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An Analytical Investigation of Energy End-Use in Commercial Office Buildings

H. A. McLain

J. M. MacDonald

D. J. Downing

Prepared for the
GAS RESEARCH INSTITUTE
and the
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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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AN ANALYTICAL INVESTIGATION OF ENERGY END-USE IN COMMERCIAL OFFICE BUILDINGS

TOPICAL REPORT

Prepared by

H. A. McLain
J. M. MacDonald
Energy Division

D. J. Downing
Computing and Telecommunications Division

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831

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GRI Project Manager
Dr. James R. Brodrick
Technology Analysis Program
Strategic Analysis and Energy Forecasting Division

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ABSTRACT

A library of data files listing the hourly values of the end-use energy components for commercial office buildings was created using the DOE-2.1B simulation program. The fractional factorial design procedure was used in selecting the input parameters, since the purpose of this study is to gain an understanding of the annual and hourly consumption in the buildings.

Per unit floor area, the annual energy consumption values for the 49,500 ft^2 and the 200,000 ft^2 buildings are relatively close, but those for the 2,500 ft^2 building are larger. The selected Chicago, IL, Fort Worth, TX, and Miami, FL climates noticeably impact the energy use values, except for the peak cooling loads. The peak cooling loads were calculated to be about the same at all three locations. Energy consumption is lower for buildings having insulated walls and double pane and/or reflective glass glazing and having variable air volume instead of multizone HVAC systems. The results suggest that the optimum HVAC system is dependent on the climate.

Internal load, such as lighting and office equipment, reduction results in lower energy consumption. Most of the savings is due to the reduction in the load itself. There is some attendant decrease in the cooling load and increase in the heating load.

EXECUTIVE SUMMARY

INTRODUCTION

The purpose of this study was to perform an analysis of commercial office building end-use energy behavior. It was not intended to be a complete in-depth study, but rather a preliminary study to gain an understanding of the effects of different parameters on the annual and hourly energy consumption in the buildings.

There appear to be substantial opportunities to develop the commercial building conservation resource. Estimates have been made that perhaps 20% of the energy consumed by the commercial buildings can be saved through energy conservation. This is equivalent to a potential annual savings of 2 quads (2×10^{15} Btu) of primary energy and $15 billion energy costs.[1]

The end-use energy data files were created using the DOE-2.1B building simulation program using weather data for Chicago, IL, Fort Worth, TX, and Miami, FL. Fractional factorial design methodology was used to select the independent parameters for each computer run and to rank the importance of the parameter effects. This methodology has the advantage of determining the importance of a large number of parameters using a minimum amount of calculations.

SELECTED PARAMETERS AND INPUT DATA

The analysis was done for three different size buildings of similar construction located in the three different cities. The buildings are: (1) a small, single story building having 2,500 ft^2 floor area, (2) a medium, three story building having 49,500 ft^2 floor area, and (3) a large ten story building having 200,000 ft^2 floor area. The buildings are flat roof structures with the lowest story being at ground level. All the floors are concrete slabs and are covered with carpet. The exterior surfaces are lightweight concrete, and 30% of the wall surface is glazing.

The independent parameters selected for this analysis are listed in Table ES1. HVAC systems for all buildings are assumed to be either multizone systems or variable air volume systems. The multizone system has a constant circulating air flow rate and regulates the temperature in each zone by mixing air supplied from hot and cold decks. The variable air volume system regulates the temperature in each zone by varying both the temperature and the flow rate of the air supplied to the zone. It was assumed that this system has a terminal heating unit in each zone requiring heat in the winter to help to control the temperature.

Energy sources available to the building are natural gas and electricity. Natural gas was selected for space heating and domestic hot water heating. Electricity was selected to be used for all the remaining energy needs, including space cooling.

Typical commercial office building occupancy and internal load schedules were assumed for this study. The HVAC systems were assumed to be turned off, except for provide protection against freezing, when the building is essentially unoccupied during nights, weekends, and holidays. Sizing of the HVAC equipment was done using the DOE-2.1B program, design day weather data, and some engineering judgement. The program data library was used to describe the HVAC equipment performance characteristics.

Test Reference Year weather data for the three selected locations were used in the analysis. The Chicago, IL data represent a cold climate, the Fort Worth, TX data represent a warm-dry climate, and the Miami, FL data represent a warm-humid climate.

To gain some idea of the impact of the values of the parameters on the energy cost to the consumer, 1985 utility price schedules for the selected locations were used with the calculated hourly energy use values for the monthly billing charges. (Dallas, TX schedules were used to approximate the Fort Worth, TX energy prices.)

Table ES1. Selected independent parameters.

1. Building size

   2,500 ft^2
   41,500 ft^2
   200,000 ft^2

2. Location

   Chicago, IL
   Fort Worth, TX
   Miami, FL

3. HVAC system

   Multizone system
   Variable air volume system

4. HVAC economizer

   No economizer
   Temperature controlled economizer, 62°F temperature limit

5. Minimum ventilation rate

   20%
   5%

6. Lighting power

   3 W/ft^2
   1.6 W ft^2

7. Occupancy and equipment power

   High: 10 people/1000 ft^2 in perimeter areas
   5 people/1000 ft^2 in core areas
   1 W/ft^2 equipment
   Low: 4 people/1000 ft^2
   0.5 W/ft^2 equipment

8. Envelope construction

   Normal: Minimal roof insulation
   No wall insulation
   Single-pane, clear glass glazing
   Energy efficient: Additional roof insulation
   Wall insulation
   Double-pane and/or reflective glass glazing

HEATING-COOLING LOADS AND END-USE ENERGY

A total of 106 DOE-2.1B calculation runs were made predicting the building loads and the end-use energy values. The results, among which are the hourly values of the loads and the end-use energy, were extracted from the DOE-2.1B output files, reformatted, and stored in smaller output files. Generally the results are presented on a unit floor area basis to allow comparison among buildings.

The choice of the input parameter values listed in Table ES1 were selected using the fractional factorial design for 96 of the 106 DOE-2.1B runs. Analysis of the building load data generated in these runs indicated that the parameters directly or in two-parameter interactions having the most effect on the building loads are the building size, location, and choice of HVAC system. Building insulation/glazing was found to be the next most important parameter. The two-parameter interactions were found to be important.

Plots of the mean loads are instructive. Figure ES1 shows plots of the mean annual and peak heating loads; Fig. ES2 shows plots of the analogous cooling loads. The mean load is defined as the average of the loads for the buildings that have common parameter values of interest. For example in Fig. ES1a, the mean heating load for the 2,500 ft^2 building in Chicago is the average of the heating loads calculated for all the fractional factorial runs for this building at this location.

The effect of the size of the small building on the loads is apparent. This accounts for the strong direct and interaction effects for this parameter. The effect of size between the other two buildings is relatively small. Location, for the three selected cities, has a strong effect on all the loads except for the peak cooling load.

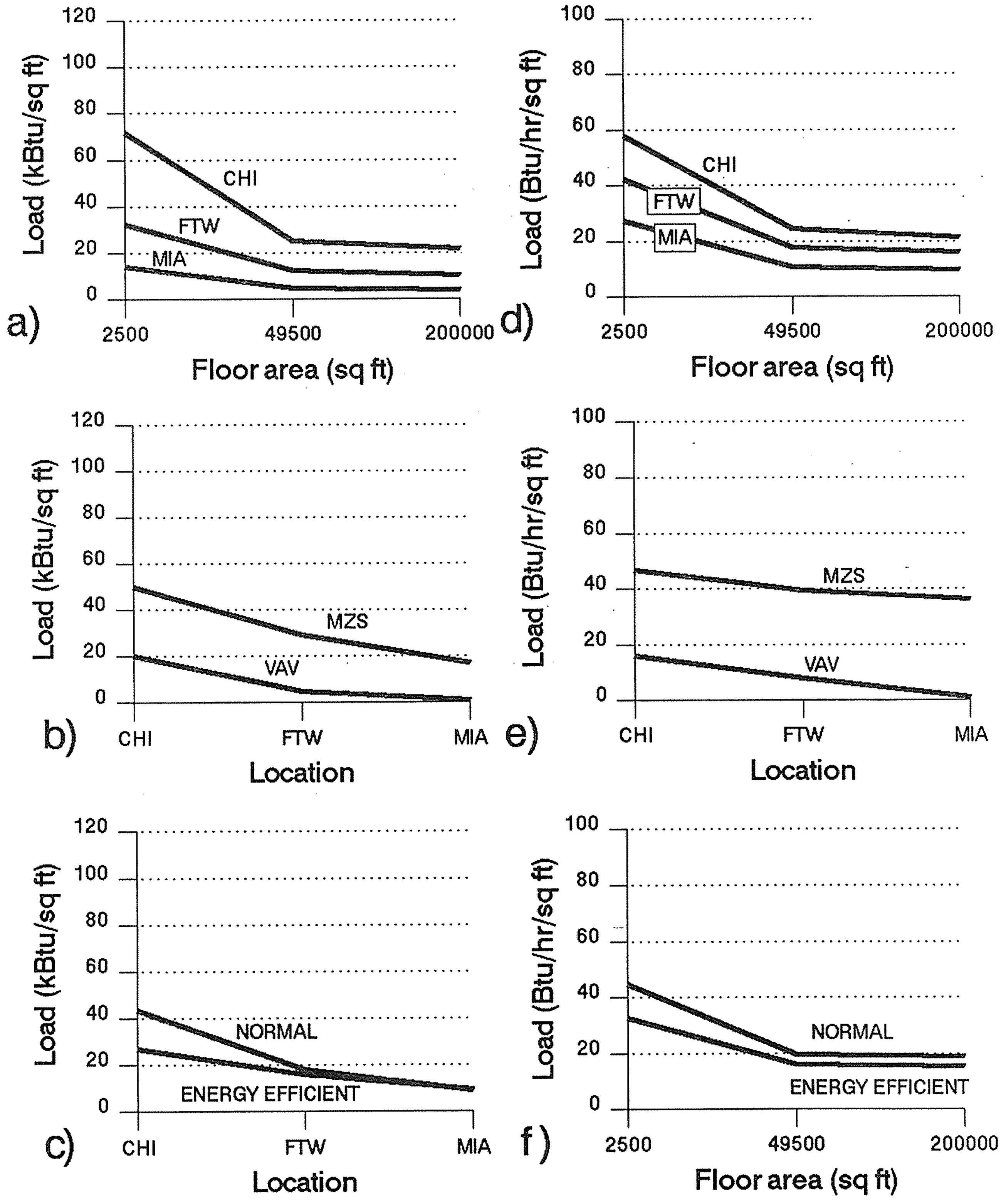


Fig. ES1. Mean building heating loads: (a) annual, size by location; (b) annual, location by HVAC system; (c) annual, location by insulation/glazing; (d) peak, size by location; (e) peak, location by HVAC system; (f) peak, size by insulation/glazing.

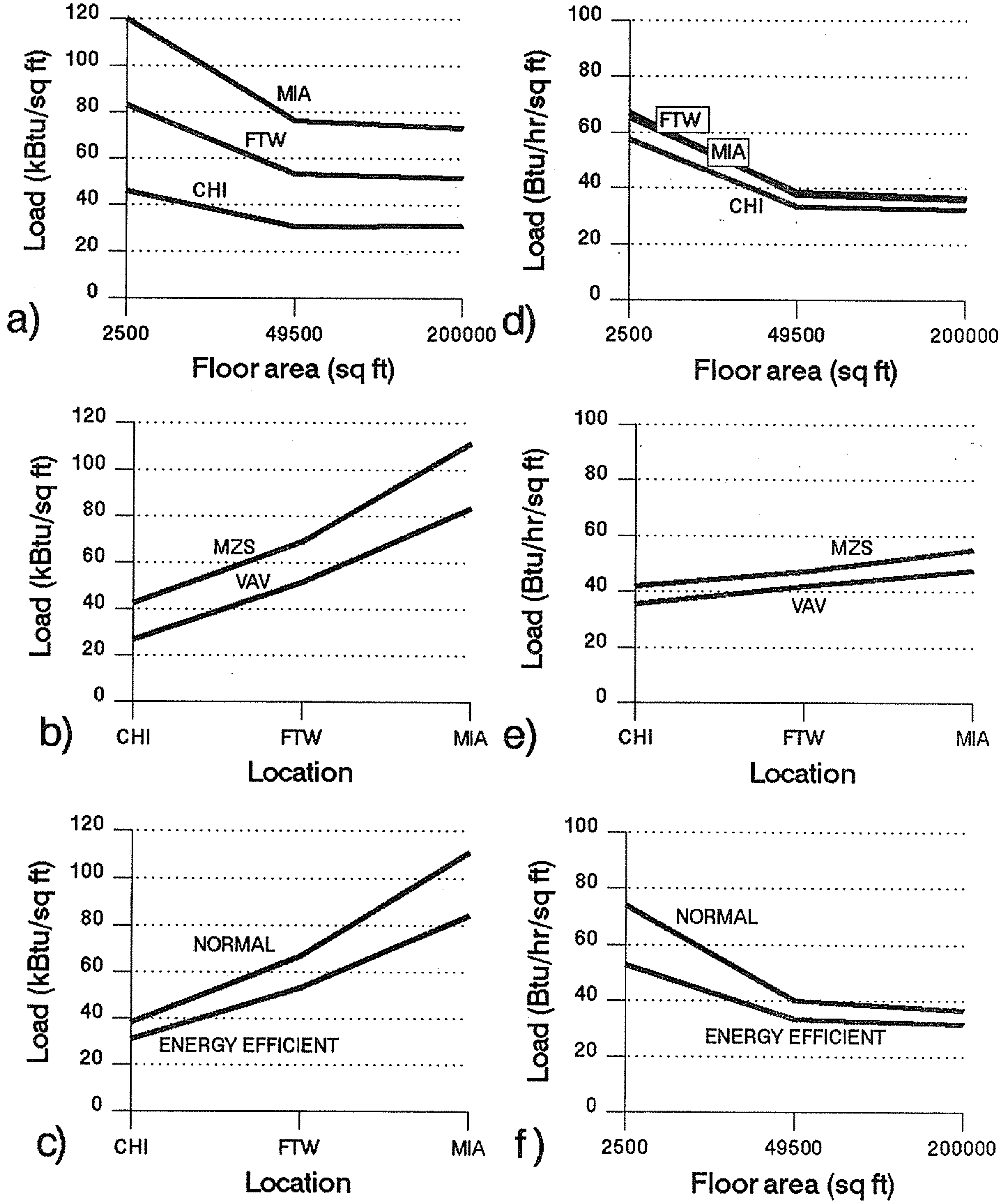


Fig. ES2. Mean building cooling loads: (a) annual, size by location; (b) annual, location by HVAC system; (c) annual, location by insulation/glazing; (d) peak, size by location; (e) peak, location by HVAC system; (f) peak, size by insulation/glazing.

The multizone and variable air volume HVAC systems selected in this study represent an extreme range in HVAC technology. This is reflected in the impact of these systems on the heating and cooling loads. There is little effect of the choice on the peak cooling load since the two systems operate essentially the same way at the time of the peak load.

The effects of the economizer and the ventilation rates were calculated to be small. These calculations were limited, and results for the economizer are suspect since the data indicated that there would be an increase in the heating loads when the economizer is used for the buildings in Chicago and Fort Worth.

The insulation/glazing impacts are most apparent during the cooling season, when buildings with energy efficient envelopes have about 20% lower loads. Although calculations were not made, it is believed that most of the savings is due to the use of reflective glazing. During the heating season, the effect of this parameter is small except for Chicago where double pane glazing is used for the energy efficient building.

Reduction of the internal loads results in decreases in the cooling loads, but increases in the heating loads. Most of the energy savings associated with these parameters is associated with the reduction of the load itself.

Values of mean annual energy consumption are shown in Fig. ES3. Location is again important, and the effect of the small building is again demonstrated. The percentage differences of the electrical energy consumption values are not as large as those for the loads. This is because other components, such as lighting and office equipment which were not assumed to be dependent on building size, location, and HVAC system, are included in the electrical load. Natural gas consumption values show much greater dependence on these parameters since its use was assumed to be limited to space and domestic hot water heating.

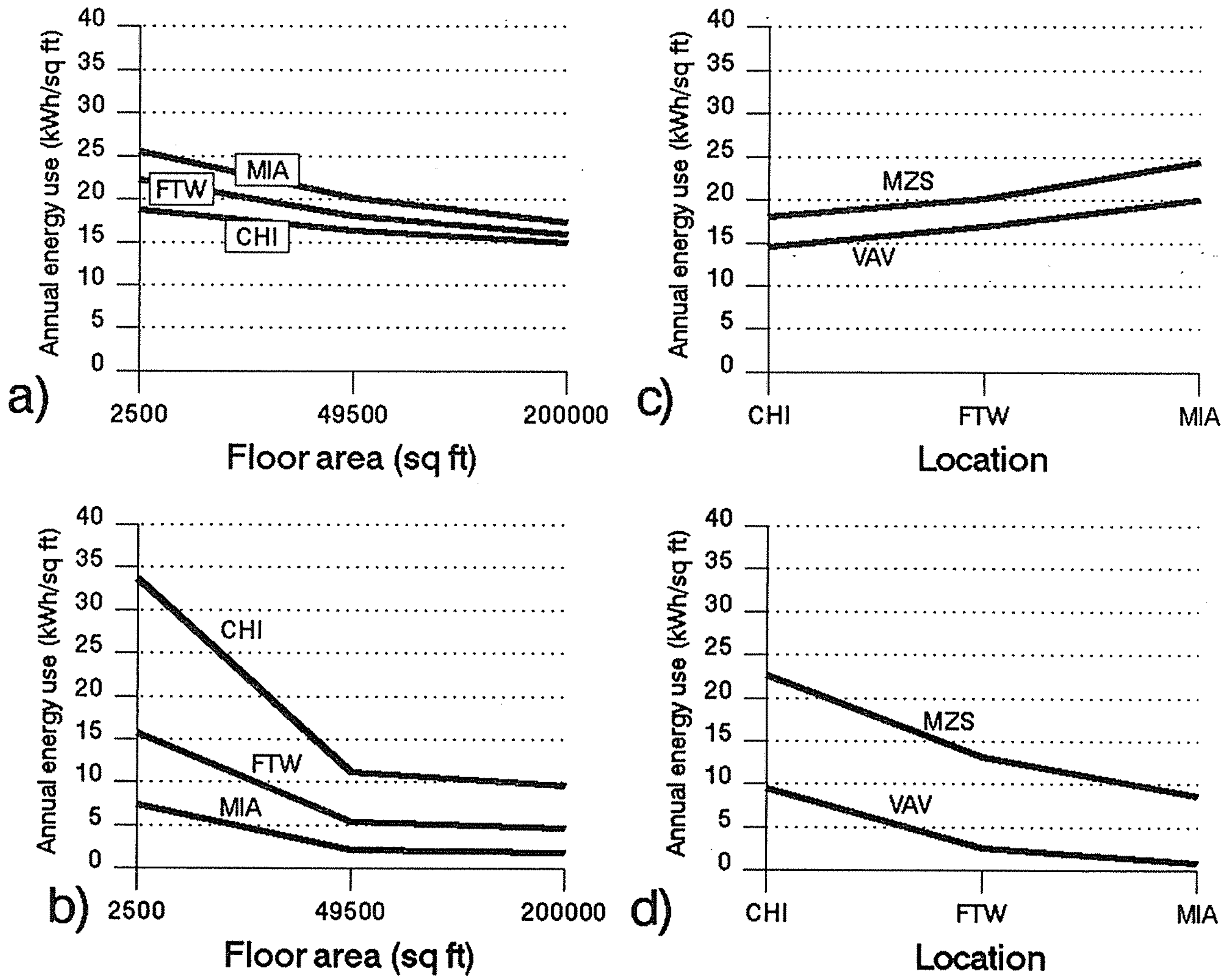


Fig. ES3. Mean annual building energy use: (a) electricity size by location; (b) natural gas, size by location; (c) electricity, location by HVAC system; (d) natural gas, location by HVAC system.

The impacts of the choice of the HVAC system are significant, as shown in Fig. ES3. Buildings using the specified variable air volume system use about 20% less electricity than those using the multizone systems. This reduction indicates the magnitude of savings that could be realized by not mixing hot and cold air at each conditioned zone and reducing power consumption by using variable air volume circulation fans. Significant natural gas savings could be realized also.

Mean values of annual average-to-peak ratios for electricity were calculated to be about 0.3. They are higher for the buildings located in Miami because of the more consistent cooling loads there. Buildings using variable air volume HVAC systems have about 10% to 20% lower ratios than the buildings using the multizone HVAC systems.

Breakdowns of the electrical energy consumption in selected buildings are shown in Fig. ES4. Lighting and office equipment are major components of the consumption values. However energy required for space cooling is large, particularly for the buildings located in Miami. HVAC system air circulating fan energy consumption ranges from 3 kWh/ft^2 to 4 kWh/ft^2. (The heating component is assumed to be the electricity required for the operation of the hot water boiler auxiliaries and hot water circulation loop pumps.)

Significant electrical energy savings could be realized by reducing the internal loads. Most of the savings is generally due to the reduced energy use by the load itself. Examples of this for the reduced occupancy/office equipment energy use are shown in Fig. ES4. For the medium and large buildings, reducing these loads resulted in about 10% decrease in the electrical energy consumption. About three-fourths of this decrease is due to reduced energy consumption by the office equipment. The remaining decrease is due to the decreased energy consumed by the fans and cooling equipment.

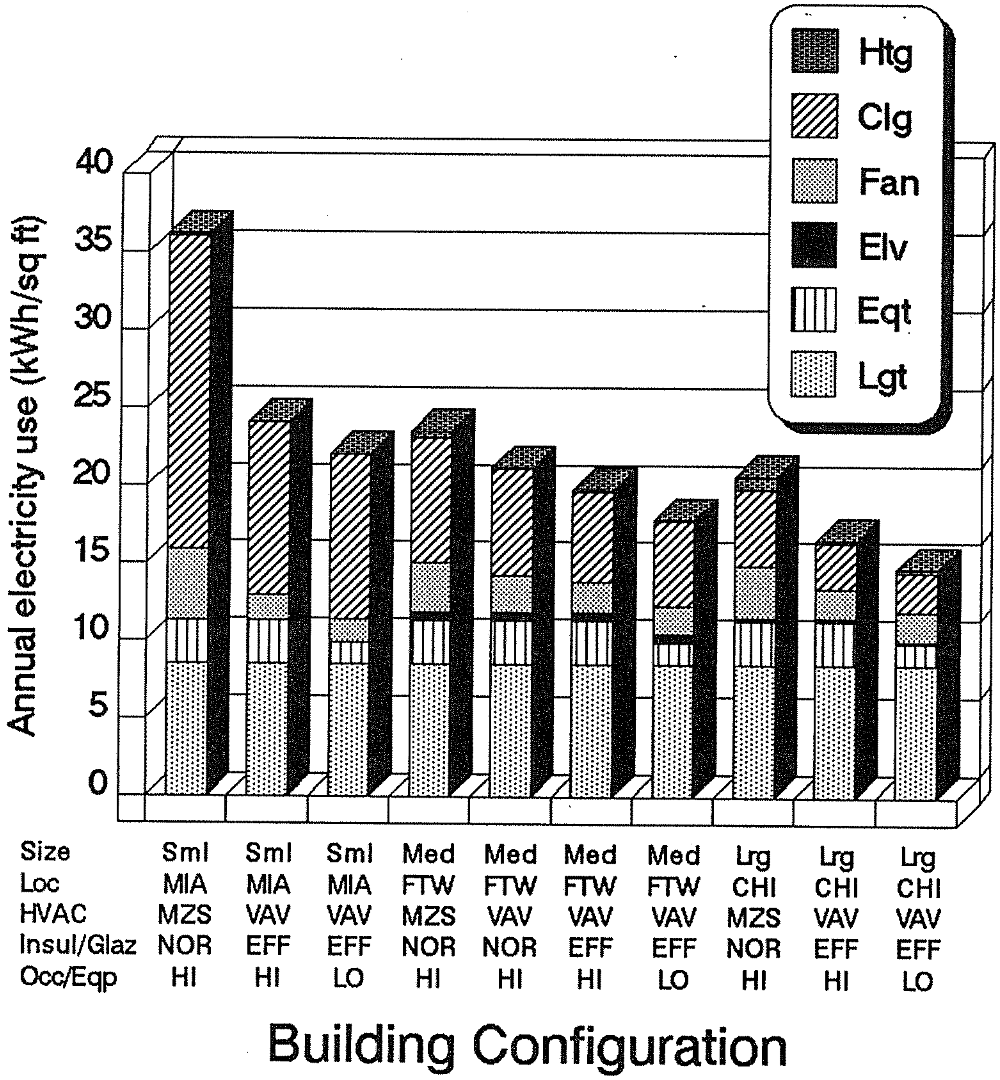


Fig. ES4. Electricity use components for selected buildings. See Table ES1 for meanings of abbreviations. All selected buildings have no HVAC economizer, 20% minimum ventilation rate, and 3 W/ft^2 lighting power.

Examination of the hourly energy use data indicated that generally the peak heating loads occurred at the beginning of the working days when the HVAC system is started. The cooling loads generally peaked during late afternoon. For the week, the loads are frequently higher during the first working day, which reflects the thermal mass of the building.

