cooking energy use at a barracks mess hall is about 5000 Btu/day/resident, or about 2300 Btu/person-meal served. These values could also be used to estimate cooking use in mess halls serving multiple barracks and/or bachelor officer quarters.

The energy use for cooking activities in administration/office buildings and commissaries is negligible unless, of course, such a building includes a cafeteria. In that case, energy consumption could be evaluated using Btu/person-meal and the number of meals served (Ref. 12).

C. Hot Water Heating

Family housing energy use for hot water heating is based on the following daily hot water usage per residence, assuming a family of four (Refs. 11 and 13):

Bathing	36	gallons
Dish washing	16	"
Laundry	8	"
Cleaning	6	"
Miscellaneous	20	"
	86	gallons.

It was assumed that each residence had a 50 gallon hot water tank; therefore, energy use for hot water heating could be attributed to the following activities for gas and electric hot water heaters (Ref. 11):

	Gas, Btu	Electric, Kw-hr
• Steady-state conduction losses through tank walls and pipes	10,000	3.0
• Off cycle chimney losses	2,000	-
• Steady-state withdrawal rate	47,300	13.8
• Combustion losses	15,700	-
Total	75,000	16.8.

Pilot lights on gas water heaters use about 12 to 25 percent of the energy used by these appliances (Refs. 10 and 11). A fifteen percent reduction in gas consumption was used as a conservative estimate for pilotless water heaters. For those buildings served by central steam plants for hot water heating, it was assumed that 66 pounds of steam (at 1000 Btu per pound) are required per day, assuming 15 percent steady state conduction losses and 87 percent heat transfer efficiency. Oil-fired water heaters are generally less efficient in combustion than are gas heaters. Energy use for oil-fired water heaters can be estimated at 95,000 Btu per day (Ref. 14).

Hot water heating usage was defined as 21 gallons per day per man in a barracks with mess hall. For a barracks without a mess hall, a value of 17 gallons/day/man was used. These values were based on the single-family hot water usage of 86 gallons/day/family of four, including 16 gallons per day for dish washing. Energy requirements per gallon of hot water used were assumed to be 550 Btu delivered to water divided by a 65 percent efficiency of delivery for gas-fired water heaters. The result was 850 Btu per gallon of hot water. Oil-fired units were estimated to use 27 percent more energy than gas-fired units, or 1070 Btu per gallon of water. Steam requirements per gallon of water heated were assumed to be the same as in steam-hot water converters in family housing. A similar assumption was used to determine electric hot water heater energy requirements in barracks.

Administration/office building hot water usage was estimated at one gallon per day per employee. It was assumed that steady-state conduction losses and off-cycle chimney losses (in fossil-fired heaters) would be a somewhat higher fraction of energy use because withdrawal rates are lower in office buildings as compared to single-family housing. Energy use per gallon of hot water demand was estimated at 1000 Btu for gas-fired facilities, 1270 Btu for oil-fired heaters, and 0.23 Kw-hr for electric water heaters. Steam-to-hot water converters require about 1.0 pound of steam for each gallon of water heated.

The energy requirements for hot water heating are estimated to be:

- 2500 Btu/day/employee for natural gas, LP gas, propane water heaters
- 3175 Btu/day/employee for oil-fired water heaters
- 2.2 lb of steam/day/employee for steam converters
- 0.6 kw-hr/day/employee for electric water heaters.

D. Laundry

Energy use in home laundry facilities was based on the following commonly used average annual values:

Automatic Washer	103 Kw-hr/yr	(Refs. 9, 11 and 14)
Non-automatic Washer	76 Kw-hr/yr	(Ref. 9)
Electric Dryer	993 Kw-hr/yr	(Refs. 9 and 11)
Gas Dryer w/pilot	90 therms/yr	(Refs. 10, 14 and 15)
Gas Dryer w/o pilot	55 therms/yr	(Ref. 10)

These values were directly applicable for family housing units with laundry installations and for families which utilize on-base laundromats. For barracks residents who utilize laundromats on-base, these values were reduced by two-thirds to apply on an individual basis. Also, it was assumed that all laundromats will have automatic washers and gas dryers. No estimates were made for the number of families or barracks residents utilizing laundromats. This estimate can only be made at the base level.

Energy use in laundries operated by or for the Army was determined on a per 1000 articles of laundry handled for each month of the year. The basis for these figures is energy use and laundry handling data provided by CERL for an Army laundry during the months January 1974 through April 1975. The data utilized, is listed below along with calculated values of energy per 1000 articles of laundry for each month.

Month		Energy Used (Standard Tons)	Thousands of Articles Laundered	Million Btu per 1000 Articles
January	1974	306.0	562.4	13.2
January	1975	292.0	570.2	
February	1974	291.0	486.9	14.4
February	1975	282.3	509.2	
March	1974	244.9	550.7	11.2
March	1975	291.4	645.2	
April	1974	195.0	549.9	8.6
April	1975	199.8	599.6	
May	1974	200.8	557.4	9.0
June	1974	175.2	584.0	7.5
July	1974	189.6	589.8	8.0
August	1974	163.3	509.0	8.0
September	1974	157.4	502.5	7.8
October	1974	236.7	574.2	10.3
November	1974	248.7	506.6	12.3
December	1974	273.0	475.2	14.4

No assumptions were made as to how much laundry any facility will handle; that can best be determined at the base level.

E. Cold Storage

Two procedures were developed for determining energy use by refrigerated storage units. The first is a simplified procedure based on estimated load ratios. The second is a more complex procedure based on cooling/refrigeration loads.

The simplified procedure utilizes estimated load factors for different outdoor temperature ranges as multipliers to the cooling system capacity in determining the energy use. For average monthly temperatures greater than 80°F, the load ratio, LR, was assumed to be 0.8. For average monthly temperatures between 50°F and 79°F, LR was assumed to be 0.5. For lower temperatures, LR was assumed to be 0.2. Monthly cooling system energy use is determined from the following equation:

$$\text{Monthly Energy Use (Kw-hr/month)} = \frac{CAP \times LR \times DM \times 24 \ \frac{\text{hours}}{\text{day}}}{3413 \ \text{Btu/Kw-hr}}$$

where,

CAP = Refrigeration system capacity in Btu/hr
LR = Load ratio based on outdoor temperature
DM = Number of days in the month.

The more complex calculation procedure for calculating energy use of cold storage units is similar to the cooling energy calculation for a building. The cooling loads due to conduction, radiation, and infiltration were calculated and average system performance was used to determine energy use.

Conduction loads are separated into three types: exterior wall, interior wall, and ground floor conduction. Each is based on the steady-state heat conduction equation:

$$q = UA\ \Delta T.$$

When this conduction rate (in Btu/hr) is multiplied by the number of hours during which the conduction takes place, during any period of time, the total load is determined for that period of time. An average ΔT was used for the hours during which heat conduction into the refrigerated space takes place. For conduction through interior walls or ground floors, heat transfer was assumed to be into the cold space at all times. Therefore, in a monthly calculation, conduction through interior walls (i.e., wall to other conditioned spaces) was determined:

$$Q = q \times (\text{hours/month}) = UA\,(T_1 - T_0)\left(\frac{\text{days}}{\text{month}}\right)\left(24\ \frac{\text{hours}}{\text{day}}\right)$$

where,

Q = refrigeration load for the month, Btu

q = average hourly refrigeration load, Btu/hr

U = thermal conductance of wall separating the cold storage space from another interior space, $\frac{\text{Btu}}{\text{hr-sq ft-°F}}$

A = area of the interior wall, sq ft

T_1 = average (or set-point) temperature of the interior space, °F

T_0 = set-point temperature of the cold storage space, °F.

To determine conduction through ground floors, the same equation was used, except that:

U = thermal conductance of the floor, Btu/hr-sq ft-°F

A = area of the floor, sq ft

T_1 = monthly average ground temperature, °F.

Conduction through exterior walls was determined in the same fashion, except the number of hours of heat gain had to be determined. This number of hours was determined from the location-specific weather data in TM 5-785 of the Department of the Army. For each month, the number of hours of temperature observations higher than the cold space set-point temperature was summed and used as the number of hours of heat gain to the cold box for that month. The weighted average outdoor temperature during those hours was also determined. Generally, refrigerator rooms are set at 35 to 40 degrees F and freezers are set at 0° to 10°F. In these cases, the temperature observations included in the calculations are from a 35 to 39 degree range and up for the refrigerator room, and 5 to 9 degrees and up for the freezer room. The equation for heat conduction load through exterior walls is:

$$Q = q \times h = UA\,(T_A - T_0 + 2) \times h$$

where,

Q = monthly conduction load due to exterior walls, Btu

q = average hourly conduction, Btu/hr

h = number of hours during which heat transfer is directed into the cold storage space, hours

U = thermal conductance of exterior walls, Btu/hr-sq ft-°F

A = area of exterior walls, sq ft

T_A = weighted average outside temperature, °F

T_O = set-point temperature inside cold space, °F.

The constant (2) in the equation is a correction factor to account for solar heating of the exterior surface. Thereby, radiation was also included in the calculation.

The infiltration load calculation was divided into two parts; a calculation for doors opening to the outside, and one for doors opening to inside spaces. Doors opening to the inside are opened frequently; therefore, daily infiltrated air was estimated to be about 2,000 cubic feet for a door with infiltration barriers in place during openings, and about 20,000 cubic feet for a door with no such barriers. Doors opening to the outside were assumed to be opened one-tenth as often; therefore, daily infiltrated air volumes are 200 and 2,000 cubic feet for doors with and without infiltration barriers, respectively. Infiltration load was determined as follows:

$$Q = (CF/D)\left[(0.18)(T_1 - T_O) + L\right]\left(\frac{\text{days}}{\text{month}}\right)$$

where,

Q = monthly infiltration load for a door, interior or exterior (calculation must be performed twice if doors of both types exist), Btu

CF/D = volume of infiltrated air, cubic feet per day

T_1 = monthly average temperature for hours of refrigeration for exterior doors; set-point temperature of adjoining space for interior doors, °F

T_O = set point of cold storage space, °F

L = factor for latent heat gain, Btu/cubic foot of air.

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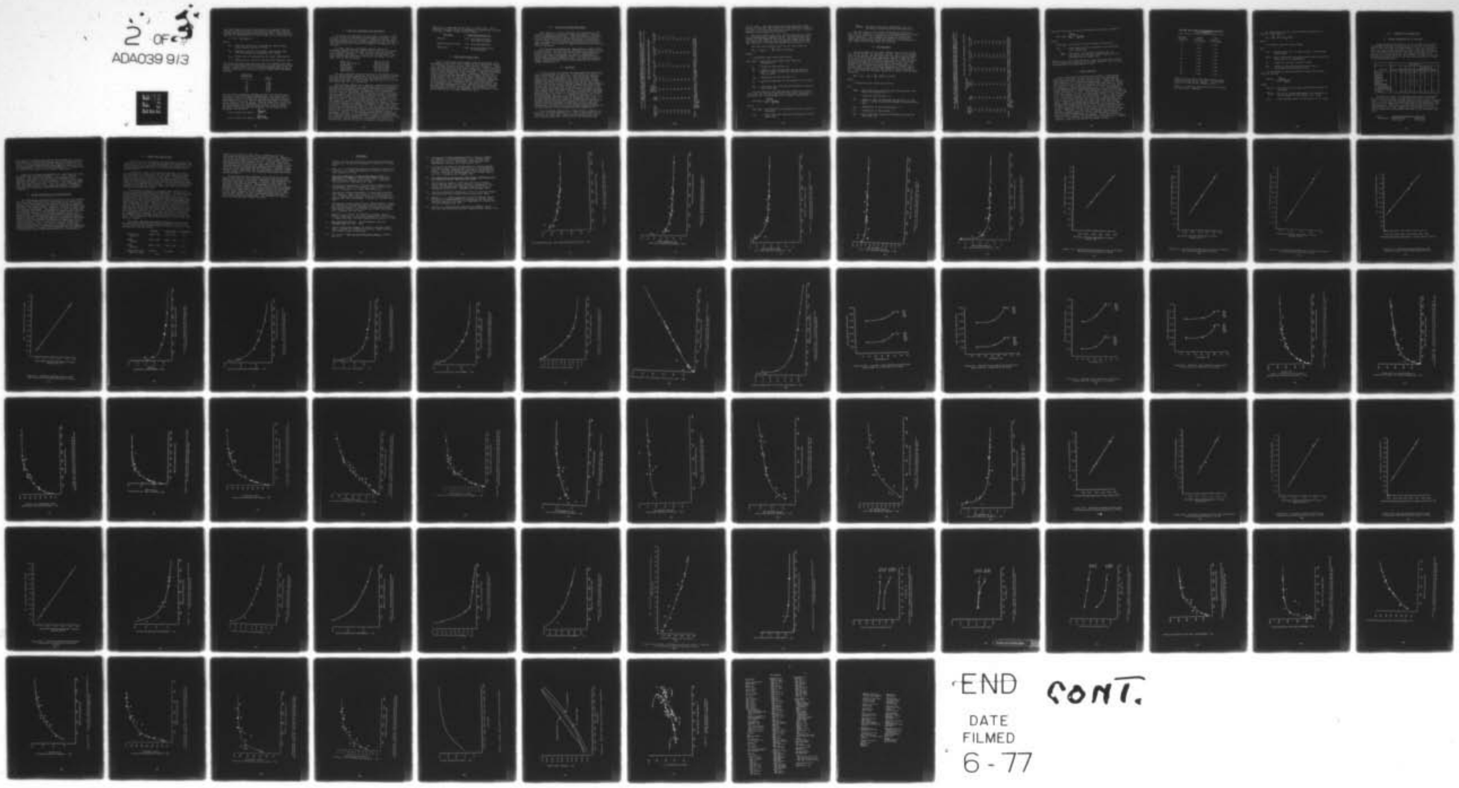

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The latent heat gain factor was based on an assumed 70 percent relative humidity inside and outside the storage space and an average outside temperature (dry bulb) of 75°F. The latent heat gain due to condensation from infiltrated air was calculated by:

$$L = (W_1 - W_0)(h_{fg})(P\ )$$

where,

W_1 = humidity ratio for air outside the cold storage space (assume 70% RH, 75°F db)

W_0 = humidity ratio for air inside cold storage space (70% RH assumed and temperature set point)

h_{fg} = latent heat of vaporization for water 1050 Btu/lbm

P = density of air at 75°F, 70% RH ≈ 0.075 lbm/cubic foot.

The following table shows the value of L for several cold space set-point temperatures with the constant outside conditions (see above). These values of L are used for determination of infiltration loads due to interior or exterior doors with reasonable accuracy.

Set-point temperature, °F	L, Btu/cf
-10	1.02
0	1.00
10	0.97
20	0.92
30	0.85
40	0.76

All the loads (conduction through exterior and interior walls and floors, and infiltration through doors to outside and to adjoining spaces) are summed and divided by the coefficient of performance (C.O.P.) of the refrigeration equipment to obtain total energy use by the system. Because these units are almost always electric, the conversion to Kw-hr of electric energy can be incorporated into the COP/system energy use by dividing the total load by the energy efficiency rating (EER) of the equipment multiplied by

$$\text{Total Energy Used (Btu)} = \frac{\sum \text{Loads}}{\text{COP}}$$

$$\text{Total Electricity (Kw-hr)} = \frac{\sum \text{Loads}}{\text{EER} \times 1000}$$

F. Electrical Equipment and Appliances

The electrical equipment and appliances included in this analysis do not include any of the equipment discussed in the preceding sections of this chapter. Lighting, cooking, water heating, laundry, and cold storage equipment are not included in this section, with the exception of plug-in refrigerators and freezers.

In family housing, the annual usage of electrical appliances amounts to about 3000 Kw-hr for such basic items as a refrigerator-freezer, an iron, a coffee pot, and numerous miscellaneous appliances. This does not include some of the major electricity users which may or may not appear in each home, such as the following:

Color TV	500 Kw-hr/year
Black and White TV	290 Kw-hr/year
Dishwasher	363 Kw-hr/year
Food Freezer	1500 Kw-hr/year
Humidifier	163 Kw-hr/year
Dehumidifier	377 Kw-hr/year.

The total appliance electricity load in any family housing unit was determined by adding the electricity consumption values for each of the major appliances in the housing unit to the base appliance load. It was assumed that the use of all of the appliances does not vary seasonally.

The appliance energy use in barracks, administration/office buildings, and commissaries was estimated based on the observed appliances and equipment installed in the buildings surveyed at Fort Belvoir and Fort Meade. Parameters, such as nameplate ratings, hours of operation, and the number of hours the building is occupied, were considered in the estimating of equipment and appliance energy use in these buildings. In the barracks, appliance electricity use was normalized to the number of residents, because in these buildings, energy use can be related to the number of people living or working there. However, the correlation between the number of occupants and appliance energy use is not linear for buildings occupied to a level less than or greater than the design capacity. The occupancy correlation factors (OCF) presented in Table 23 were used to adjust appliance electricity use per resident value for one hundred percent occupancy. However, in the administration/office building and the commissary, much of the equipment is going to be operating at a constant level independent of the number of people utilizing the building. Normalization for the administration/office building was done on the basis of occupants, whereas for the commissary, it was done on the basis of floor area. Daily electrical energy used due to equipment and appliances in these buildings is shown in the following table.

Building	Electrical Energy Use	
Barrack	0.30	Kw-hr/day/resident (at 100% occupancy)
Administration/office	2.45	Kw-hr/day/employee
Commissary	0.06	Kw-hr/day/square foot of floor area

G. Additional Energy Users

Every installation will probably have unique energy using equipment or facilities which cannot be given particular notice in a document directed at Army installations in general. Therefore, at each facility where total energy use is being analyzed, particular attention must be paid to identify energy users which have not been recognized in this document. Some of these energy users, such as outdoor gas lights, emergency lighting, and electricity-generating equipment may be common to many facilities; however, the utilization of these energy users may vary significantly from one base to another. Therefore, energy use by such systems and equipment cannot be estimated properly in the general case. Personnel at each Army installation can best estimate consumption of their own particular energy uses by observing the number of hours that the equipment is used, the nameplate rating of the equipment, and an observed or estimated load factor, or normal operating level.

VII. PIPELINE DISTRIBUTION LOSSES

This chapter is used to determine the efficiency of distributing energy in the form of steam, hot water, or chilled water in underground pipelines. Such distribution efficiency is associated with central generating plants which produce steam or hot or chilled water for utilization in other buildings for purposes such as space heating and cooling and hot water heating. This chapter is not concerned with distribution within a building.

The procedures developed for computation of pipeline distribution losses and distribution efficiencies are based on two primary sources. The hot and chilled water distribution are based on an analysis performed for the U.S. Department of Housing and Urban Development's Modular Integrated Utility System (MIUS) program (Reference 16). The steam distribution losses are based on data from the Baltimore Gas and Electric Company (Reference 17).

A. Hot Water

The daily heat loss values for underground hot water pipelines are presented in Table 28. These values are based on hourly heat losses for 180°F water and 54°F ground temperatures, or $\Delta T = 126$ (Reference 16). For simplicity, it was assumed that the properties of the earth (including thermal conductivity equal to 0.833 Btu/hr-ft-°F) do not vary significantly within the range of ground temperatures (approximately 40° to 70°F) likely to occur below the frost line, and it was assumed that the properties of the pipe and insulation do not vary significantly over the range of likely hot water temperatures (about 170°F to 210°F). Further, calculations were made assuming that the portion of the pipeline which is not buried below the frost line (i.e., is exposed to outside air or is passing through the upper layer of earth above the frost line) is sufficiently small to allow the assumption that losses through this portion are identical to the losses identified in Table 28 without introducing significant error to the total pipeline loss calculation. On the basis of the preceding assumptions, the heat losses could be determined per degree ΔT, thereby allowing variable ground and water temperatures.

The insulation referred to in Table 28 has a thermal conductivity of 0.0367 Btu/hr-ft-°F. This is equivalent to an R value of 2.3 per inch. The U values listed in the table were computed using the resistivity of the insulation and

Table 28. DAILY HEAT LOSSES FOR UNDERGROUND HOT-WATER PIPE AND PIPE CONDUITS PER DEGREE TEMPERATURE DIFFERENCE FROM HOT WATER TO GROUND (BTU/DAY-FOOT-°F)

			Pipe w/Casing, Air Gap Outside of Insulation			
Nominal Pipe Size (in.)	Bare Pipe	Pipe w/ Casing & Air Gap U=1.0	0.5 in. thick U=0.5	1.0 in. thick U=0.3	1.5 in. thick U=0.23	2.0 in. thick U=0.18
1.5	27	14	7.4	5.4	4.6	3.9
2.0	29	15	8.3	6.3	5.2	4.6
3.0	31	19	11.	6.5	6.5	5.7
4.0	33	21	12.	9.3	7.6	6.5
6.0	37	26	16.	12.	10.	8.5
8.0	40	30	19.	14.	12.	10.
10.0	44	33	22.	17.	14.	12.
12.0	47	37	24.	19.	15.	13.
14.0	48	38	27.	20.	17.	14.

Source: "MIUS Technology Evaluation, Thermal Energy Conveyance," prepared by Oak Ridge National Laboratory for the U.S. Department of Housing and Urban Development, May 1976.

the air space. Any resistance due to the pipe walls themselves was ignored. Most pipes will fall within the range of U values in the table because more insulation than 2 inches is generally not economically justified.

The total monthly heat loss for the distribution system can be determined by summing over all sections of pipe the product of the length of the section, the proper daily heat loss value from Table 28, and the number of days each month that hot water is transferred through that section of line.

Then the total monthly heat loss for the system is,

$$HL_m = (T_{HW} - T_G) \times \sum_i (DHLV_i)(L_i)(DM_i)$$

where,

i designates each unique pipe section

and, $DHLV_i$ = daily heat loss values from Table 28, Btu/day-ft-°F

L_i = length of pipe section, ft

DM_i = number of days in the month during which hot water is being transferred through the pipe section, days

T_{HW} = temperature of the hot water, °F

T_G = average temperature of the ground for the month, °F

HL_M = total heat loss from the distribution system for the month, Btu.

The efficiency of the distribution system can be determined from the following equation if the sum of hot water requirements for all buildings on the system is determined.

$$DIST\text{-}HW_m = \frac{\sum HWD_m}{HL_m + \sum HWD_m}$$

where,

$DIST\text{-}HW_m$ = efficiency of distribution for the system for the month

HL_m = total heat loss from the distribution for the month, Btu.

$\sum HWD_m$ = the sum of hot water requirements "at the building" for the system for the month, Btu.

The efficiency of the entire distribution system was utilized for simplicity, in spite of the knowledge that delivery over a short distance is somewhat more efficient than for longer distances. This reduces the number of distribution efficiency calculations to one per month per distribution system, rather than one per month per building.

B. Chilled Water

The development of heat gain through chilled water piping was similar to that for hot water piping. That is, the properties of the ground, the water, and the insulation were assigned to be invariant within the temperature ranges of application. No values for the chilled water lines with two inches of insulation are provided, since this configuration is not considered economically feasible for chilled water (Reference 16). The values in Table 29 were derived from values calculated for chilled water at 50°F, and ground temperature of 62°F ($\Delta T=12$), but have been normalized on a per degree ΔT basis (Reference 16). Total heat gain during a month for an entire chilled water system is:

$$HG_m = (T_G - T_{CW}) \times \sum_i (DHGV_i)(L_i)(DH_i)$$

where,

i designates each unique pipe section

and,

$DHGV_i$ = daily heat gain value from each pipe section from Table 29, Btu/day-ft-°F

L_i = length of pipe section, ft

DH_i = number of days of the month during which chilled water is being transferred through the pipe section, days

T_{CW} = temperature of the chilled water, °F

T_G = temperature of the ground, °F

HG_m = total heat gain from the distribution system for the month, Btu.

Table 29. DAILY HEAT GAINS FOR UNDERGROUND CHILLED-WATER PIPE AND CONDUITS PER DEGREE TEMPERATURE DIFFERENCE BETWEEN CHILLED-WATER AND GROUND (BTU/DAY-FOOT-°F)

Nominal Pipe Size (in.)	Bare Pipe	Pipe w/Casing and Air Gap U=1.0	Pipe with Casing, Air Gap Outside of Insulation		
			0.5 in. thick U=0.5	1.0 in. thick U=0.3	1.5 in. thick U=0.23
1.5	27	13	6.6	5.0	4.2
2.0	29	13	7.4	5.6	4.6
3.0	31	16	9.4	7.2	5.8
4.0	33	18	11.0	8.4	6.8
6.0	37	22	14.0	11.0	9.0
8.0	41	25	17.0	13.0	11.0
10.0	44	29	20.0	15.0	13.0
12.0	46	32	22.0	17.0	14.0
14.0	48	33	24.0	18.0	15.0

Source: "MIUS Technology Evaluation, Thermal Energy Conveyance," prepared by Oak Ridge National Laboratory for the U.S. Department of Housing and Urban Development, May 1976.

Then the efficiency of the chilled water distribution system is:

$$DIST\text{-}CW_m = \frac{\sum CWD_m}{HG_m + \sum CWD_m}$$

where,

$DIST\text{-}CW_m$ = efficiency of chilled water distribution

HG_m = total heat gain for the month in the distribution system, Btu

CWD_m = the sum of chilled water demands (at the building) for cooling or cold storage, for all building on the system, Btu.

Whenever T_G is less than or equal to T_{CW}, the heat gain or loss for the month was considered to be zero; therefore, the distribution efficiency for that month is 1.00.

C. Steam Pipelines

Heat losses due to distribution of steam in underground pipelines are defined in Table 30 for high- and low-pressure steam pipes and for a variety of pipe sizes. These data are representative of a steam distribution with a variety of insulation levels and can be used as average heat loss data for steam distribution. These data are based on the district steam system in downtown Baltimore, MD (Reference 17). This system encompasses 89,000 feet of underground pipelines, not including individual building feed lines. Pipe diameters range from 2 inches to 24 inches nominal size and line pressures range from 15 psig to 200 psig. Low pressure lines are those under 50 psig. High-pressure lines are usually between 100 and 200 psig. The system is made up of a wide range of types and levels of insulated pipe, the newest of which is the pipe-in-a-pipe type with insulation between. Because the temperature the steam is so high (steam temperatures ranging from 250 to 280°F for low pressure, 280 to 380°F for high pressure lines), the variation in ground temperature between 40° and 80°F will have a small effect on heat losses. Therefore, it has been assumed that the values for the Baltimore system (Table 30), with a central location with respect to ground temperature, can be used nationally without causing errors of more than 10 percent. These data can be applied to a distribution system efficiency calculation in a manner similar to that for hot and chilled water systems.

Table 30. HEAT LOSSES FOR UNDERGROUND STEAM PIPES (LB OF STEAM/DAY-FT)

Nominal Pipe Size (in.)	High* Pressure Line Losses	Low* Pressure Line Losses
2	1.15	0.79
4	1.70	1.15
6	2.14	1.44
8	2.59	1.73
10	3.05	2.04
12	3.48	2.33
14	3.84	2.59
16	4.30	2.88
24	4.82	3.24

*High pressure values used for pipelines where pressure exceeds 50 psi (gauge). Low pressure values for lines 50 psi (gauge) or less.

Source: R. Gallina, Steam Division of Baltimore Gas and Electric Company

The total heat loss for the distribution system for a month is determined by:

$$SL_m = \sum_i (DSTV_i)(L_i)(DM_i)$$

where,

i designates specific pipe sections

and,

SL_m = monthly heat loss in steam system, in equivalent lb of steam

$DSTV_i$ = daily steam loss value from each pipe section from Table 30, lb of steam/day-ft

L_i = length of the pipe section in feet

DM_i = number of days of the month that steam is distributed through this section.

The efficiency of the distribution system can be determined as follows:

$$DIST\text{-}S_m = \frac{\sum SD_m}{SL_m + \sum SD_m}$$

where,

$DIST\text{-}S_m$ = efficiency of the steam distribution system for the month.

$\sum SD_m$ = sum of all steam requirements for the month at all buildings on the system, lb of steam

SL_m = total system losses for the month, lb of steam.

VIII. SUMMATION OF ENERGY USES

A. Energy Consumption of a Building

Energy consumption summation for any building was done by disaggregating energy uses according to the fuel (or energy) source that enter the building boundary. That is, electricity, coal, oil, gas, steam, hot water, and chilled water consumptions are computed by defining the fuel source for each energy use activity in the building. The range of probable fuel sources for each activity for which energy consumption has been determined by application of the preceding algorithms is shown in the following matrix.

	Fuel Source							
Activity	Electricity	Coal	Oil	Gas	Steam	Hot Water	Chilled Water	Other
Heating	X	X	X	X	X	X		X
Cooling	X			X	X		X	X
Lighting	X							
Cooking	X			X				
Water Heating	X	X	X	X	X	X		X
Laundry	X			X	X			
Cold Storage	X			X	X		X	
Electric Equip. and Appliances	X							
Additional Energy Users	X	X	X	X	X	X	X	X

Electricity, coal, oil, and gas usage can be accumulated for the entire building. Energy sources such as steam, hot water, or chilled water must be traced to their source of generation. In this case, the generation plant's efficiency and fuel type are to be identified. Distribution system efficiency must be determined. Then the steam, hot water, or chilled water generation plant's fuel consumption attributable to the building of study can be determined according to the following equation.

$$\text{Fuel Consumption} = \frac{\text{Energy Consumption in Building}}{\text{Distribution Efficiency} \times \text{Generation Efficiency}}$$

Fuel usage at a generation plant (on-base energy use) can now be added to the in-structure energy use on the appropriate fuel type. Electric heating and cooling consumptions must be converted to kilowatt-hours before being added to other electricity consumptions. Similarly, steam consumption, in pounds, must be converted into Btus (1 lb of steam = 1000 Btus).