ENERGY COSTS

Annual energy costs for selected buildings are given in Fig. ES5. The effect of climate is relatively small for the locations investigated. Although use of natural gas is much higher in the colder climates, the fact that the gas prices are much lower than the electricity prices (1985) helps to minimize the differences in the energy costs. Per unit floor area, the energy costs for the small building are higher than for the other buildings because of the higher heating and cooling loads for these buildings. Except for the small building in Miami, the electricity demand charges are 35% to 50% of the total electricity charges. (For small commercial customers in Miami, there is a small customer charge instead of a demand charge.)

The magnitudes of the energy cost reductions associated with some of the parameters are shown in Fig. ES5. Switching from multizone HVAC systems to variable air volume HVAC systems results in reduction of electrical energy and natural gas charges, but there is little change in the electrical demand charges. This is because there is not much difference between the peak demands for the two systems.

GENERAL RESULTS AND CONCLUSIONS

A library of data files listing the hourly values of the end-use energy for commercial office buildings were generated in this investigation. The fractional factorial design was effective in gaining an understanding of building energy consumption with a minimum of computer calculations.

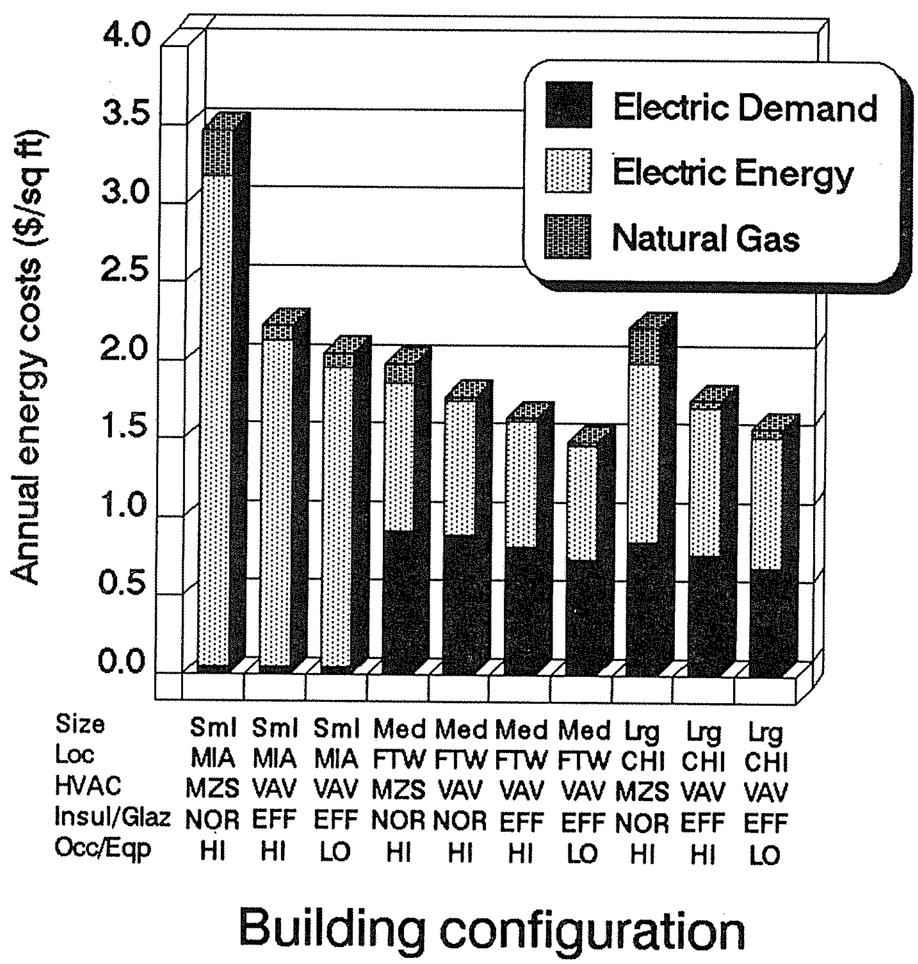


Fig. ES5. Annual energy costs for selected buildings. See Table ES1 for meanings of abbreviations. All selected buildings have no HVAC economizer, 20% minimum ventilation rate, and 3 W/ft^2 lighting power.

Building size, location, and HVAC system type have major impacts on building energy use. Two parameter interactions that included these parameters were found to be important. Per unit floor area, the energy use values in the small building are greater than those in the medium and large buildings. The differences between the values for the latter two size buildings are much smaller. A separate investigation for buildings having floor areas less than 8000 ft^2 would be useful.

Building location is important for the annual heating load, peak heating load, and annual cooling load. It is of less importance for the peak cooling load.

The type of HVAC system greatly impacts the energy use values. The two systems investigated are somewhat the extremes used in buildings, and the differences were apparent. The peak cooling loads are about the same for the two systems, since they operate about the same way for this situation. At other times, the two systems operate differently, which influences the energy use rates. Since these rates are climate dependent, this suggests that the optimum choice for the specific types of HVAC systems for a building is dependent on the building location. Future work should be done in this area.

The impacts of HVAC system economizers were limited and should be studied further. Reducing the minimum air ventilation rates generally resulted in some energy savings. Building insulation and glazing significantly impact the loads, particularly the cooling loads. It is believed that most of the difference is due to the glazing, although calculations were not made to confirm this.

Buildings in Chicago consume the greatest amounts of natural gas and those in Miami consume the greatest amounts of electricity in this study. The effect of location on the total energy costs (1985 rate schedules) are not as large as the energy differences. In general, cost savings could be realized by reducing electrical consumption at the expense of using natural gas.

Average-to-peak electrical use ratios are about 10% to 15% lower for buildings using variable air volume systems than those using multizone systems. This is reflected in energy costs, where buildings having the variable air volume systems have lower electrical energy charges, but about the same demand charges. There are opportunities for lowering demand cost by using energy storage techniques or alternative energy supplies. These options should be investigated further.

Internal load reduction results in lower energy consumption and costs. Most of the savings is due to the direct effects of the decreased loads. There are heating load increases associated with the internal load reduction, but the overall impact is generally beneficial.

REFERENCE

1. MacDonald, J. M., "A Research Plan for Commercial Sector Retrofits," p. 3.106 in Proceedings from the ACEEE 1986 Summer Study on Energy Efficiency in Buildings: Large Building Technologies, 1986.

AN ANALYTICAL INVESTIGATION OF ENERGY END-USE IN COMMERCIAL OFFICE BUILDINGS

1. INTRODUCTION

1.1 BACKGROUND

Energy use in commercial buildings has been receiving considerable attention recently. These buildings consumed about 5.7 quads (5.7×10^{15} Btu) of energy in the U.S. during 1984.[1] This is equivalent to about 12 quads of primary energy, which is about 15% of the nation's primary energy consumption and represents an annual expenditure of about $70 billion.[2]

During the past 15 years, conservation trends resulted in a 16% decrease in the end-use energy consumed in these buildings per unit area, but the primary energy consumption per unit area did not decrease significantly. The total energy consumption for the sector has increased due to a continuous expansion of the commercial building floor area. Moreover, the cost of energy for these buildings has increased 96% in constant dollars during this same period. This partially reflects the increased use of electrical energy in these buildings.[2]

In addition to consuming large quantities of energy, commercial buildings often have an important impact on electric utility load profiles.[3,4] Since many commercial buildings are occupied and used for limited periods of time, e.g., 8 a.m. to 5 p.m. during weekdays, their contribution to daytime peaks can be pronounced. Commercial building cooling requirements can account for as much as 40% of an electric utility's peak demand.[5] Many utilities include demand charges, in addition to the consumed energy charges, in their commercial rate structures to reflect the cost of meeting peak power demand.

There appear to be substantial opportunities to develop the commercial building energy conservation resource. Estimates have been made that perhaps 20% of the energy consumed by commercial buildings can be saved through energy conservation. This is equivalent to a potential annual savings of 2 quads of primary energy and $15 billion energy costs.[6]

In addition to the annual energy savings, there are potential benefits for the utilities and, ultimately, the consumer in developing measures that will smooth the commercial building energy demand profiles. Considerable work has been done in this area, such as using daylighting for illumination and ice or cold water storage for air conditioning. There are also other opportunities in this area, including cogeneration or alternative mixes of supply energy.

This analysis was directed towards understanding energy measures in existing buildings. Considerable work has been done analyzing annual energy use in buildings having different thermal envelopes and heating, ventilating, and air conditioning (HVAC) equipment for the development of new energy conservation standards.[7,8,9] However, those studies concentrated on predicting annual energy use in new buildings designed to meet the new standards. This investigation examined energy use in buildings having older types of construction and HVAC systems. Previous analysis of the annual energy use in typical, existing, small commercial buildings was made for the Commercial and Apartment Conservation Service (CACS) Program.[10,11] Another study, sponsored by the Northeast Utilities, surveyed end-use energy consumption for office buildings in northeastern United States.[12] In that study, typical energy use profiles were generated using an hourly computer program with data based on the survey results.

1.2 PURPOSE

The purpose of this study was to perform a preliminary analysis of office building end-use energy consumption characteristics. This is not a complete in-depth study, but rather an initial study to gain some understanding of the annual and hourly energy consumption in these buildings. It is a limited parametric study to help to determine the key variables influencing the building heating and cooling energy demands. In order to ascertain the importance of different parameters, the building construction and operation were assumed to be similar for all buildings in all cities. A secondary purpose of this study was to create a library of simulated hourly data files for heating, cooling, and other end-use energy consumed in office buildings.

The reason this study focused on office building end-use energy is that office buildings have a large subsector in the functionally diverse commercial building sector (Fig. 1.1).[1] The end-use energy consumed by this group is the greatest of any group in this sector (Fig. 1.2).[1]

1.3 APPROACH

An analytical approach was used to generate the hourly end-use energy values. The DOE-2.1B building simulation program[13] was used to generate these values. Input data files for three different size buildings were generated from data presented in the literature, discussions with knowledgeable people, and DOE-2.1B program data files. Typical Reference Year (TRY) weather data for Chicago, IL, Fort Worth, TX, and Miami, FL[14] were used in the calculations.

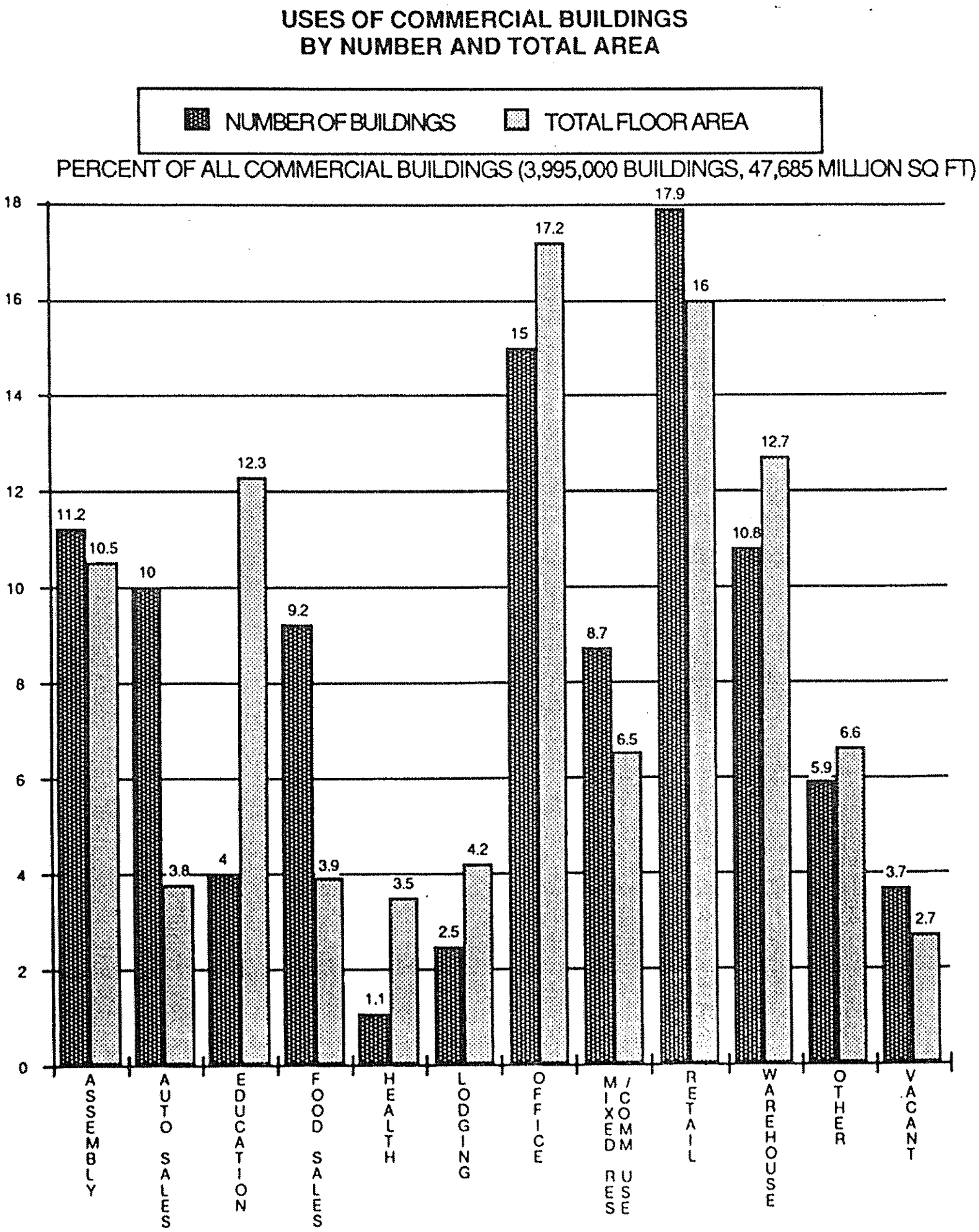


Fig. 1.1. Number and total floor area distribution of commercial buildings by building type.

Source: J. R. Brodrick, Commercial Buildings Energy Consumption and Natural Gas Markets, Gas Research Institute Report, June, 1986.

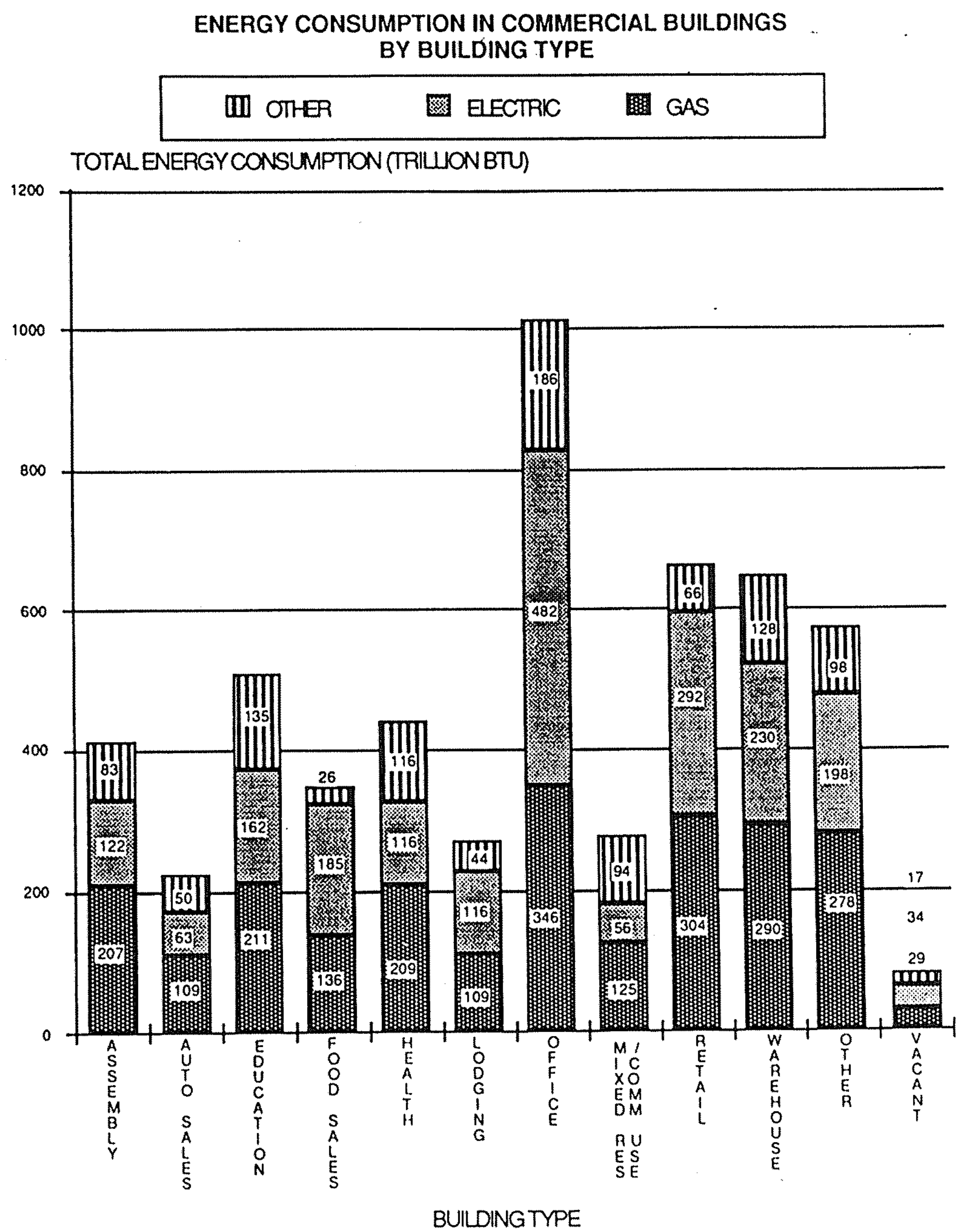


Fig. 1.2. End-use energy consumption in commercial buildings by building type.

Source: J. R. Brodrick, Commercial Buildings Energy Consumption and Natural Gas Markets, Gas Research Institute Report, June, 1986.

A fractional factorial design[15] was used to specify the different parameter combinations for the DOE-2.1B calculations. This design allows for the determination of the importance of different parameter "levels" and their interactions using a minimum number of DOE-2.1B calculations. (The term "levels" is the number of versions of a parameter, e.g., a three-level parameter for climate could have the levels, Chicago, Fort Worth, or Miami.) The design assumes that the effect between parameter levels is linear and that the higher order interactions are not significant. While these two conditions were not completely true for this study, the design is sufficient to identify the important parameters and two factor interactions.

Comparisons were made of the mean values of energy consumption per unit floor area as a function of the different parameter levels. Because of the assumption of linearity and not all the basic parameter levels were not specified as numerical values, e.g., multizone versus variable air volume HVAC systems, the effect of the parameters should be regarded as semi-quantitative. They do, however, indicate the magnitudes of the energy that would have been used in the buildings and the impacts of the parameter levels on these magnitudes.

A post-processing computer routine was used to extract and reformat the desired data from each of the DOE-2.1B output files. In addition, the implied electric and gas utility costs were calculated from predicted hourly data using the commercial building utility rates for each city investigated.

1.4 TOPICAL ORGANIZATION

This report presents the methodology used to predict the end-use energy for buildings and an analysis of the predicted results. The approach and the methodology used to generate and analyze the energy values are described in Sect. 2. Building and weather input data used for this investigation are given in Sect. 3. Section 4 presents the predicted end-use energy values for the buildings and an analysis of the values. The impact of the energy use values on the energy costs for the buildings is addressed in Sect. 5. The conclusions of this investigation, together with some recommendations, are given in Sect. 6.

2. APPROACH AND CALCULATION PROCEDURE

2.1 OVERALL APPROACH

The thrust of this study was to gain an understanding of the end-use energy characteristics of commercial office buildings. The DOE-2.1B building simulation program[13] was used to calculate the building end-use energy values. Since the energy values are dependent on many parameters, the best approach for selecting the independent parameters is to use the fractional factorial design. This procedure has the advantage of determining the importance of a large number of factors using a minimum number of DOE-2.1B calculations.[15]

The fractional factorial design is based on the assumption that the magnitude of the effects of different parameters tend to follow a hierarchy. The parameter direct effects are assumed to be the largest; two parameter interactions are the next largest; and so on with the total parameter interactions being the lowest. This approach can be thought of in terms of a Taylor series expansion of a response function. The direct effects represent the first order terms of the expansion, the two-factor interactions represent the second order terms, and so on. Frequently, the higher order terms of a Taylor series are ignored since they contribute very little to the value of a function when compared to the first and second order terms. The same approach is used in fractional factorial design, where the higher order interactions are assumed to be negligible.[15]

The DOE-2.1B program was used to calculate the hourly and annual end-use energy values for the cases selected using the fractional factorial design. A post-processing routine was written for extracting the desired energy data and reformatting the data for permanent storage. Subroutines for calculating the utility billing costs from the hourly energy values were incorporated in the post-processing routine.

The importance of parameter direct effects and two-parameter interactions were evaluated using linear regression relations and by examining the mean energy values across the levels of the parameter or interaction. Plots of the annual and the hourly end-use energy data were made to help interpret the results.

2.2 PARAMETERS INVESTIGATED

The specific energy use components and costs that were investigated are listed in Table 2.1. The total amounts of electricity and natural gas required for the operation of the building were determined, as well as the different components of the electrical energy use. Natural gas was assumed to be used for heating, but a limited amount of electricity is required for operation of heating equipment auxiliaries -- such as the supply air fans. Both the total heating and cooling and the space heating and cooling requirements were calculated. The difference between the total and the space values reflects domestic hot water (DHW) heating and heat losses and gains in the circulating water loops that transport energy from the primary equipment to the air-handling units (AHUs).

From the energy consumption values, the resultant implied electricity and natural gas costs were calculated using the 1985 utility rate schedules for the cities considered. The electrical schedules include both demand and energy consumption charges.

Table 2.1. Predicted end-use energy components and costs.

Annual and Hourly Values	
Electricity	Natural Gas
Total	Total*
Heating	
Cooling	
Fans	
Lights	
Equipment	
Elevators	
Heating	Cooling
Total	Total
Space	Space
DHW	
Annual and Monthly Values	
Electricity	Natural Gas
Consumption	Consumption
Demand	Cost
Cost	

*Mostly used for space heating, but includes some energy for domestic hot water use.

Independent parameters selected for this analysis are listed in Table 2.2. These are discussed in more detail in Sect. 3. To facilitate the handling of the computer runs, a nine digit building configuration identifier, shown in Fig. 2.1, was devised. For example, "200,000,000" shown in the figure, is for a large building, located in Chicago, having a multizone air-handling system with no economizer, 20% minimum building ventilation, high occupancy, and normal construction and lighting power.

2.3 DOE-2.1B PROGRAM

The DOE-2.1B program is a public domain computer program that describes the flow of energy in a building and the associated equipment on an hourly basis. The program uses detailed data for the building geometry and construction, for the HVAC systems, and for the weather to predict the energy flows in the building. Internal heat loads in the form of people, lights, and equipment are incorporated in the energy flow description.

The program uses the transfer function method to describe the flow of heat through the building components and to and from the HVAC systems. Heat flow through all the internal and external surfaces is assumed to be one-dimensional. Although one-hour time steps are generally satisfactory for the simulation, there are some phenomena, such as thermostat setback, which have smaller time constants. The program incorporates averaging algorithms that correct for these situations.[16] Details of the program algorithms are presented in the engineers' manual for the program.[17]

The program uses a sequential approach to calculate the energy consumption. It first calculates the heat loss or gains in each building zone assuming that the temperature in each zone is set to a

Table 2.2. Selected independent parameters.

A_1* Building Size	
$A_1 = 0$	2,500 ft^2
$= 1$	49,500 ft^2
$= 2$	200,000 ft^2
A_2 Location	
$A_2 = 0$	Chicago, IL
$= 1$	Ft. Worth, TX
$= 2$	Miami, FL
A_3 HVAC System	
$A_3 = 0$	Multizone System (Low Efficiency)
$= 1$	Variable Air Volume System (High Efficiency)
A_4 HVAC Economizer	
$A_4 = 0$	No economizer
$= 1$	Temperature controlled economizer; 62°F temperature limit
A_5 Minimum Ventilation	
$A_5 = 0$	20%
$= 1$	5%
A_6 Lighting Power	
$A_6 = 0$	Normal (3 W/ft^2)
$= 1$	Reduced (1.6 W/ft^2)
A_7 Occupancy and Equipment Power	
$A_7 = 0$	High (10 people/1000 ft^2 in the perimeter areas and 5 people/1000 ft^2 in the core areas, 1 W/ft^2 equipment)
$= 1$	Low (4 people/1000 ft^2, 0.5 W/ft^2 equipment)
A_8 Envelope Construction and Glazing	
$A_8 = 0$	Normal
$= 1$	Energy efficient

*A_1, etc., stands for digit 1, etc., in the configuration identifier.

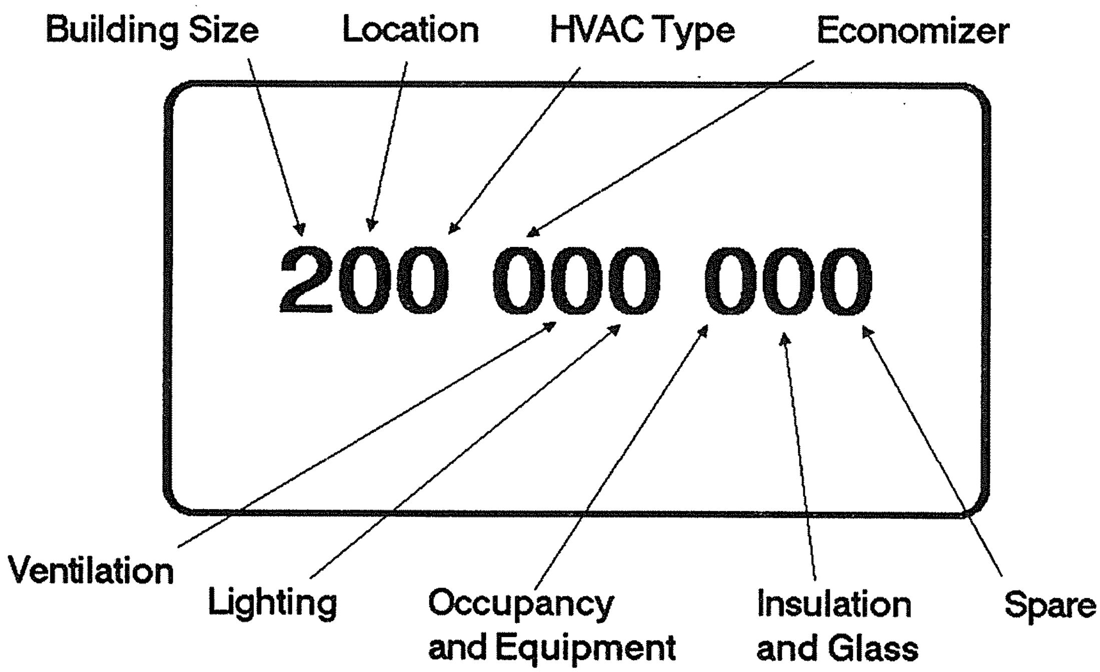


Fig. 2.1. Building configuration identifier scheme.

fixed value specified by the user of the program. In this part of the program, called LOADS, the quantity of heat that must be added to or extracted from each zone to maintain the specified temperature is calculated. This calculation accounts for the building mass, internal load conditions, and weather effects.

The heat load data predicted in LOADS is passed to the next part of the program, called SYSTEMS, where the actual amount of heat added or extracted from each building zone by the air-handling system is calculated. In this step, the air temperature in each zone is allowed to vary while accounting for the building mass, air-handling equipment performance characteristics, time-varying temperature controls, and HVAC equipment operating schedules.

Unless primary equipments are packaged units, such as self-contained HVAC units, the total amount of heat added or extracted by the air-handling systems is passed to the next section of the program, called PLANT. In this part of the program, the fuel requirements for the primary equipment, such as boilers or chillers, are calculated while accounting for the performance characteristics of the primary equipment. For packaged units, this is done in the SYSTEMS part of the program.

There is a fourth part of the program, called ECONOMICS, which addresses the cost aspects of the equipment, fuel, and labor. This part of the program was not used in this study. Instead a post-processing routine was written to calculate the energy costs based on the rate schedules for each city investigated.

The DOE-2.1B program is designed to accept detailed input data regarding the building geometry and construction and HVAC design and performance characteristics. Many of these data do not have to be specified to use the program. In these cases, the program can draw upon its library of default data and routines to fill in the missing input data. The default data and relations were used to describe the performance characteristics of the HVAC equipment.

2.4 POST-PROCESSING ROUTINE

The post-processing routine mentioned above was written to extract the desired data from the DOE-2.1B program output file, calculate the implied utility billing costs, and reformat the data for storage. Typically, each DOE-2.1B output file in this study required about 6.5 Mbytes of disk storage space. The reformatted files require about 1 Mbyte.

The billing costs were calculated from the hourly energy use data and the rate schedules for each city investigated. Demand charges and time-of-day pricing were included in the calculations, when applicable.

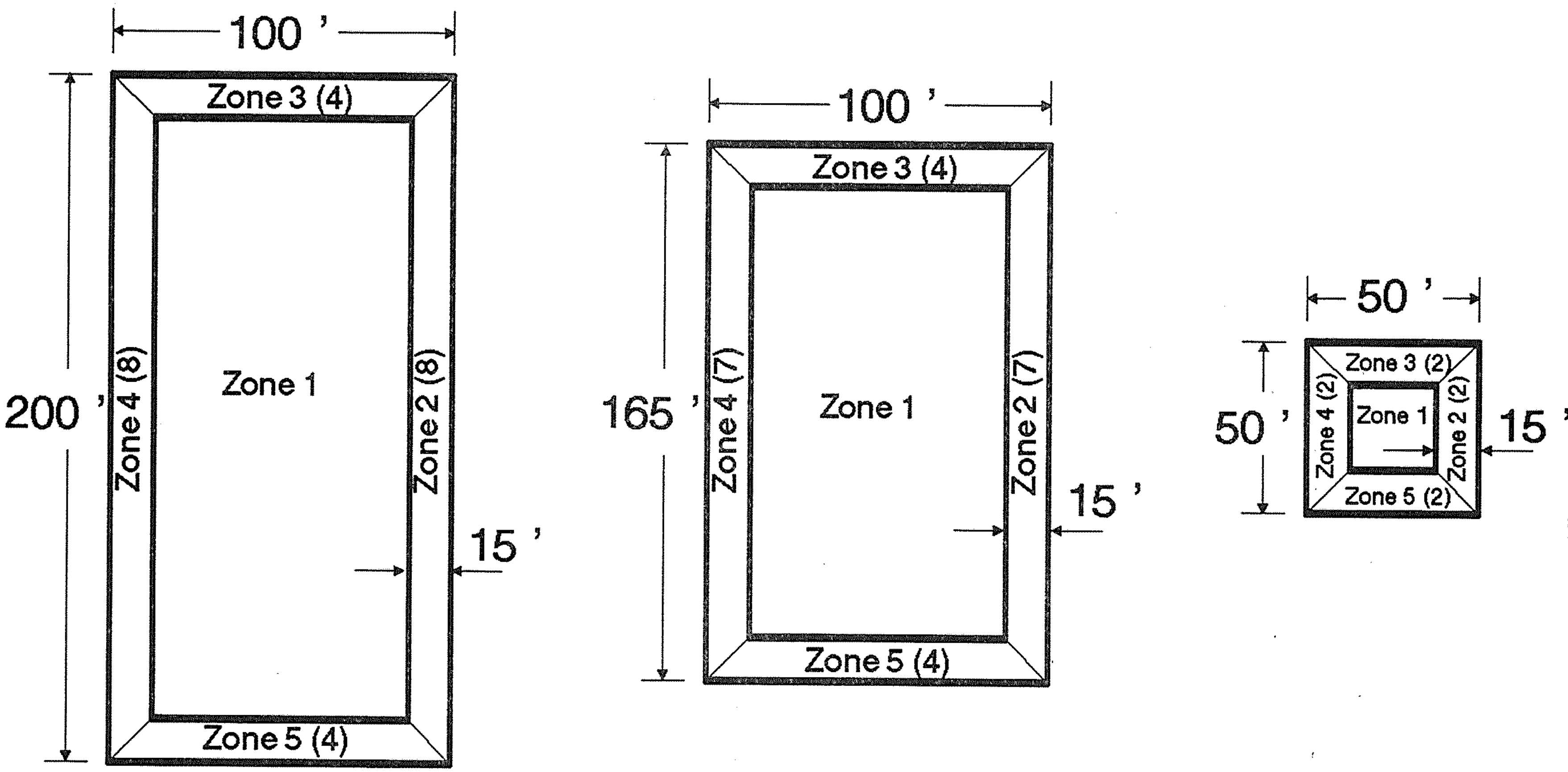
3. BUILDING, WEATHER, AND ENERGY COST DATA

Hourly energy consumption values were calculated for each of three sizes of office buildings located in three different climate regions. The general building construction and internal loads per unit floor area were kept the same in order to determine the influence of the building size and climate on energy consumption. The DOE-2.1B input files used for the calculations are listed in Appendix A. The salient points of the data are described below. In addition, price schedules used for electricity and natural gas are presented.

3.1 BUILDING GEOMETRY

The buildings selected for this study were designated as the large office building, the medium office building, and the small office building. These buildings have floor areas of 200,000 ft^2, 49,500 ft^2, and 2,500 ft^2, respectively. Schematic floor plans for these buildings are shown in Fig. 3.1.

The large office building is a 10-story structure, with each floor measuring 100 ft by 200 ft. This building is a modification of the 32-story office building described in the DOE-2 Sample Run Book.[18] The building is built at ground level on a slab. Floor-to-floor height is 12 ft, which includes a 3-ft-high ceiling plenum. For simulation purposes, it was assumed that each floor is divided into five zones. These are an interior zone and four exterior zones, each having a 15-ft depth. The exterior zones were subdivided to better model the thermal behavior, and the number of subdivisions are shown within the parentheses in Fig. 3.1.



(a) Large 10 story building

(b) Medium 3 story building

(c) Small 1 story building

Fig. 3.1. Office building floor plans and zone definitions.

The medium office building is a 3-story structure, with each floor measuring 100 ft by 165 ft. This building is a free interpretation of the medium office building simulated in the energy conservation standards program.[9] Other geometrical features of the building are similar to those for the large building described above.

The small office building is a 1-story structure, measuring 50 ft by 50 ft. Again, this building is a free interpretation of the small office building simulated in the energy conservation standards program.[9] The remaining geometrical features of the building are again similar to those for the large building.

3.2 BUILDING CONSTRUCTION

As stated earlier, all buildings were assumed to have similar construction. This was done to eliminate the effect of this parameter on the impacts of the building size and location. Two levels of building insulation, designated as normal construction and energy efficient construction, were specified. The normal construction specification is typical for office buildings constructed after World War II. The energy efficient construction specification includes more insulation to the building exterior envelope and the use of reflecting and/or double-pane glazing. The latter specification easily meets the criteria stated in the 1980 ASHRAE building design standard.[19]

The components of the building construction are summarized in Table 3.1. These specifications were selected after reviewing building construction data for the selected buildings in the Building Energy Performance Standards (BEPS) program,[7] the commercial building conservation standards program,[8,9] and the CACS program.[10]

Table 3.1. Building construction components.

Component	Thermal resistance, h-ft²-F/Btu Normal	Energy Efficient	
Exterior Wall			
Outside surface	0.17	0.17	
4 in. lightweight concrete	1.60	1.60	
R-11 mineral wool insulation	-	11.83	
Airspace	0.92	0.92	
5/8 in. gypsum board	0.56	0.56	
Inside surface	0.68	0.68	
	3.93	15.76	
Windows (30% wall surface)			
Outside surface	0.17[a]	0.17[b]	0.17[c]
Glazing	0.04	1.06	0.04
Inside surface	0.68	0.68	0.68
	0.89[a]	1.91[b]	0.89[c]
Roof			
Outside surface	0.17	0.17	
1/2 in. roof gravel	0.05	0.05	
3/8 in. built-up roofong	0.33	0.33	
1 in. fiberboard insulation	2.78	2.78	
3 in. expanded polystyrene	-	12.50	
4 in. heavyweight concrete	0.44	0.44	
Metal form	-	-	
Inside surface	0.61	0.61	
	4.38	16.88	
Ground Floor			
2 1/2 ft earth	5.00	5.00	
4 in. heavyweight concrete	0.44	0.44	
Carpet and pad	2.08	2.08	
Inside surface	0.61	0.61	
	8.13	8.13	

[a]Single-pane glazing with 0.79 transmittance and 0.07 reflectance.

[b]Double-pane glazing with 0.35 transmittance and 0.08 reflectance in Chicago.

[c]Single-pane glazing with 0.20 transmittance and 0.45 reflectance in Fort Worth and Miami.

Table 3.1. (continued)

Component	Thermal resistance, h-ft^2-F/Btu Normal	Energy Efficient
Interior Wall		
Surface	0.68	0.68
5/8-in. gypsum board	0.56	0.56
Air layer	0.89	0.89
5/8-in. gypsum board	0.56	0.56
Surface	0.68	0.68
	3.37	3.37
Ceiling		
Surface	0.92	0.92
Acoustic tile	1.26	1.26
Surface	0.61	0.61
	2.79	2.79
Floors Above Ground Level		
Surface	0.61	0.61
4-in. heavyweight concrete	0.44	0.44
Carpet and pad	2.08	2.08
Surface	0.92	0.92
	4.05	4.05

The external walls of the buildings are constructed of lightweight concrete, and 30% of the wall area is glazed. All the floors are 4-in. ordinary concrete covered with a carpet. The roofs are flat 4-in. ordinary concrete slabs with insulation and built-up roofing on the exterior surface. Gypsum board is used as the material of construction for all exterior wall inner surfaces and all interior walls. The conditioned spaces and the ceiling plenum on each floor are separated by acoustical tile.

Windows for the buildings having the normal construction are glazed with ordinary, single-pane, glass. For energy efficient construction, the glazing depends on the location. In Chicago, the buildings have double-pane, reflective glazing. In Fort Worth and Miami, they have single-pane, reflective glazing. This is typical of current office building construction in the southern part of the United States, where the double-pane windows tend to result in higher air conditioning loads in the buildings.

The windows have movable drapes. In the simulation, it was assumed that they would be closed when the magnitude of the solar energy transmitted through the windows is greater than 100 Btu/h. When they were closed, the transmitted solar energy was reduced by 35%. It was further assumed that the drapes did not influence the heat transmitted by conduction through the windows.

3.3 INTERNAL LOADS

The internal load specification is an important part of the office building simulation, since it is known that energy consumption in this type structure is strongly dependent on the building use and schedule.[3,9] Lighting and office equipment are large portions of the building's energy demand. Furthermore, reduced internal loads imply increased heating loads and decreased cooling loads.

The peak internal loads assumed for this study are listed in Table 3.2, and the load schedules are shown in Fig. 3.2. These loads were selected after reviewing the data presented in the literature[20-22] and the data summarized in a Gas Research Institute sponsored study.[23] The assumed schedules are slight modifications of those presented in the energy conservation standards study.[20]

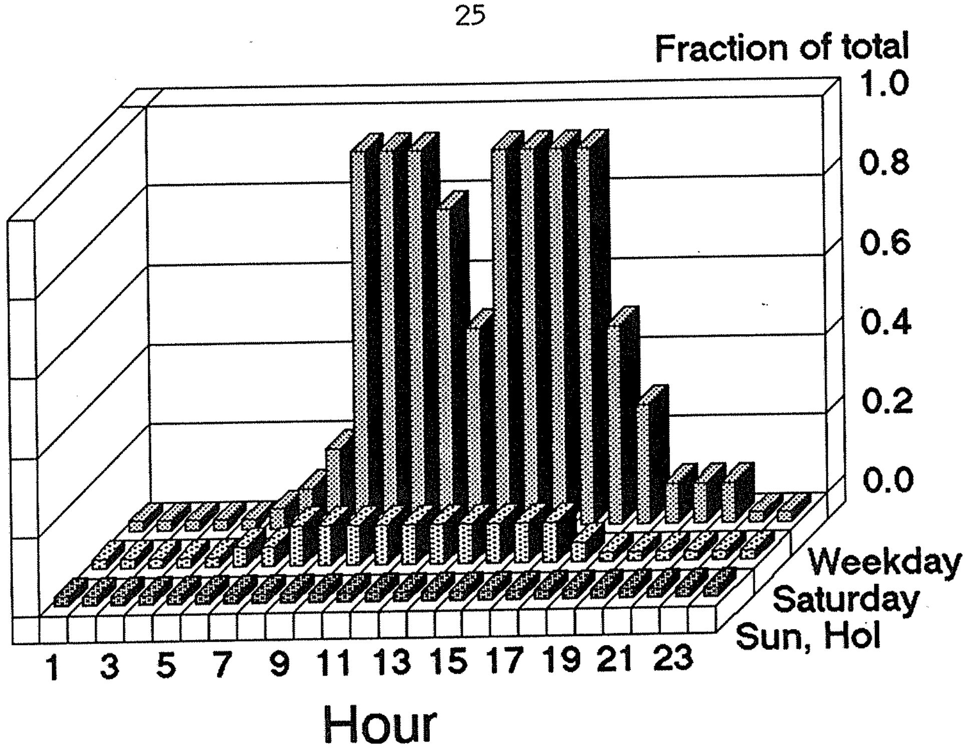
Occupancy of buildings varies depending on their use. The national average for office buildings is 3.75 people/1000 ft^2, but it varies from 1 to 10 people/1000 ft^2.[23] In the high density occupancy case, shown in Table 3.2, it was assumed that the density is higher in the areas along the building perimeter. Total, sensible and latent, heat rate generation by each individual was assumed to be 450 Btu/h.

Lighting power in office buildings generally varies from 2 to 3 W/ft^2. Using daylighting and efficient task lighting, it appears possible to reduce this to about 1.6 W/ft^2. Therefore, the extremes of 3 W/ft^2 and 1.6 W/ft^2 were investigated. The lights were assumed to be recessed fluorescent fixtures with 80% of the generated heat transferred to the conditioned spaces and the remainder transferred to the return air plenums. The 80% value was increased to 90% for the efficient lighting situation, since the individual task lights probably would be located within the conditioned spaces.

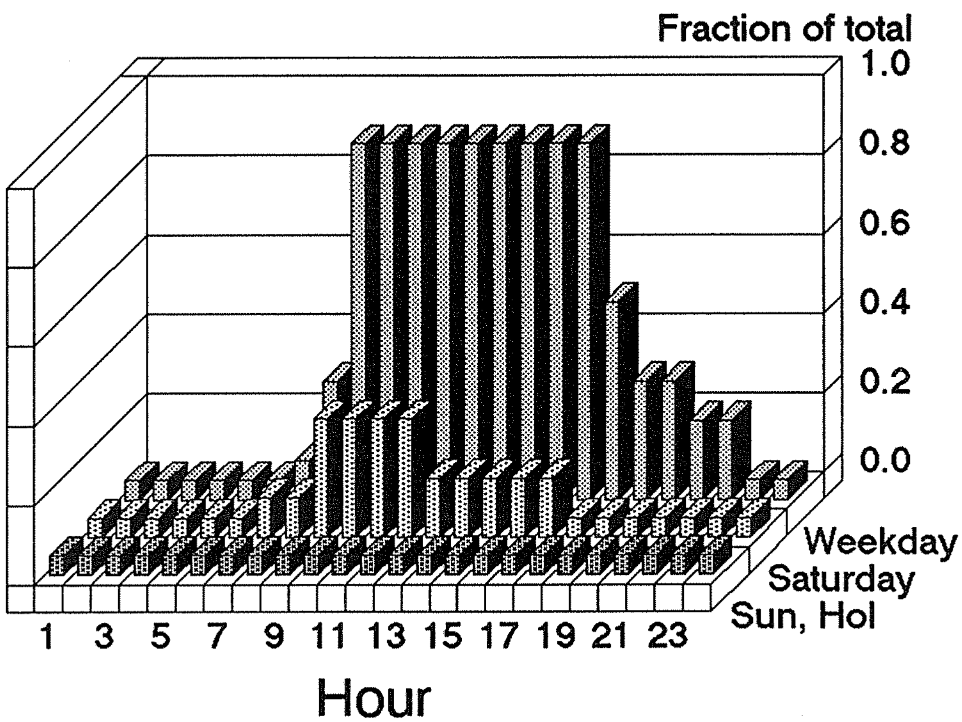
Office equipment typically adds 0.5 to 1 W/ft^2 to the power levels in office areas. With the advent of electronic office equipment, this value has been increasing. A value of 1 W/ft^2 was assumed for the high occupancy case and 0.5 W/ft^2 for the low occupancy case. These values do not include any heat generated by a large mainframe computer. Such computers often are located in the large office buildings and generate 15 to 150 kW of heat.[12] However, they are generally in constant use and have a dedicated HVAC system for heat removal.

Table 3.2. Peak internal loads.

Type	High	Low
Occupants, people/1000 ft^2		
Core	5	4
Perimeter	10	4
Lights, W/ft^2	3	1.6
Fraction heat in conditioned space	0.8	0.9
Equipment, W/ft^2	1	0.5
Domestic hot water, Btu/h		
Large building	100,000	100,000
Medium building	25,000	25,000
Small building	3,000	3,000
Elevator, kW		
Large building	25	25
Medium	18	18

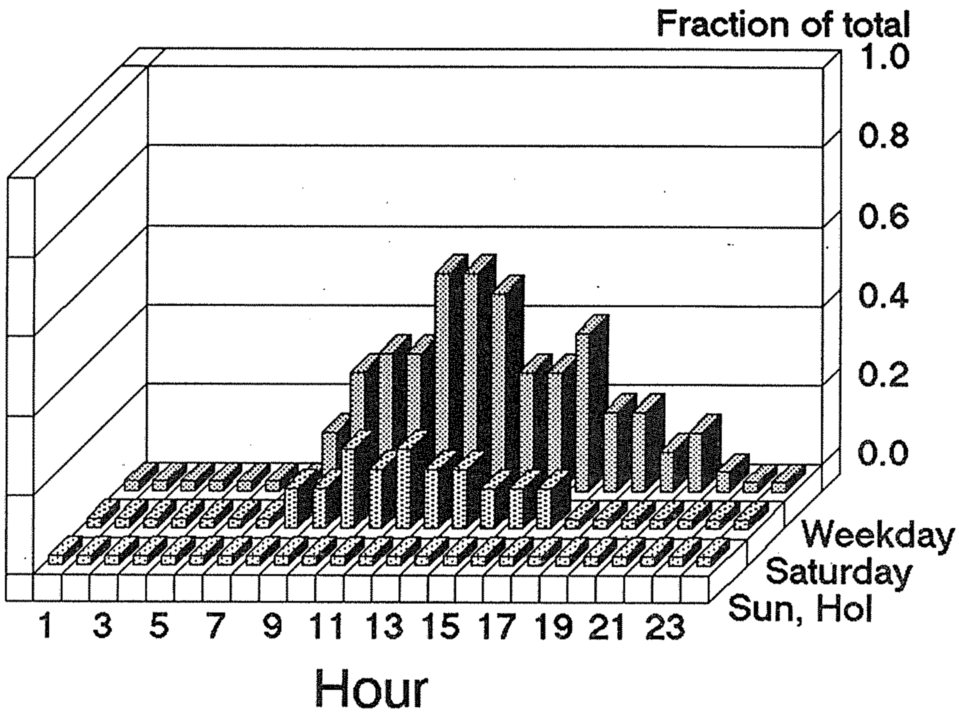


(a) Occupancy and equipment

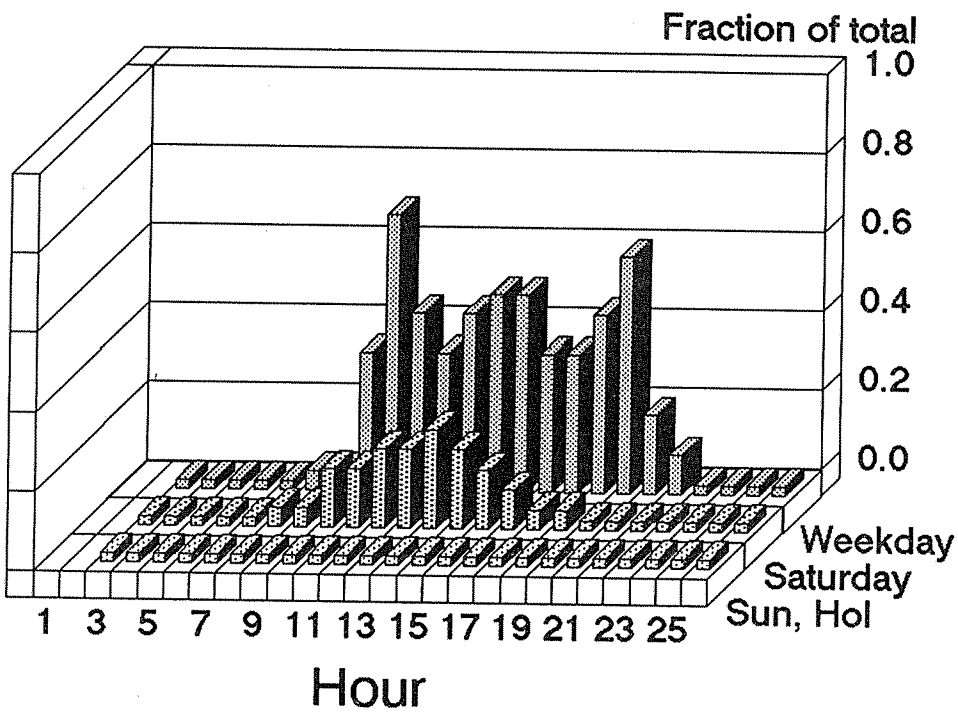


(b) Lighting

Fig. 3.2. Internal load schedules.



(c) Domestic hot water



(d) Elevators

Fig. 3.2. Internal load schedules (continued).

Energy is used for domestic water heating and elevator operation. These contribute to the building's energy demand but not to the HVAC system load. This is because they are generally located outside conditioned space areas. For the domestic hot water systems, the heating units were sized on the criterion that each occupant consumes 1 gallon of domestic hot water per day.

Energy consumed by the elevators depends on the type of the installed elevator. Hydraulic elevators have the lowest initial cost, but are less efficient. Elevators in tall buildings are generally counterweighted to increase their efficiencies, as well as to reduce the instantaneous loads. Some of these are fitted with electric regeneration units to further increase their efficiencies. It was assumed in this study that the medium office building was equipped with a single hydraulic elevator, and that the large office building was equipped with four counter-weighted elevators equipped with electric regeneration units.

3.4 HEATING/COOLING SYSTEMS

Space heating and cooling systems for the buildings are varied. Built-up systems using central heating and cooling units are commonly used in larger buildings while packaged unit installations are more common in smaller buildings. The AHUs in the buildings are also varied. Dual duct systems, having hot and cold decks, were common until energy costs started to escalate in the 1970's. Since then, variable air volume systems, having variable circulating air flow rates have come into favor. Direct radiation, fan coil, and induction systems have been installed in many buildings, particularly in perimeter areas.