Summation of energy consumptions for a building can be performed for any time period desired, i.e., daily, monthly, annually. The result is a series of five numbers which represent energy use in the building of five fuel source types (electricity, coal, oil, gas, and other). Any number of these fuel type totals may be zero. Coal, oil, and gas consumption when converted from Btus into a physical measure, represent required fuel purchases, along with the electric consumption in Kw-hrs.

B. Energy Consumption of an Installation

The methodology developed here can easily be used to determine the total energy use by all buildings on an installation within the five categories considered (single-family detached housing, town house residences, barracks, administration/office buildings, and commissaries). However, buildings of other types must also be considered. The energy use in such buildings can be estimated using this methodology by assigning every building to a category nearest to its use and occupancy type. Some examples are: a classroom building might be considered as an administration/office building because its occupancy schedule would be similar; a warehouse might be considered an administration/office building with a low set-point temperature and reduced occupancy. Also, a dining hall could be categorized as a barrack with mess hall, at least for cooking energy use. Other buildings must be categorized according to the judgment of on-base personnel, utilizing their knowledge of base operations to approximate total energy consumption by an installation.

IX. SUMMARY AND CONCLUSIONS

The objective of development of algorithms for energy use computations for the five Army buildings was accomplished. The verification of the developed methodology and suggestions for further development and analysis in this area of study are presented here.

In order to verify the developed algorithms, an office building located in Baltimore, MD, for which energy use data was available, was selected as a test case. The structural details, HVAC system, occupancy, and other pertinent information affecting energy use for the selected building was used, along with Baltimore weather data for the time period for which energy use information was available. Since the available data was not quite complete, default values provided in the algorithm were used when necessary.

The building analyzed was a twelve-story, 60,000 sq ft office structure, occupied by 300 employees. The structure had an equivalent envelope U value of 0.47 Btu/hr-sq ft-°F. The winter and summer set-point temperatures were 70°F and 72°F, respectively. Baltimore experienced a 4200 heating degree day heating season and a cooling season of 1235 cooling degree days during the year for which energy use data was available (May 1974 through April 1975). The glass area of the building was 4275 sq ft, and the total envelope area was 42,100 sq ft. The heating and cooling distribution system was a combination of a multizone fan system for six floors and a multizone fan system with two-pipe fan-coils for the other six floors. Because of the combination of systems, in system energy use calculations, an average of the provided values for the two system types was used. The ventilation rate of 0.20 cfm per sq ft of floor area was also assumed.

The actual and computed energy consumption values, using the administration/office building algorithms for this building, are shown in the following table, along with the percentage difference in the two values.

	Actual	Calculated	% Difference
Electricity (Btu/yr)	5638×10^6	5170×10^6	-8.3
Steam (Btu/yr)	2437×10^6	2625×10^6	+7.7
Total (Btu/yr)	8074×10^6	7795×10^6	-3.5
Energy Use Index (Btu/sq ft/yr)	134,600	129,900	-3.5

Based on the results of this test, it appeared that the algorithms developed here have reasonable validity. However, the universal validity and level of accuracy of these algorithms can not be proclaimed on one such test. The accuracy can be determined only after numerous tests. The tests, which could best measure the accuracy of the algorithms with respect to its intended purpose, would be tests made on Army buildings of the types for which the algorithms were developed. However, energy use data on such buildings was not available during the period of this study. Such tests are suggested when appropriate data become available.

The accuracy of the algorithms, when applied to building types other than the five studied, may vary significantly, depending on the type of building. Therefore, the testing of the existing algorithms on buildings of various types should be included in future programs. Development of algorithms for additional building types, and a more detailed and multifaceted approach to heating and cooling system analysis are encouraged. Evaluation of HVAC systems was somewhat limited by the scope of this study; however, it has become apparent that the selection of HVAC systems and their operational modes have very significant impacts on energy use. The selection of such systems and modes warrants further analysis.

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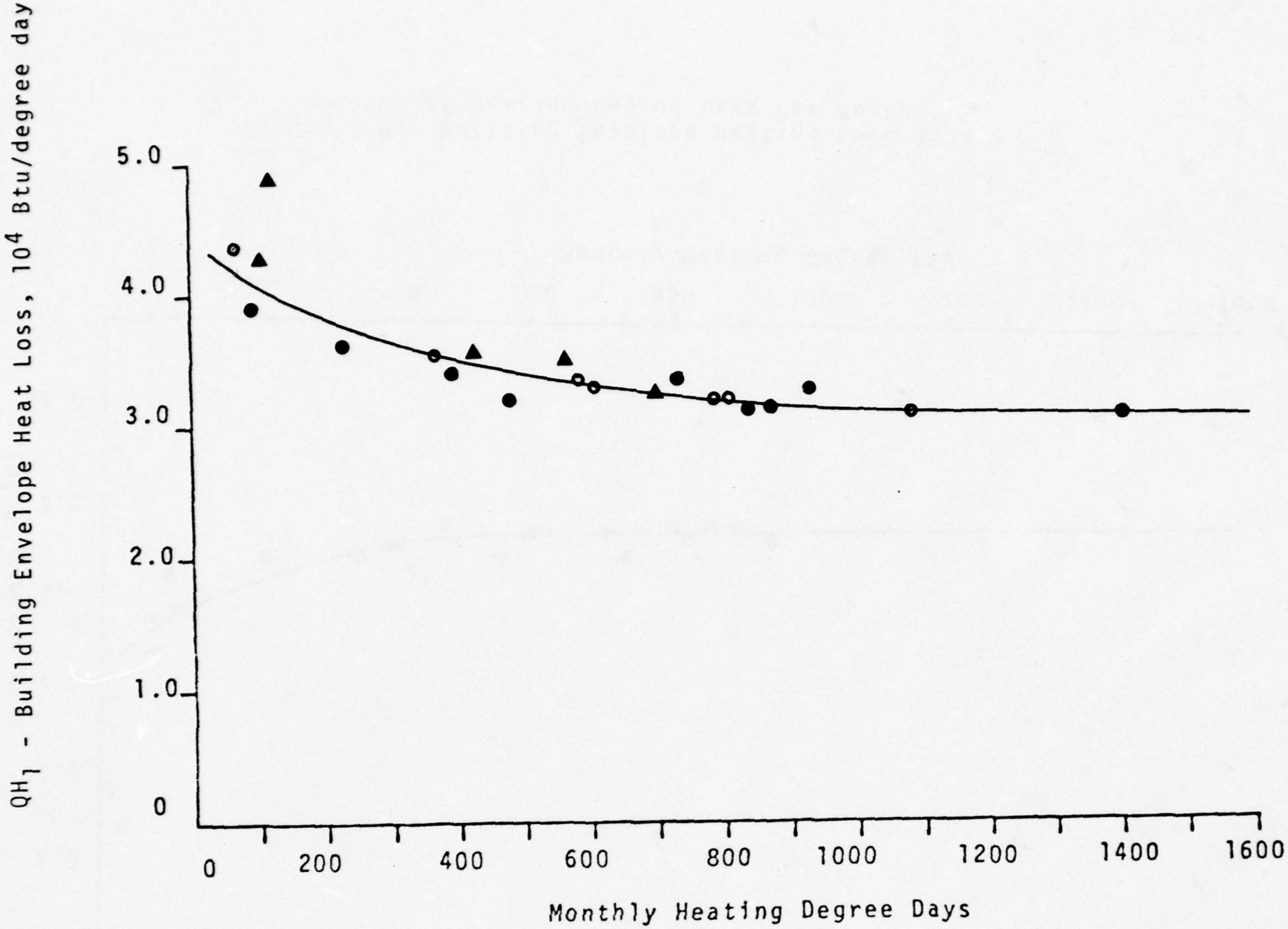

Figure 1-A. Building Envelope Heating Load As a Function of Heating Degree Days Per Month

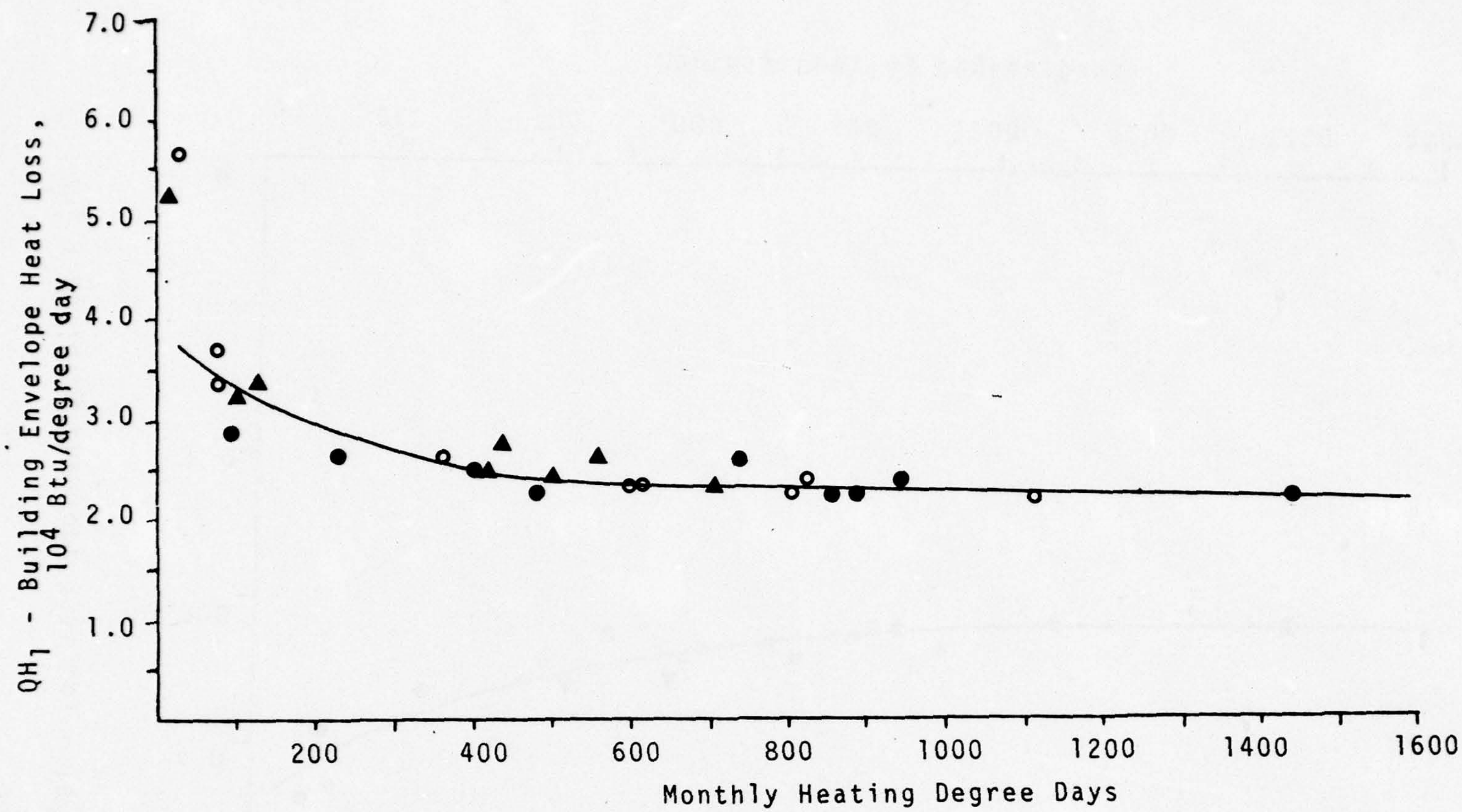

Figure 1-B. Building Envelope Heating Load As a Function of Heating Degree Days Per Month

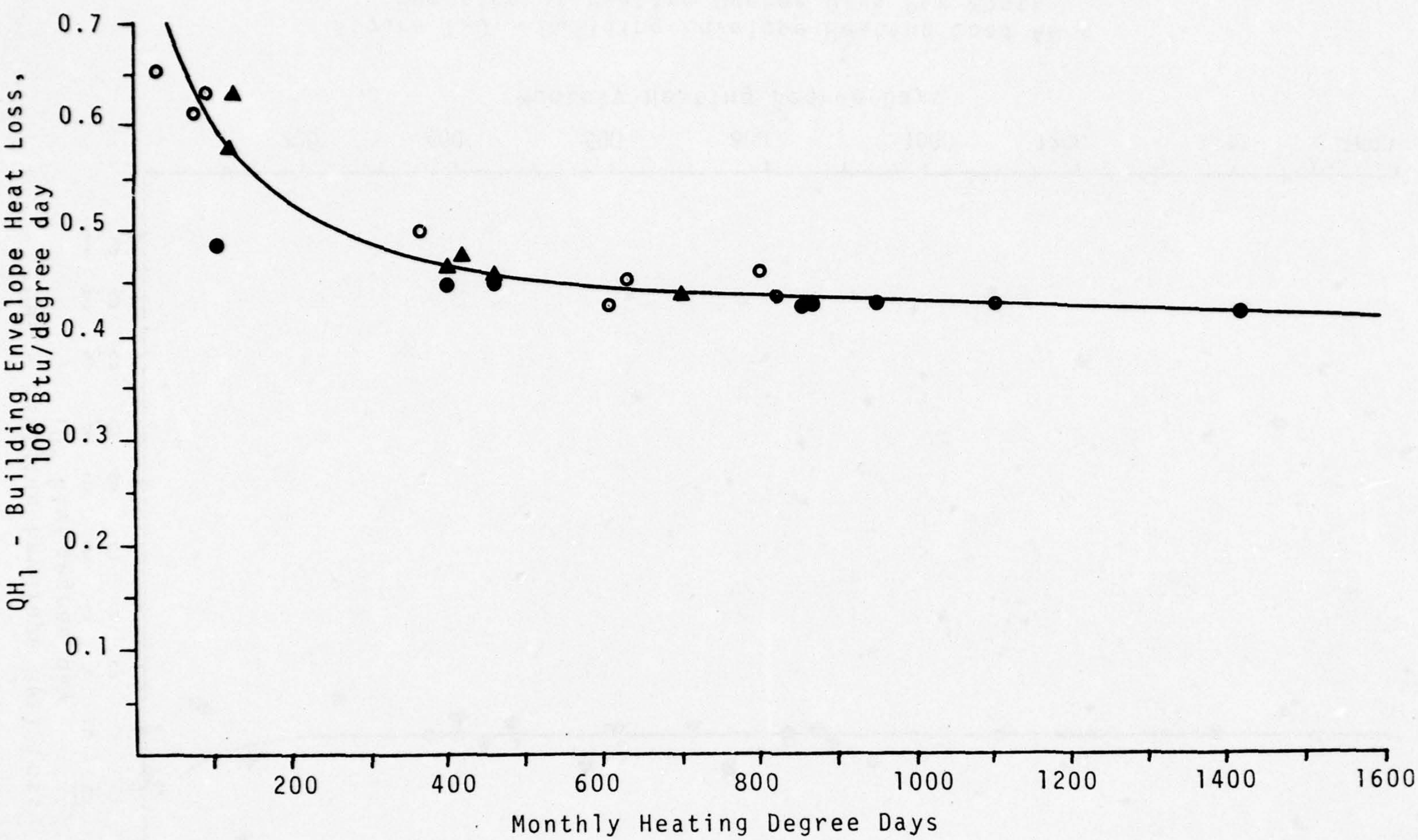

Figure 1-C. Building Envelope Heating Load As a Function of Heating Degree Days Per Month

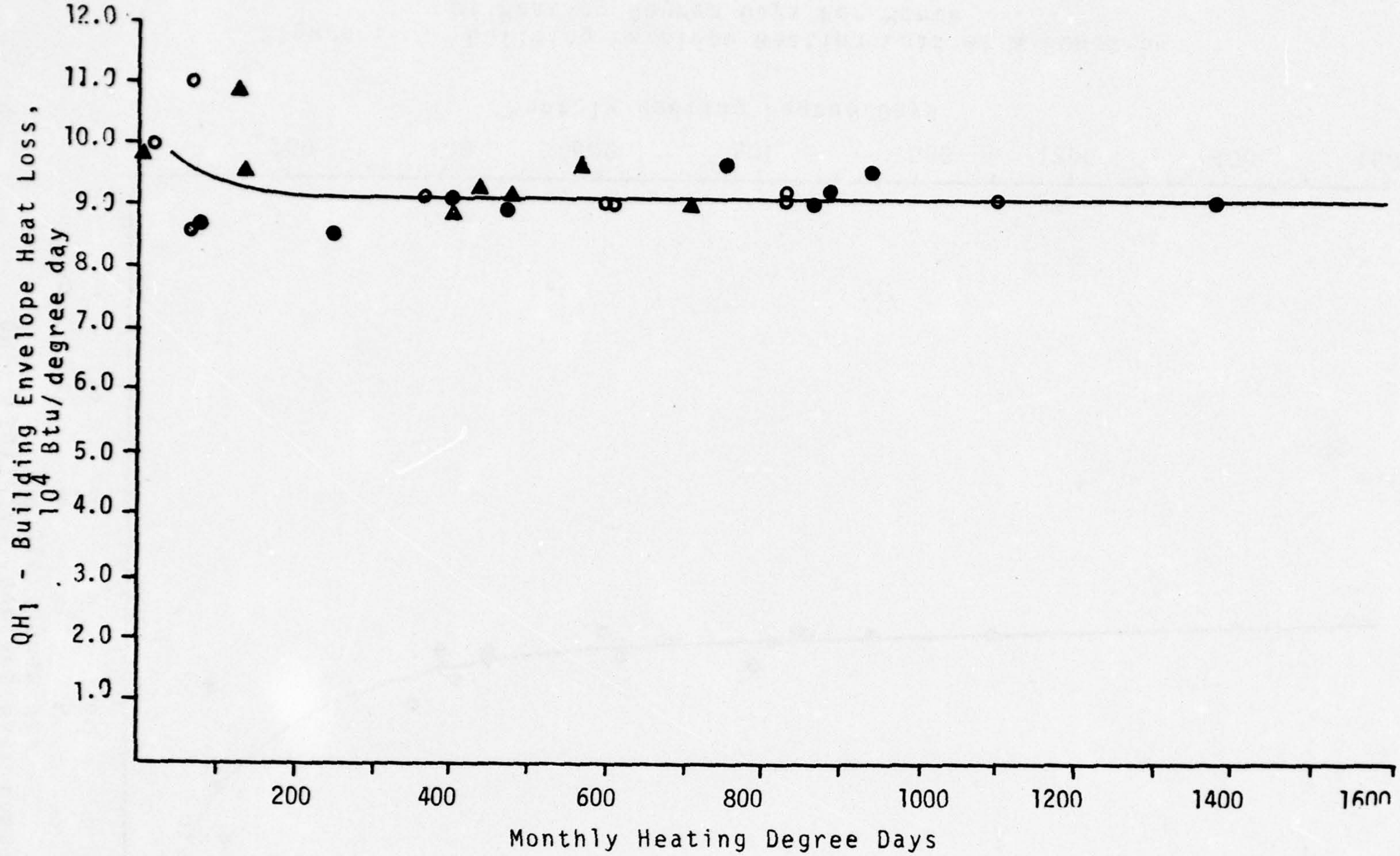

Figure 1-D. Building Envelope Heating Load As a Function of Heating Degree Days Per Month

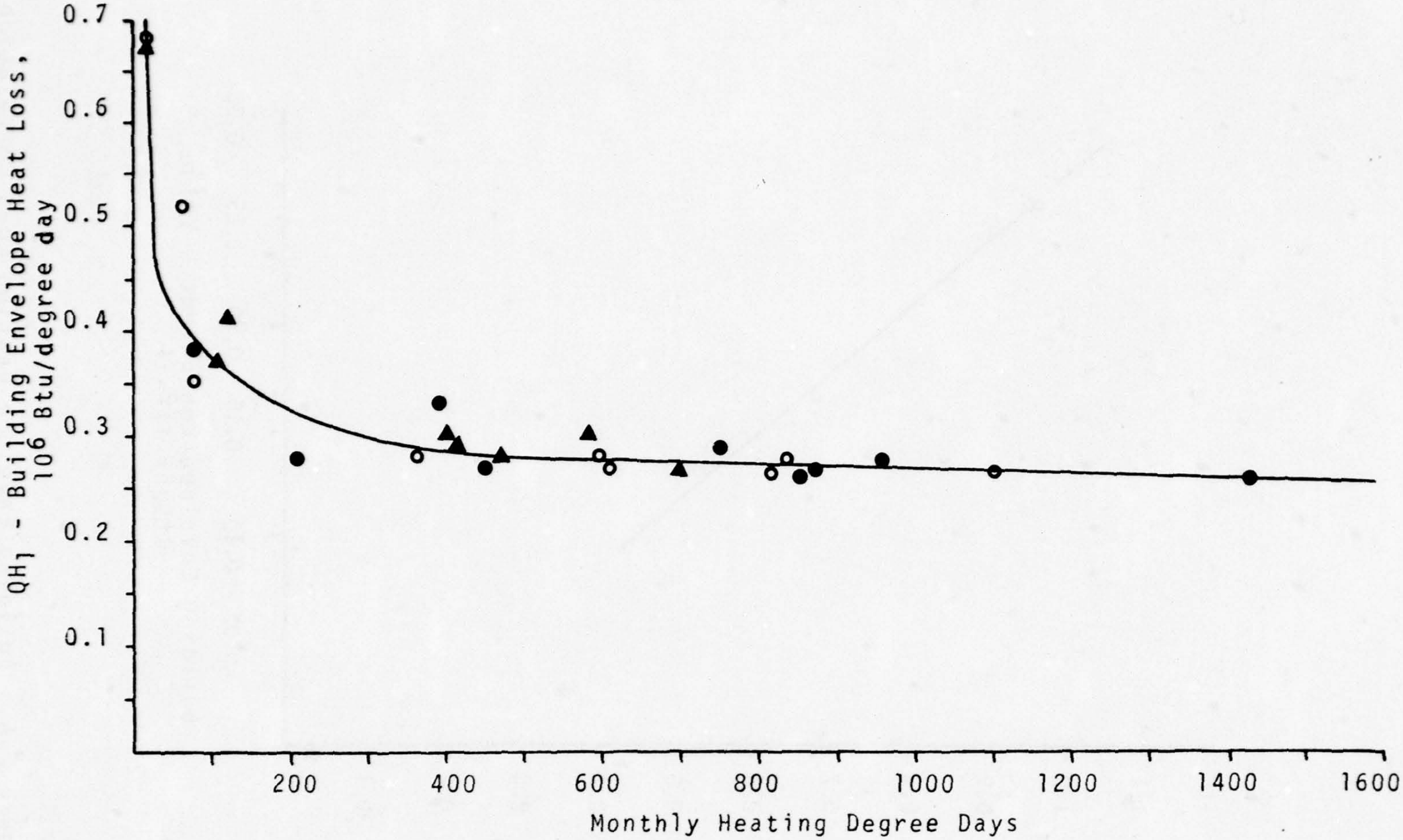

Figure 1-E. Building Envelope Heating Load As a Function of Heating Degree Days Per Month

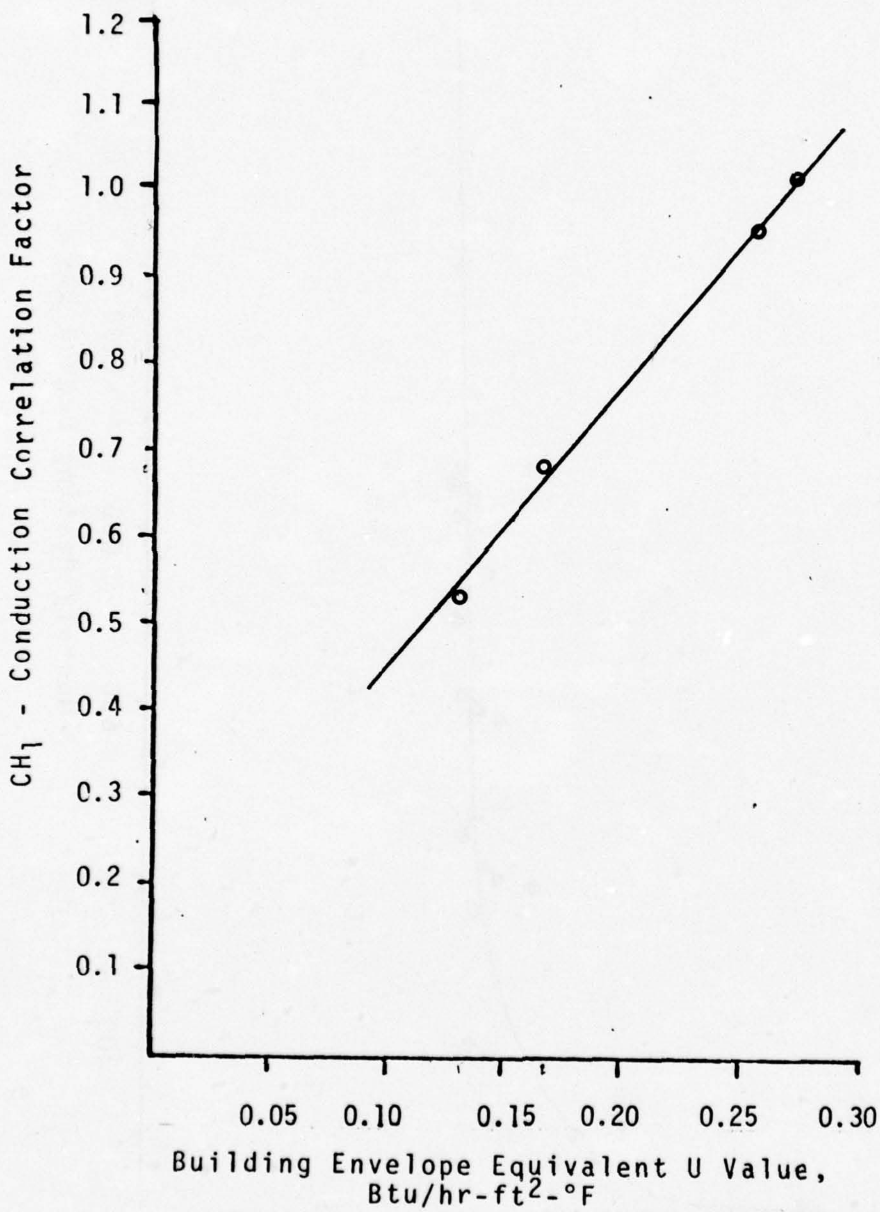

Figure 2-A. Building Envelope Heating Load Correlation With Building Equivalent U Value

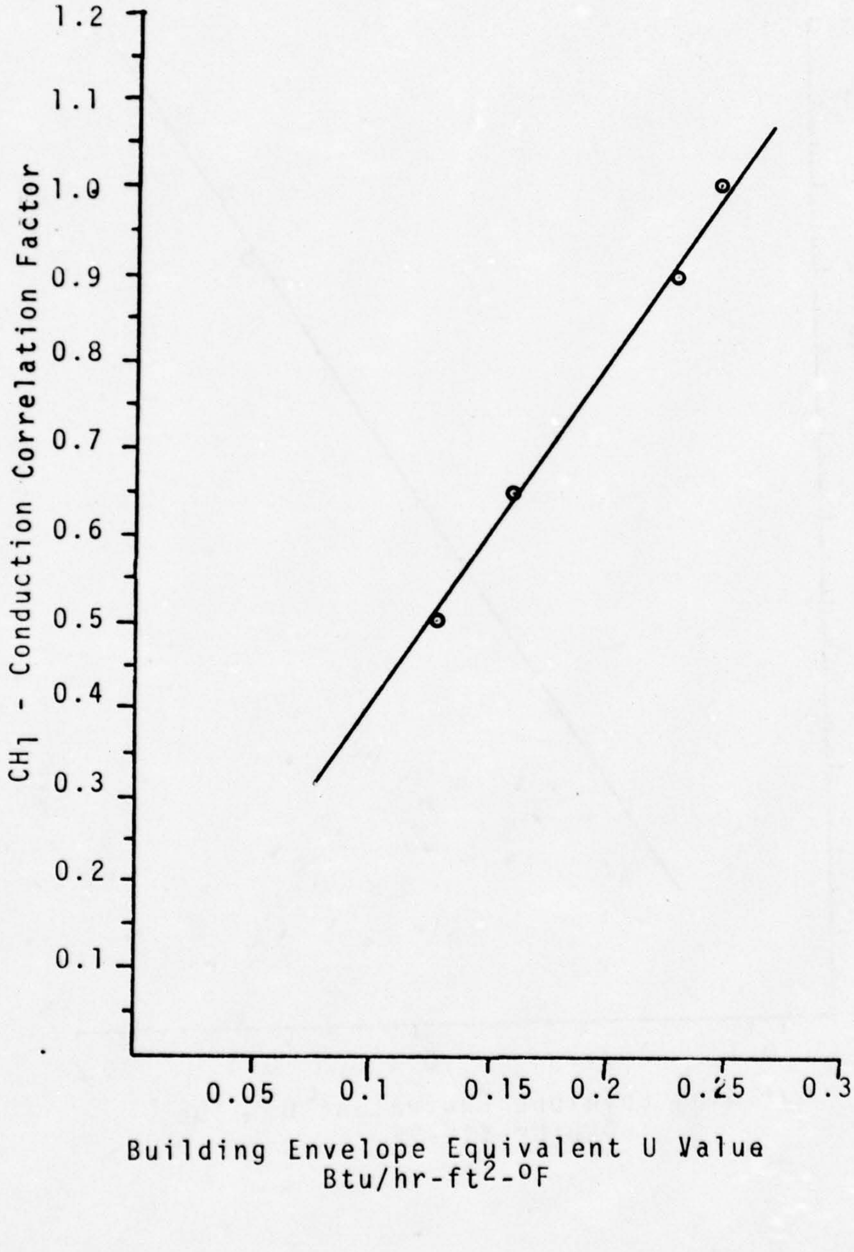

Figure 2-B. Building Envelope Heating Load Correlation With Building Equivalent U Value