For this investigation it was assumed that the HVAC system was either a multizone dual duct system or a variable air volume system. For the multizone system there is a thermostat in each conditioned zone that regulates the mix of the hot and cold air entering that zone. The variable air volume system uses only a single duct and is fitted with a terminal heating unit in each zone to help supply heat required to maintain the desired heating temperature. For both of these systems, a temperature controlled economizer option was invoked in some cases. Without this option, it was assumed that the amount of makeup air for the building is fixed.

The primary equipment for supplying and extracting heat to and from the air-handling systems selected for this analysis are typical of the type of equipment used for this purpose. For the large and medium buildings, heat is supplied to the air-handling and the DHW systems by a central gas-fired hot water boiler. For the small building, a gas-fired furnace is used for the multizone system and a gas-fired hot water boiler is used for the variable air volume system. A separate gas-fired heater is used to heat the water for the small building DHW system. It is recognized that small commercial buildings generally are heated and cooled by single-zone or packaged HVAC. For consistency in this investigation, however, it was assumed that a multizone or a variable air volume HVAC system is used in all buildings.

For the large building, cooling is supplied to the AHUs by four hermetic centrifugal chillers discharging heat to the atmosphere through cooling towers. For the medium building, two hermetic reciprocating chillers, discharging heat to the atmosphere through cooling towers, are used to supply cooling for the AHUs. Packaged direct expansion air cooled units are used for the small building HVAC systems. DOE-2.1B default values and relations[13] were used to describe performance characteristics of the HVAC equipment.

The primary equipment units were sized using design day weather data, given in Appendix A. The first step in sizing the HVAC equipment was to use the DOE-2.1B program to determine the circulating air flow rate in each building zone using the design day data. For this calculation, the design space temperatures were 72°F for heating and 76°F for cooling. The minimum air supply temperature was assumed to be 55°F, and the maximum air supply temperature was assumed to be 72°F in the building core zone and 105°F in the building perimeter zones. It was found that the highest circulating air flow rates were required during the cooling season, and the buildings in Fort Worth have the highest peak loads. It was assumed that the higher internal loads and outside air ventilation rates existed in the buildings for these calculations.

For the multizone air-handling systems, the circulating air flow rates in the perimeter zones were assumed to be a value slightly greater than those required using the Fort Worth design day weather data. It was assumed to be 0.7 cfm/ft^2 in the core zones. It was also assumed that for the three locations studied, the specified perimeter flow rate values are dependent on the building size and insulation level, but independent of the other parameters. The primary heating and cooling plants were then sized employing these specified circulating air flow rates in the DOE-2.1B program. These values were then increased by slightly more than 10% to approximate design practice.

For the variable air volume system, it was assumed that the minimum circulating air flow rate is 30% of the design values and terminal heating was available during the heating season, if required. The capacities of the terminal heating units were calculated by first determining the minimum circulating air flow rates required during the winter design day for a system having no terminal heating units. The terminal unit capacities were calculated from these values assuming that the minimum circulating air flow rate is at 30% of the design value. The heating and cooling plants were then sized using the same procedure as for the multizone system.

As is frequently done in practice, it was assumed that the HVAC systems operate only during working hours, except for the limited times when heat is supplied for freeze protection during the winter months. In this study, the HVAC systems (including the circulating air fans) were specified to operate from 6:00 a.m. to 6:00 p.m., Monday through Friday, except for holidays.

3.5 WEATHER DATA

Test Reference Year (TRY) weather data for Chicago, IL, Fort Worth, TX, and Miami, FL were selected for this analysis. These data represent a cold climate, a warm-dry climate, and a warm-humid climate, respectively.

TRY weather data were selected by the National Climatic Center for a number of cities from a 27-year log of hourly surface weather observations for these cities. The selection of the representative year for each of these cities was done by an elimination process discarding the years containing months with extremely high or low temperatures until one year record remained. The representative year is 1974 for Chicago, 1975 for Fort Worth, and 1964 for Miami. This process does not imply that the selected year data are typical for each city, but rather is a standard to be used for energy consumption comparisons.[13,14]

Surface weather observations normally do not include solar data. These data are estimated by the DOE-2 simulation program from the cloud cover data, included in the weather data, and the position of the sun.[18]

3.6 UTILITY RATE SCHEDULES

Utility rate schedules for commercial customers during the year 1985 are listed in Tables 3.3 and 3.4. These schedules are for Chicago, IL, Dallas, TX, and Miami, FL. These correspond to the locations used for the weather data. The Fort Worth energy prices were approximated by the Dallas rate schedules.

The electrical rate schedules all have demand charges in addition to the consumption rate schedules. The demand charges are based on the peak power demand during each month. In addition, the large commercial customers in Chicago have time of day electricity schedules. For this study, hourly peak values were used to determine the monthly peak demands. The small commercial rate data were used to calculate the billing costs for the small buildings, and the large commercial rate data were used to calculate the billing costs for the medium and large buildings. In some cases, the building maximum electrical consumption exceeded the maximum specified for the rate schedule used in the calculation. Since this study is directed towards the analysis of trends, the errors introduced by this should not be sufficient to alter the overall conclusions.

The natural gas rate schedules have no demand charges. However, like the electrical rate schedules, they do have different rates during the heating and cooling seasons.

Table 3.3. 1985 monthly electric rate schedules.

Item		Energy Rate, $/kWh	Fuel Cost Adjustment, $/kWh	Demand Charge, $/kW	Customer Charge, $	Minimum Charge, $	Taxes, %
Chicago, IL, Large Commercial, >10 kW and <500 kW maximum							
Oct-May	On-peak[a]	0.05510	0.00208	8.33	484.60	17.35	9.59003
	Off-peak	0.02700					
Jun-Sept	On-peak[a]	0.05510	0.00123	10.65	484.60	17.35	9.59003
	Off-peak	0.02700					
Chicago, IL, Small Commercial, <10 kW maximum							
Oct-May	First 30,000 kWh	0.04809	0.00208	8.33	6.65	17.35	9.59003
	Next 470,000 kWh	0.03694					
	Over 500,000 kWh	0.03320					
Jun-Sept	First 30,000 kWh	0.04809	0.00123	10.65	6.65	17.35	9.59003
	Next 470,000 kWh	0.03694					
	Over 500,000 kWh	0.03320					
Dallas, TX, Large Commercial, >10 kW maximum							
Nov-Apr	First 1800 kWh	0.04500	0.027461	0.00, ≤10 kW 8.30[b], >10 kW	10.00	10.00	6.25000
	Next 3500 kWh	0.02500					
	Over 5300 kWh	0.00670					
May-Oct	First 1800 kWh	0.04500	0.031036	0.00, ≤10 kW 8.30[b], >10 kW	10.00	10.00	6.25000
	Next 3500 kWh	0.02500					
	Over 5300 kWh	0.00670					

Table 3.3. (continued)

Item		Energy Rate, $/kWh	Fuel Cost Adjustment, $/kWh	Demand Charge, $/kW	Customer Charge, $	Minimum Charge, $	Taxes, %
Dallas, TX, Small Commercial, <10 kW maximum							
Nov-Apr	First 2500 kWh	0.04500	0.027461		10.00	10.00	6.25000
	Next 3500 kWh	0.02500					
	Over 6000 kWh	0.00670					
May-Oct	First 2500 kWh	0.04500	0.031036	8.30	10.00	10.00	6.25000
	Next 3500 kWh	0.02500					
	Over 6000 kWh	0.00670					
Miami, FL, Large Commercial, >20 kW and <499 kW maximum							
Dec-Mar		0.01433	0.02929	6.25	41.00	3166.00	16.00000
Apr-Nov		0.01625	0.02891	6.25	41.00	3166.00	16.00000
Miami, FL, Small Commercial, <20 kW maximum							
Dec-Mar		0.04311	0.02933	0.00	9.00	9.00	16.00000
Apr-Nov		0.04612	0.02895	0.00	9.00	9.00	16.00000

[a]9:00 a.m. to 10:00 p.m. Monday through Friday, except holidays.

[b]Includes $4.25/kW demand charge in block electrical energy rate.

Source: J. R. Brodrick, Gas Research Institute, personal communication to H. A. McLain, Oak Ridge National Laboratory, December 19, 1985

Table 3.4. 1985 monthly natural gas rate schedules.

Item	Heat Content, Btu/ft	Energy Rate, $/100ft^3	Fuel Cost Adjustment, $/100ft^3	Customer Charge, $	Minimum Charge, $	Taxes, %
Chicago, IL, All Commercial						
	1030	0.12632	0.32360	6.00	0.00	13.32000
Dallas, TX, All Commercial						
	1020	0.52296	-0.03462 (Nov-Apr) -0.04638 (May-Oct)	7.00	7.00	6.12500
Miami, FL, All Commercial						
	1000	0.14650	0.36580 (Dec-Mar) 0.34590 (Apr-Nov)	13.00	13.00	10.00000

Source: J. R. Brodrick, Gas Research Institute, personal communication to H. A. McLain, Oak Ridge National Laboratory, December 19, 1985.

4. HEATING-COOLING LOADS AND END-USE ENERGY

4.1 PREDICTED DATA

A total of 106 DOE-2.1B calculation runs were made predicting the heating-cooling loads in the buildings and the end-use energy values. The results, among which are the hourly values of the loads and the end-use energy, were extracted from the DOE-2.1B output files, reformatted, and stored in smaller output files. Generally, the results are presented on a unit floor area basis to allow comparison between buildings.

Summaries of the annual heating-cooling loads and the annual end-use energy values for each of the runs are presented in Appendix B. In addition to the tabular summaries, the appendix includes bar graphs for the annual values of

1. Heating-cooling loads,
2. Energy use,
3. Average to peak energy use, and
4. Electric energy end-use.

Heating-cooling data for 96 of the 106 runs were used in the fractional factorial design analysis to assess the importance of the selected parameters. This analysis is presented in Appendix C.

In the discussion below, abbreviations are used in the figures to describe the values of the independent parameters. To aid the reader, the abbreviations and their meanings are summarized in Table 4.1. In addition, some of the results are presented for buildings having the "baseline" parameter configuration. Buildings designated by this configuration have the following specified parameters:

Table 4.1. Summary of abbreviations for the parameter values used in the figures and their meanings.

Parameter	Abbreviation	Meaning
Building Size	SML	Small, 2,500 ft^2
	MED	Medium, 49,500 ft^2
	LRG	Large, 200,000 ft^2
Location	CHI	Chicago, IL
	FTW	Fort Worth, TX
	MIA	Miami, FL
HVAC System	MZS	Multizone system
	VAV	Variable air volume system
Economizer	No	No economizer
	Yes	Temperature controlled economizer (62°F temperature limit)
Ventilation	20%	20% minimum ventilation
	5%	5% minimum ventilation
Occupancy and Equipment	HI	5 people/1000 ft^2 in core areas 10 people/1000 ft^2 in perimeter areas 1 W/ft^2 equipment power
	LO	4 people/1000 ft^2 0.5 W/ft^2 equipment power
Envelope Construction	NOR	Minimum insulation (Table 3.1) Single-pane, clear glazing
	EFF	Insulated walls and roof (Table 3.1) Double-pane and/or reflective glazing

HVAC system, Multizone system
Economizer, None
Minimum ventilation rate, 20%
Lighting power, 3 W/ft^2
Occupancy, 5 people/1000 ft^2 in core areas
10 people/1000 ft^2 in perimeter areas
Equipment power, 1 W/ft^2
Envelope construction and glazing, Normal (Table 3.1), minimum insulation and single-pane, clear glass glazing.

4.2 HEATING-COOLING LOADS

The fractional factorial design was used to determine the importance of the impacts of the selected independent parameters on the annual total heating load, the annual peak (hourly) heating load, the annual total cooling load, and the annual peak (hourly) cooling load. These loads are the quantities of energy that are added to the building for heating or are extracted from the building for cooling. The analysis was directed at determining: (1) which of the 8 independent parameters caused the greatest impact on the results, and (2) which of the 8 parameters plus the 28 two-parameter interactions caused the greatest impact on the results.

The sum-of-squares-for-error-drop method was used to rank the 8 independent parameters. In this method, described in Appendix C, the output data values are correlated by a linear model using all the parameters and again with all the parameters except the parameter being ranked. The difference in the sum-of-squares-for-error using the two correlations is a measure of the importance of the parameter.

The rankings of the importance of the individual parameters on the loads are listed in Table 4.2. The building location, size, and HVAC system type were calculated to have the most importance. The amount of insulation and the type of glazing, minimum building ventilation rate, and if there is an economizer or not are of intermediate importance. Internal loads, such as lighting, occupancy, and office equipment, have the least influence. For the annual loads, the building location was calculated to be the most important parameter, and for the peak loads, the building size was calculated to be the most important parameter. Furthermore, for the peak cooling load, insulation/glazing is of high importance, and location is of relatively low importance.

Impacts of the 8 individual parameters plus the 28 two-parameter interactions (36 terms) were analyzed by: (1) looking at the range of mean values across the levels of a parameter interaction, and (2) examining the standard deviation of the mean values across the levels of a parameter or interaction. These analyses, including the rankings of all 36 terms, are discussed in Appendix C. The terms having the top 10 rankings are listed in Table 4.3. The two analysis methods yielded similar results, although there were some minor differences in the ranking order.

The calculations showed that the interactions are important in assessing the building loads overall. In particular, some important parameters in the interaction terms are building size, location, type of HVAC system, amount of insulation, and glazing. Interaction effects between the building size and the other parameters are important because of the large differences of the loads for the small buildings and those for the larger buildings. The interaction between the building location and the HVAC system type was ranked next in importance. This suggests that the benefits of an optimal HVAC system for a building is strongly dependent on its location.

Table 4.2. Importance of the individual parameters on the building, loads, as determined by the sum-of-squares-for-error drop method.

Rank	Annual heating	Peak heating	Annual cooling	Peak cooling
1	Loc	Size	Loc	Size
2	Size	HVAC	Size	Ins/Glaz
3	HVAC	Loc	HVAC	HVAC
4	Ins/Glaz	Ins/Glaz	Ins/Glaz	Vent
5	Econ*	Econ*	Vent	Loc
6	Vent	Vent	Econ*	Lights
7	Occ/Eqp	Lights	Lights	Occ/Eqp
8	Lights	Occ/Eqp	Occ/Eqp	Econ*

*The analysis of the economizer was limited, and the results are suspect.

Table 4.3. Importance of individual parameters and two parameter interactions having the top ten rankings, as determined by the values of the range of means and by the values of the standard deviations.

	Annual heating		Peak heating	
Rank	Range of means	Std. deviation	Range of means	Std. deviation
1	Size x Loc	Size x Loc	Size x HVAC	HVAC
2	Loc x HVAC	Loc x HVAC	Size x Loc	Size x HVAC
3	Size x HVAC	Size x HVAC	Loc x HVAC	HVAC x Econ*
4	Loc x Ins/Glaz	HVAC	HVAC x Ins/Glaz	HVAC x Ins/Glaz
5	Loc x Econ*	HVAC x Econ*	HVAC x Vent	HVAC x Vent
6	Loc x Occ/Eqp	HVAC x Ins/Glaz	HVAC x Econ*	HVAC x Occ/Eqp
7	HVAC x Econ*	HVAC x Occ/Eqp	HVAC x Lights	HVAC x Lights
8	Loc x Vent	HVAC x Lights	HVAC x Occ/Eqp	Loc x HVAC
9	HVAC x Ins/Glaz	HVAC x Vent	HVAC	Size x Loc
10	HVAC x Occ/Eqp	Loc	Size x Ins/Glaz	Size

	Annual cooling		Peak cooling	
Rank	Range of means	Std. deviation	Range of means	Std. deviation
1	Size x Loc	Loc	Size x Ins/Glaz	Size
2	Loc x HVAC	Loc x HVAC	Size x HVAC	Size x Ins/Glaz
3	Loc x Ins/Glaz	Loc x Ins/Glaz	Size x Vent	Size x HVAC
4	Loc x Vent	Loc x Vent	Size x Loc	Size x Vent
5	Loc x Lights	Loc x Econ*	Size x Lights	Size x Lights
6	Loc x Econ*	Size x Loc	Size x Occ/Eqp	Size x Occ/Eqp
7	Size x HVAC	Loc x Lights	Size x Econ*	Size x Econ*
8	Loc x Occ/Eqp	Loc x Occ/Eqp	Size	Size x Loc
9	Size x Ins/Glaz	Size x HVAC	Loc x Ins/Glaz	Loc x Ins/Glaz
10	Loc	Loc	Loc x Vent	Ins/Glaz

*The analysis of the economizer was limited, and the results are suspect.

Plots of the mean heating and cooling loads are instructive. The mean load is the average of the heating or cooling loads for all the buildings that have common parameter values of interest. For example, in Fig. 4.1a, the mean heating load of 71.8 kBtu/ft^2 for the small (2500 ft^2) building in Chicago is the average of the heating loads calculated in all of fractional factorial design runs for small buildings in Chicago.

Figure 4.1 shows plots of the mean annual and peak heating loads, and Fig. 4.2 shows plots of the analogous cooling loads. The impact of the building size on the loads in this analysis is very apparent. In particular, the loads per unit floor area for the small buildings are much greater than those for the medium and large buildings. This accounts for the strong interaction effects due to the building size.

The heating and cooling loads are lower for the larger buildings since, for the geometries examined in this investigation, they have lower exterior envelope area to building volume ratios. The exterior envelope surface to building volume ratios are 0.163 ft^{-1}, 0.060 ft^{-1}, and 0.038 ft^{-1} for the small, medium, and large buildings, respectively.

Location has a major effect on both the annual heating and cooling loads. The mean annual heating load for the large building was calculated to be about 22 kBtu/ft^2 for Chicago, 10 kBtu/ft^2 for Fort Worth, and 4 kBtu/ft^2 for Miami. These quantities are slightly greater for the medium building and much greater for the small building. Other parameters can impact the heating loads.

Figure 4.3 shows the heating loads for buildings having the baseline parameter configuration. The loads for this configuration are higher than the mean values, e.g., 29 kBtu/ft^2 vs 22 kBtu/ft^2 for the large building in Chicago.

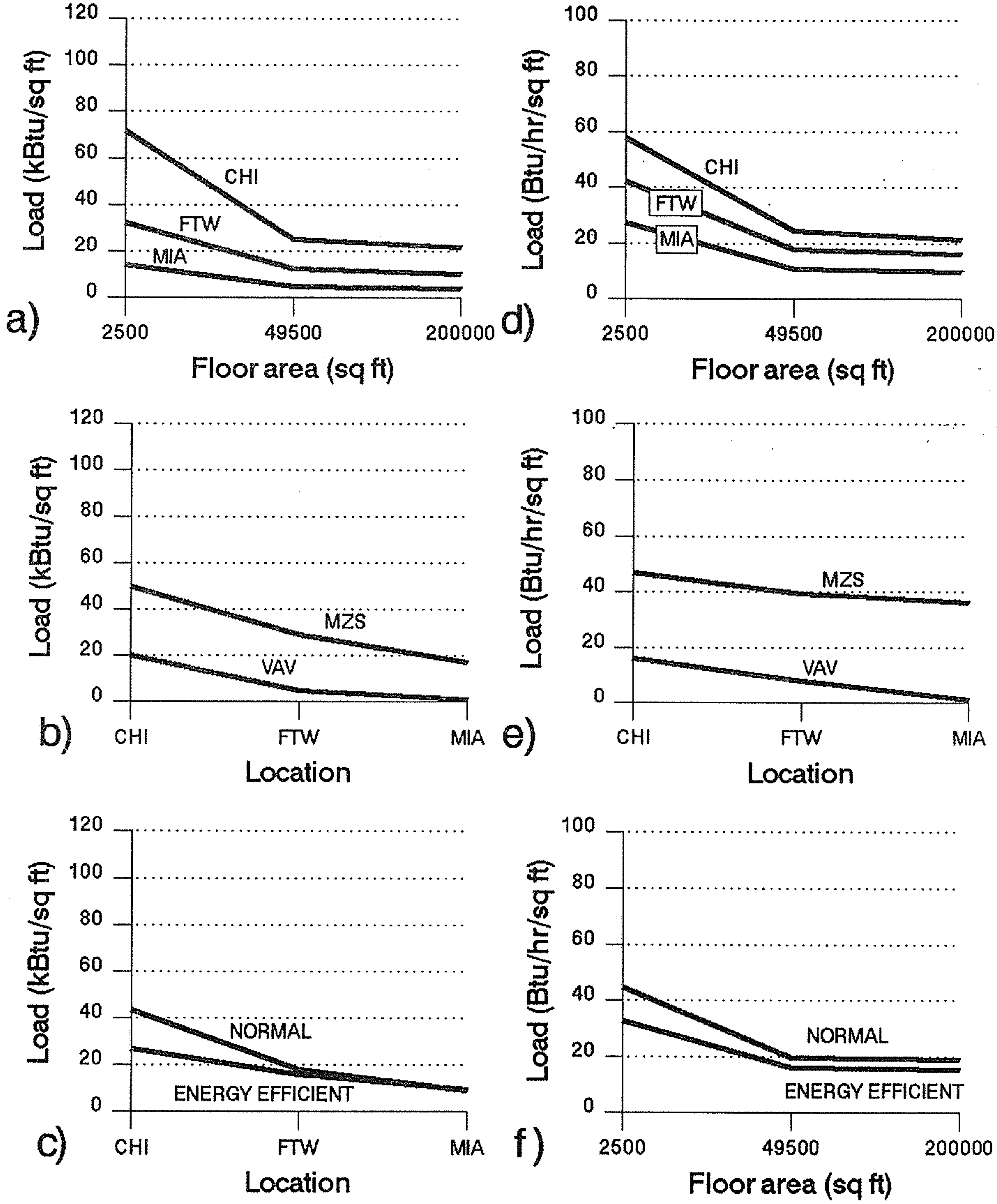


Fig. 4.1. Mean building heating loads: (a) annual, size by location; (b) annual, location by HVAC system; (c) annual, location by insulation/glazing; (d) peak, size by location; (e) peak, location by HVAC system; (f) peak, size by insulation/glazing.

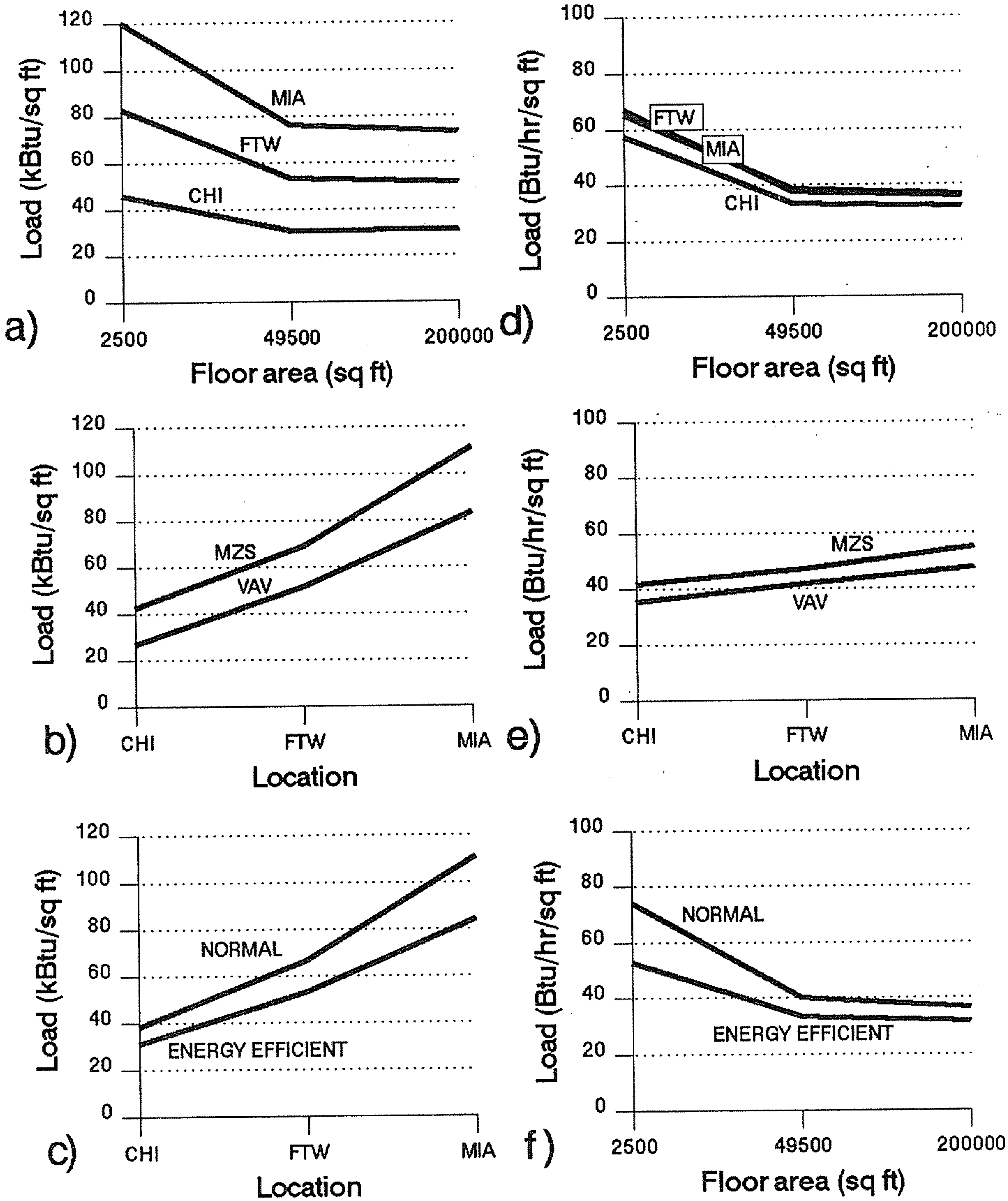


Fig. 4.2. Mean building cooling loads: (a) annual, size by location; (b) annual, location by HVAC system; (c) annual, location by insulation/glazing; (d) peak, size by location; (e) peak, location by HVAC system; (f) peak, size by insulation/glazing.

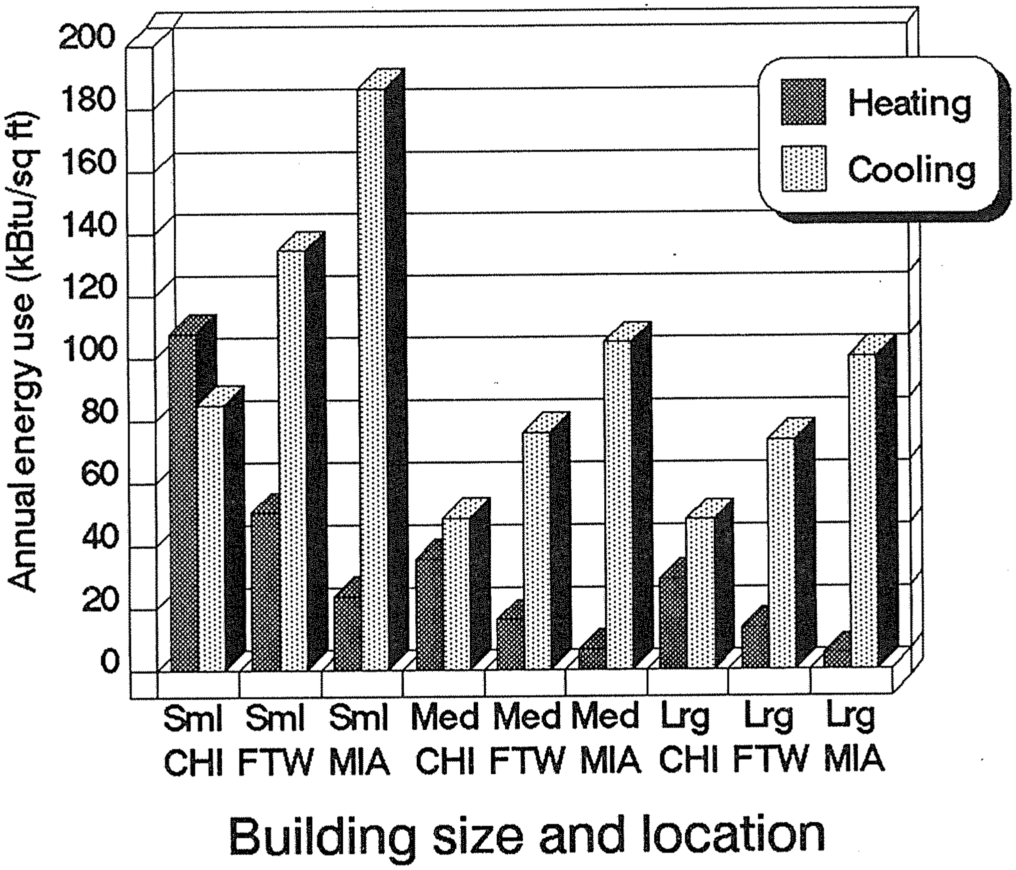


Fig. 4.3. Annual heating-cooling loads in buildings having the baseline parameter configuration.

The peak heating loads also are strongly dependent on the building size and location. Mean values are shown in Fig. 4.1, and values for the buildings having the baseline parameter configurations are shown in Fig. 4.4. The shape of these plots are similar to those for the annual heating loads.

For cooling, location has a major impact on the annual load. Except for the small building located in Chicago, the heat extracted is greater than the heat added to the building. The mean values for the large building are 31 $kBtu/ft^2$ in Chicago, 51 $kBtu/ft^2$ in Fort Worth, and 73 $kBtu/ft^2$ in Miami, as shown in Fig. 4.2. The baseline parameter configuration buildings, again, have higher values, as shown in Fig. 4.3. For the large building, they are 48 $kBtu/ft^2$ for Chicago, 74 $kBtu/ft^2$ for Fort Worth, and 100 $kBtu/ft^2$ for Miami.

Peak cooling loads, however, vary by building size but not much by building location, as shown in Figs. 4.2 and 4.4. For the medium and large buildings, the means are in the range of 33 $kBtu/ft^2$ to 38 $kBtu/ft^2$. These values are in the range of 39 $kBtu/ft^2$ to 46 $kBtu/ft^2$ for the medium and large buildings having the baseline parameter configuration.

The choice of HVAC systems has a major impact on the annual heating and cooling energy loads. The multizone and variable air volume systems represent an extreme range in HVAC technology. The multizone system mixes hot air and cold air to control temperatures in each zone, while the variable air volume system only heats or cools the air supplied to each zone. Moreover, the amount of air supplied to each zone can be reduced during off peak periods when using the

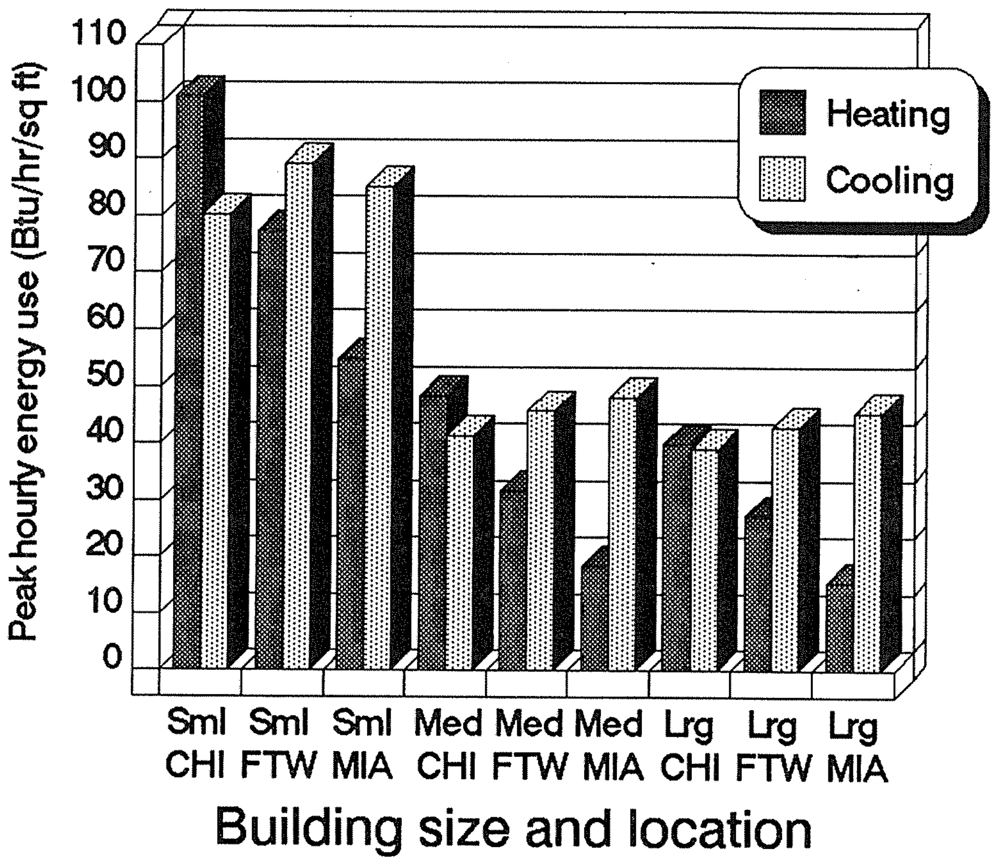


Fig. 4.4. Peak heating-cooling loads in buildings having the baseline parameter configuration.

variable air volume system. These factors reduce the amount of energy required to heat or cool the building. The location impact on the energy consumed by the HVAC system is very apparent. For example, use of a variable air volume system (or simpler single zone systems) in Miami eliminates the need for space heating.

The choice of the HVAC system has little effect on the peak cooling load, however, as shown in Fig. 4.2. This is because the multizone system requires very little, if any, hot air for temperature control and the variable air volume system is operating at flow full rate at the peak load.

It should be reiterated that the schedule for the HVAC system operation impacts the building loads. It was assumed in this investigation that these systems were basically shut down to minimum protection levels when the building is unoccupied. Loads for other equipment operation schedules were not calculated.

The effects of the economizer and the minimum building ventilation rate on the loads is shown in Fig. 4.5. An economizer having a 62°F air temperature limit is most effective in reducing the cooling load in Chicago, reducing it about one-third on the average. However, the analysis shows the heating energy is increased by about one-third, on the average, in that city. In Miami, the influence of the economizer is negligible, and in Fort Worth, the influence is between the extremes in Chicago and Miami. It should be noted that the analysis of the economizer was limited and the results are suspect, particularly in the view that the heating load values were predicted to increase during the economizer operation.

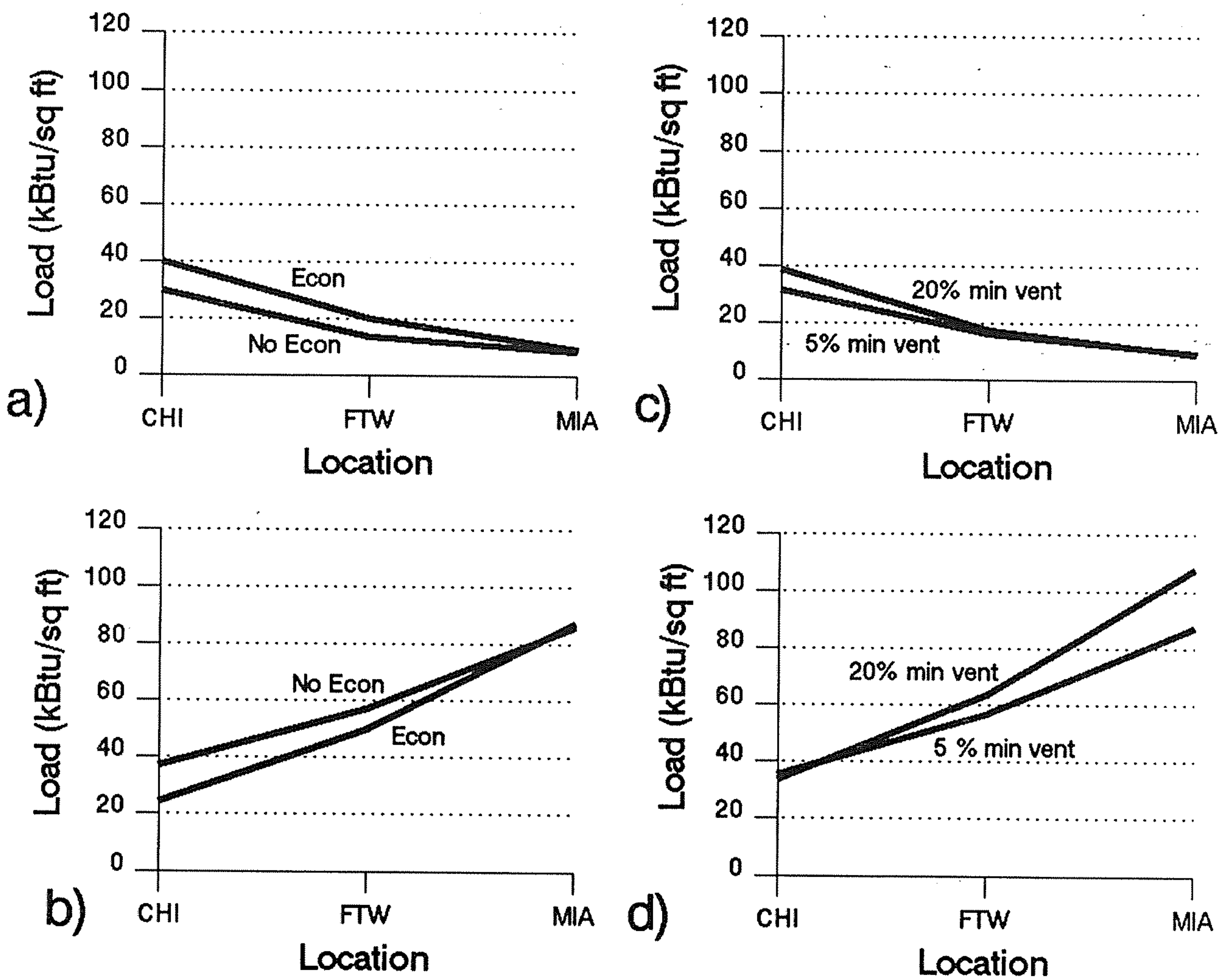


Fig. 4.5. Impacts of the economizer and minimum ventilation on the annual loads: (a) heating, location by economizer; (b) cooling, location by economizer; (c) heating, location by minimum ventilation rate; (d) cooling, location by minimum ventilation rate.

Building minimum ventilation rate impacts the cooling load in Miami, where reducing it from 20% to 5% decreases the cooling load about 20% on the average. It has a negligible effect on the building heating in that city. In Chicago it has very little effect on the cooling load, but this ventilation reduction decreases the heating load about 20%. It has a small effect on both the heating and cooling loads in Fort Worth.

The building insulation/glazing effects are most apparent during the cooling season. Buildings having energy efficient envelopes have about 20% lower annual loads, as shown in Fig. 4.2. Although calculations were not made to confirm this, it is believed that most of the savings is due to the use of reflective glazing for the energy efficient building. The peak cooling loads are also reduced, as shown in Fig. 4.2. The greatest percentage reduction is for the small building.

During the heating season, the insulation/glazing impact is small except for the buildings in Chicago, as shown in Fig. 4.1. This is believed to be partially due to double-pane glazing being used for the energy efficient building in Chicago as compared to the single-pane glazing for those in Fort Worth and Miami.

Internal loads such as lighting and equipment and occupancy impact the loads. Reducing the lighting load from 3 W/ft^2 to 1.6 W/ft^2 reduces the cooling load about 10%, on the average. There is an increase in the heating load associated with this parameter. Building occupancy and equipment, again, changes the cooling load up to 10%, for the range of parameters specified in this investigation. There is also a change in the heating load for this parameter.

4.3 END-USE ENERGY

Plots of the mean end-use energy values were made from the data generated in the 96 DOE-2.1B runs specified by the fractional factorial design. Analysis of the energy values to obtain a ranking of the parameter effects was not done in this case, however. The plots for mean annual electricity and natural gas use are shown in Fig. 4.6. The mean annual electricity use ranges from about 15 kWh/ft^2 for the large building in Chicago to about 26 kWh/ft^2 for the small building in Miami. The impact of the small building is again noted, although it is not as large as for the building loads. This is because other components, such as lighting and office equipment which were not assumed to be dependent on building sizes, location, and HVAC system, are included in the electrical loads.

The natural gas use data are plotted as kWh/ft^2 to allow a direct comparison with the electricity data. The mean annual use values for natural gas show a much stronger dependence on the building size and location than those for electricity. This is because, in this study, the use of natural gas was limited to space and domestic hot water heating. This also accounts for the lower values for natural gas as compared to electricity -- except for the small building in Chicago, which has a relatively high space heat demand.

Figure 4.7 shows the annual energy consumption in buildings having the baseline parameter configuration, defined in Sect. 4.1. The values for these buildings are greater than the mean values, but the trends are the same as those shown in Fig. 4.6.

The impacts of the choice of the HVAC system are also shown in Fig. 4.6. Buildings using the variable air volume system consume about 20% less electricity than those using the multizone system.

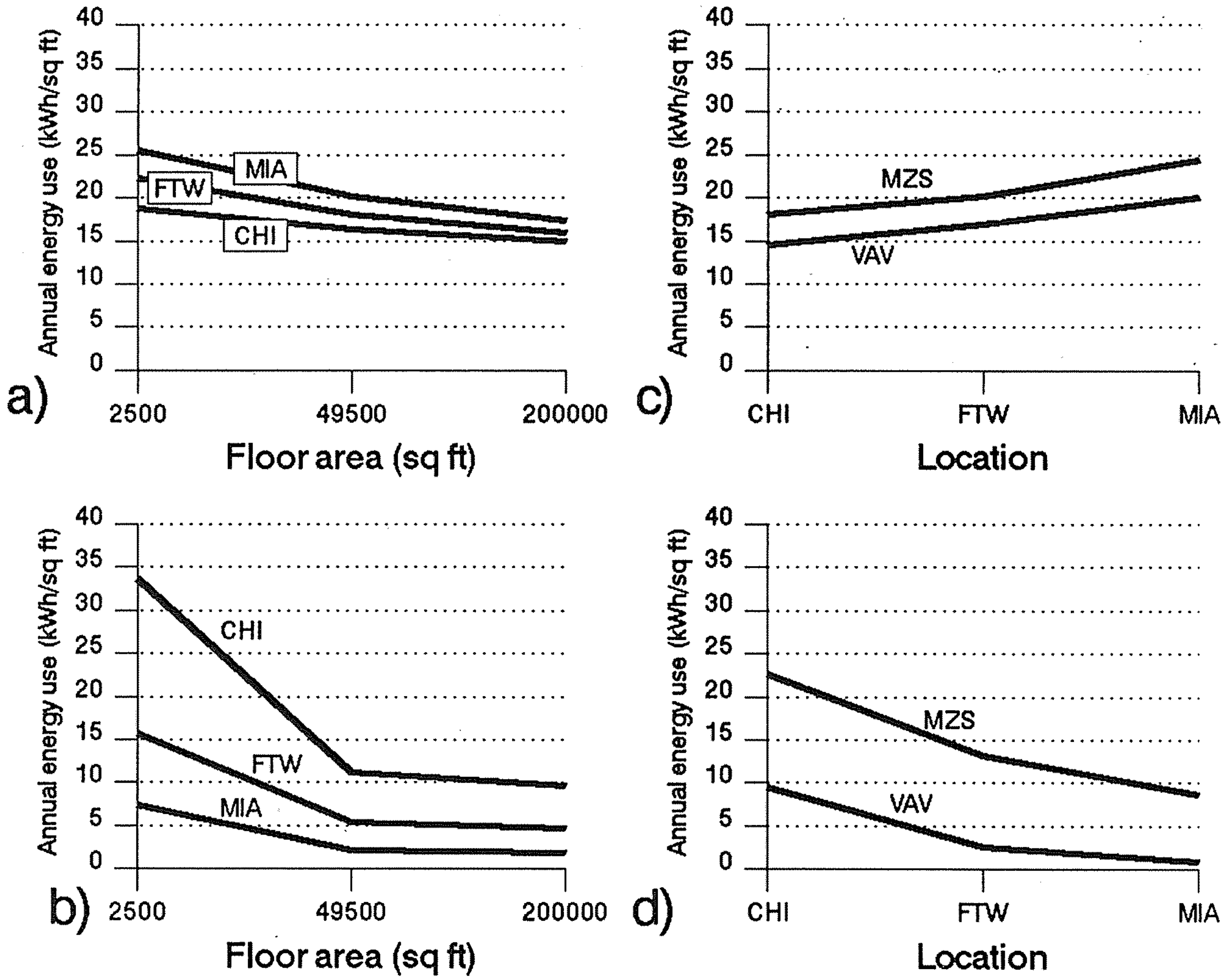


Fig. 4.6. Mean annual building energy use: (a) electricity, size by location; (b) natural gas, size by location; (c) electricity, location by HVAC system; (d) natural gas, location by HVAC system.

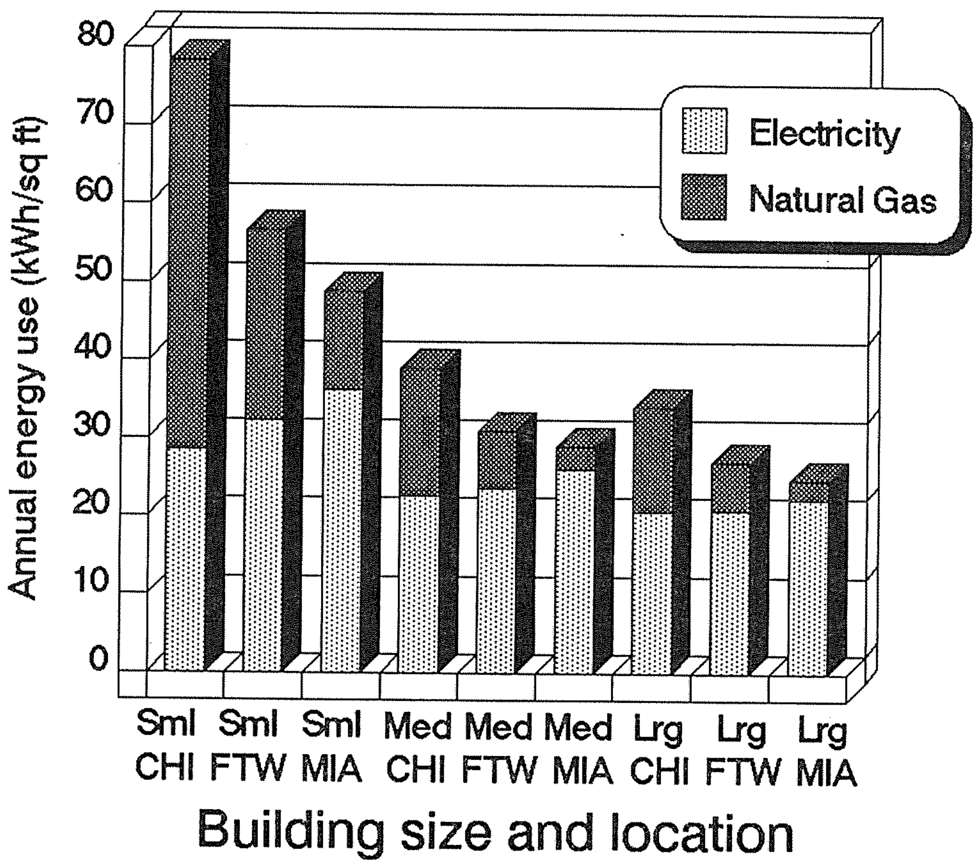


Fig. 4.7. Annual energy use in buildings having the baseline parameter configuration.

This reduction indicates the magnitude of savings that could be realized by not mixing hot and cold air at each conditioned zone and reducing power consumption by using variable air volume circulation fans. The calculations also indicate that much of the natural gas is saved using the variable air volume system. Using this system in Miami, the natural gas usage is limited essentially to generating domestic hot water.

Electrical load factors are of interest because of demand charges which reflect the cost of increased utility generating capacity. Some idea of the magnitude of these factors can be gained by calculating the average-to-peak ratios of electricity use in the buildings. Values of the mean values of this parameter are shown in Fig. 4.8. The greatest mean value of 0.30 was calculated for the medium and large buildings in Miami. It is between 0.27 and 0.28 for the same buildings in Chicago and Fort Worth. This difference is speculated to be due to the higher, more consistent cooling loads for the buildings located in Miami. The factor is 10% to 20% lower for the small building, possibly due to the quicker response of this building to changes in climatic conditions.

Use of a variable air volume HVAC system, instead of a multizone system, reduces the average-to-peak electricity use about 10% to 15%. This change shows little difference between the peak loads for the two systems, but less electrical energy is used by the variable air volume system during offpeak conditions.

A breakdown of the annual electricity use in the buildings having the baseline parameter configuration is shown in Fig. 4.9. For the small building, the largest portion of the electricity is generally used for cooling, and for the medium and large buildings, the largest portion of it is generally used for lighting.