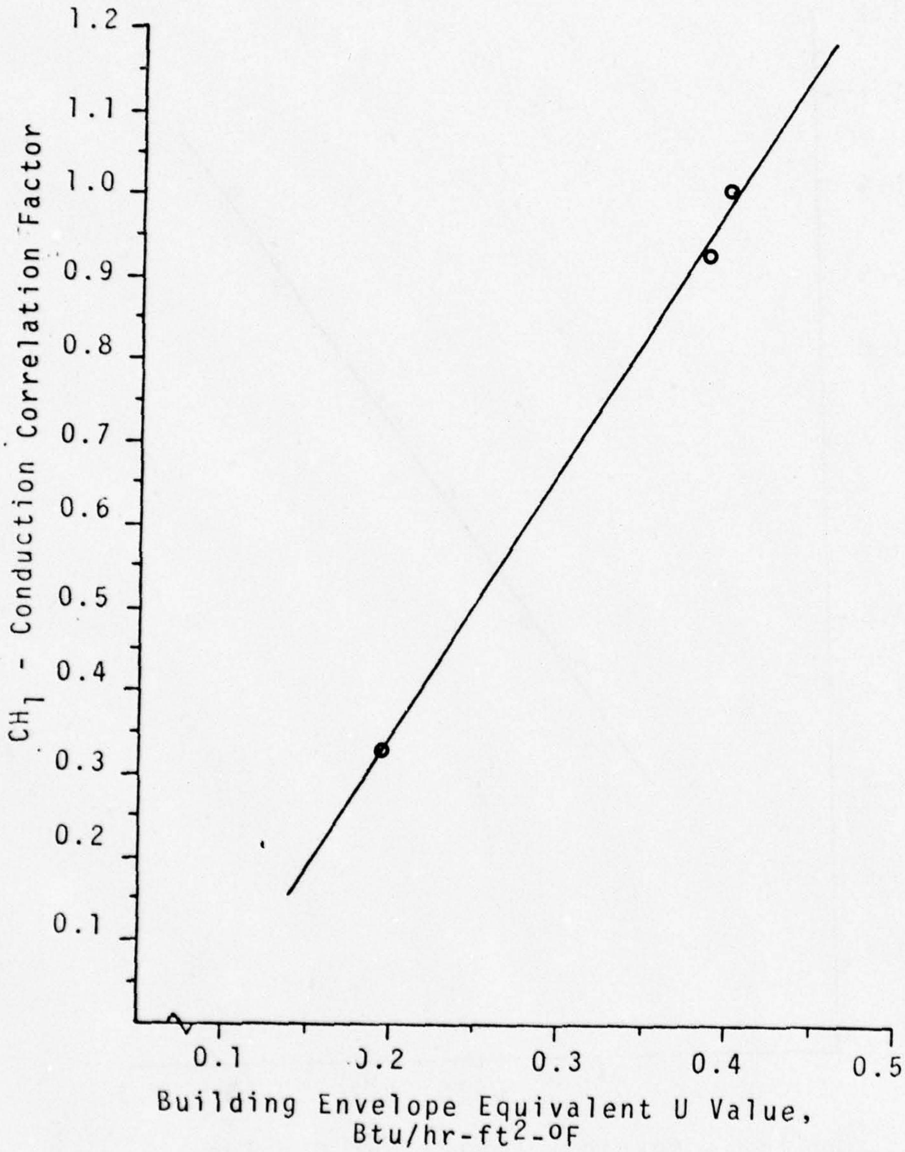

Figure 2-C. Building Envelope Heating Load Correlation With Building Equivalent U Value

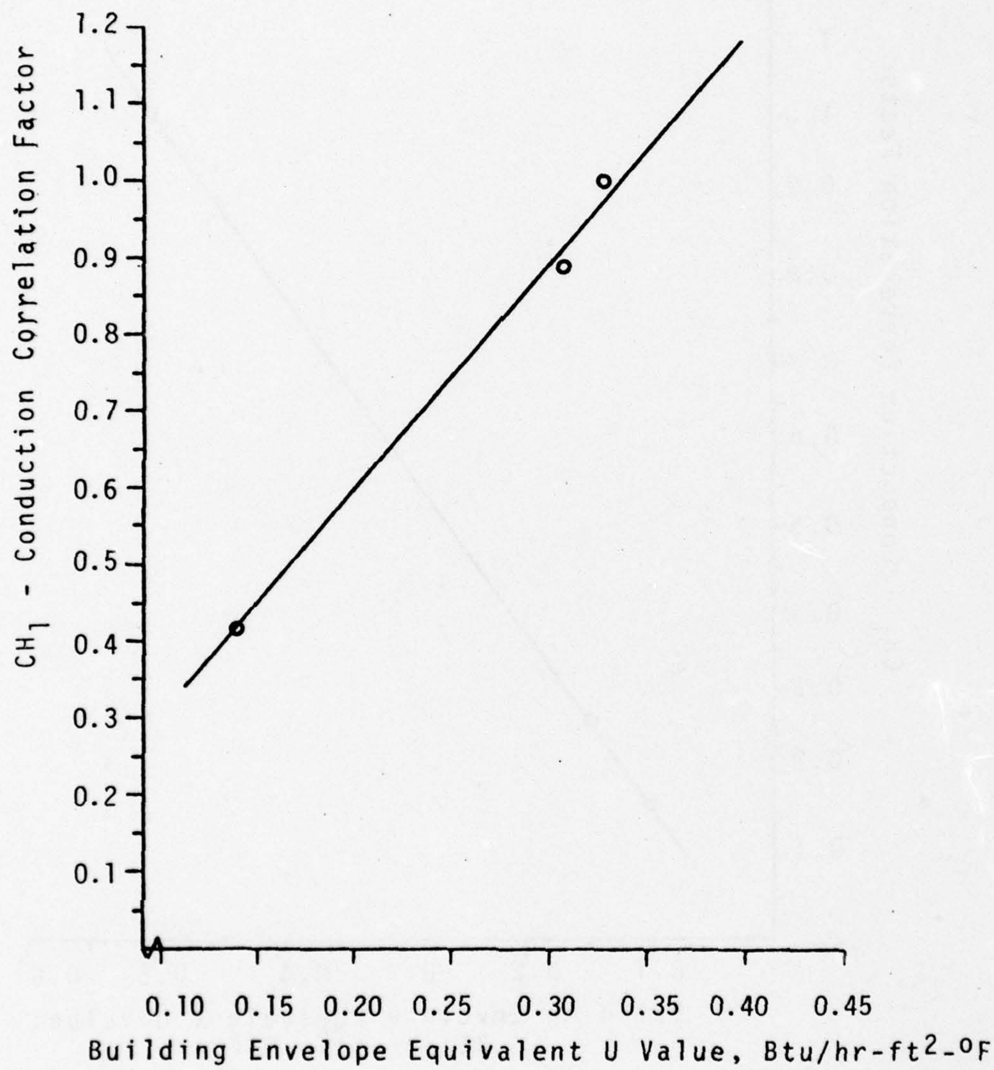

Figure 2-D. Building Envelope Heating Load Correlation With Building Equivalent U Value

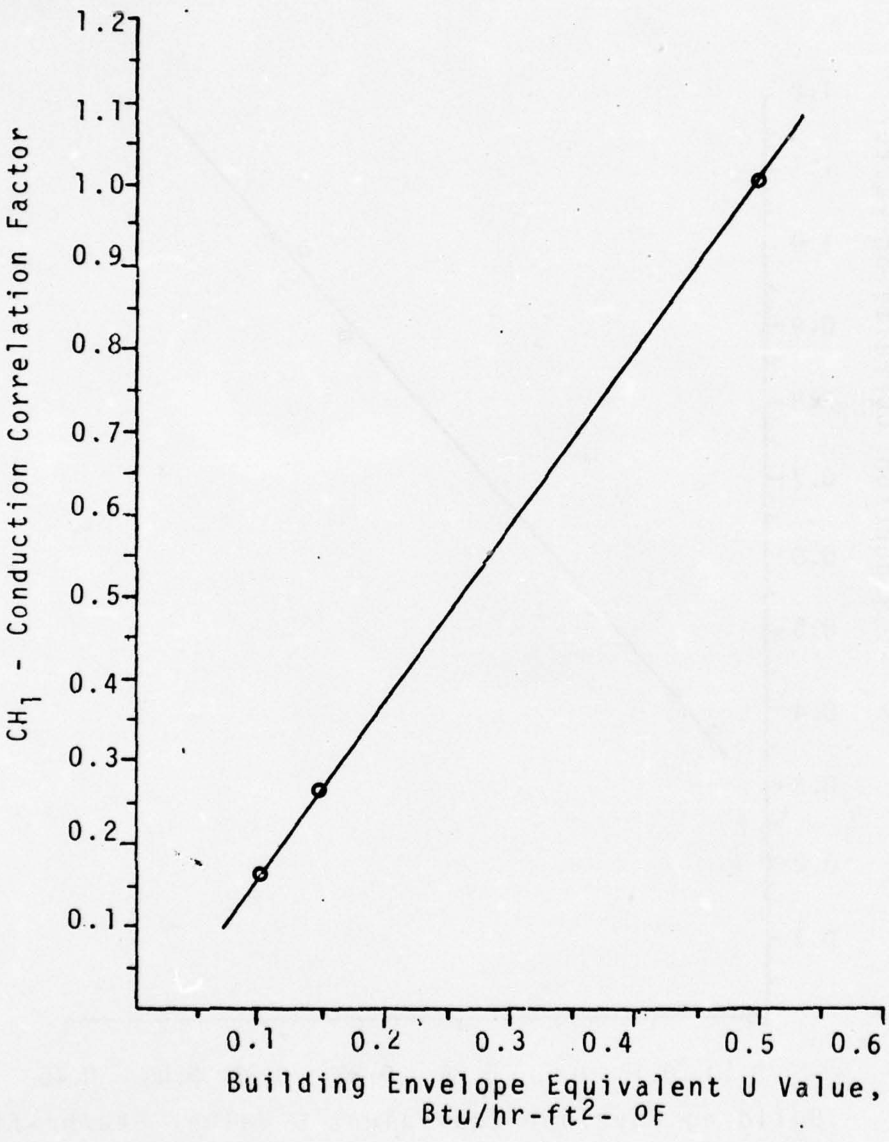

Figure 2-E. Building Envelope Heating Load Correlation With Building Equivalent U Value

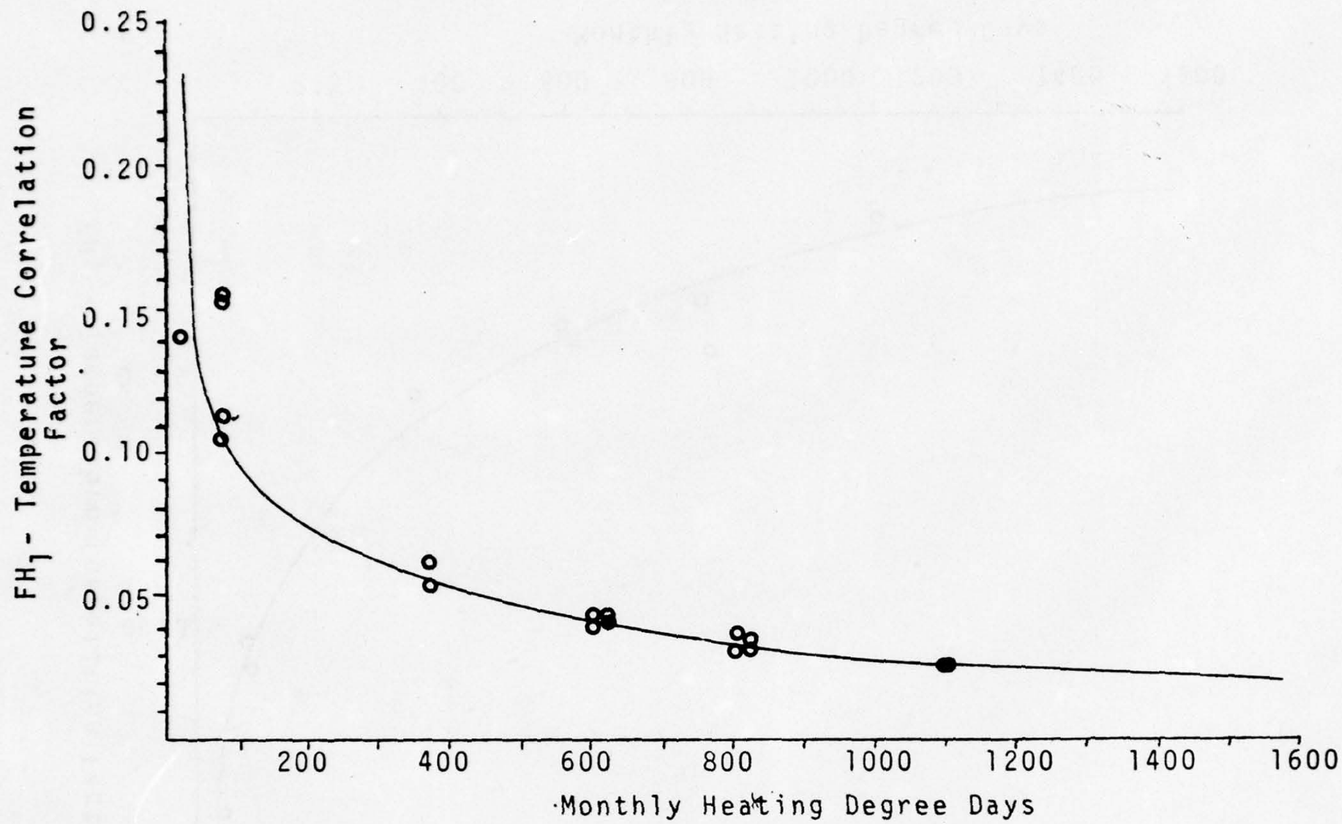

Figure 3-A. Building Envelope Heating Load Correlation With Set-Point Temperature

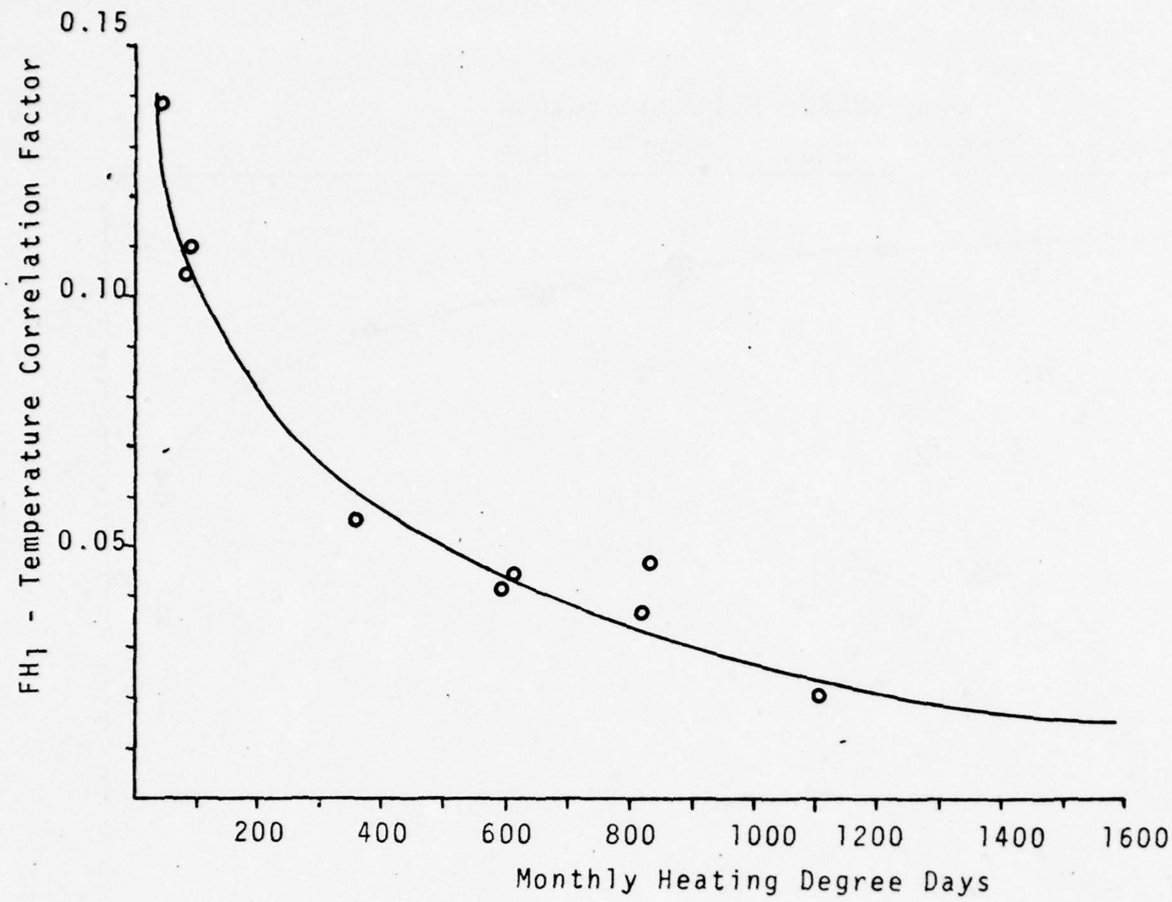

Figure 3-B. Building Envelope Heating Load Correlation With Set-Point Temperature

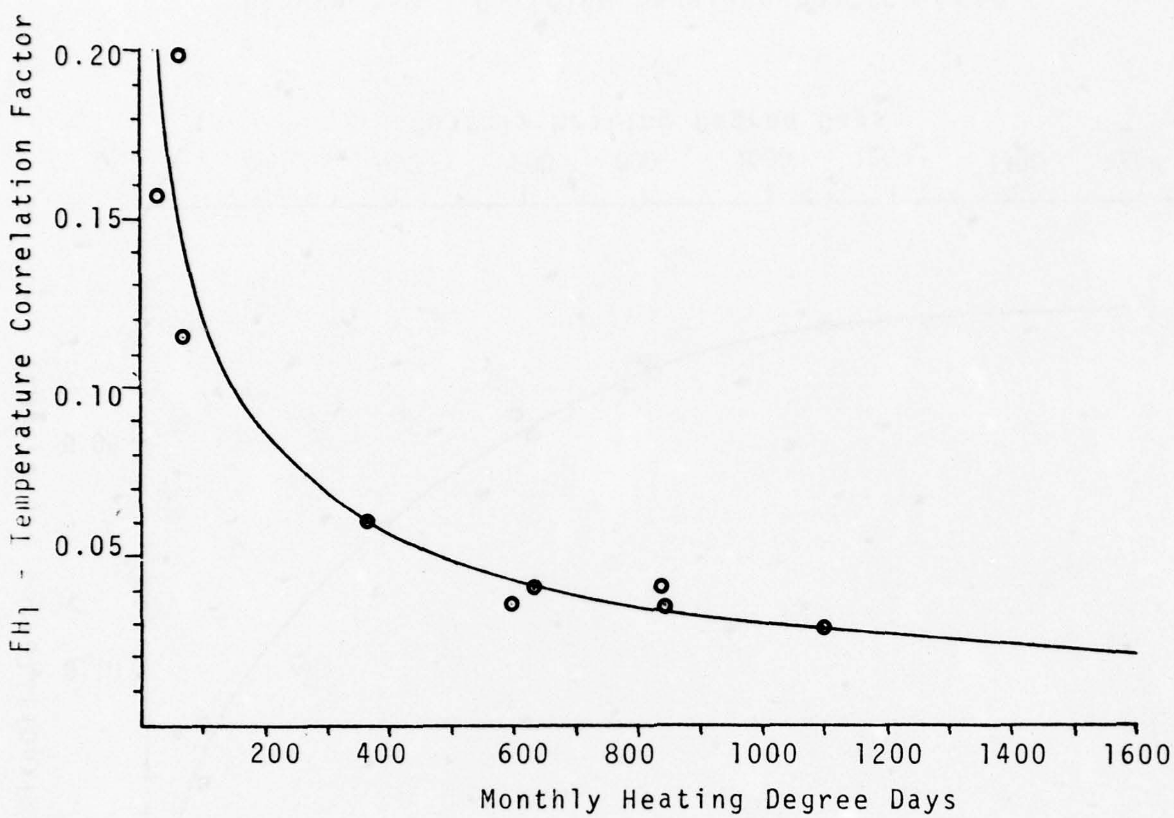

Figure 3-C. Building Envelope Heating Load Correlation With Set-Point Temperature

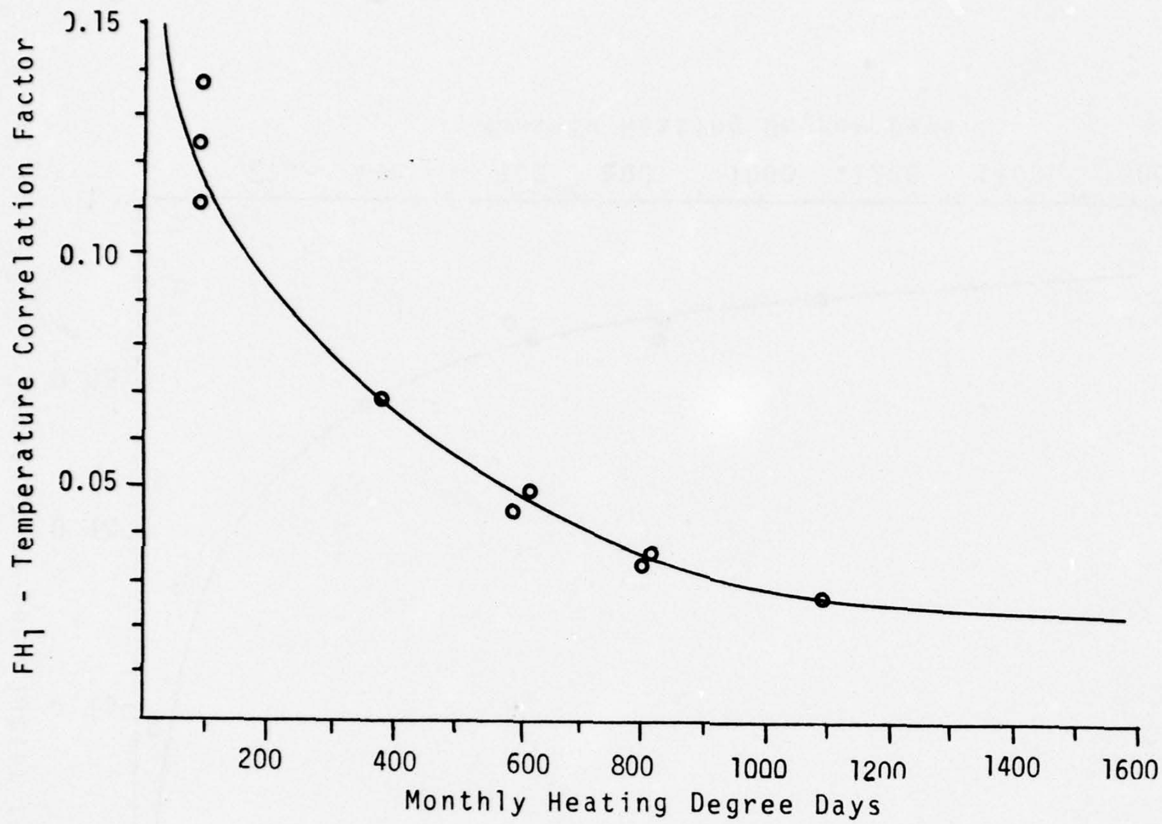

Figure 3-D. Building Envelope Heating Load Correlation With Set-Point Temperature

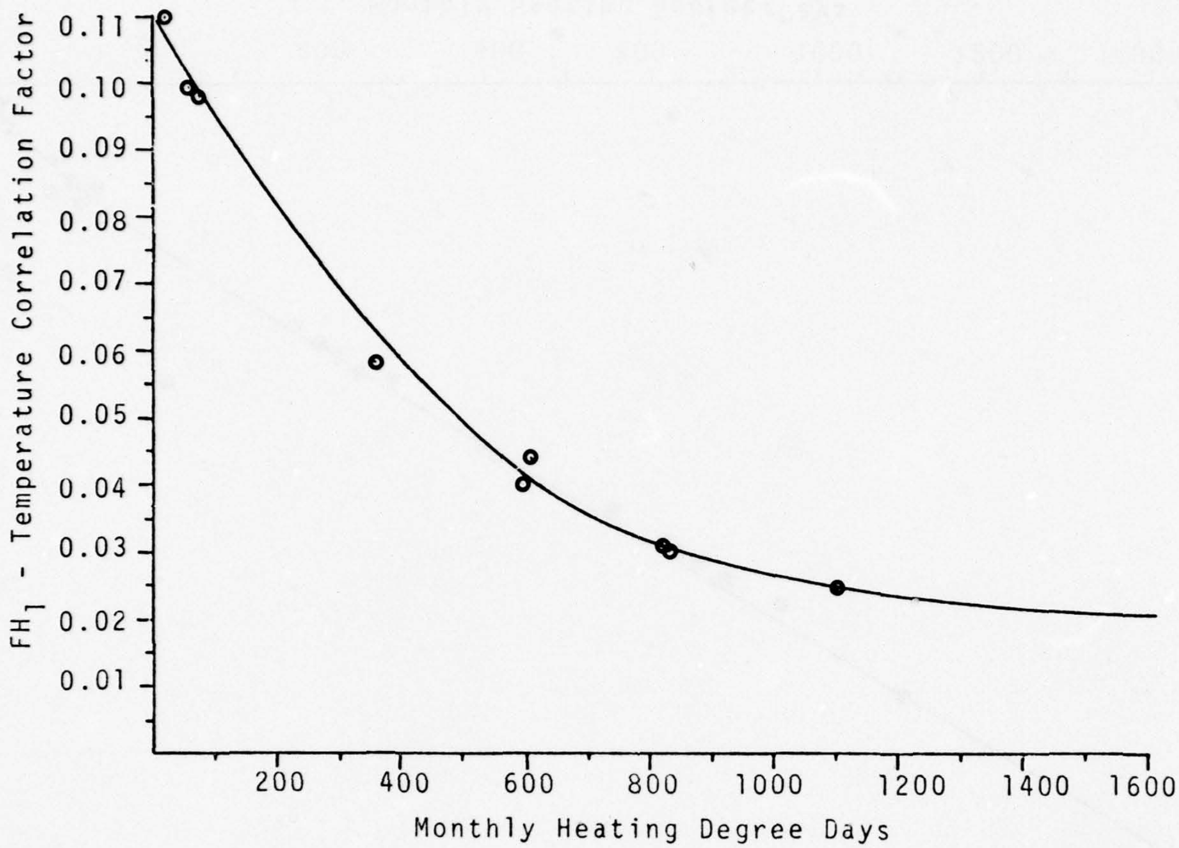

Figure 3-E. Building Envelope Heating Load Correlation With Set-Point Temperature