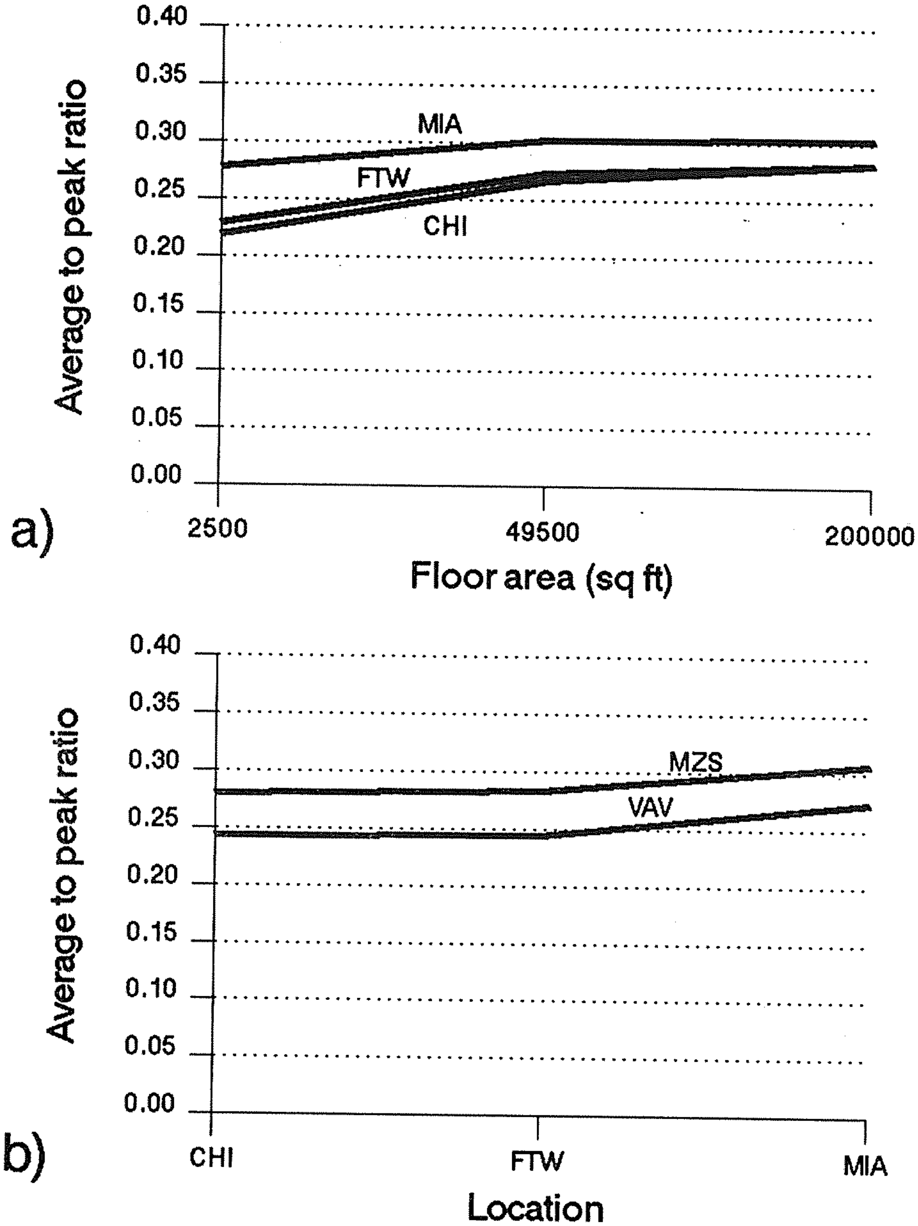


Fig. 4.8. Mean average-to-peak building electricity use: (a) for size by location; (b) for location by HVAC system.

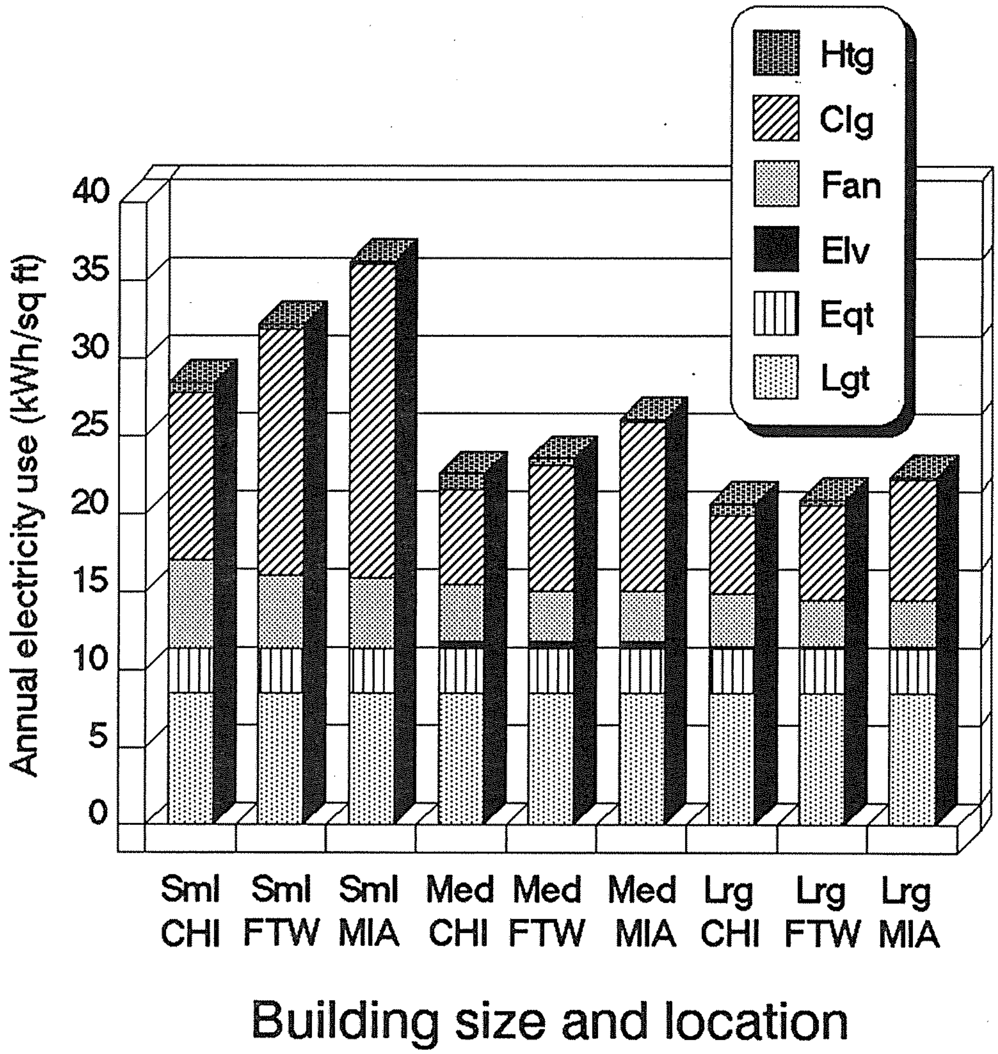


Fig. 4.9. Annual electricity use in buildings having the baseline parameter configuration.

However, cooling is still a very large part of the annual electrical load in the larger buildings. (A very small amount of electricity is assumed to be used for heating, operation of the hot water boiler auxiliaries, and the pumps in the building hot water circulation loops.) The cooling energy values do not include the energy consumed by the circulating air fans, which can be significant. For the baseline buildings, fan electricity consumption was about 3 kWh/ft^2 to 4 kWh/ft^2 annually. Adding in these values, the HVAC systems consume about 45% to 50% of the electricity used annually in the medium and large buildings. The percentage is greater for the small buildings.

The HVAC system loads can be reduced by using more efficient systems that do not require mixing of hot and cold air and using variable speed circulating air fans, as shown in Fig. 4.10. The analysis indicates about an 18% reduction in the cooling energy (neglecting the fan energy) and 10% reduction in the annual electricity consumption for the medium building in Fort Worth, as shown in Fig. 4.11. An additional reduction is indicated for the energy efficient construction (reflective glazing). For the medium building in Fort Worth, the energy efficient construction adds another 6% to the electrical energy reduction. The greatest reduction is indicated for the small building in Miami because of the relatively large thermal envelope area, location, no mixing of hot and cold air, and using variable air volume control.

If the internal loads are reduced, further reduction in the cooling and electrical energy would be realized. The impact of reducing the occupancy and equipment load is shown in Figs. 4.10 and 4.11. Most of the electrical savings is due to the reduction of the load itself, since the cooling system has an annual average coefficient of performance of 2.5 in this investigation. Reduction of

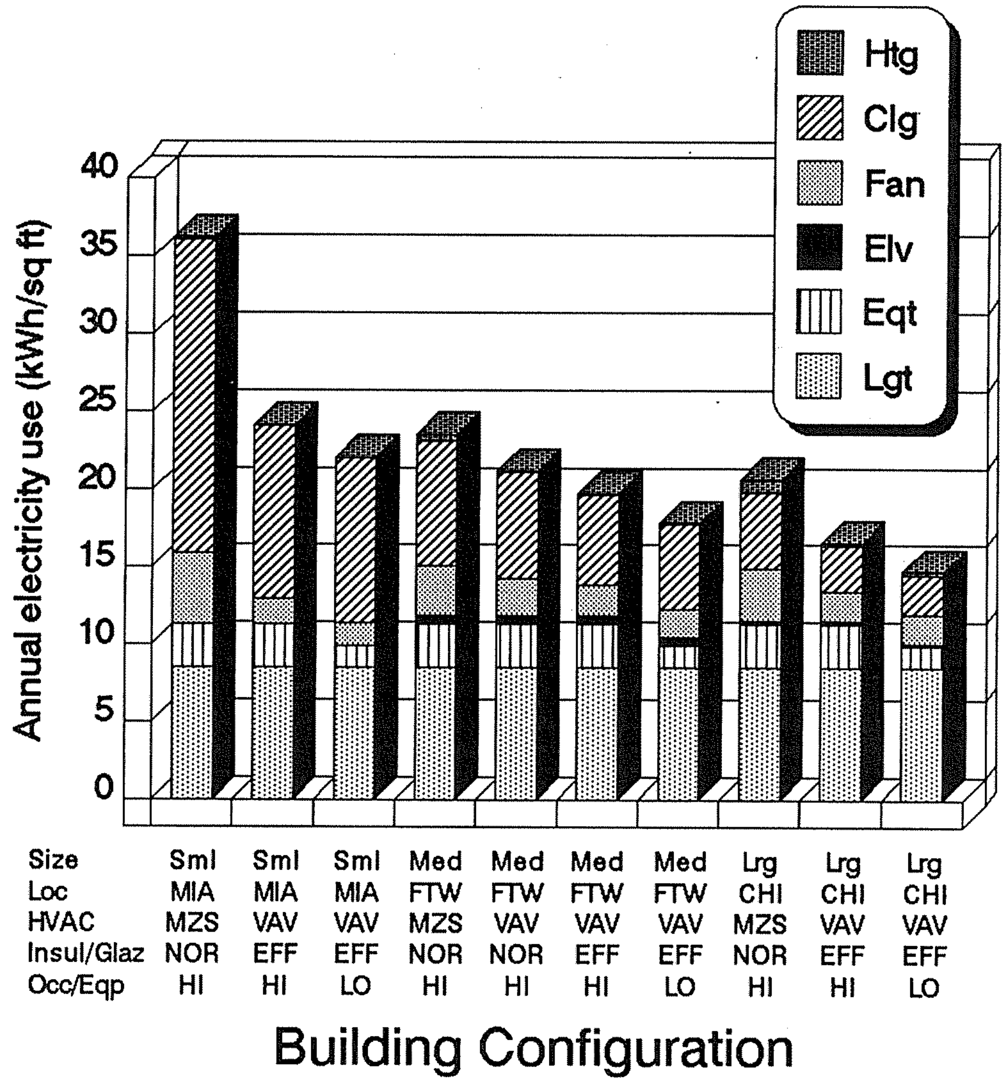


Fig. 4.10. Comparison of annual electricity use in selected buildings. See Table 4.1 for meanings of abbreviations. All selected buildings have no HVAC economizer, 20% minimum ventilation rate, and 3 W/ft^2 lighting power.

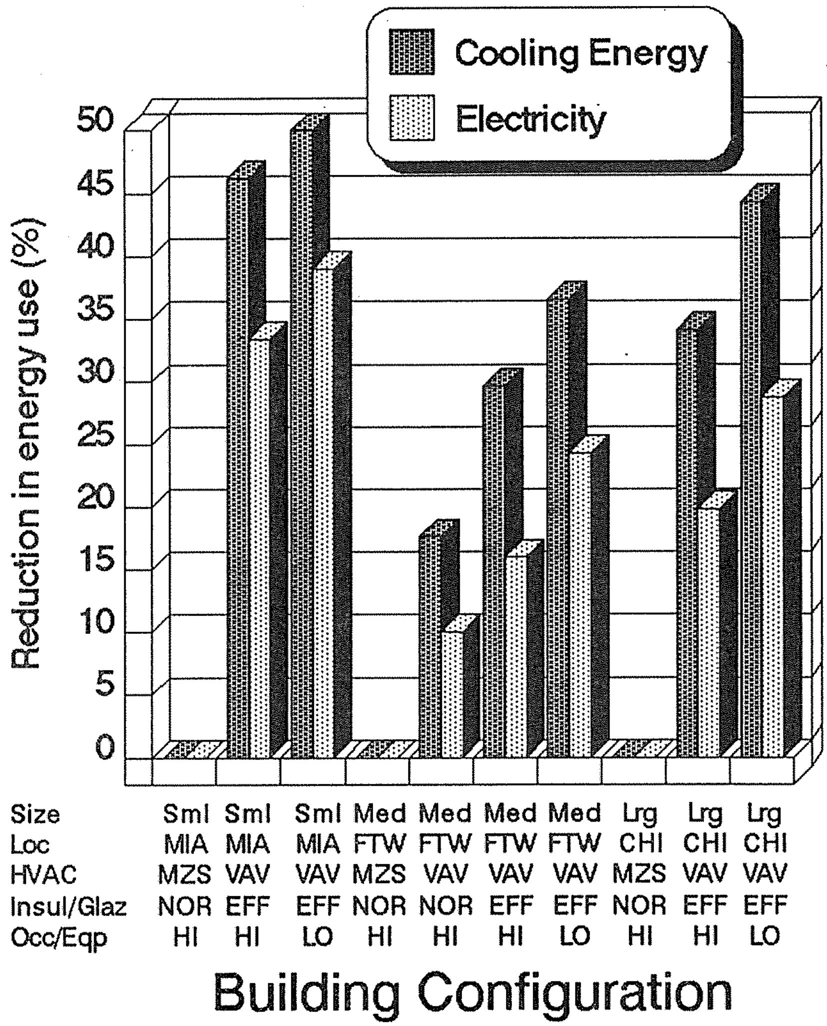


Fig. 4.11. Comparison of annual energy use reduction in selected buildings. See Table 4.1 for meanings of abbreviations. All selected buildings have no HVAC economizer, 20% minimum ventilation rate, and 3 W/ft^2 lighting power. For each size building, base configuration is indicated for the building having 0% reduction in energy use.

the lighting energy has a similar impact, as shown in Fig. 4.12. There are small reductions in the average-to-peak electrical use associated with these changes.

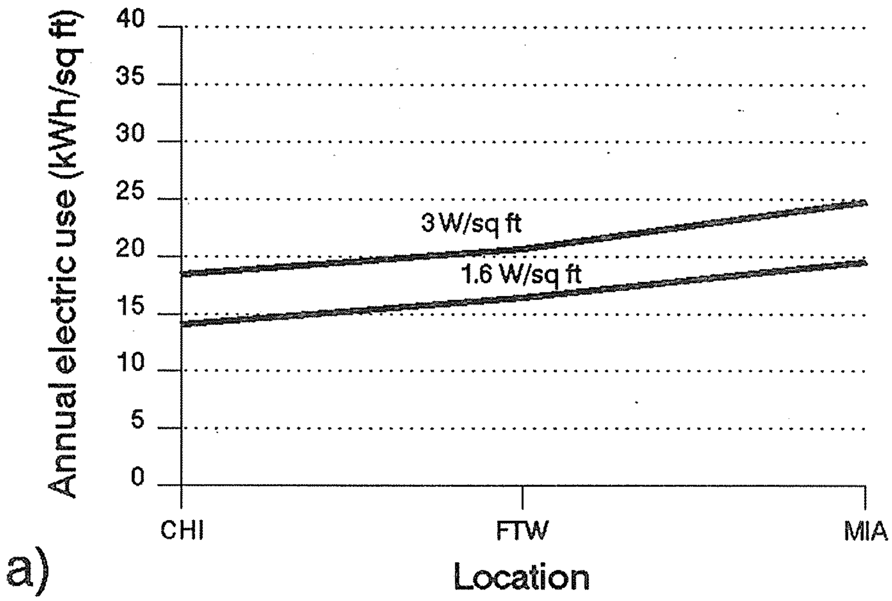
Reduction of the internal loads results in some increase in the heating energy required for the building. The financial impact of this is relatively small in this study because of the lower price of natural gas as compared to the price of electricity (Sect. 5).

4.4 HOURLY LOAD AND END-USE ENERGY PROFILES

Heating and cooling load profiles covering each hour of the year for three selected large buildings are presented in Figs. 4.13, 4.14, and 4.15. The profiles represent the heat added to or extracted from the building by the HVAC systems.

The values shown in Fig. 4.13 are for a building having the basic configuration (Sect. 4.2) located in Chicago. The HVAC system for this building is a multizone system, which has mixing of hot and cold air during the entire year. The heating loads generally peak at the beginning of the day when the HVAC system is turned on, and the cooling loads generally peak during the late afternoon. For the week, the loads are frequently higher during the first working day of the week, which reflects the thermal mass effect of the building. There is some heating of the building during the night hours and weekends in the winter for freeze protection.

There are significant reductions in the heating and cooling loads when the HVAC system is changed to a variable air volume system and energy efficient building envelope construction is used, as shown in Fig. 4.14. There is a minimal heating load during the summer because this system has no mixing of hot and cold air. The cooling load exists most of the year, although it is relatively small in the winter.



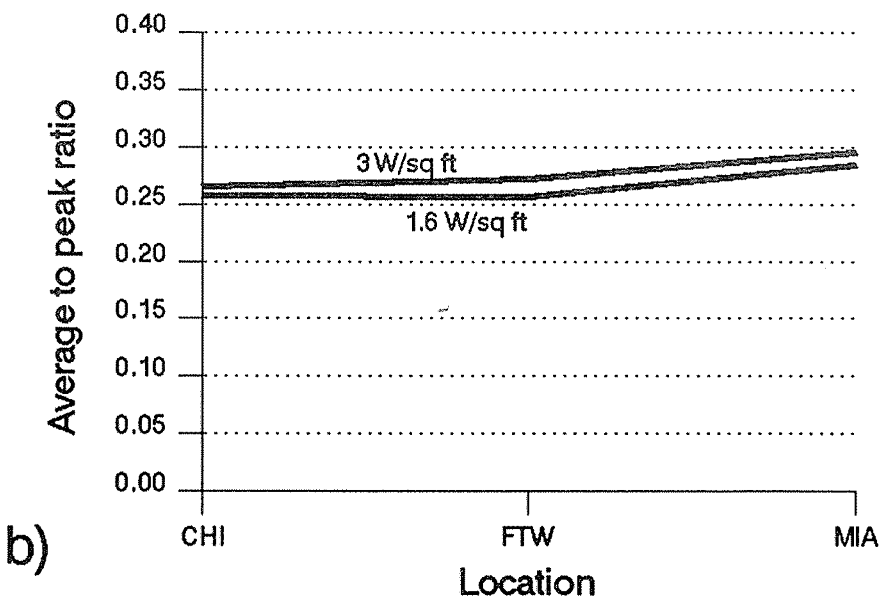
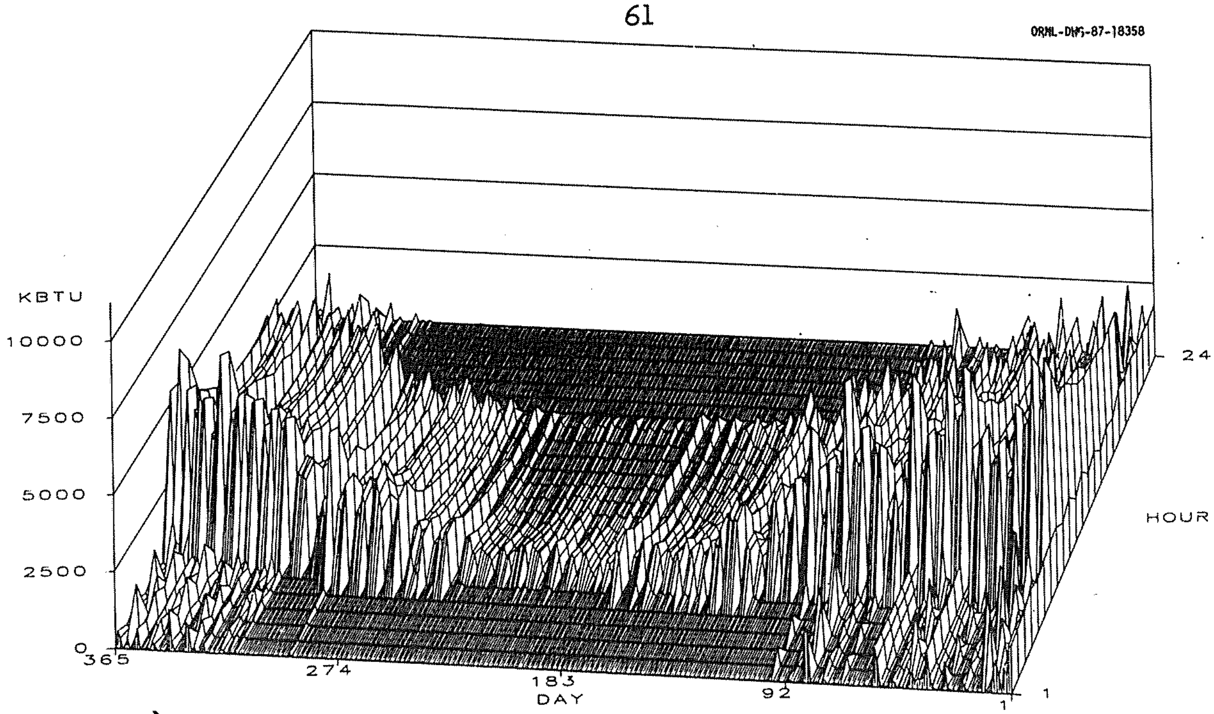
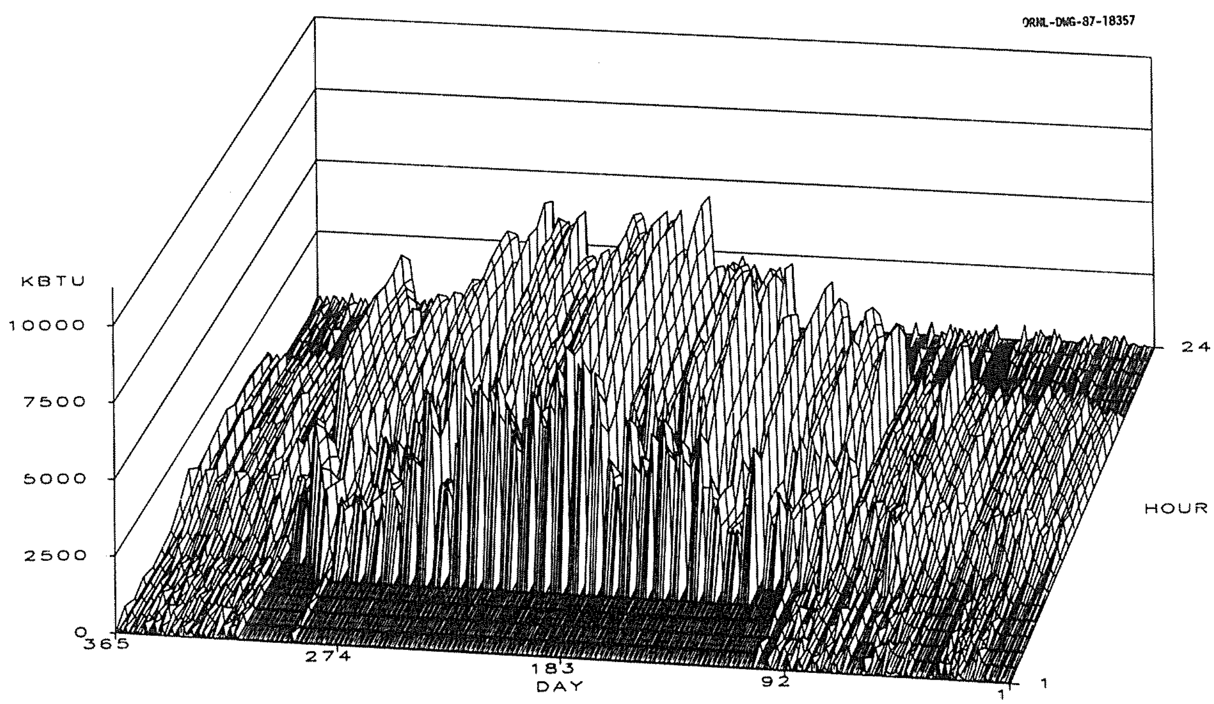


Fig. 4.12. Mean electrical energy use for location by lighting: (a) annual, (b) average-to-peak.