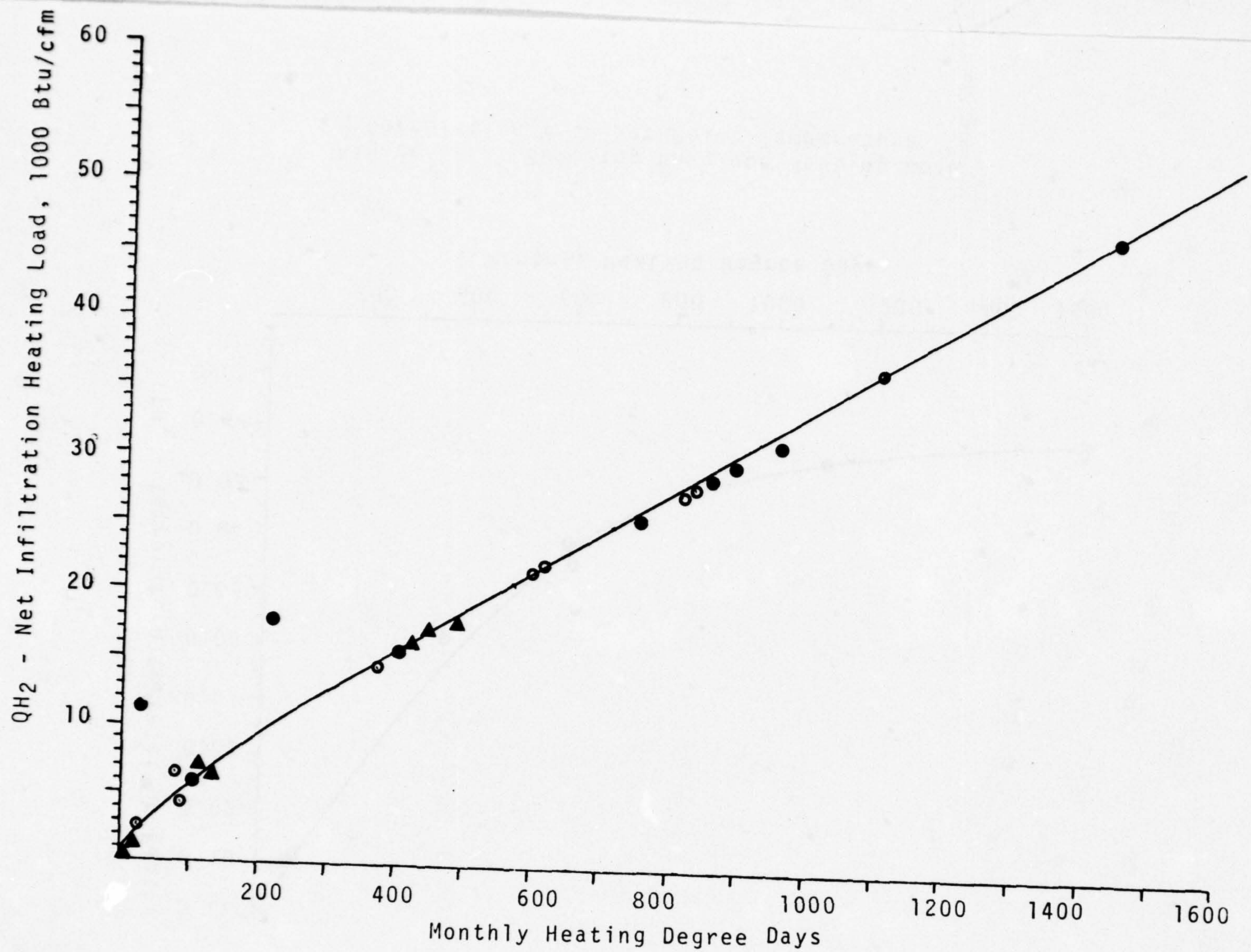

Figure 4-A,B,C,D,E. Infiltration Heating Load As A Function of Heating Degree Days Per Month

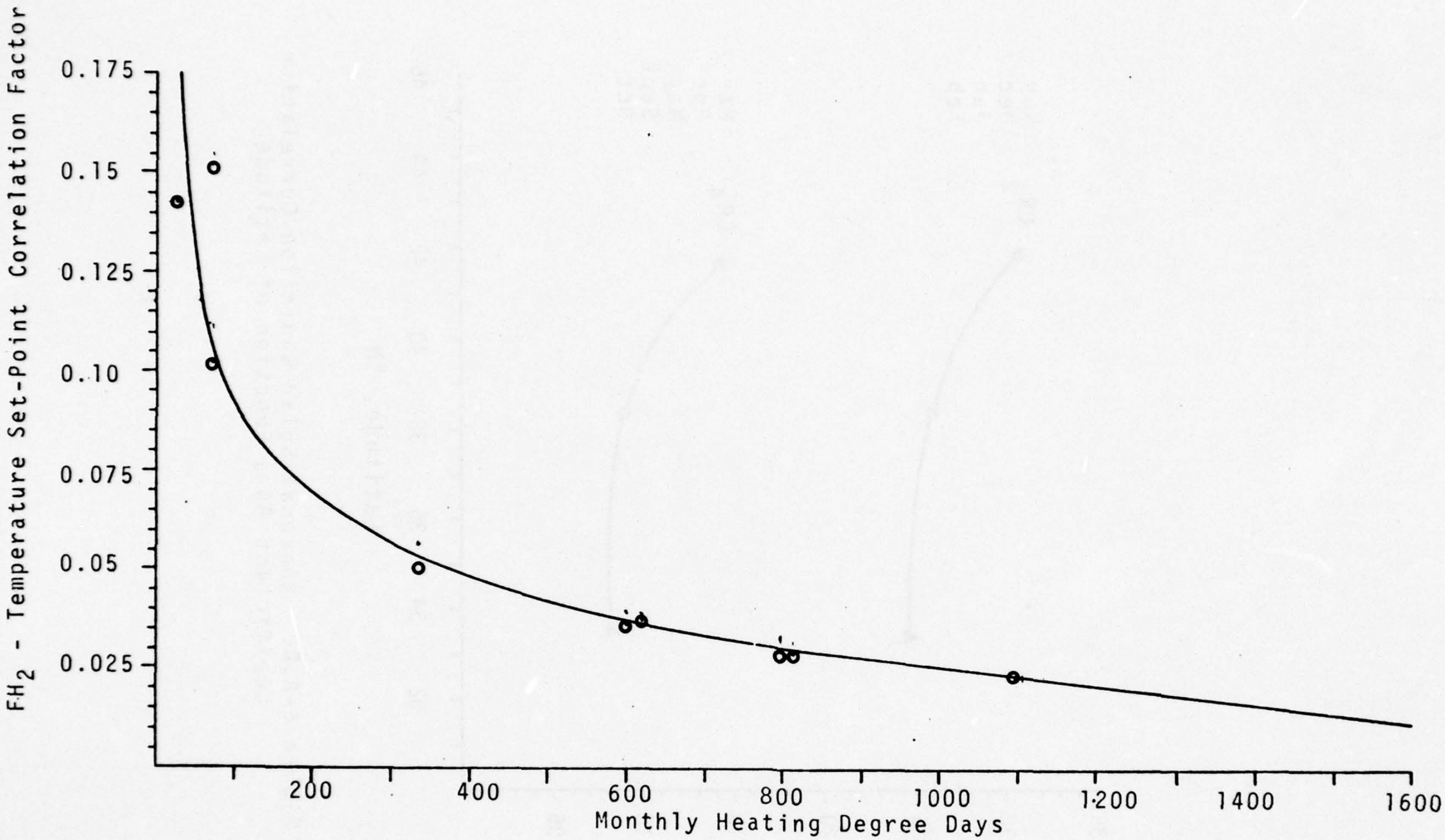

Figure 5-A,B,C,D,E. Infiltration Heating Load Correlation With Set-Point Temperature

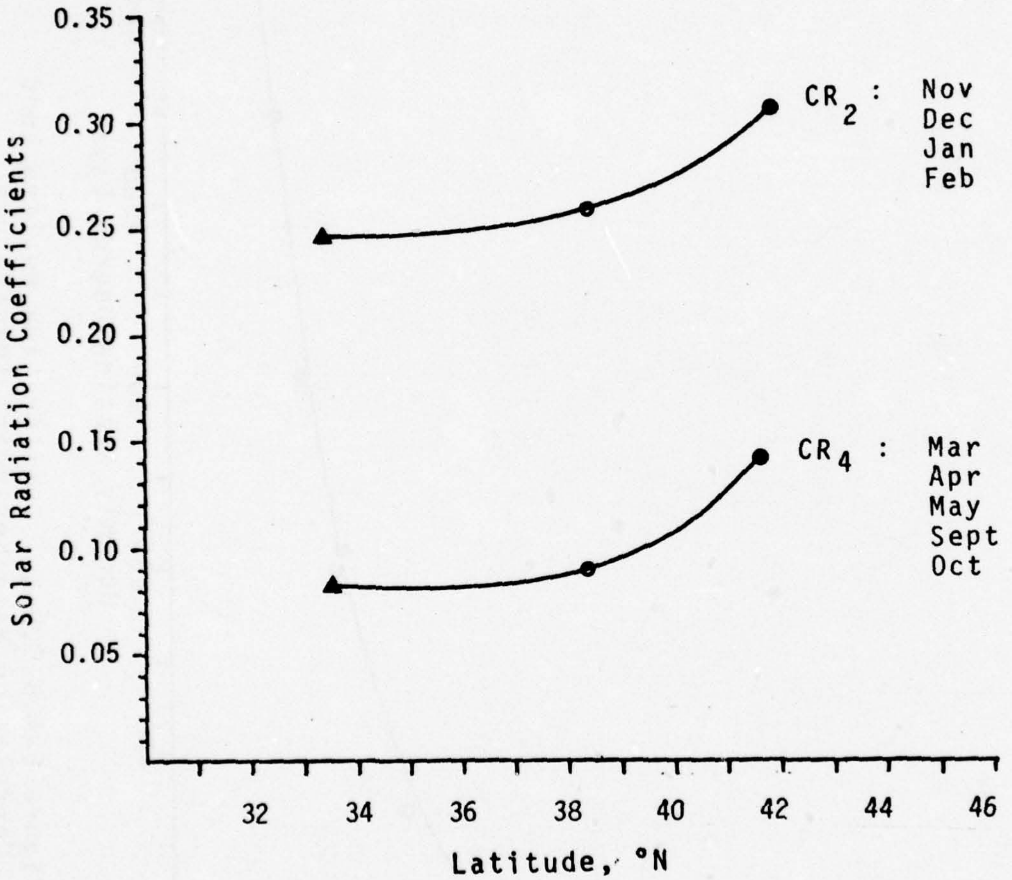

Figure 6-A,B. Seasonal Solar Radiation Correlation Coefficient As a Function of Latitude

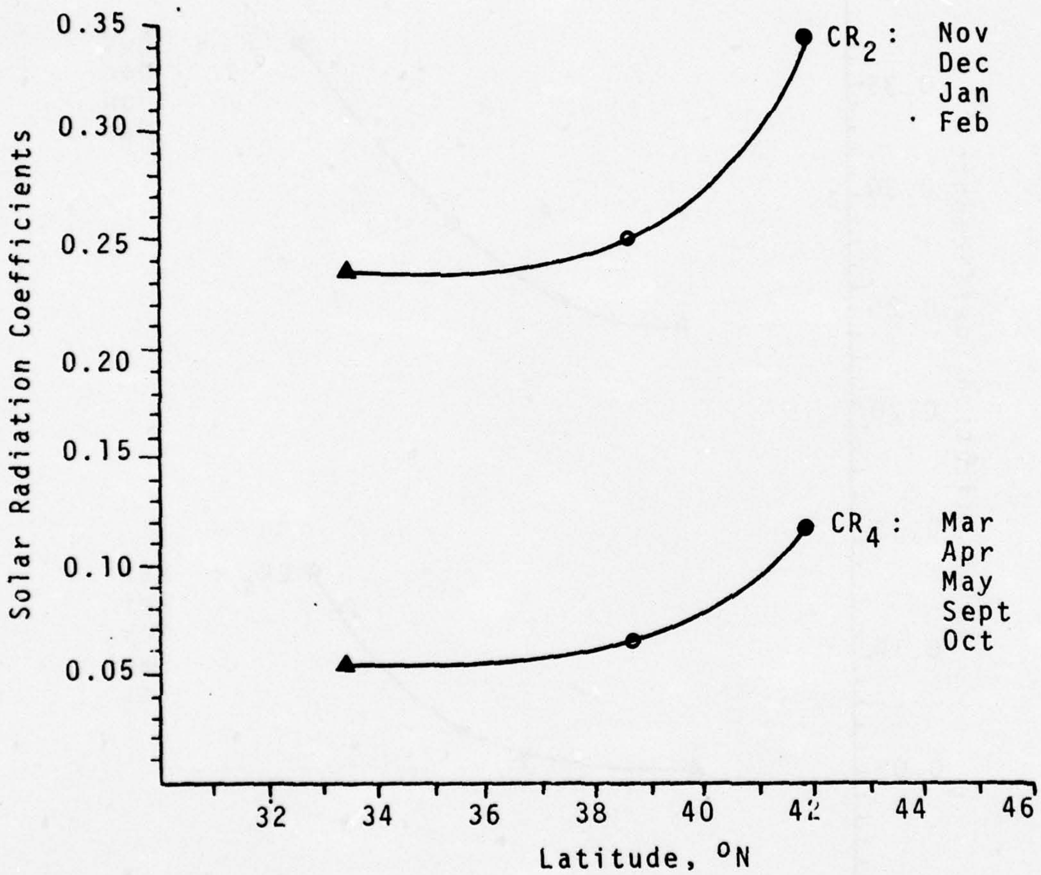

Figure 6-C. Seasonal Solar Radiation Correlation Coefficient As a Function of Latitude

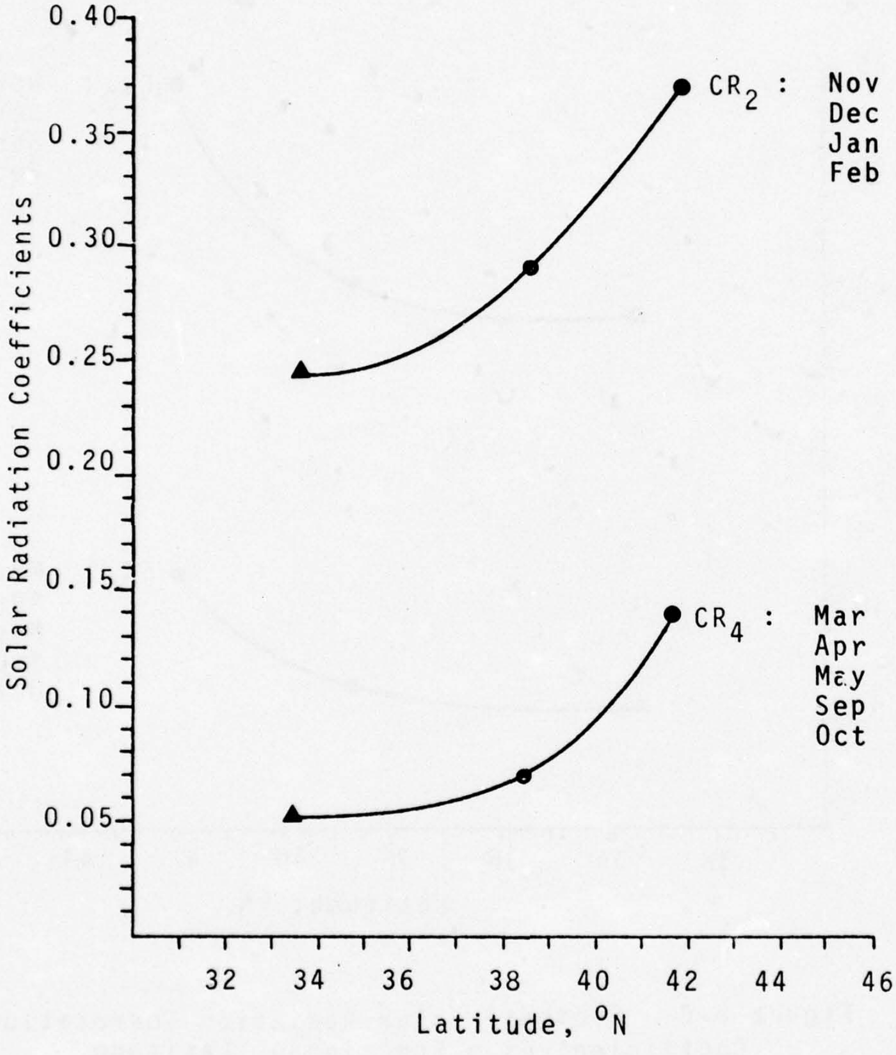

Figure 6-D. Seasonal Solar Radiation Correlation Coefficient As a Function of Latitude

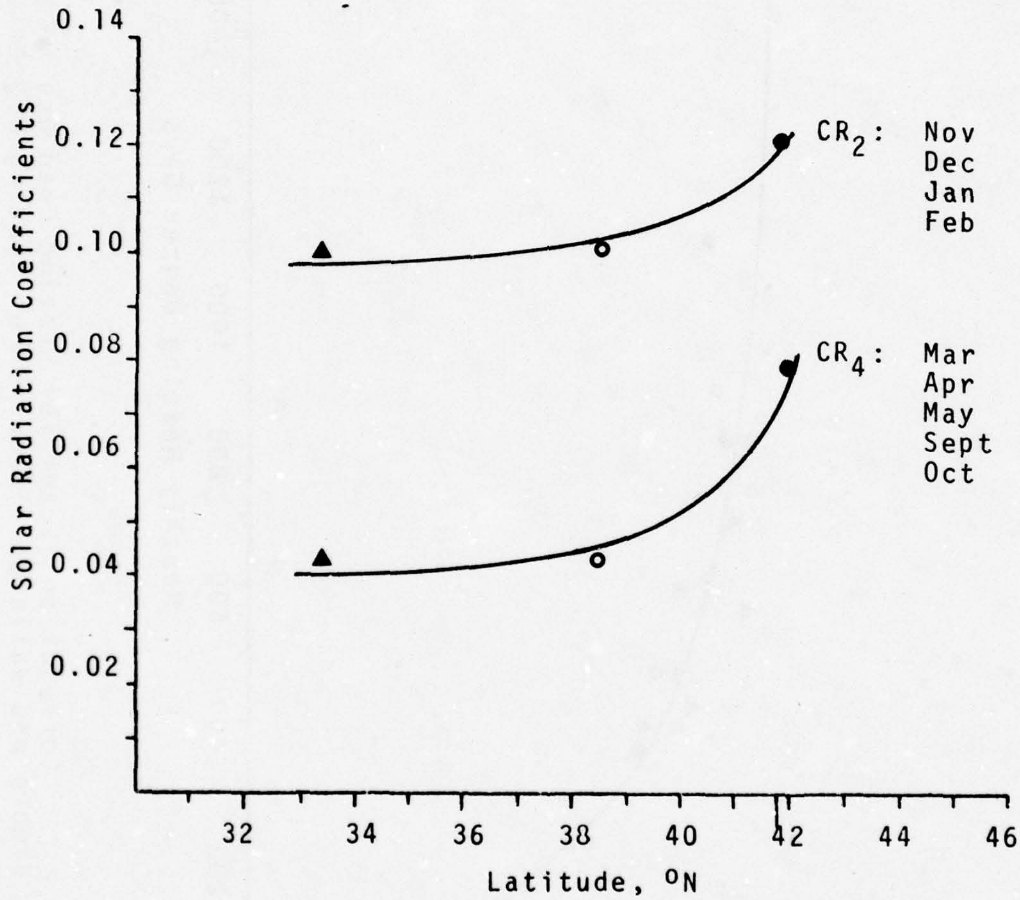

Figure 6-E. Seasonal Solar Radiation Correlation Coefficient As a Function of Latitude

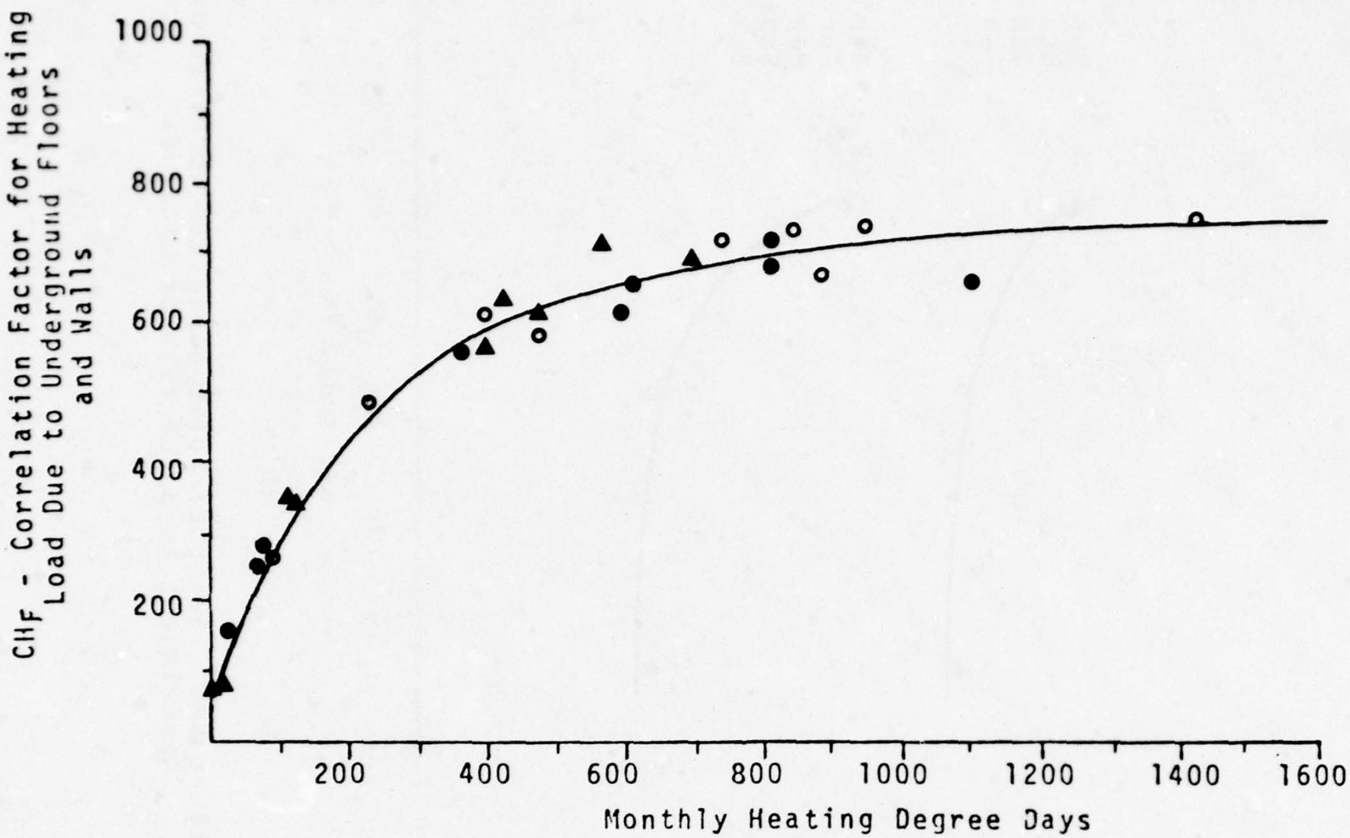

Figure 7-A,B,C. Correlation Factor for Heating Load Due to Underground Floors and Walls as a Function of Heating Degree Days

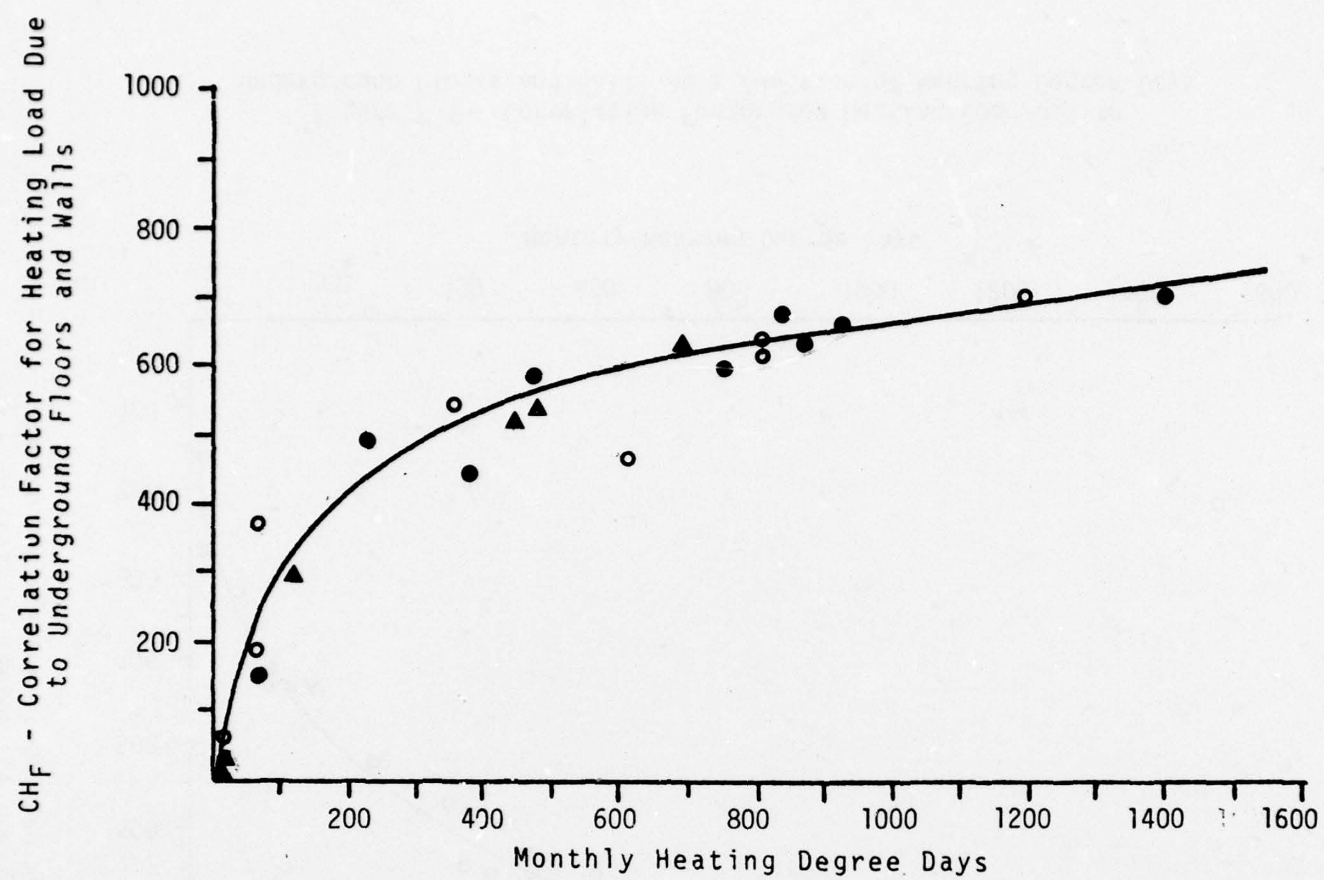

Figure 7-D. Correlation Factor for Heating Load Due to Underground Floors and Walls As a Function of Heating Degree Days

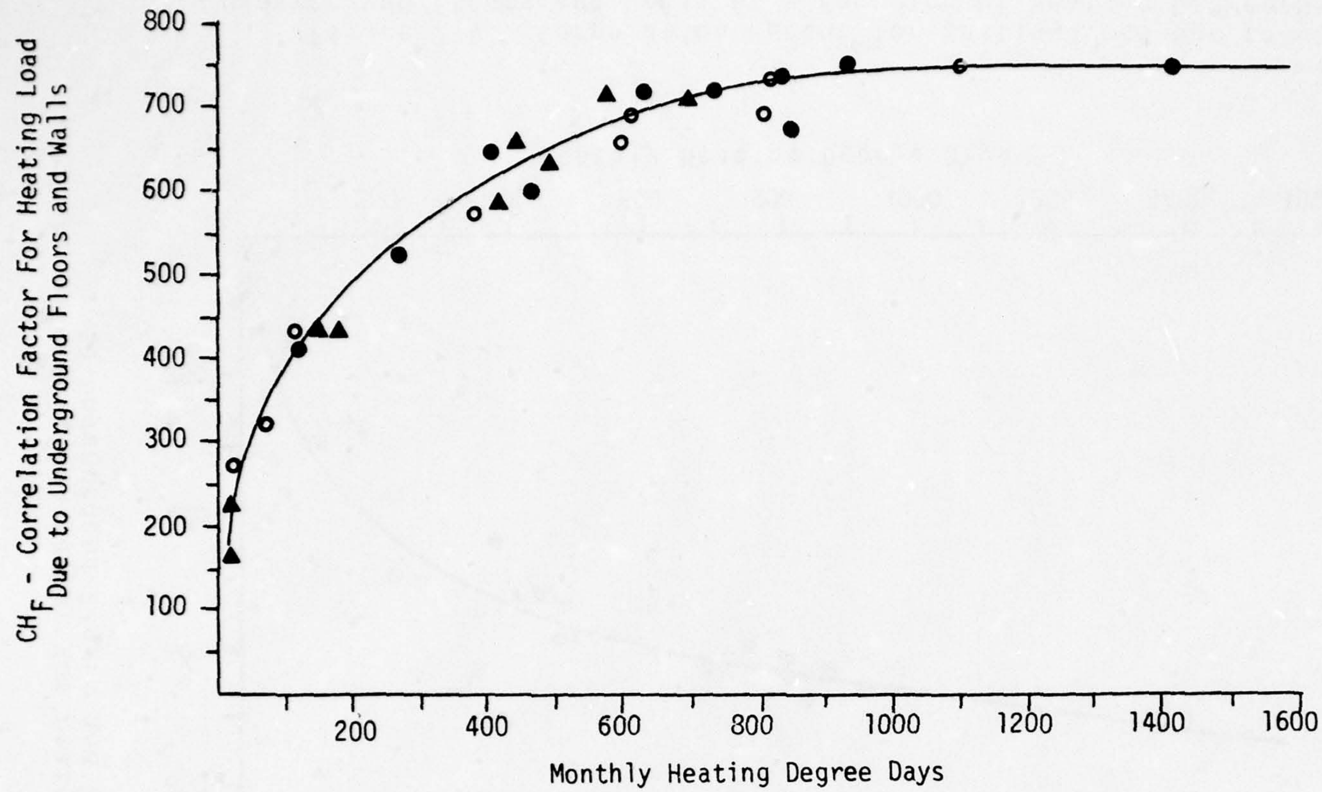

Figure 7-E. Correlation Factor for Heating Load Due to Underground Floors and Walls As a Function of Heating Degree Days

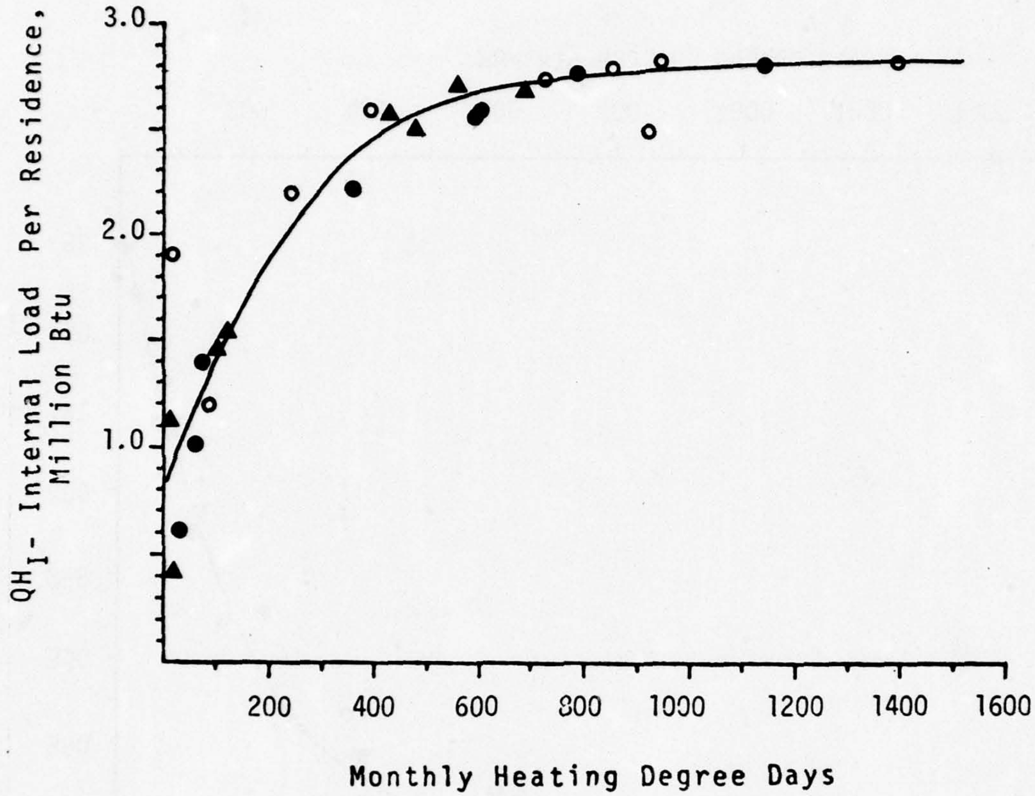

Figure 8-A,B. Internal Heat Generation During Heating Season As a Function of Heating Degree Days

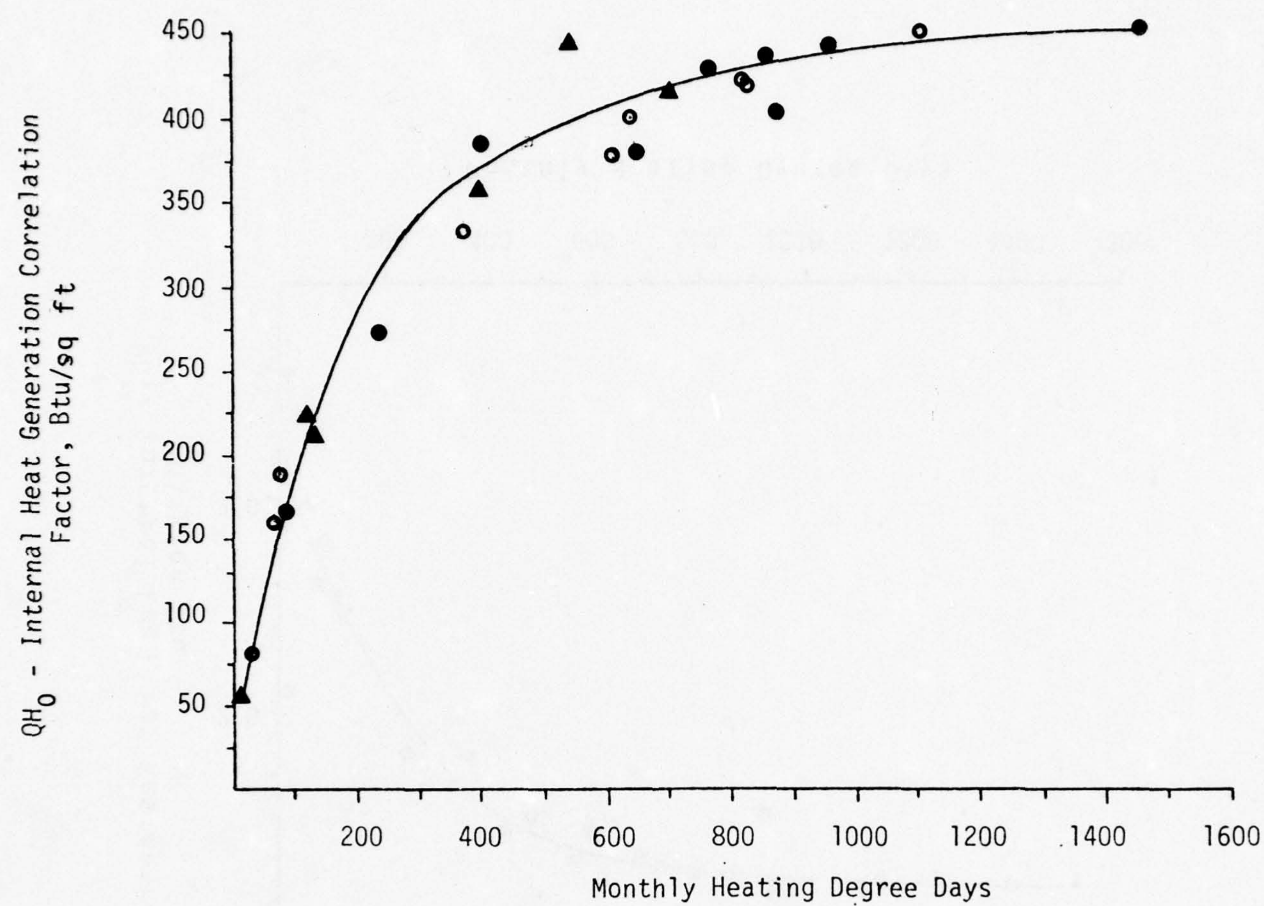

Figure 8-C. Internal Heating Load Correlation Factor During Heating Season As a Function of Heating Degree Days

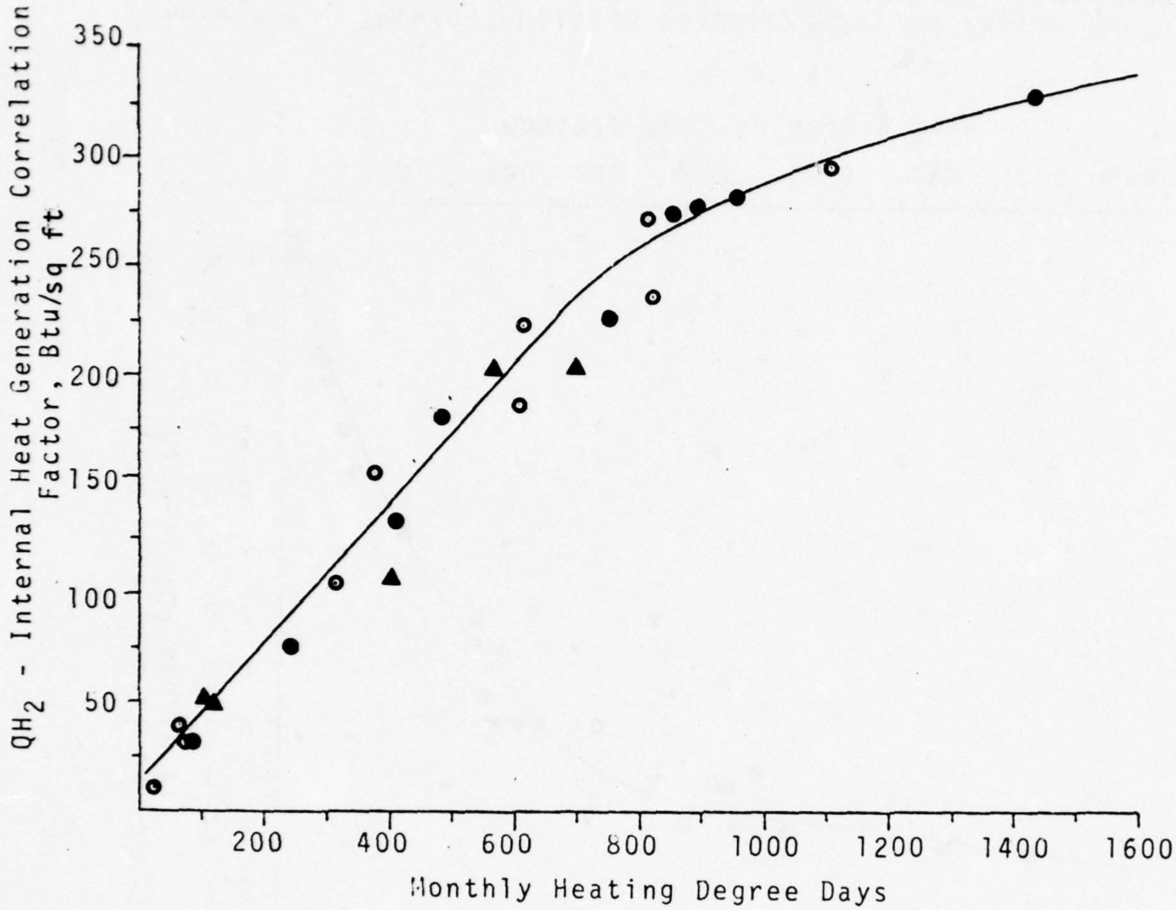

Figure 8-D. Internal Heating Load Correlation Factor During Heating Season As a Function of Heating Degree Days

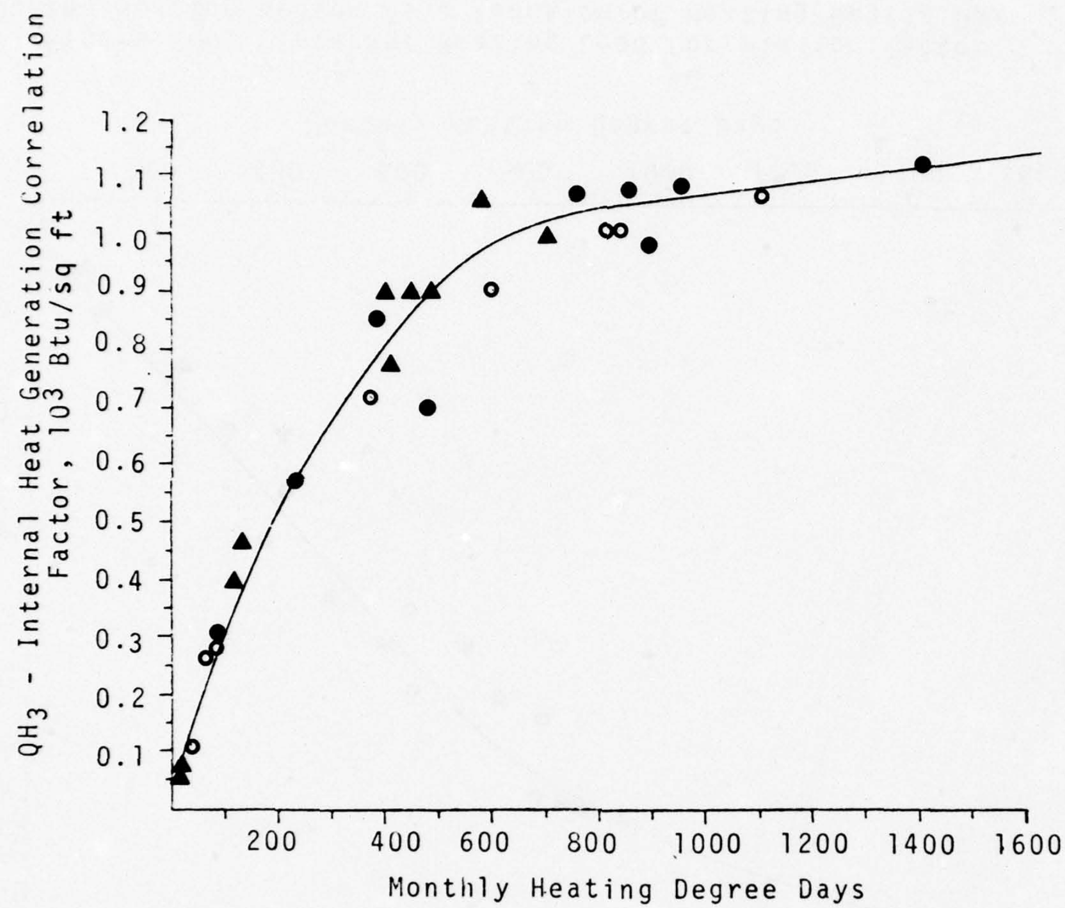

Figure 8-E. Internal Heating Load Correlation Factor During Heating Season As a Function of Heating Degree Days

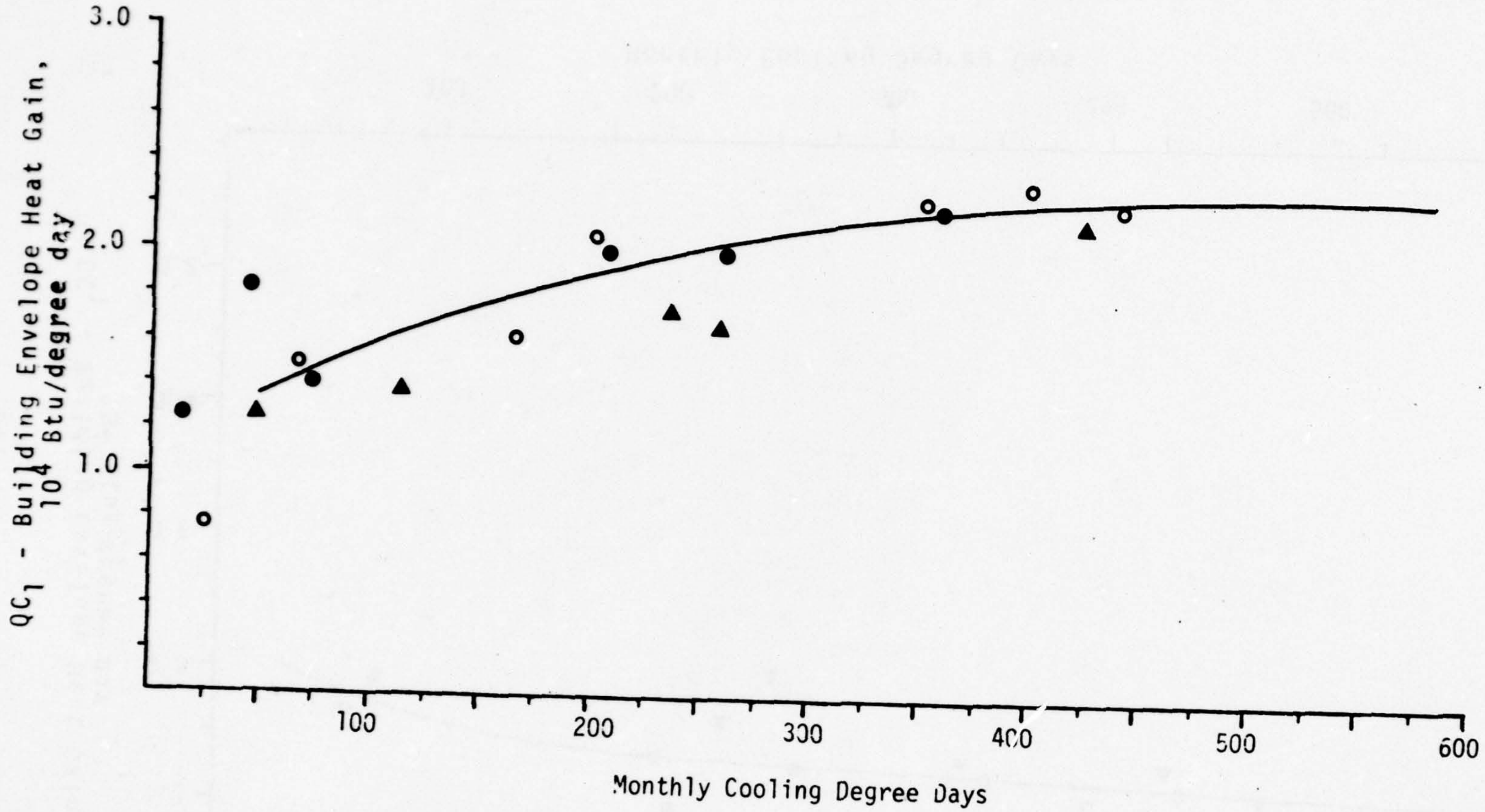

Figure 9-A. Building Envelope Cooling Load As a Function of Cooling Degree Days Per Month

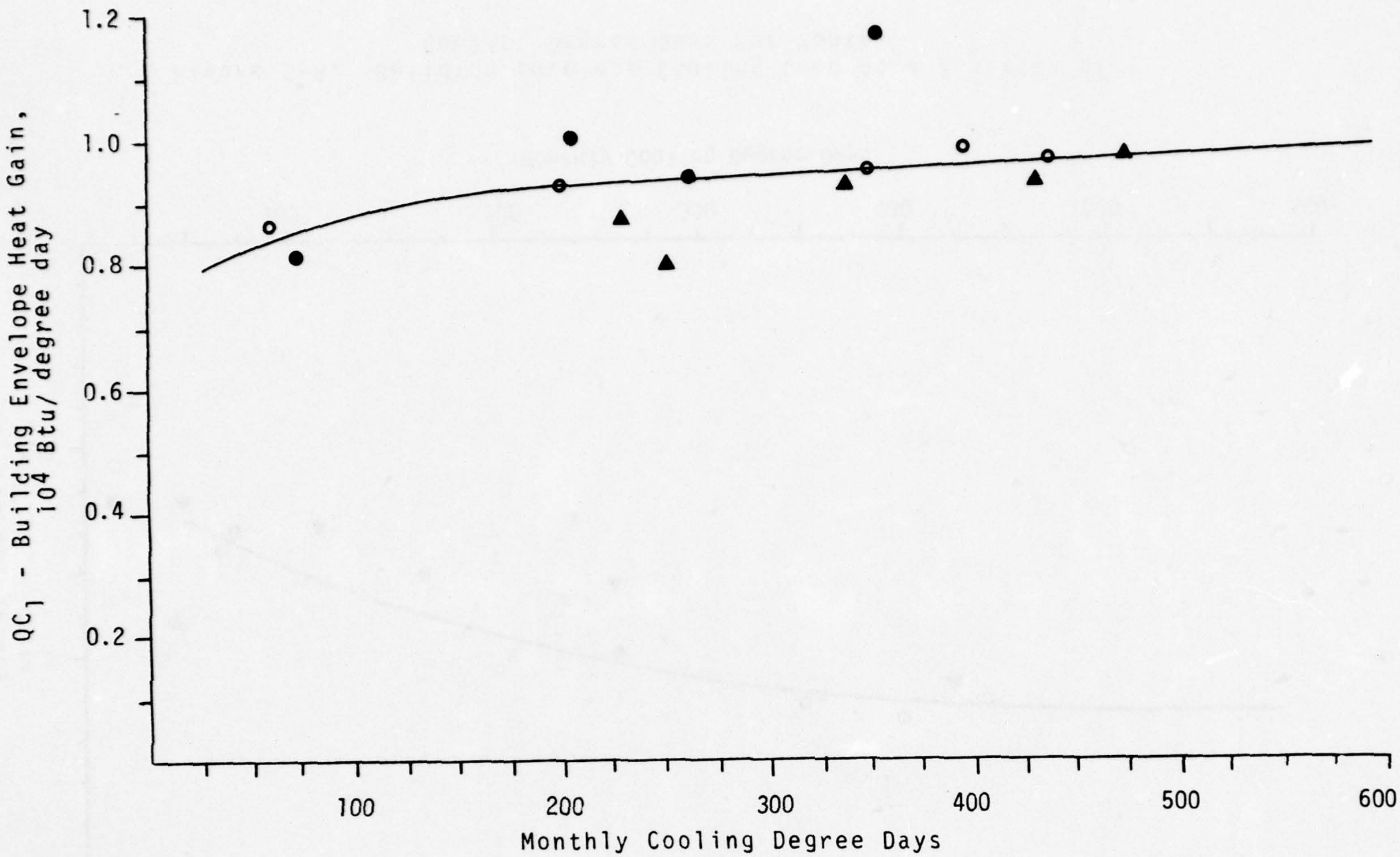

Figure 9-B. Building Envelope Cooling Load As A Function of Cooling Degree Days per Month

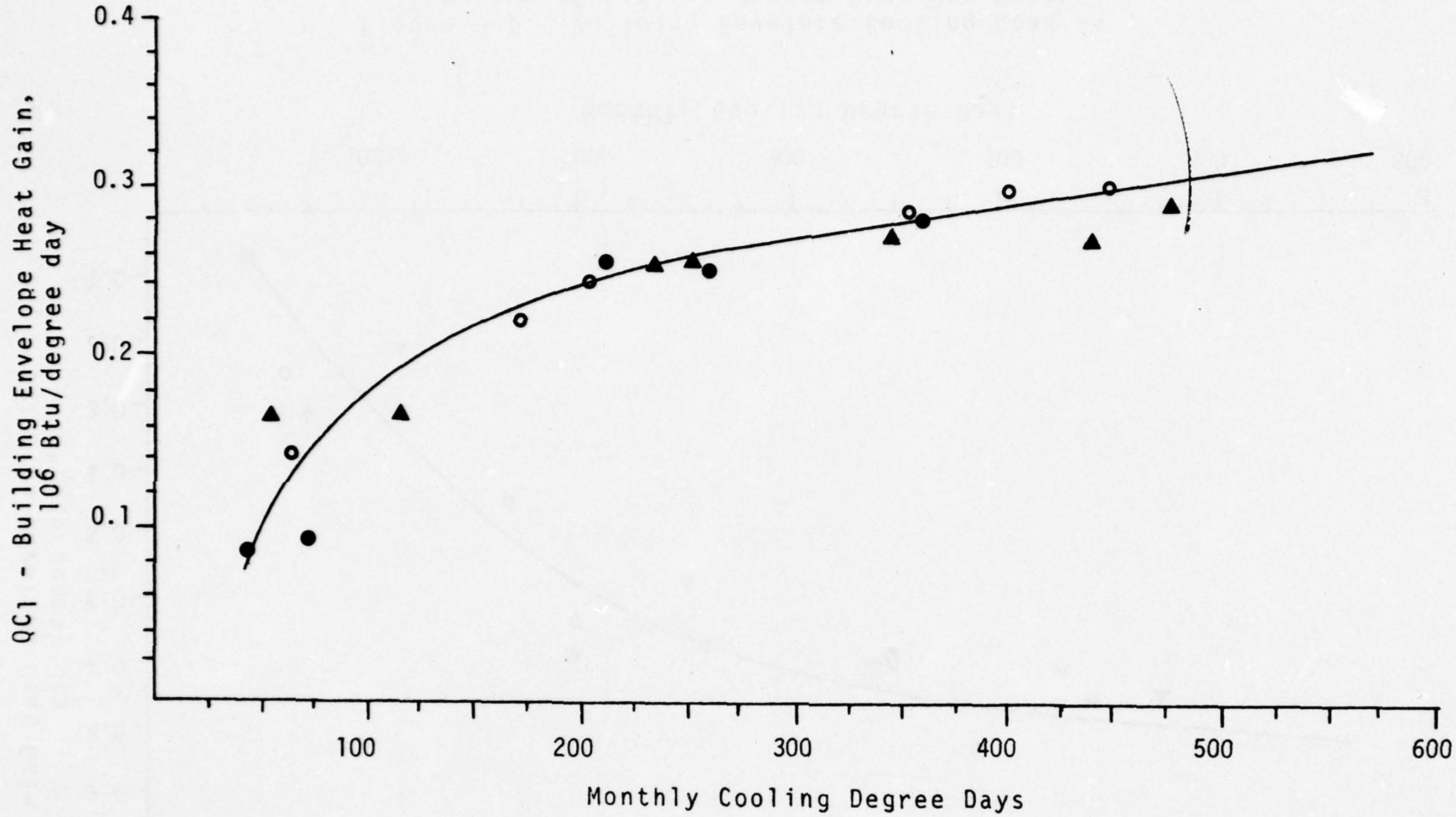

Figure 9-C. Building Envelope Cooling Load As a Function of Cooling Degree Days Per Month

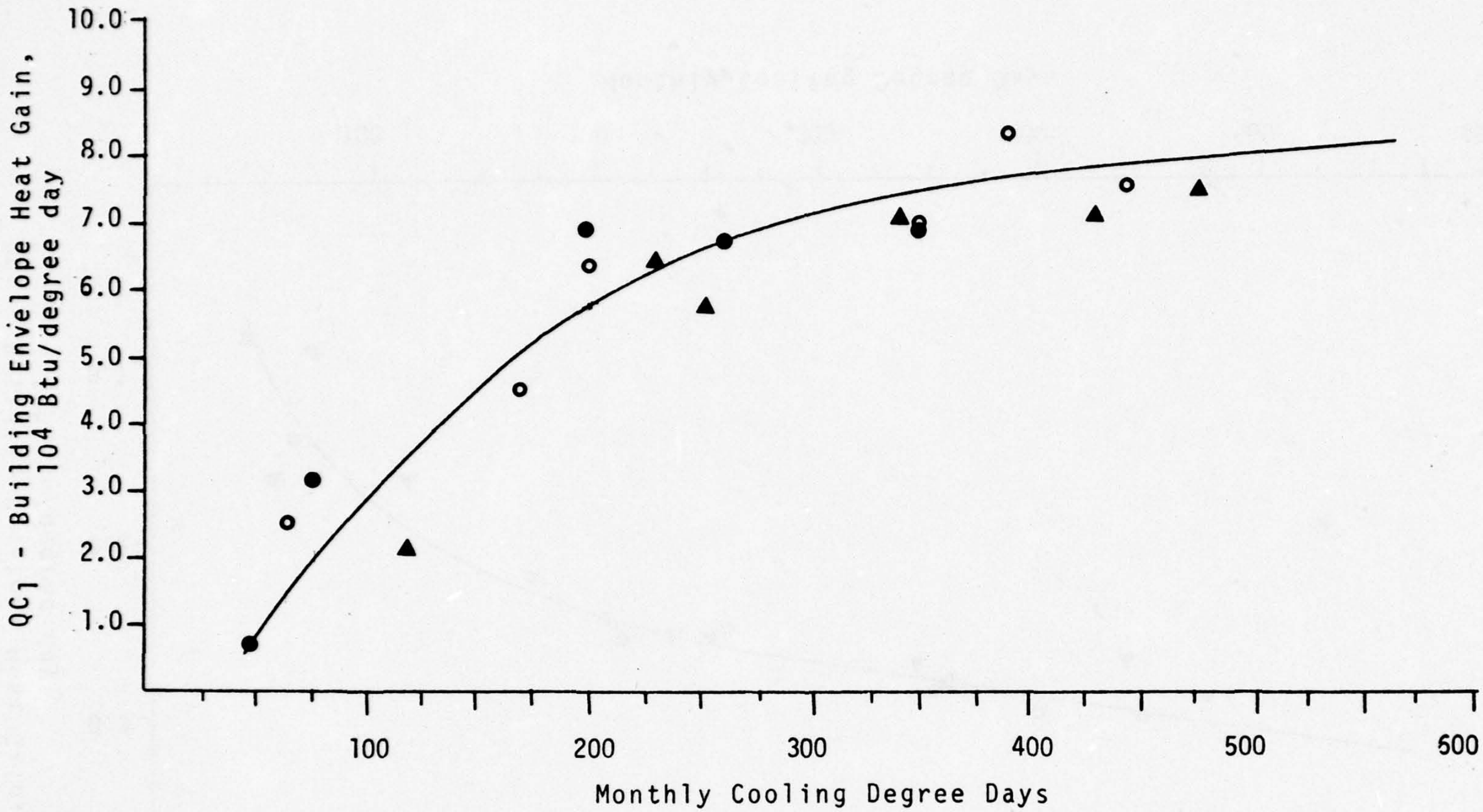

Figure 9-D. Building Envelope Cooling Load As a Function of Cooling Degree Days Per Month