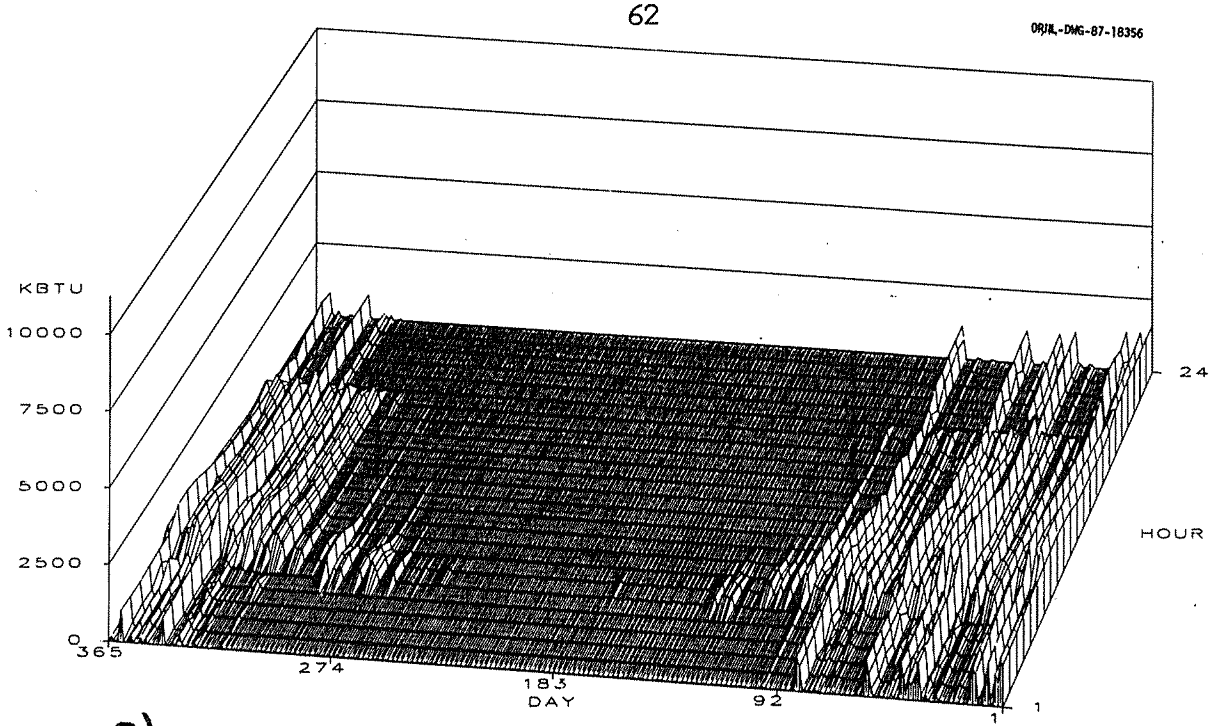


a)

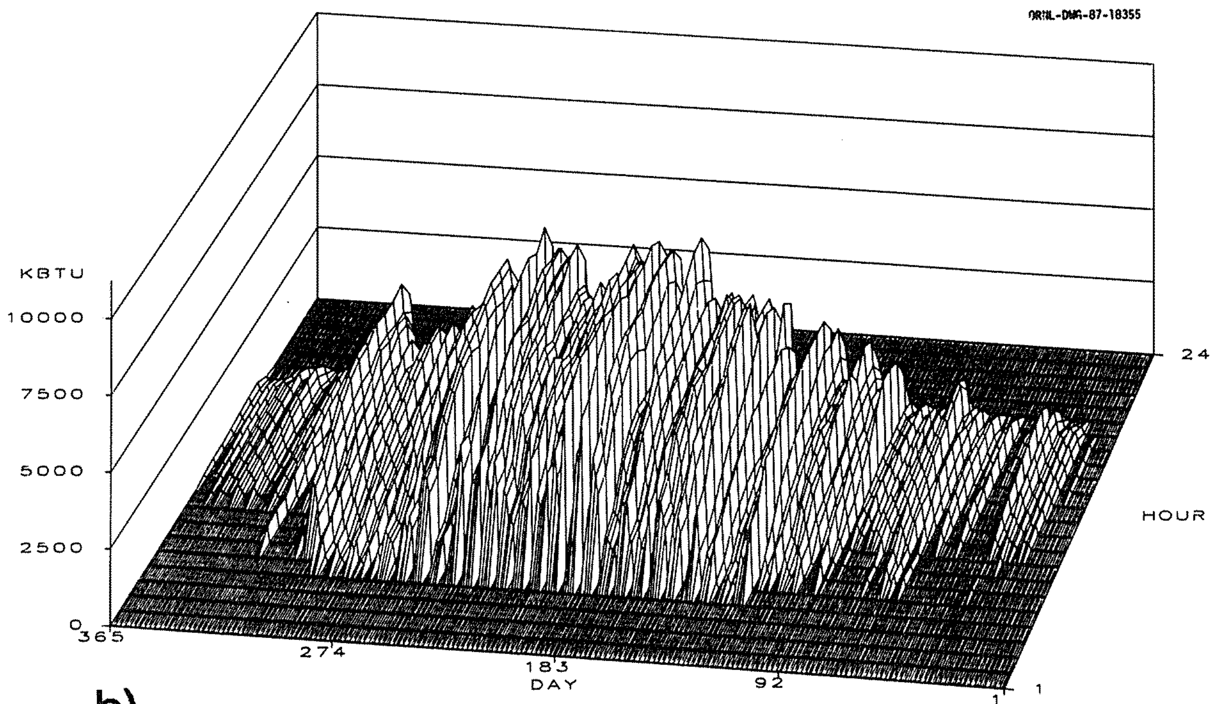


b)

Fig. 4.13. Hourly values of heat added and extracted by HVAC system for large building having the baseline parameter configuration, in Chicago: (a) heat added, (b) heat extracted.



a)



b)

Fig. 4.14. Hourly values of heat added and extracted by HVAC system for large building having the baseline parameter configuration, modified to use a variable air volume HVAC system and energy efficient construction, in Chicago: (a) heat added, (b) heat extracted.

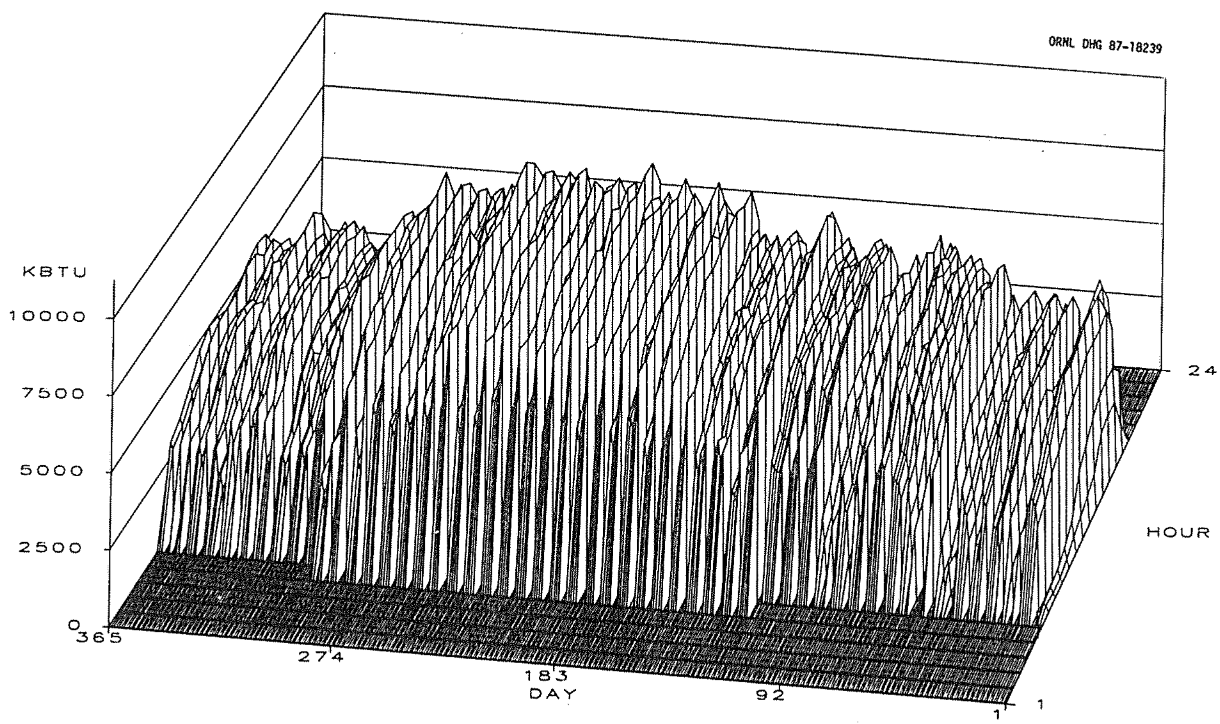


Fig. 4.15. Hourly values of heat extracted by HVAC system for large building having the baseline parameter configuration, modified to use a variable air volume HVAC system, in Miami.

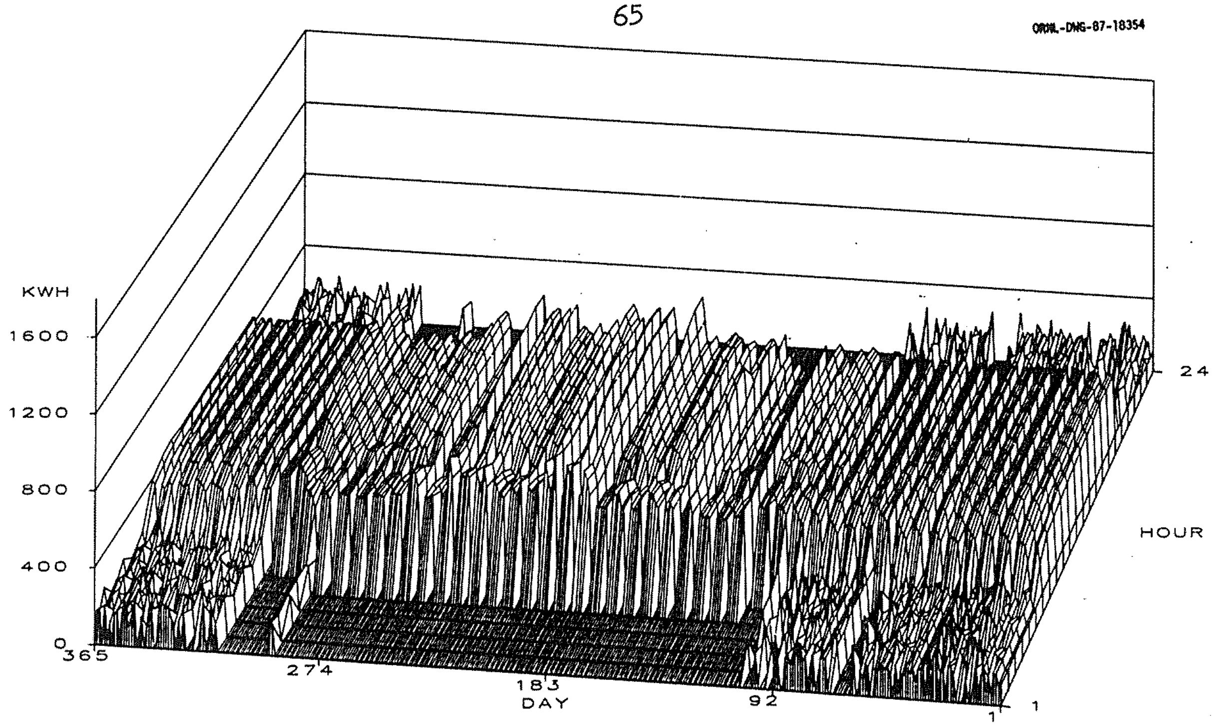
For Miami the cooling loads are much higher. The values shown in Fig. 4.15 are for the large building having the baseline configuration except that the HVAC system is a variable air volume system. The space heating loads for this situation are negligible.

The profiles for HVAC system electricity use (including the fan energy) for these three cases are shown in Fig. 4.16. The variable air volume system uses less electricity but has a lower average to peak electricity use ratio than does the multizone system. The values for Miami are higher because of the higher cooling load in that city. All these profiles show peaking on startup following system shutdown during the nights and weekends. They are, again, generally higher for the first working day of the week.

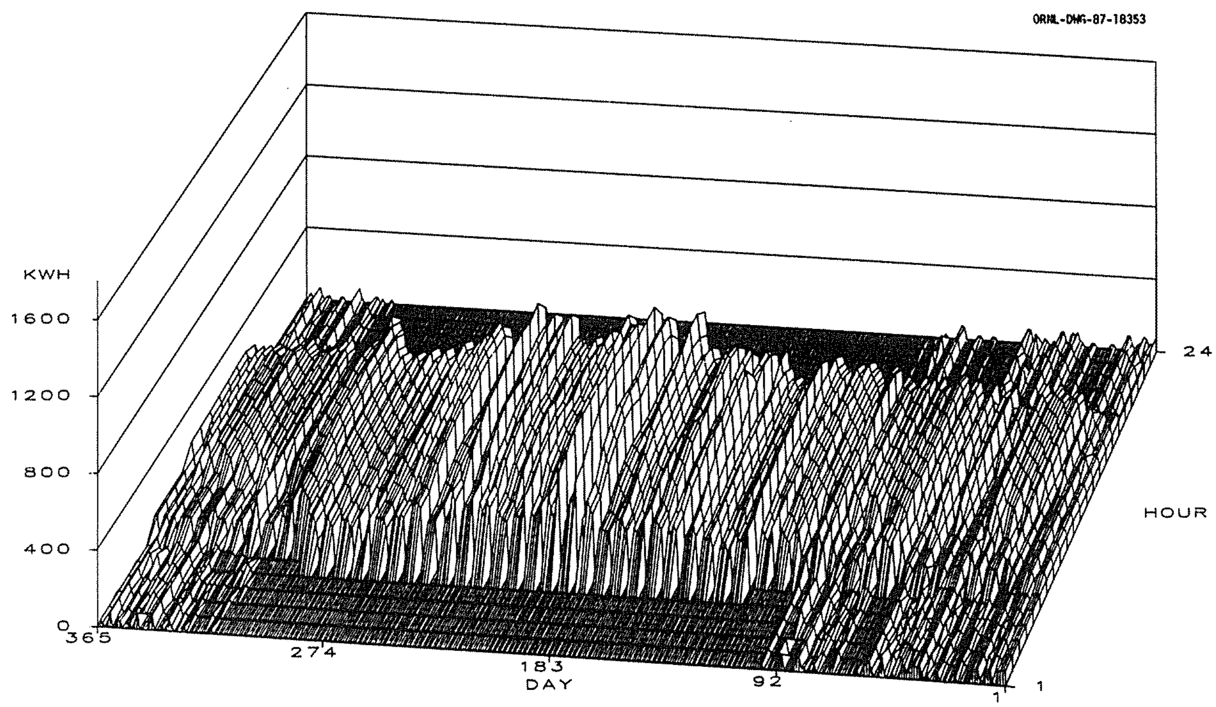
Profiles for natural gas use are not presented since they are similar to the heating load profiles shown in Figs. 4.13a, 4.14a, and 4.15a. This is because of the assumption of natural gas being used for only space and domestic hot water heating.

For comparison, the profiles for the total electrical use for these three cases are shown in Fig. 4.17. The building in Miami consumes the most electricity, reflecting the relatively large cooling load. For Chicago, the fraction of the total electrical energy consumed by the HVAC system is much less.

Breakdowns of the electrical consumption by the two selected buildings using the variable air volume HVAC systems are given in Figs. 4.18 and 4.19. The data are for a working day in January, when the cooling loads are small, and for a working day in July, when the cooling loads are high. (Electricity consumed by the heating equipment is for the heating equipment auxiliaries, such as fans and circulating water pumps.) In Chicago, the lighting and office equipment

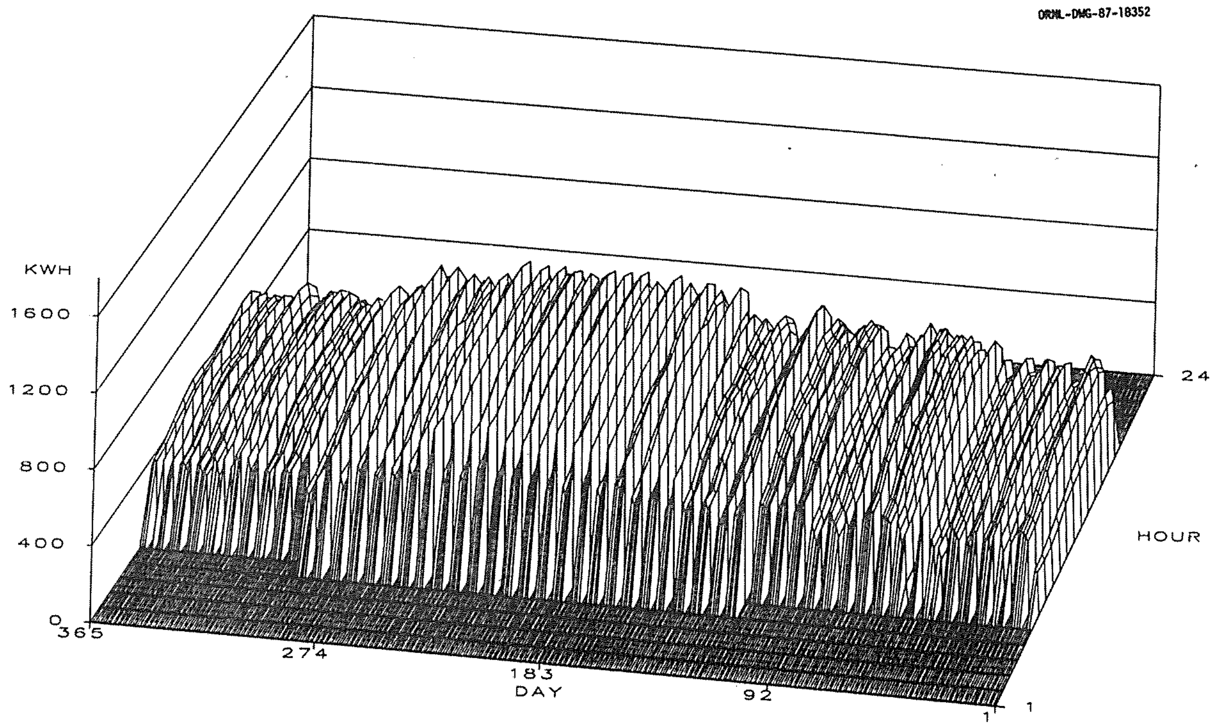


a)



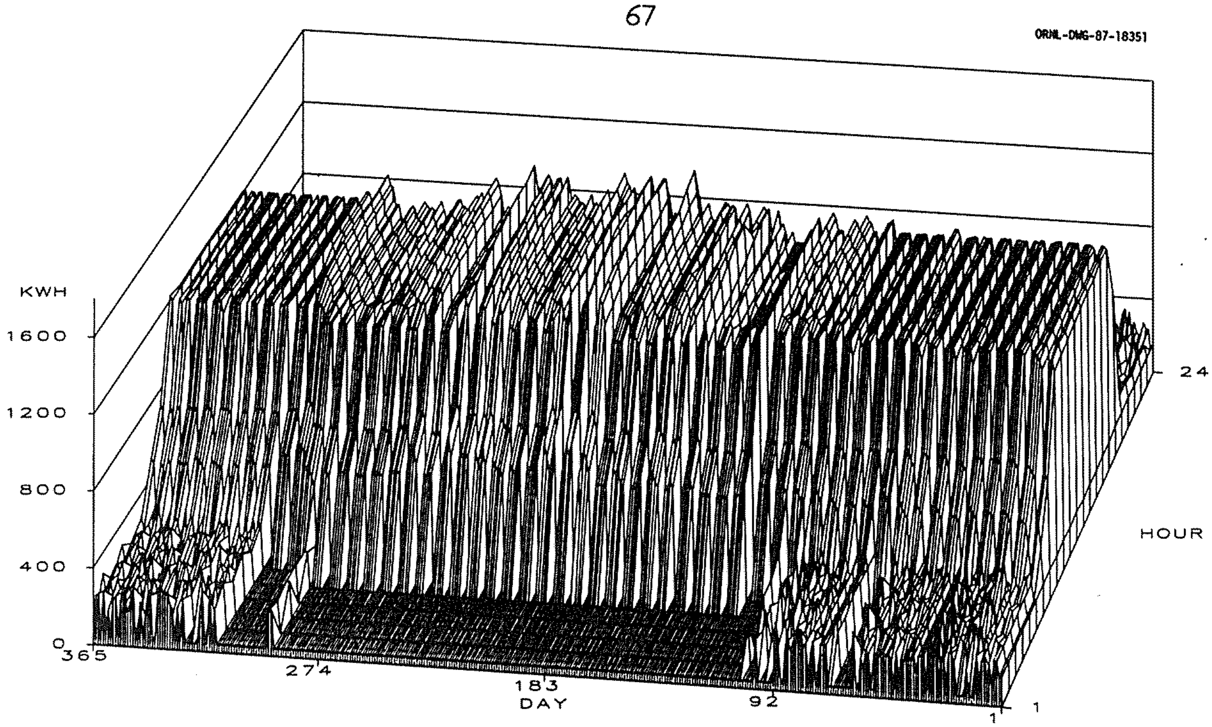
b)

Fig. 4.16. Hourly values of HVAC electricity consumption for large building: (a) baseline parameter configuration, Chicago, (b) baseline parameter configuration, modified to use a variable air volume HVAC system and energy efficient construction, Chicago.

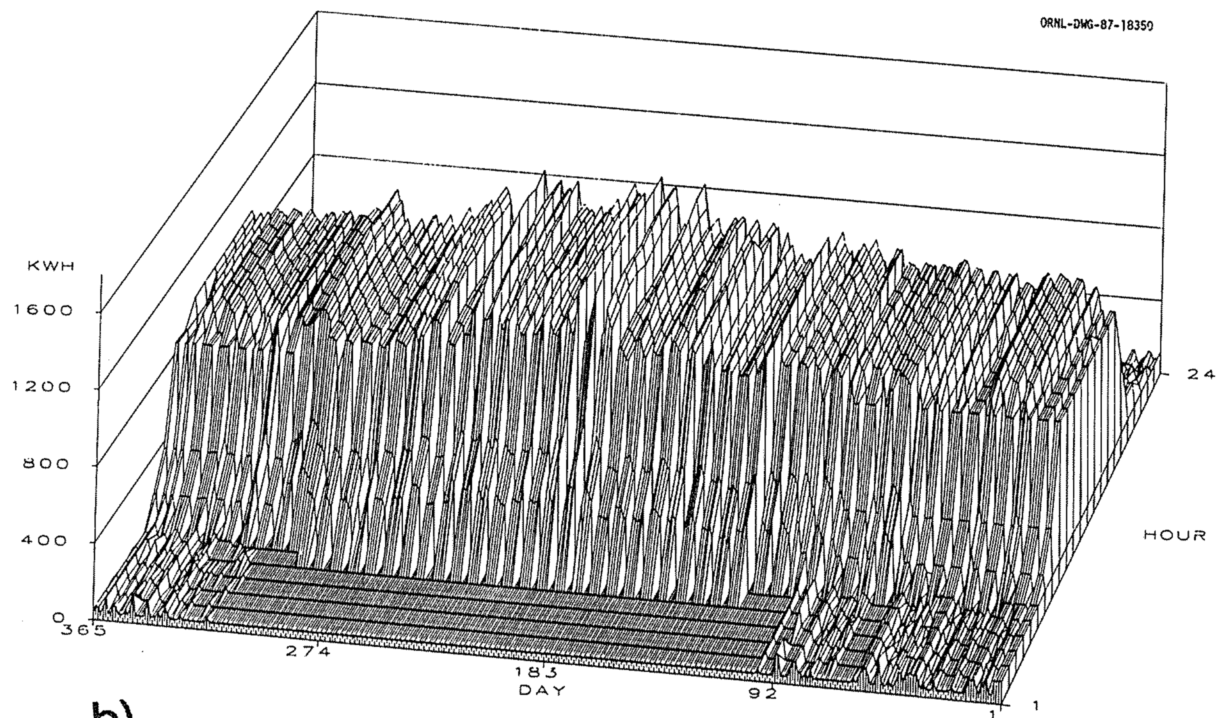


c)

Fig. 4.16. Hourly values of HVAC electricity consumption for large building (continued): (c) baseline parameter configuration, modified to use a variable air volume HVAC system, Miami.



a)



b)

Fig. 4.17. Hourly values of total electricity consumption for large building: (a) baseline parameter configuration, Chicago, (b) baseline parameter configuration, modified to use a variable air volume HVAC system and energy efficient construction, Chicago.

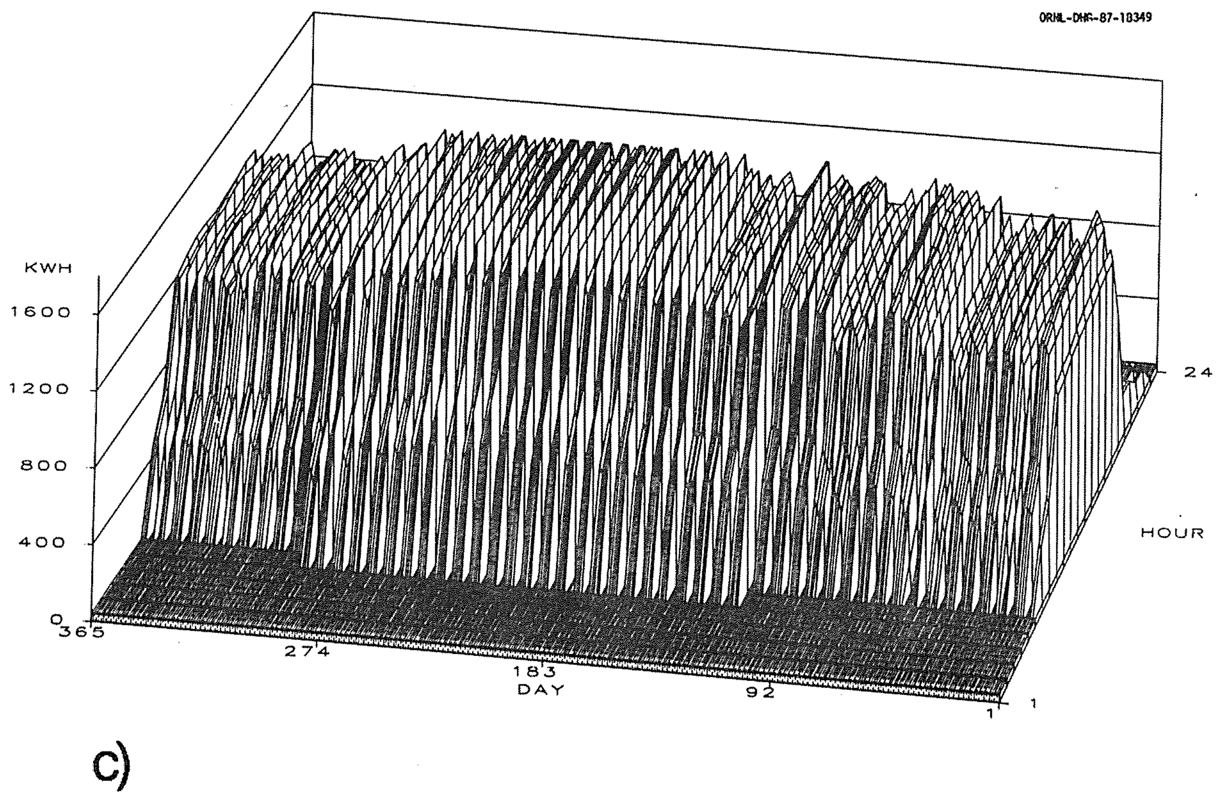


Fig. 4.17. Hourly values of total electricity consumption for large building (continued): (c) baseline parameter configuration, modified to use a variable air volume HVAC system, Miami.