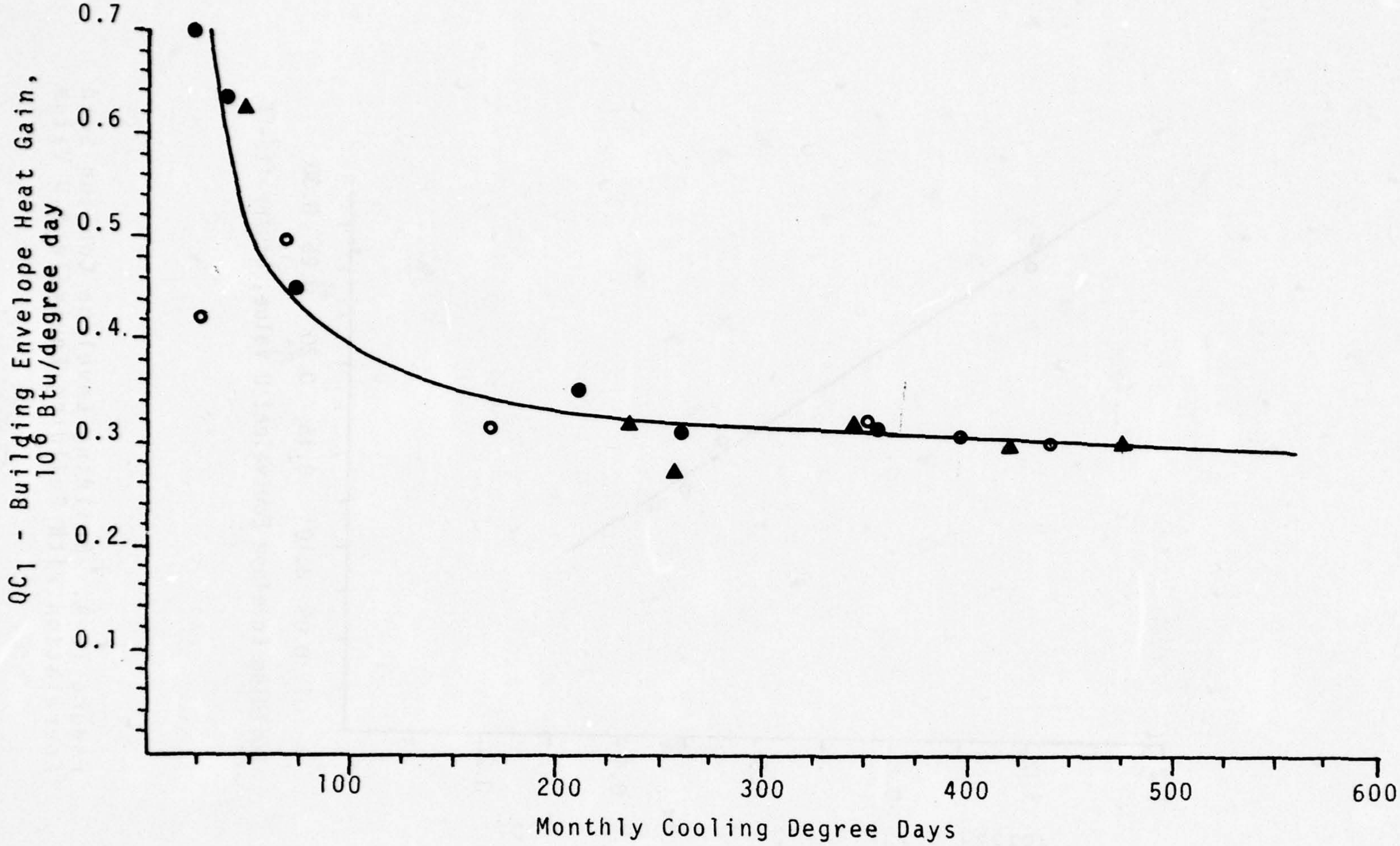

Figure 9-E. Building Envelope Cooling Load As a Function of Cooling Degree Days Per Month

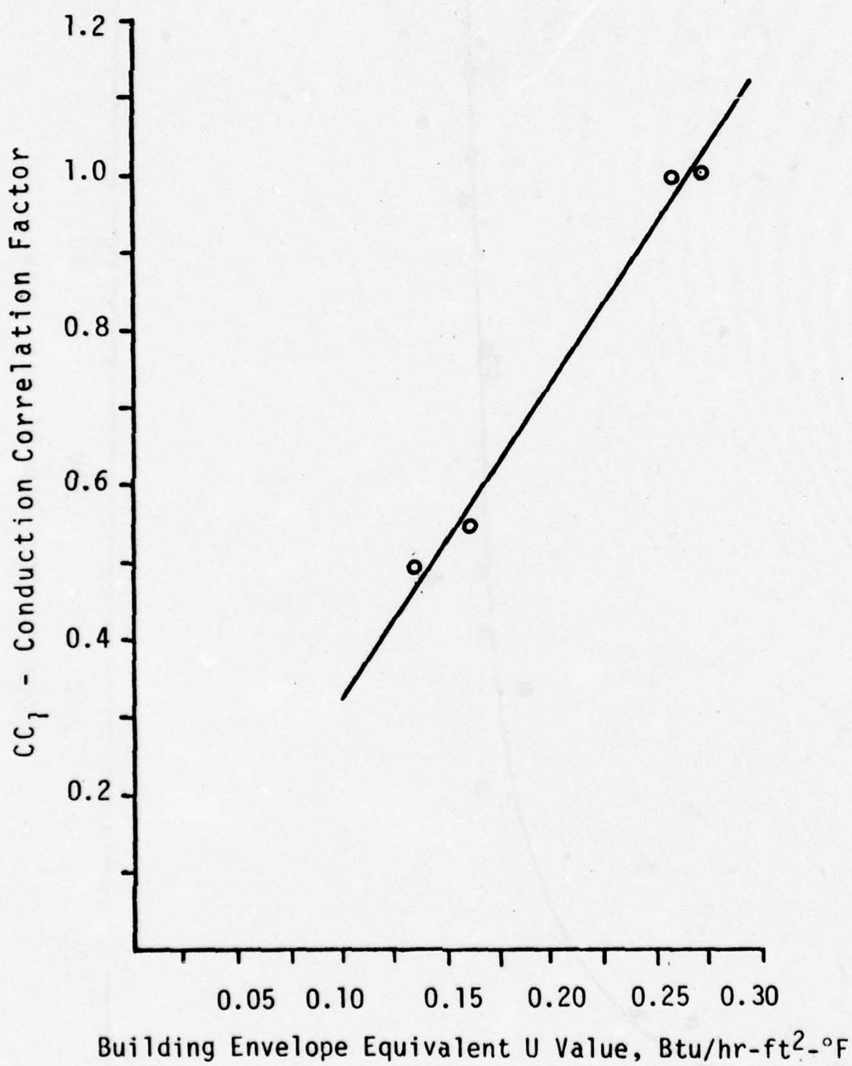

Figure 10-A. Building Envelope Cooling Load Correlation With Building Equivalent U Value

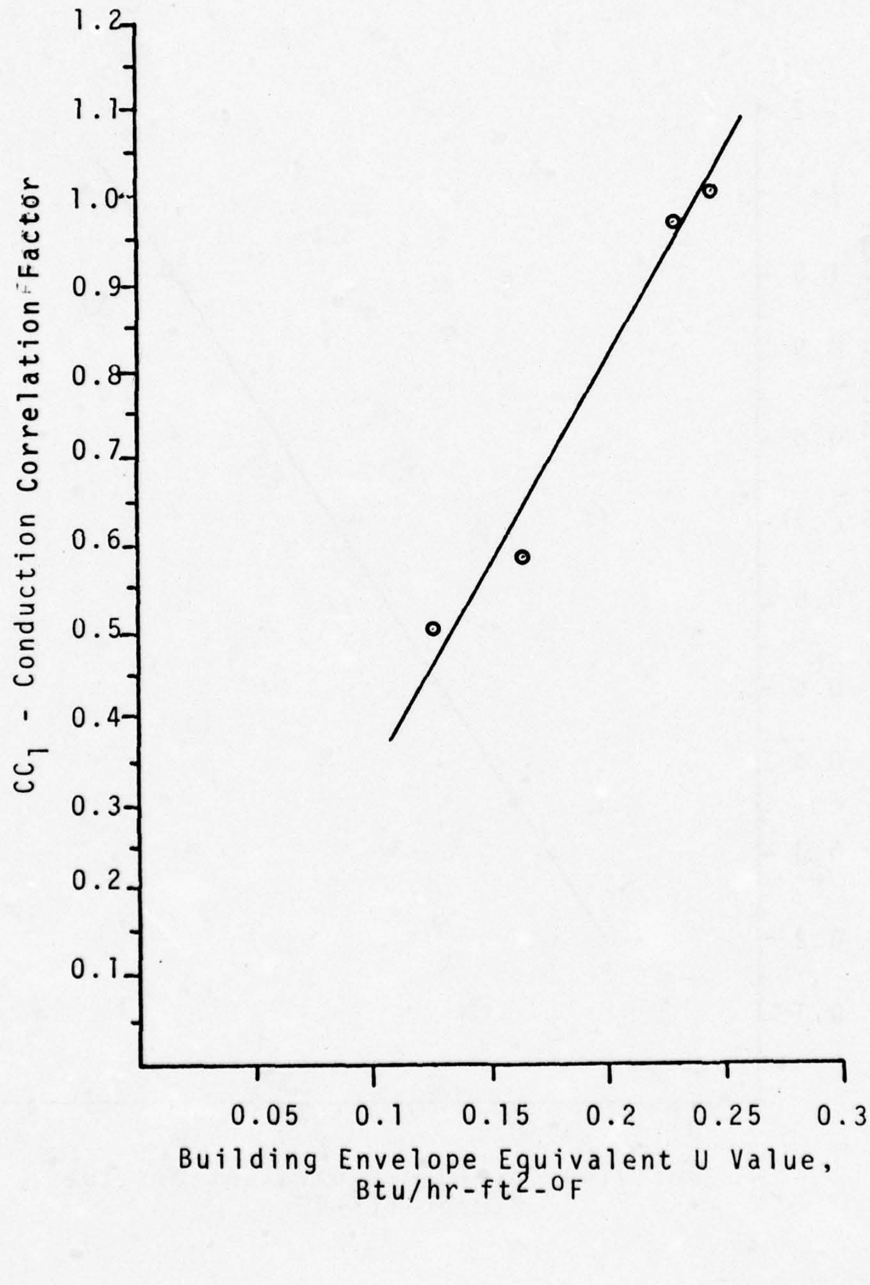

Figure 10-B. Building Envelope Cooling Load Correlation With Building Equivalent U Value

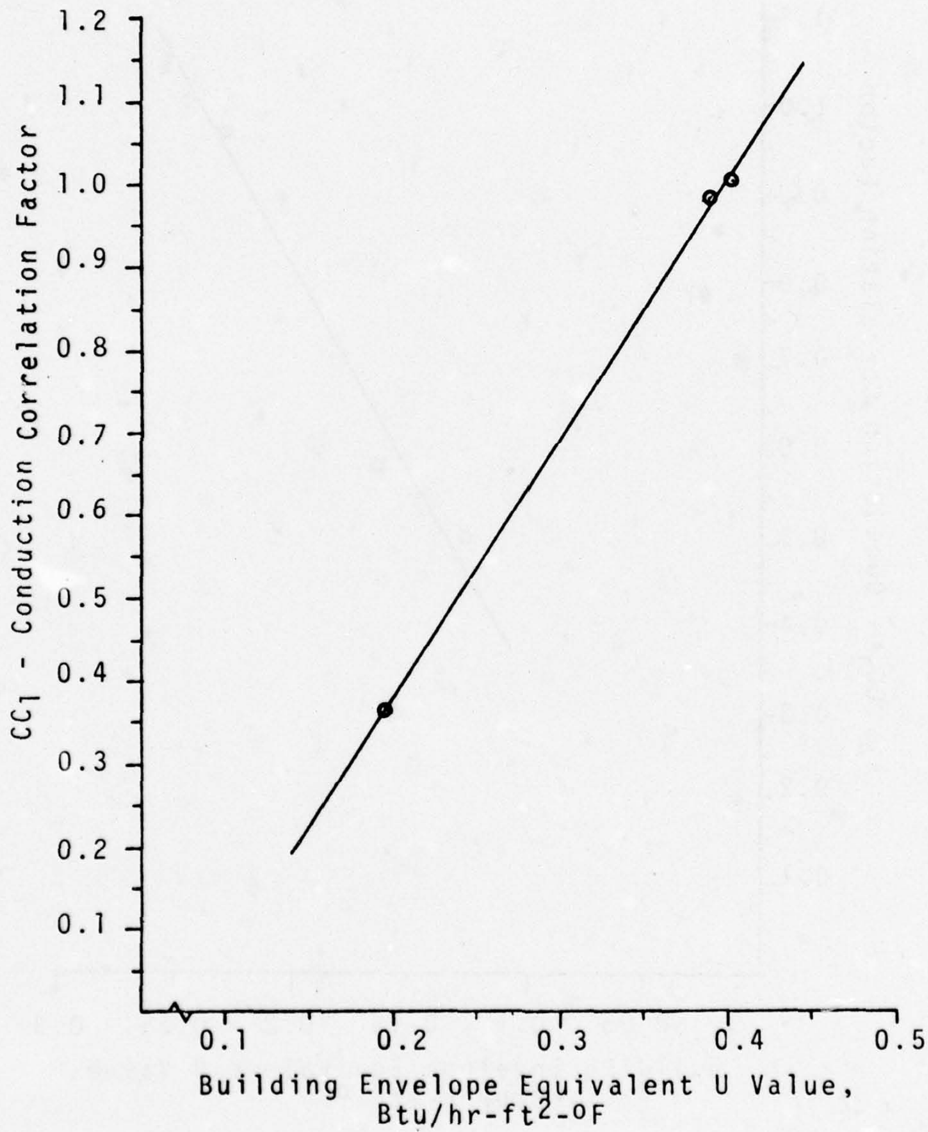

Figure 10-C. Building Envelope Cooling Load Correlation With Building Equivalent U Value

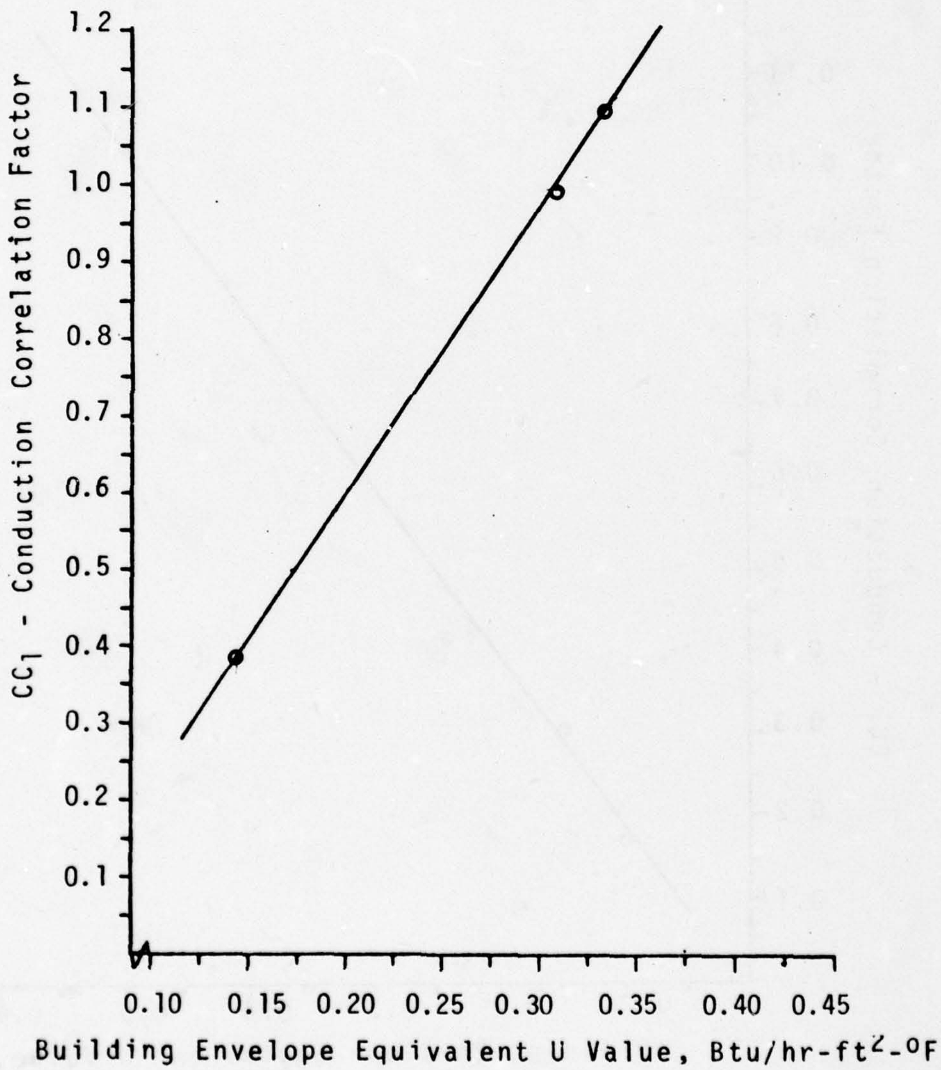

Figure 10-D. Building Envelope Cooling Load Correlation With Building Equivalent U Value

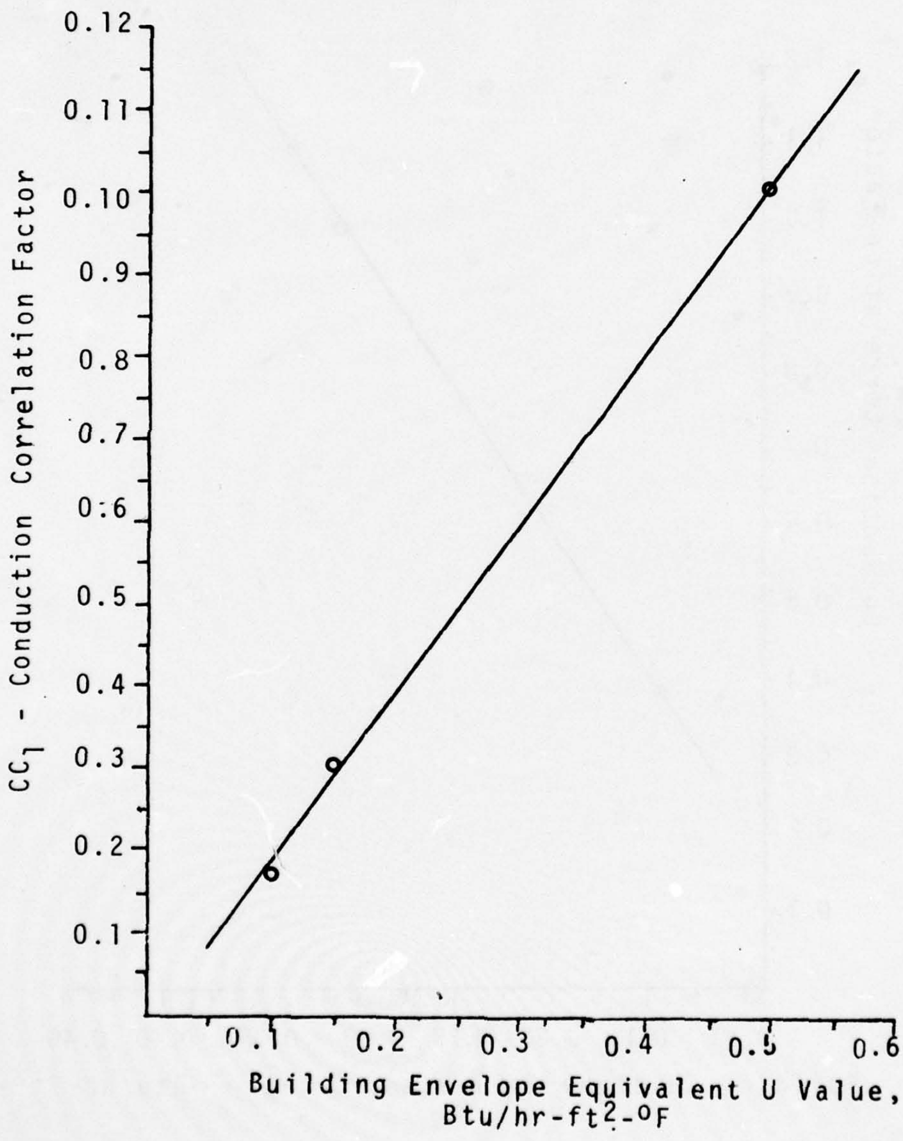

Figure 10-E. Building Envelope Cooling Load Correlation With Building Equivalent U Value

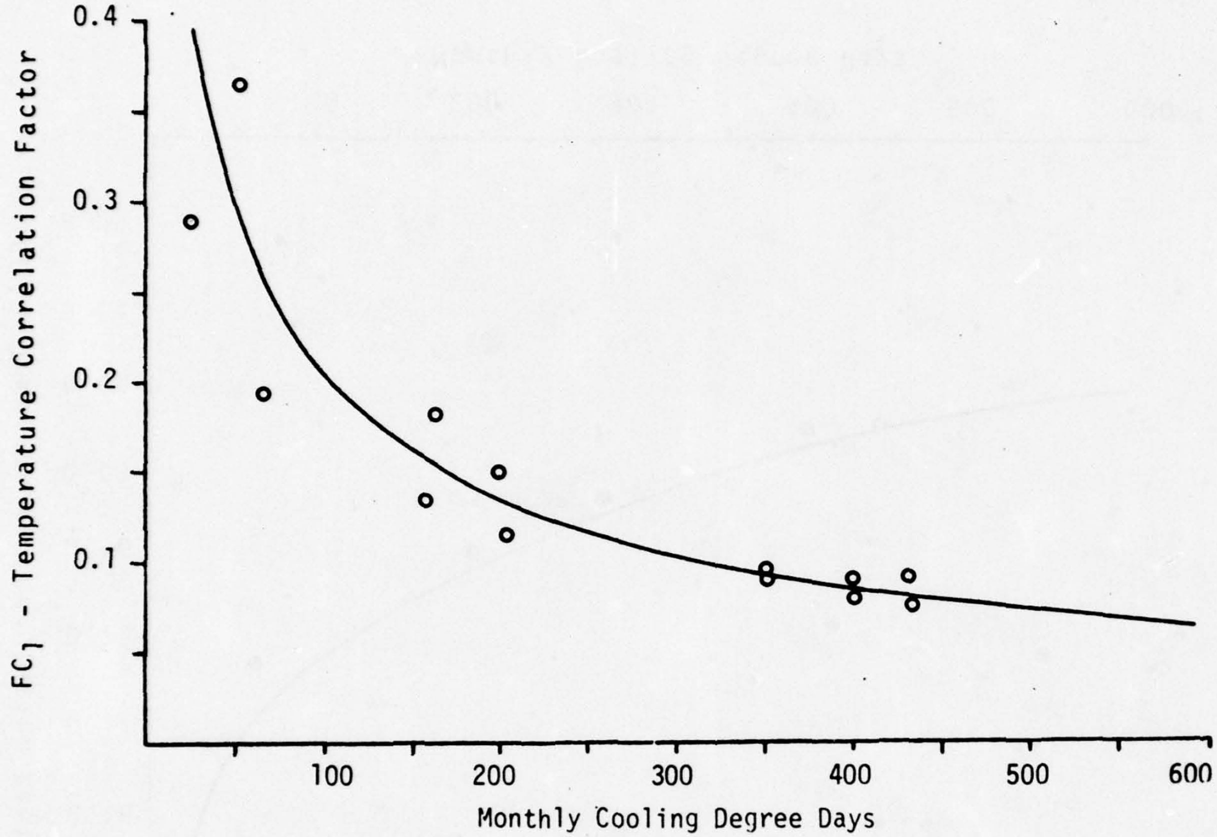

Figure 11-A. Building Envelope Cooling Load Correlation With Set-Point Temperature

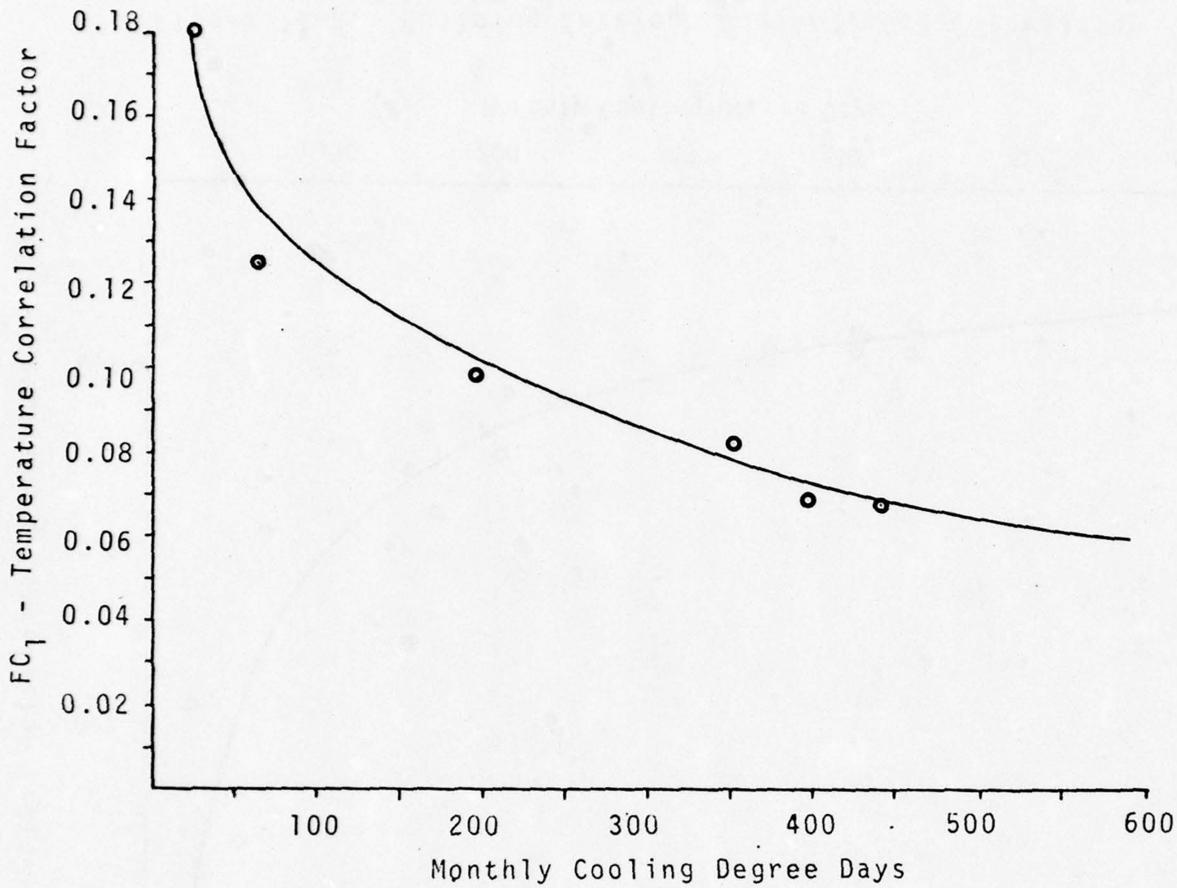

Figure 11-B. Building Envelope Cooling Load Correlation With Set-Point Temperature

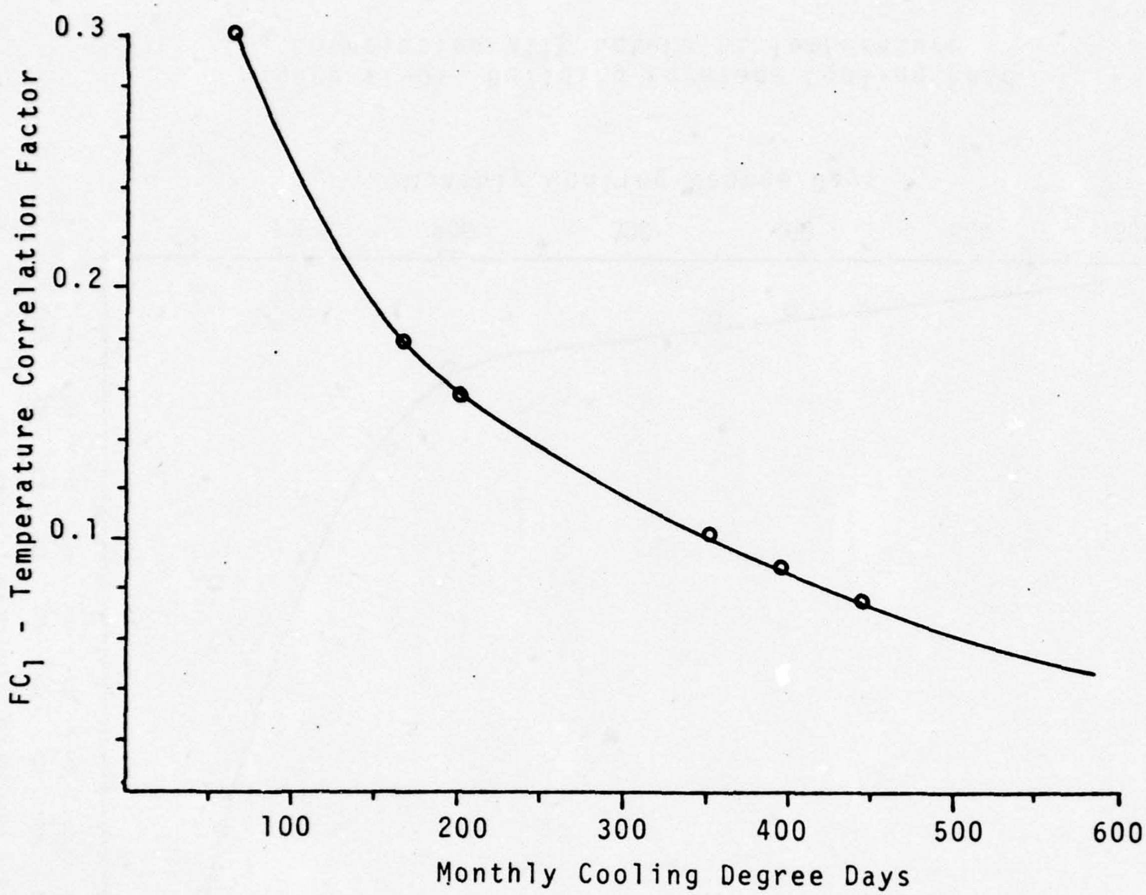

Figure 11-C. Building Envelope Cooling Load Correlation With Set-Point Temperature

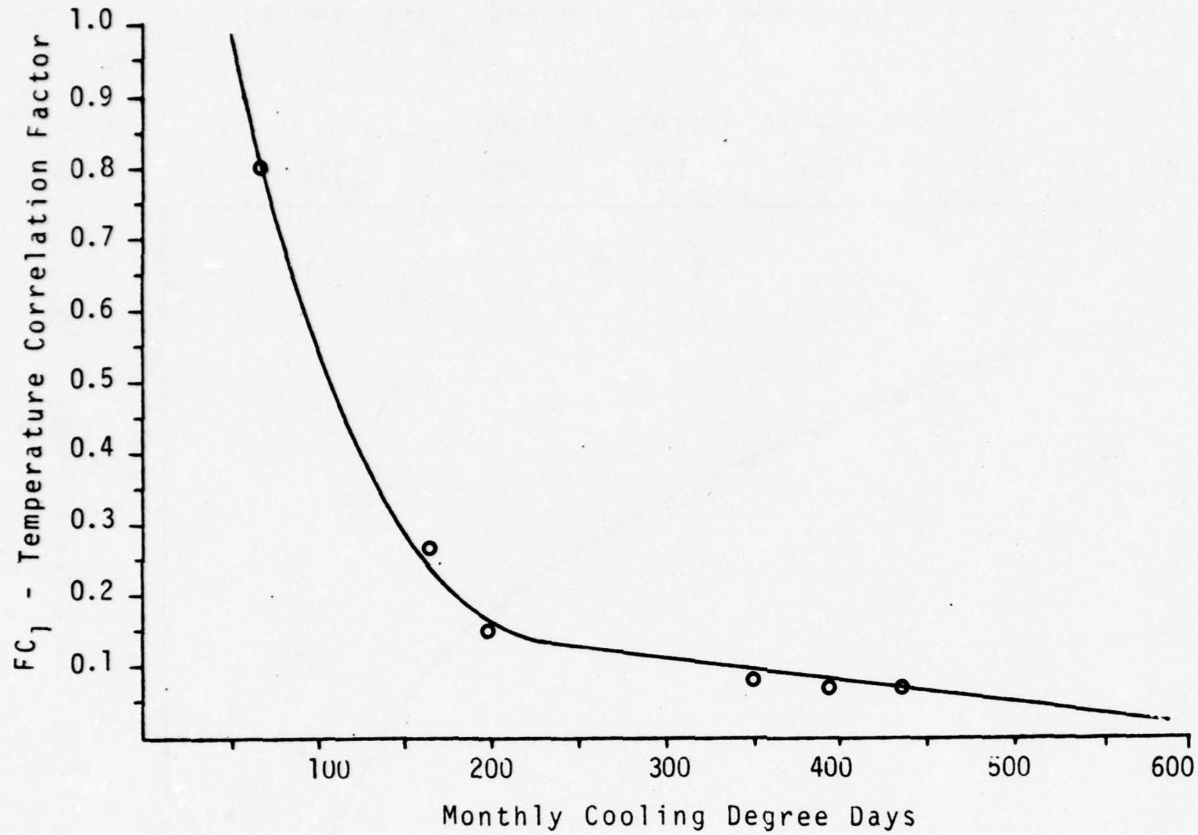

Figure 11-D. Building Envelope Cooling Load Correlation With Set-Point Temperature

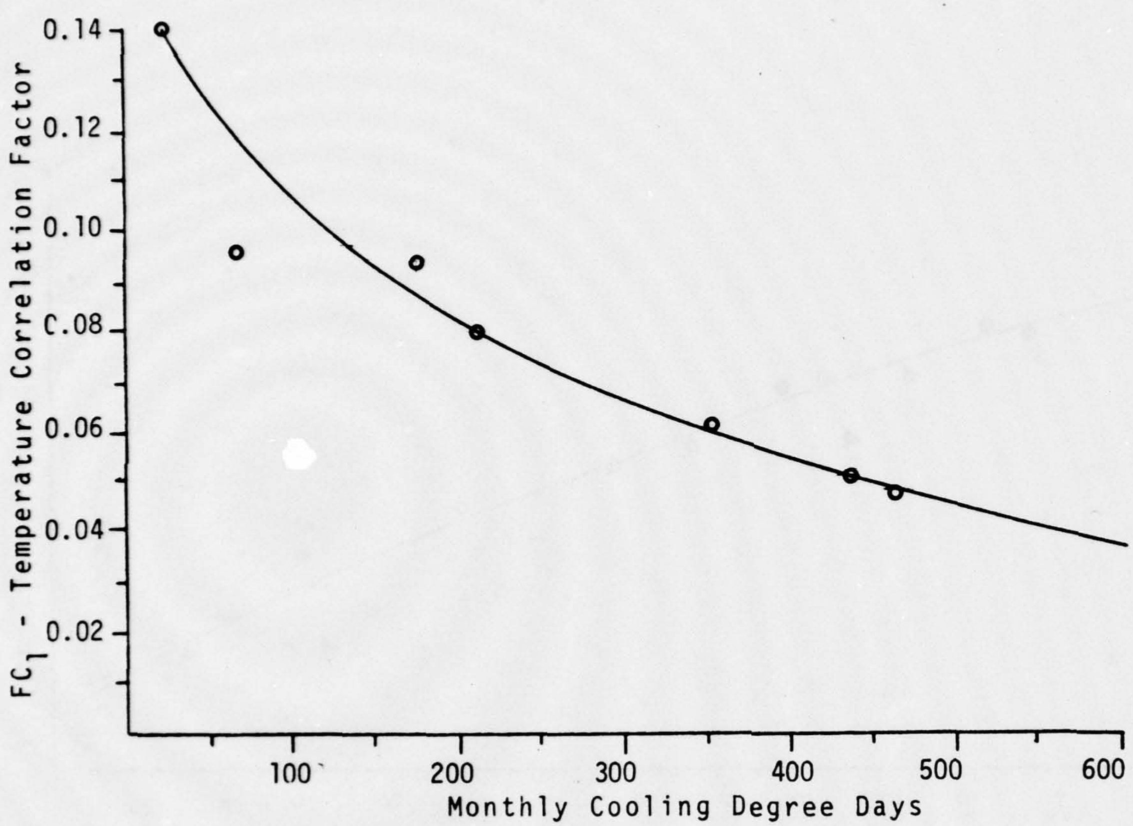

Figure 11-E. Building Envelope Cooling Load Correlation With Set-Point Temperature

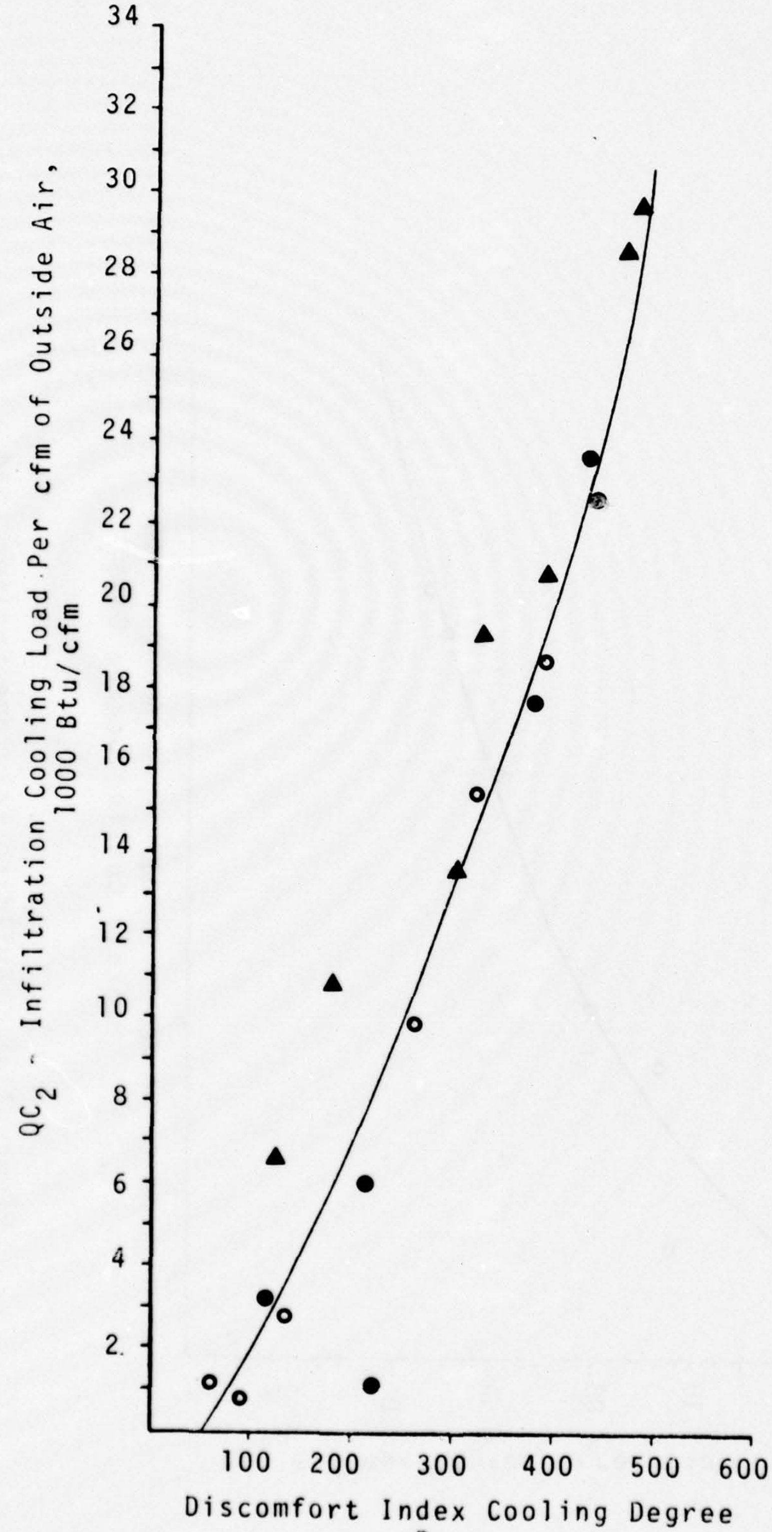

Figure 12-A,B,C,D,E. Infiltration Cooling Load As a Function of Discomfort Index Cooling Degree Days

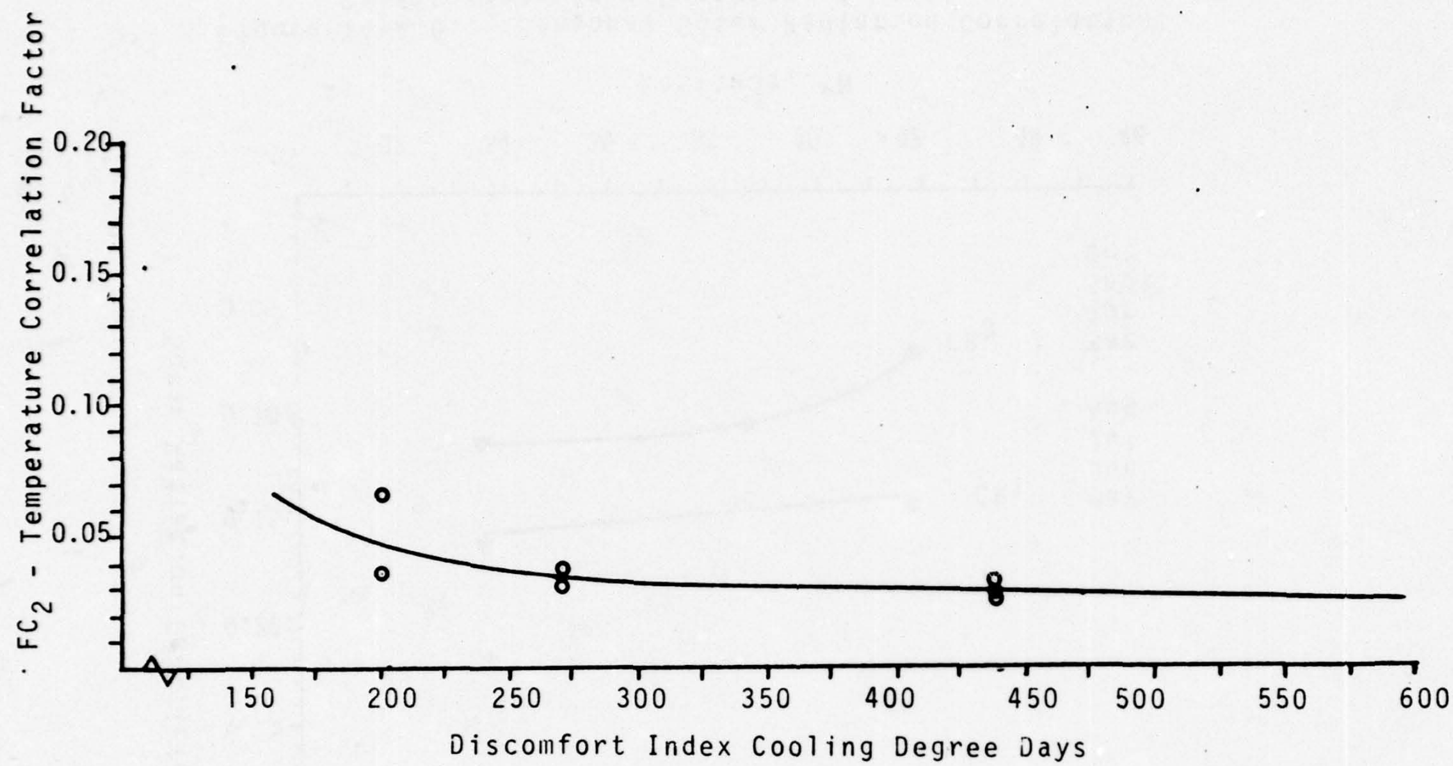

Figure 13-A,B,C,D,E, Infiltration Cooling Load Correlation with Set-Point Temperature

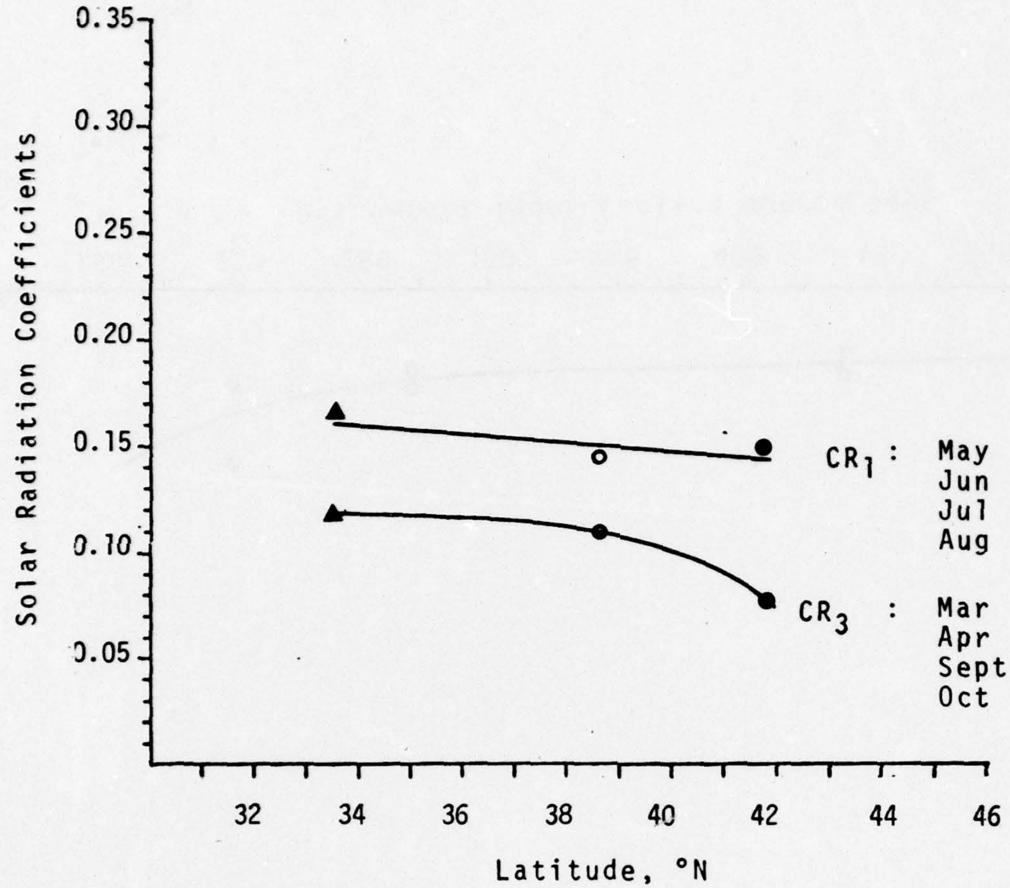

Figure 14-A,B.. Seasonal Solar Radiation Correlation Coefficients As a Function of Latitude

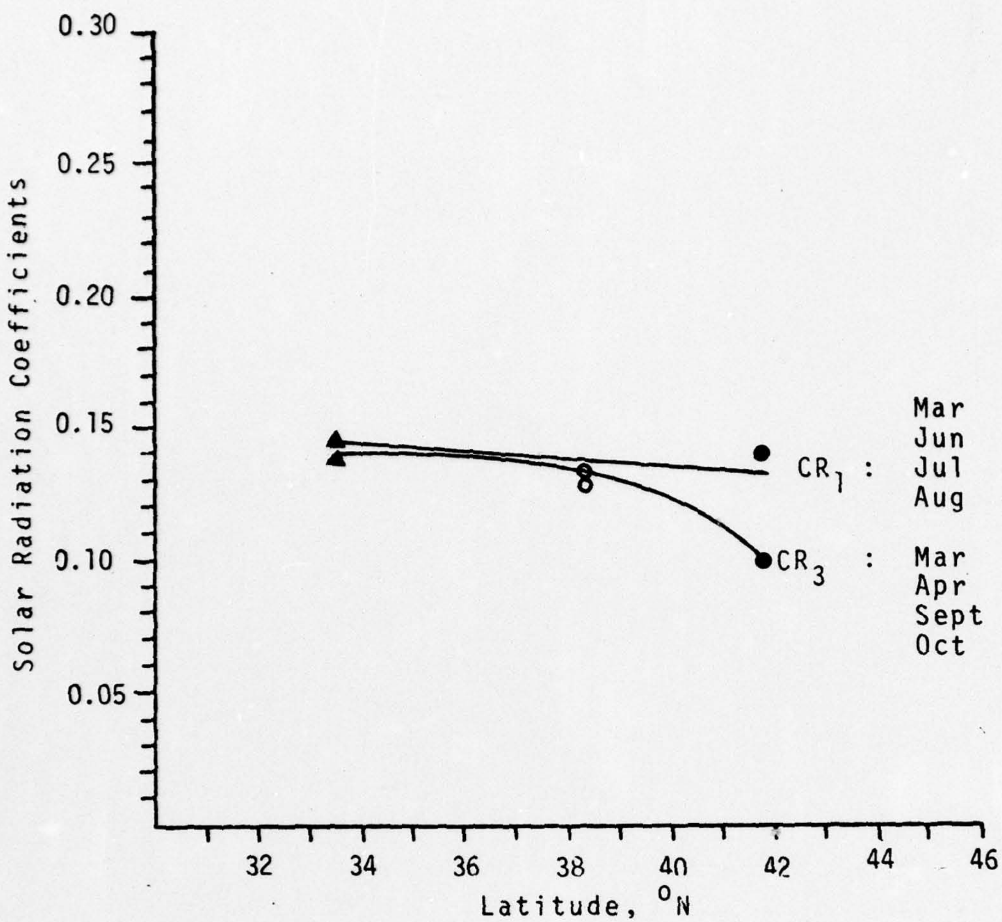

Figure 14-D. Seasonal Solar Radiation Correlation Coefficients As a Function of Latitude

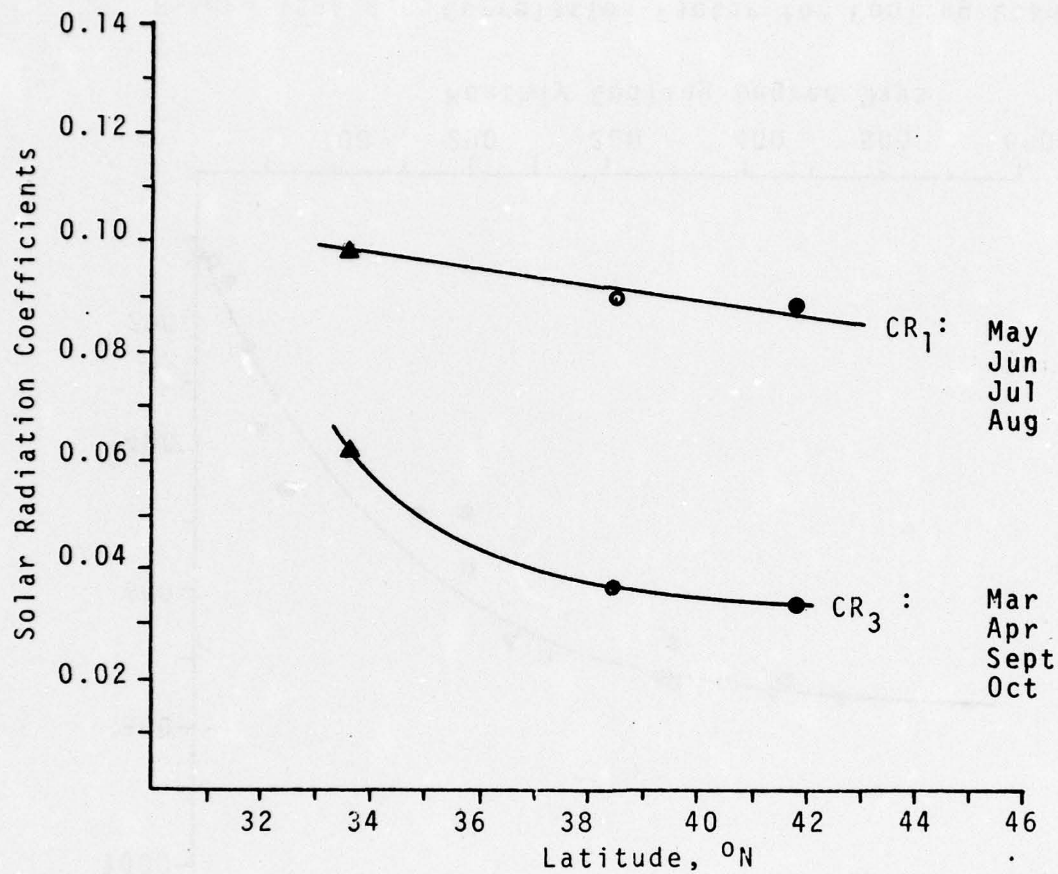

Figure 14-E. Seasonal Solar Radiation Correlation Coefficients As a Function of Latitude

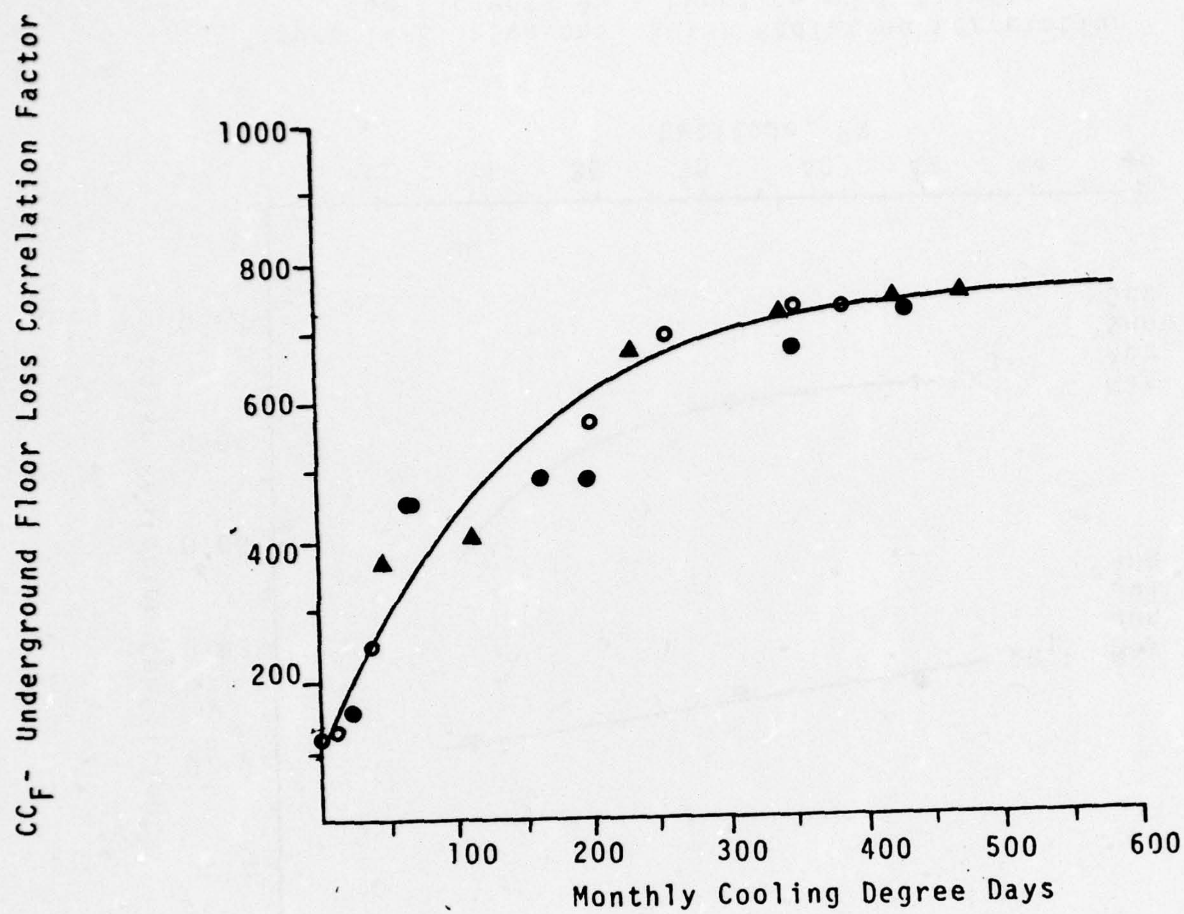

Figure 15-A,B,C. Correlation Factor for Cooling Load Due to Underground Floors and Walls As a Function of Cooling Degree Days

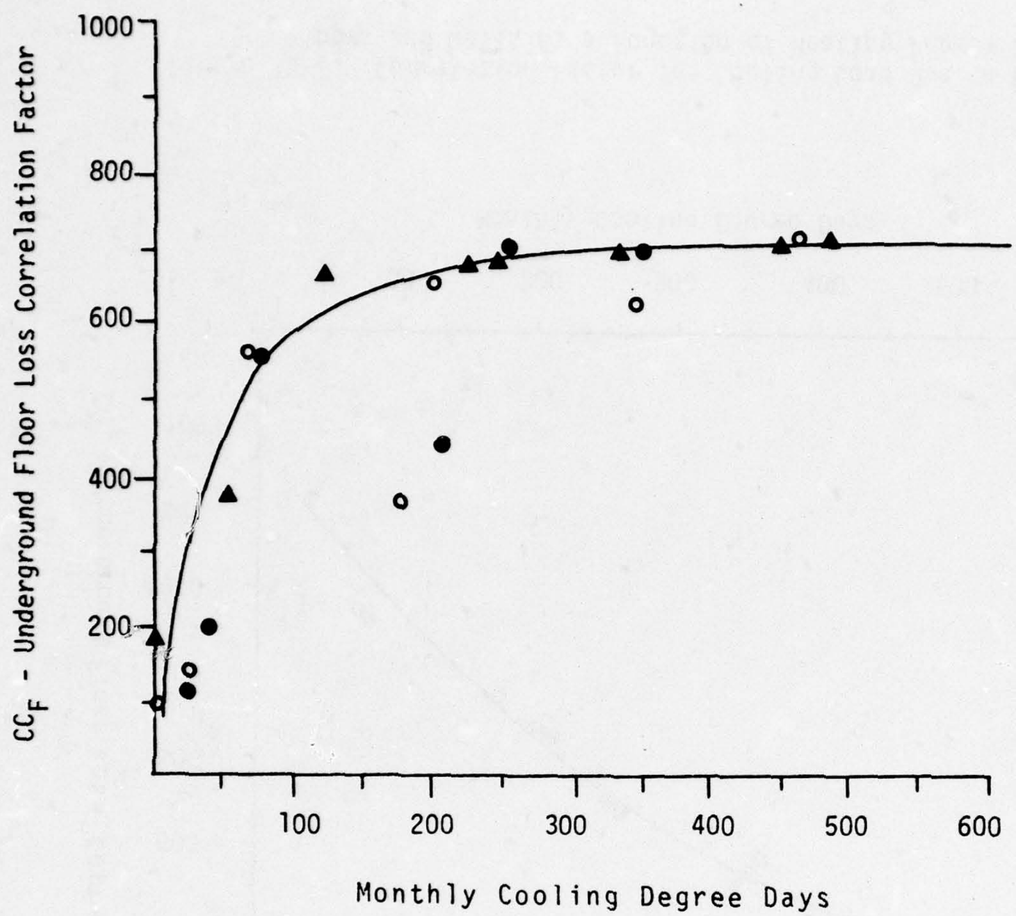

Figure 15-D. Correlation Factor for Cooling Load Due to Underground Floors and Walls As a Function of Heating Degree Days

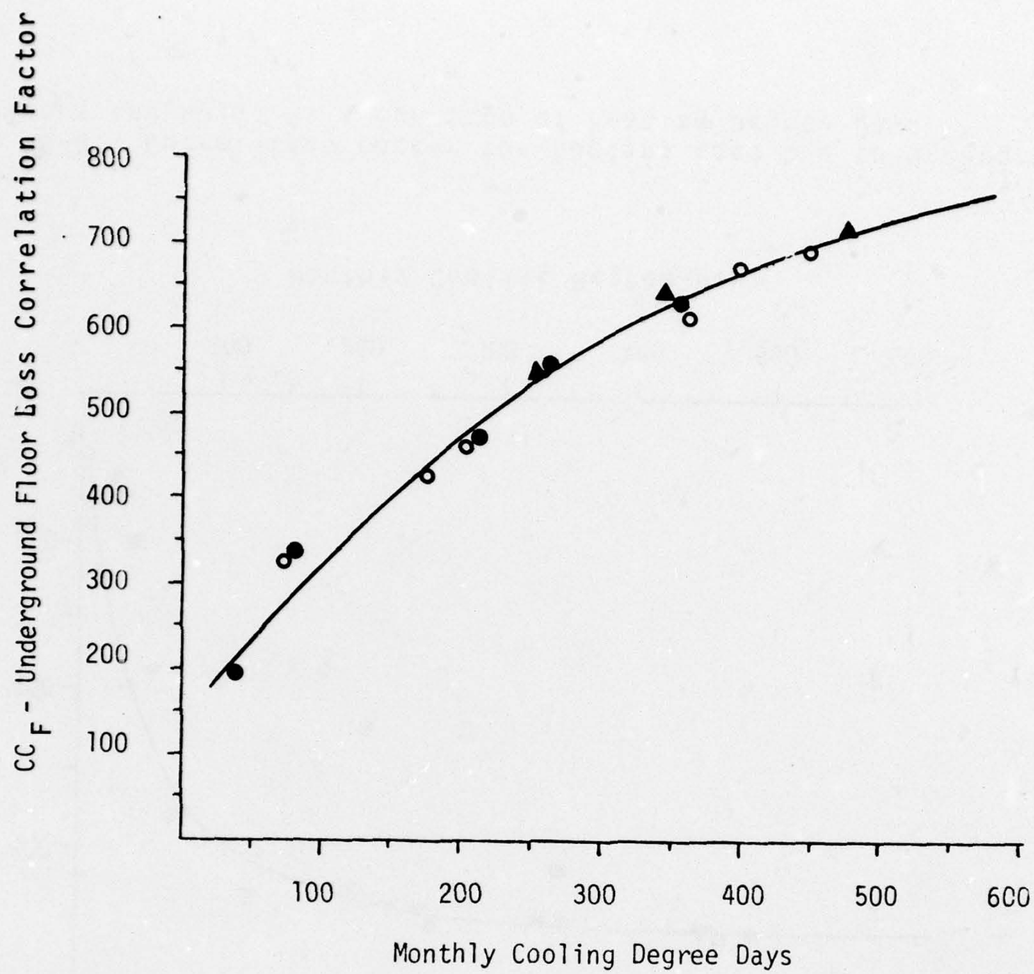

Figure 15-E. Correlation Factor for Cooling Load Due to Underground Floors and Walls As a Function of Heating Degree Days

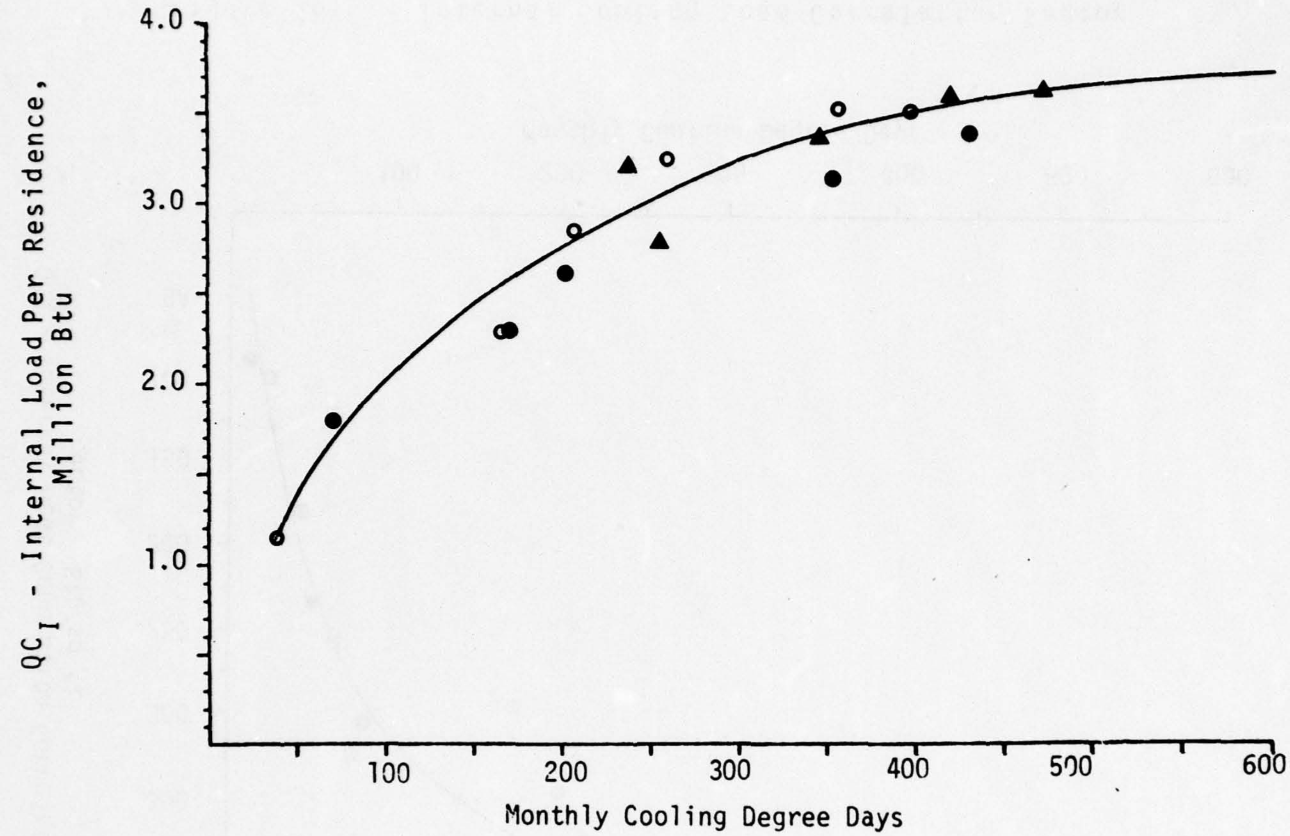

Figure 16-A,B. Internal Heat Generation During Cooling Season As a Function of Cooling Degree Days

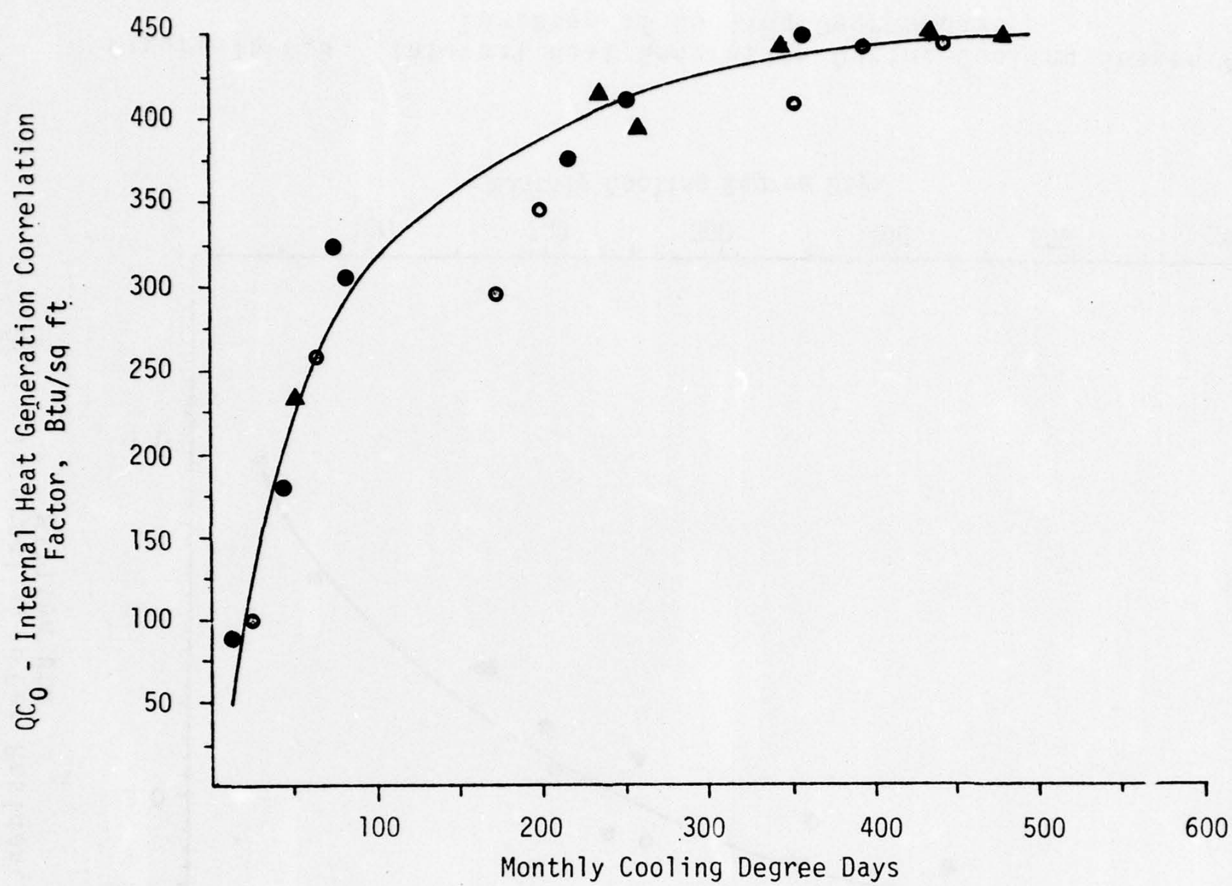

Figure 16-C. Internal Cooling Load Correlation Factor During Cooling Season As a Function of Cooling Degree Days

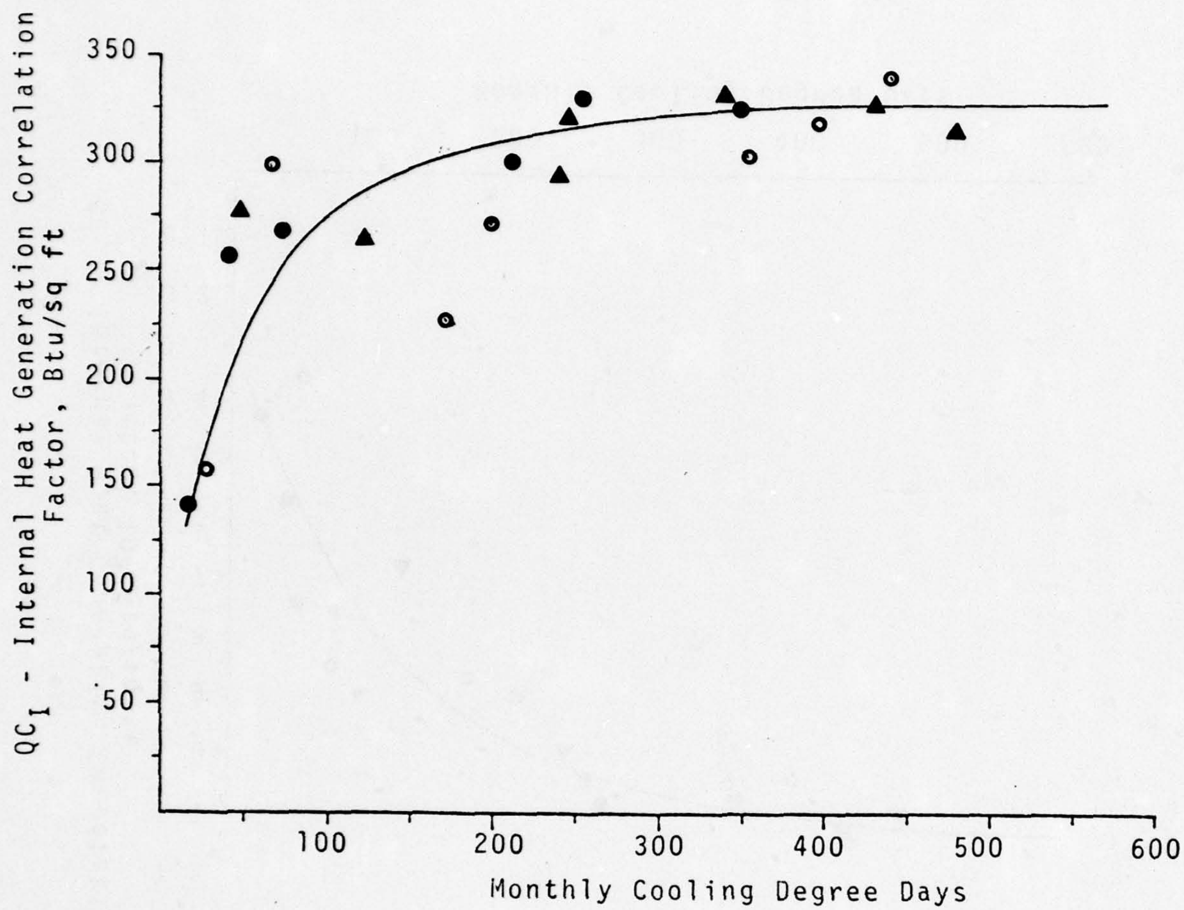

Figure 16-D. Internal Cooling Load Correlation Factor During Heating Season As a Function of Heating Degree Days

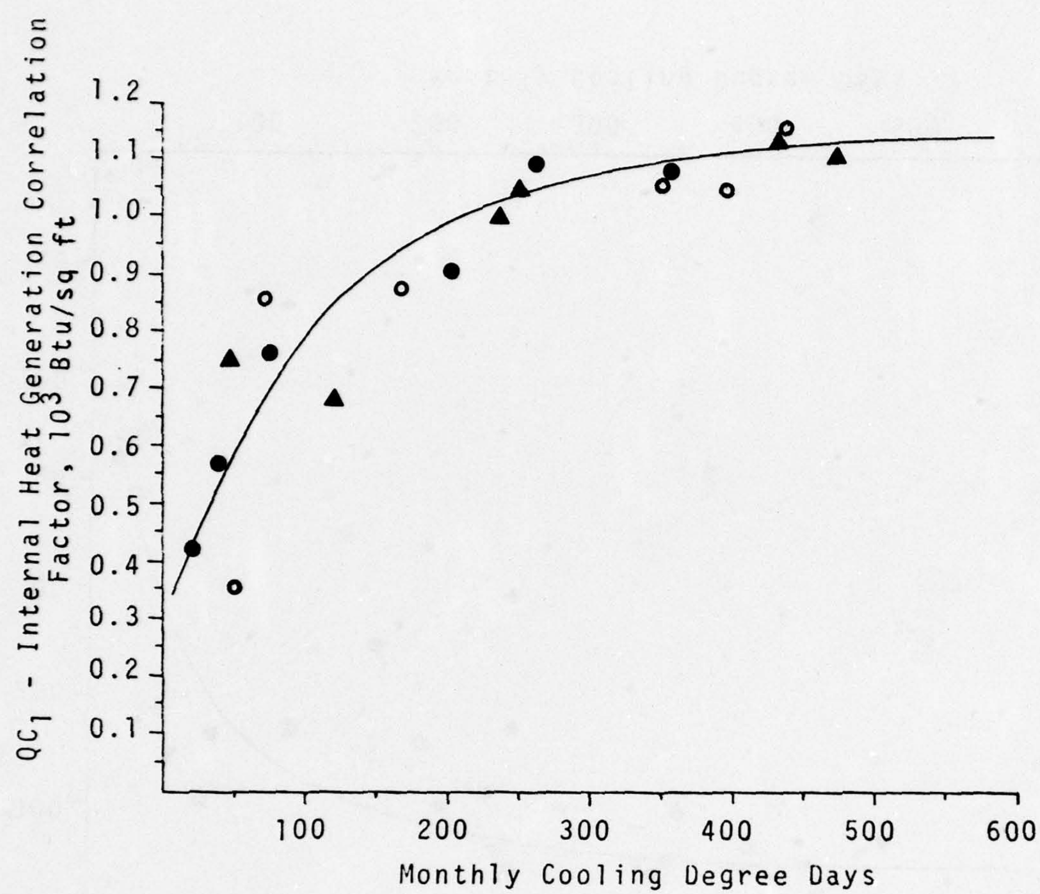

Figure 16-E. Internal Cooling Load Correlation Factor During Cooling Season As a Function of Cooling Degree Days

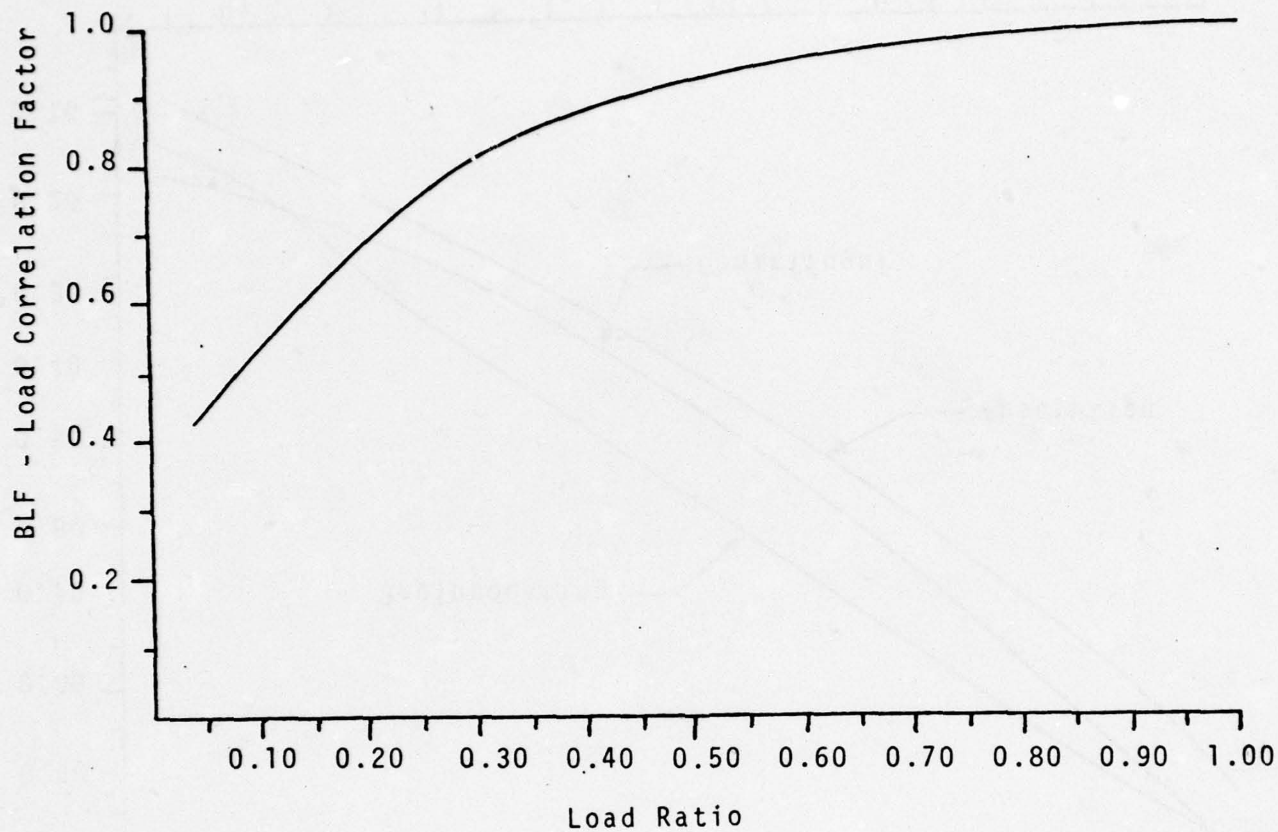

Figure 17. Boiler Load Factor As A Function of Load Ratio

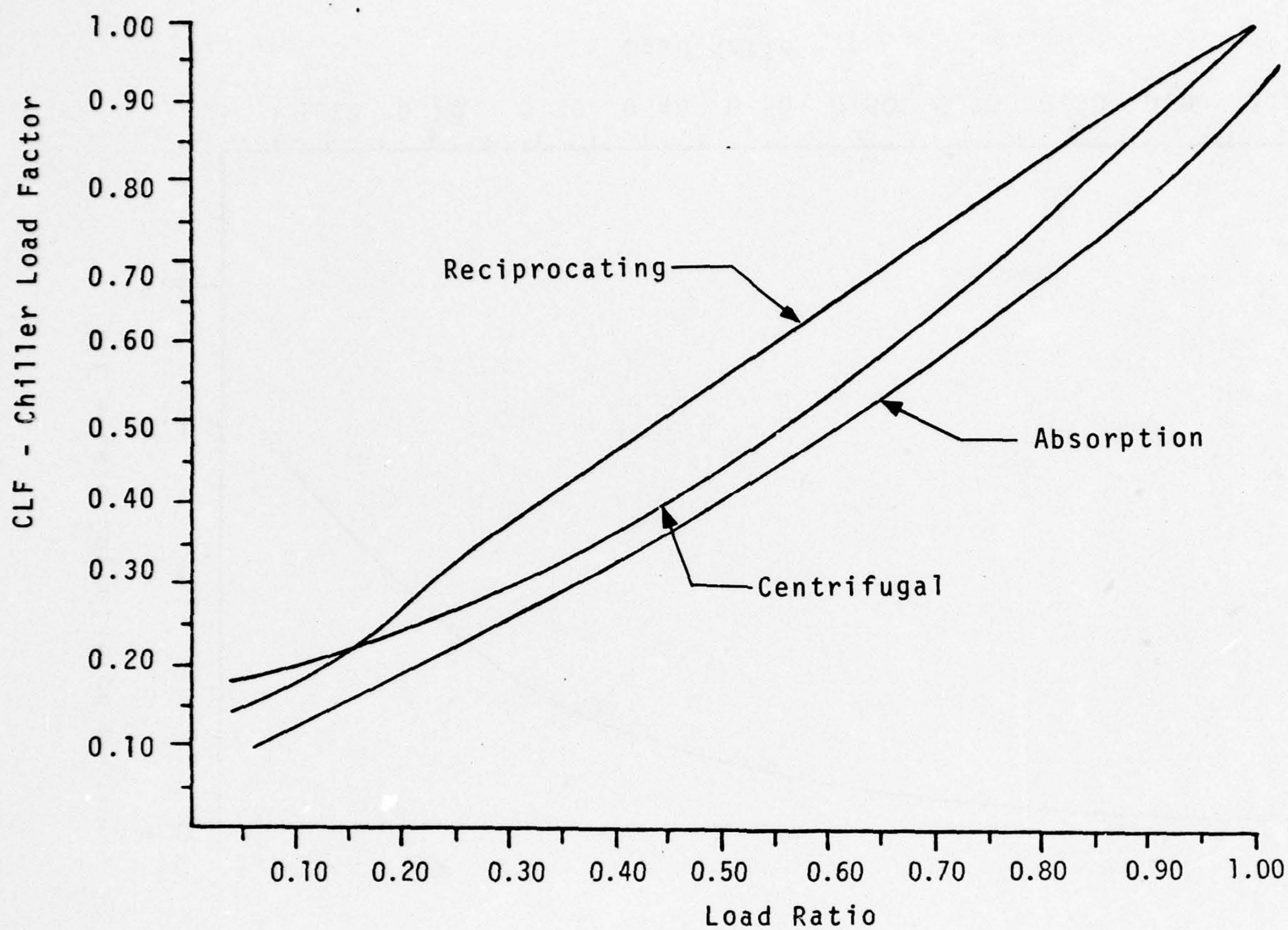

Figure 18. Chiller Load Factor As a Function of Load Ratio

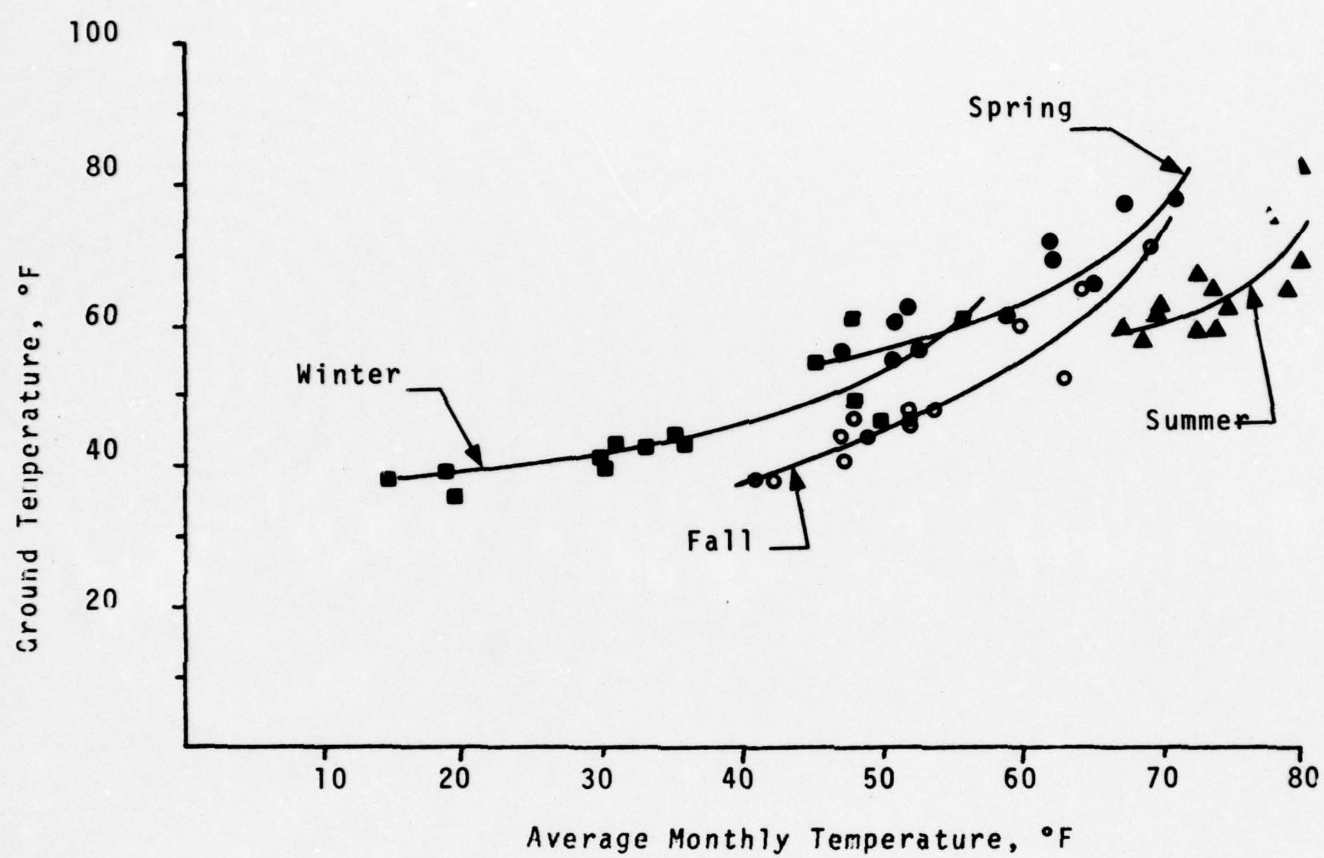

Figure 19. Ground Temperature as a Function of Average Monthly Temperature

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