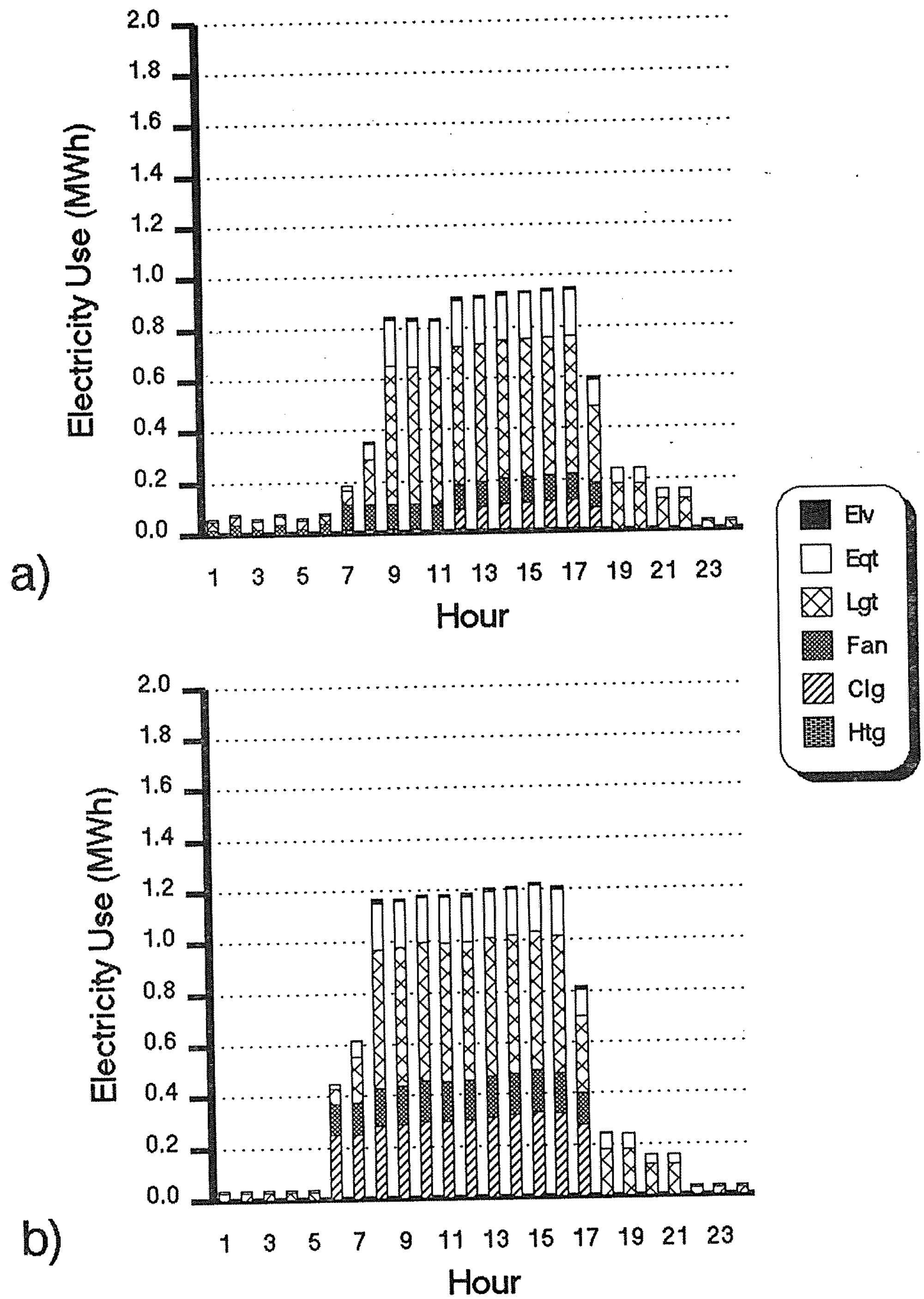


Fig. 4.18. Hourly values of electricity end-use components for large building having the baseline parameter configuration, modified to use a variable air volume HVAC system and energy efficient construction, in Chicago: (a) January 21, (b) July 22.

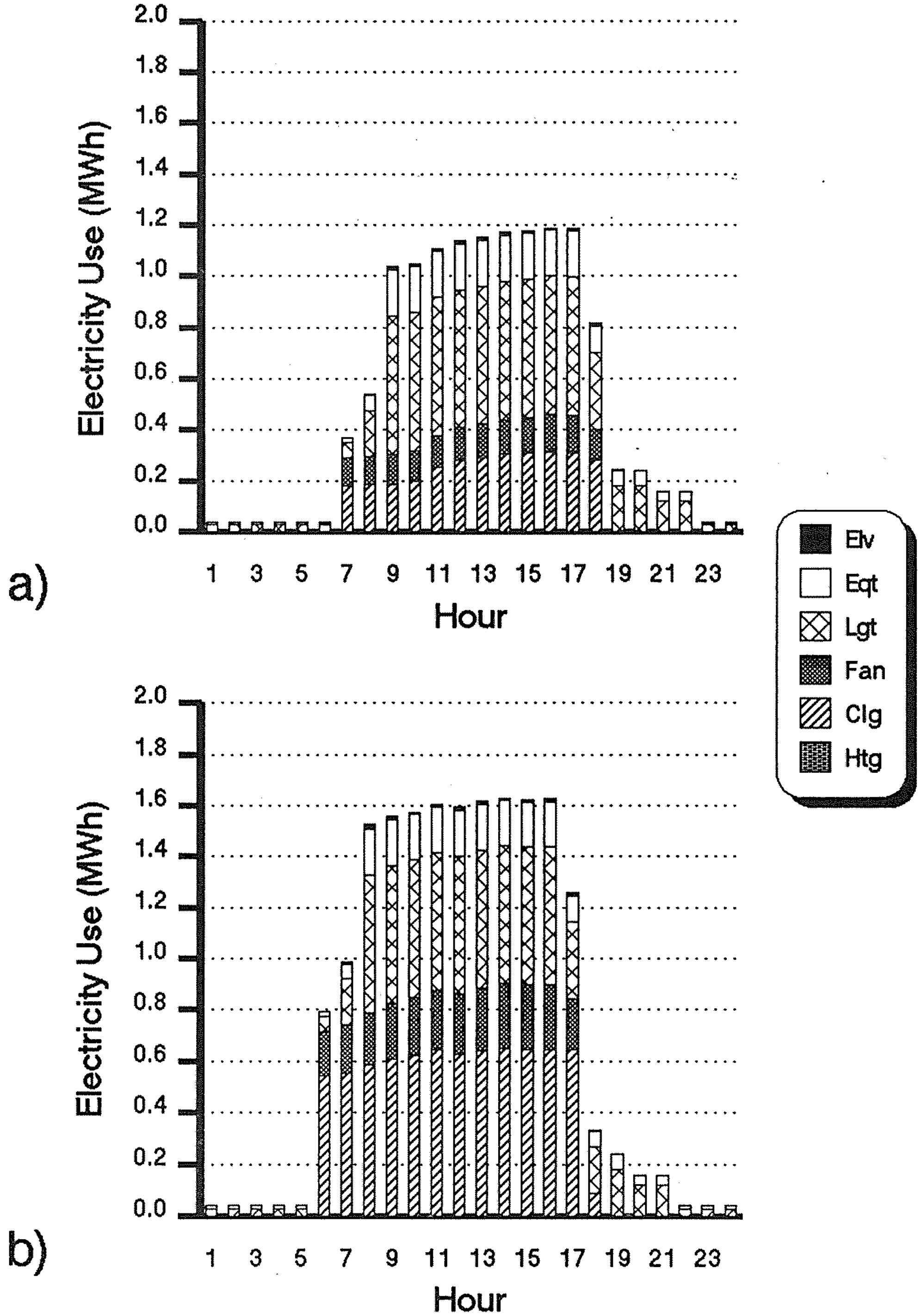


Fig. 4.19. Hourly values of electricity end-use components for large building having the baseline parameter configuration, modified to use a variable air volume HVAC system, in Chicago: (a) January 21, (b) July 22.

consume the greatest part of the electricity, but the HVAC system consumes a very significant part, over one-third, during the summer. For Miami, the HVAC system consumes a large part of the electricity during the entire year, over one-half, during the summer days.

5. ENERGY COSTS

End-use energy costs were calculated from the hourly energy consumption data using the 1985 energy price schedules listed in Tables 3.3 and 3.4. It is recognized that energy prices vary from location to location and change frequently, but these results give some indication of the effects of the parameters on the cost of the end-use energy for the buildings.

The costs per unit area for each case are listed in Appendix B. Bar graphs of the annual energy costs are also presented in Appendix B. These graphs show the electric demand and energy costs and the natural gas cost for each of the 106 cases investigated.

The annual energy costs for the buildings having the baseline parameter configuration (Sect. 4.1) are shown in Fig. 5.1. The difference between the energy costs for the buildings at the three locations investigated is relatively small. Although use of natural gas for heating is much higher in the colder climates (Fig. 4.7), the fact that the gas prices (1985) are lower than the electricity prices helps to minimize the difference in the energy costs at the different locations. The energy costs per unit floor area are the greatest for the small building because of its higher loads per unit area. The electrical loads for the buildings in Chicago are the lowest in three cities, but the electrical costs are higher in that city (during 1985) resulting in slightly greater total energy costs. Except for the small building in Miami, the electricity demand charges are 35% to 50% of the total electricity charges. (For small commercial customers in Miami, there is a small customer charge instead of a demand charge.)

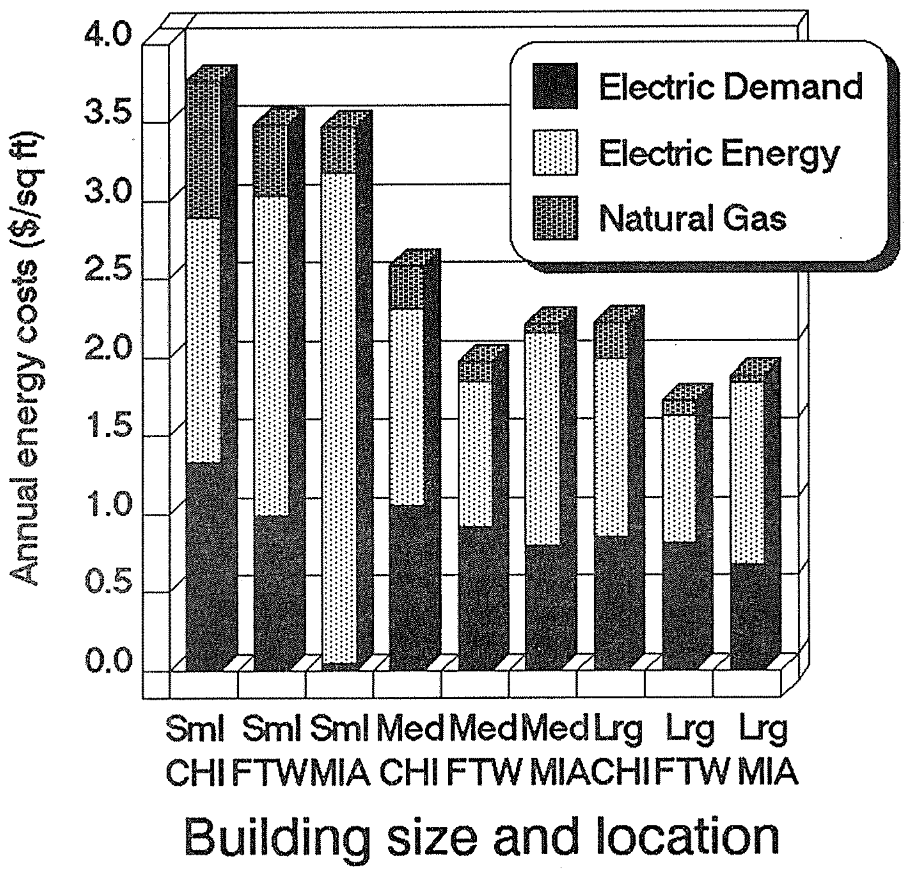


Fig. 5.1. Annual energy costs for buildings having the baseline parameter configuration.

The magnitude of energy cost savings for the selected buildings (refer to Figs. 4.10 and 4.11 for energy use reduction) are shown in Fig. 5.2. It is interesting to note that switching from multizone HVAC systems to variable air volume systems results in reduction of electrical energy and natural gas charges, but there is little change in the electrical demand charges. Again, this is because there is not much difference between the peak demands for the two systems. Use of external wall insulation and reflective glazing results in additional cost savings. Reducing the internal loads reduces the cooling loads, which results in additional cost savings.

The values of the annual energy costs in Fig. 5.2 are on a $\$/ft^2$ basis. For the cases presented in this figure, the total annual energy cost reduction associated with these changes are $3,550, $24,650, and $129,000 for the small, medium, and large buildings, respectively.

For the economizer and the minimum ventilation rates, the impacts on the energy costs are small, as shown in Fig. 5.3. To the limited extent that these parameters were analyzed in this investigation, there generally are savings in the electricity costs. The economizer showed the greatest savings in Chicago (Fig.4.7). For the example in Fig. 5.3, use of the economizer resulted in about a 1% reduction in the total energy cost. As indicated previously, the economizer results are suspect.

Reducing the minimum ventilation rate reduces the heating loads the greatest in Chicago and the cooling loads the greatest in Miami, as shown in Fig. 4.7. The overall impact for the selected buildings is about a 3% to 4% reduction in total energy cost at all three locations.

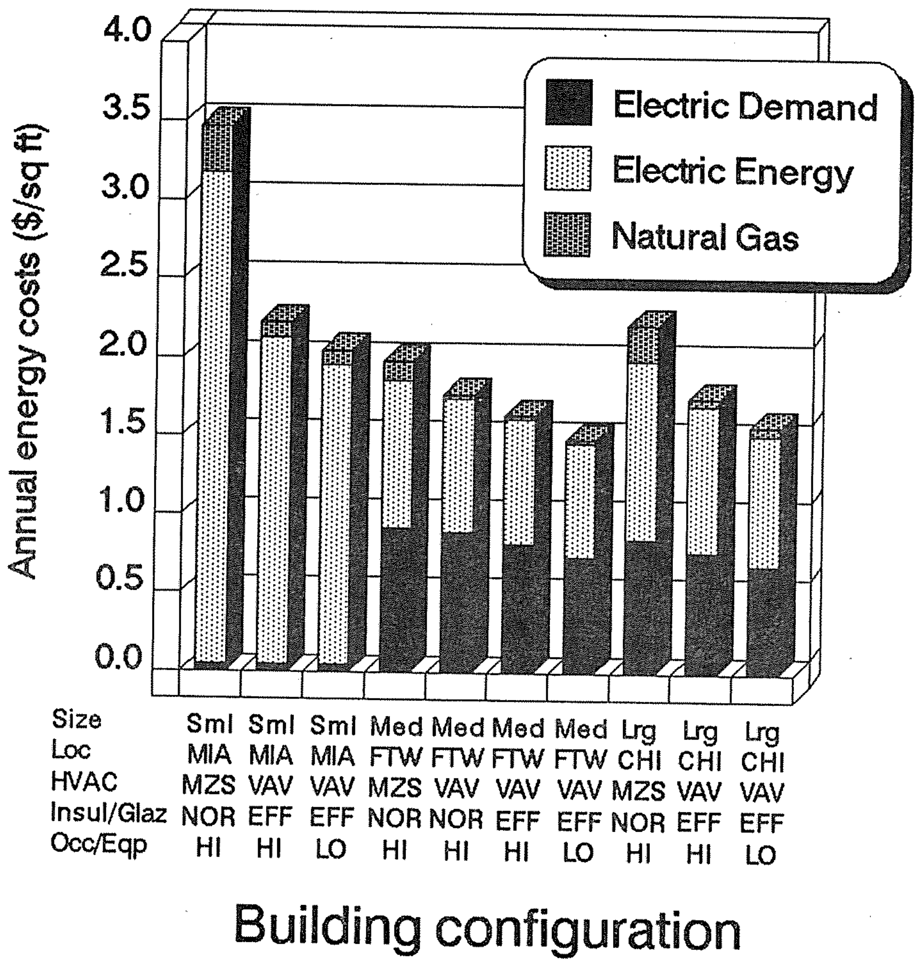


Fig. 5.2. Comparison of annual energy costs for selected buildings. See Table 4.1 for meanings of abbreviations. All selected buildings have no HVAC economizer, 20% minimum ventilation rate, and 3 W/ft^2 lighting power.

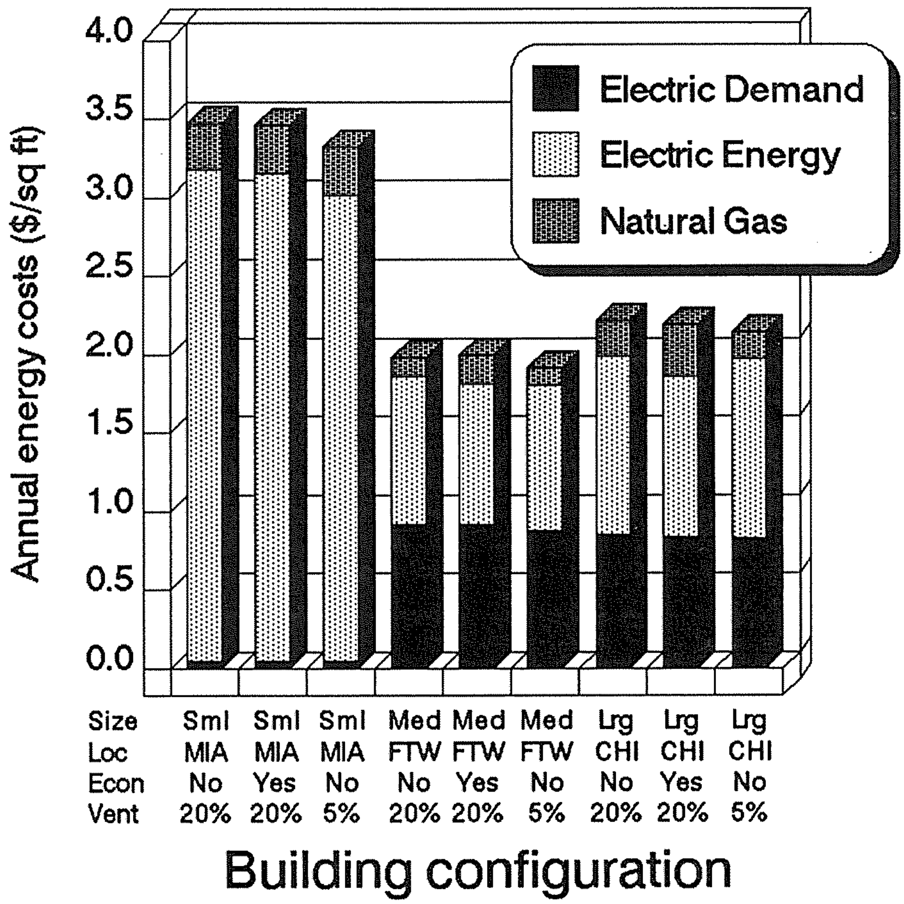


Fig. 5.3. Impacts of economizer and minimum ventilation rate on the annual energy costs for selected buildings. See Table 4.1 for meanings of abbreviations. All selected buildings have multizone HVAC systems, 3 W/ft^2 lighting power, 10 occupants per 1000 ft^2 in perimeter areas, 5 occupants per 1000 ft^2 in core areas, 1 W/ft^2 equipment power, minimal insulation, and clear, single-pane glazing.

6. GENERAL RESULTS AND CONCLUSIONS

A library of data files listing the hourly values of the end-use energy components for commercial office buildings was generated in this investigation. The generated data were sufficient for the investigation purpose of gaining an understanding of the energy consumption behavior in the buildings. The fractional factorial design was an effective method of developing this understanding with a minimum of computer calculations.

The data files were stored on magnetic tapes and can be used directly or as a point of departure for future studies. For example, the predicted heating and cooling loads for a particular building could be used to evaluate the effectiveness of HVAC system options, such as natural gas fueled cooling equipment.

In the course of this investigation, a shell processing routine was developed automating much of the procedure for submission of the DOE-2.1B program with the input data to the computer, extracting the desired data from the program output files and storing the extracted data. This processing routine is in modular form and can be modified readily to use other input data files and other output routines for extracting and processing the data for similar studies.

It was found that the building size, location, and the HVAC system type have major impacts on the building energy use, and the mean effects of those parameters were estimated. The energy use per unit floor area in small buildings, for the configurations assumed in this investigation, is much greater than in the medium and large buildings. The differences between the energy use values for the medium and large buildings are relatively small. For the hourly energy demands, the values for the small buildings show more response to changes in weather conditions. The small building has a larger portion of the conditioned space adjacent to the building thermal envelope than for the other buildings, and this is reflected in the energy use trends.

A separate investigation would be useful for small (less than 8,000 ft^2) buildings using the construction and HVAC systems typical for those buildings. These parameters were made similar to those for the medium and large buildings in this study to gain an understanding of the size impacts. However, it is apparent that the energy use behavior in the small buildings is different from those in the larger buildings.

The building location and HVAC system type, and the interaction between these two parameters, have major impacts on the building heating and cooling loads. The heating loads are the greatest in Chicago and the least in Miami. For the large building, the mean values are 22 kBtu/ft^2 and 4 kBtu/ft^2, respectively. The cooling loads are generally greater at all locations, with the highest being at Miami and the lowest being at Chicago. The large building cooling load mean values are 31 kBtu/ft^2 in Chicago and 73 kBtu/ft^2 in Miami. The building location has some effect on the peak heating rate, but very little effect on the peak cooling rate.

The choice of the HVAC system greatly impacts the energy use in the building. The two systems used in this study are somewhat the extremes used in buildings. The multizone system mixes hot air and cold air for the air supplied to each zone, while the variable air volume system only heats or cools the air supplied to each zone. Moreover, the amount of air supplied to each zone is reduced during offpeak periods for the variable air volume system. This influences the amount of heat that is added to and extracted from the building, as well as the end-use energy consumption, and these are impacted by the location. This suggests that the optimum choice for the specific type of a HVAC system is dependent on the location of the building. Future work should be done in this area.

The study indicated that there are some benefits for installing economizers and reducing the building minimum ventilation rates. Use of economizers appears to be beneficial in Chicago but not in Miami. This conclusion should be regarded as preliminary since all aspects of economizer operation were not investigated. Reducing the minimum ventilation rates results in small savings at all locations. In Chicago, the savings are primarily in the form of heating energy, and in Miami, the savings are primarily in the form of cooling energy.

This study did not examine the impact of the different building use and HVAC system operation schedules. A typical occupancy schedule was assumed, and the HVAC systems were assumed to be shut down to minimum protection levels when the building was essentially unoccupied. Different operating schedules certainly would impact the building energy consumption. Furthermore, mainframe computers were not included in the analysis. Frequently located in the larger office buildings, the units operate 24 hours a day and generate 15 kW to 150 kW of heat per unit. Future studies evaluating computer impacts would be useful.

Building insulation and glazing significantly impact the loads, particularly the cooling loads. Although calculations were not made to confirm this, it is believed that most of the difference is due to the glazing. Use of reflective glazing reduces the cooling loads in the buildings investigated in this study. This should be studied further.

The impacts of the parameters are reflected on the building energy end-use and energy costs. Buildings in Chicago consume the greatest amounts of natural gas, while those in Miami consume the greatest amounts of electricity. The small buildings have the biggest differences. The effects of location on the energy costs are not as large, however. This is due to the differences in the electricity and natural gas rate structures at the different locations. In general, cost savings could be realized by reducing electrical consumption at the expense of using natural gas.

Typically, the large building electric use is about 15 $kWh/ft^2/yr$ in Chicago and about 17 $kWh/ft^2/yr$ in Miami. A large part of the building energy is consumed by the HVAC system. Including the building circulating air fans (3 kWh/ft^2 to 4 $kWh/ft^2/yr$), the HVAC system can consume up to 50% of the electricity used by the building. Measures such as using more efficient variable air volume HVAC systems and reflective glazing help greatly to reduce this percentage. This further demonstrates the influence of the HVAC systems on the building energy consumption. Most of the natural gas supplied to the building was assumed to be used for space heating.

Some idea of the building load factors were determined by calculating the average-to-peak electric use ratio for the buildings. For the medium and large buildings, the mean ratio varied from 0.27 in Chicago to 0.30 in Miami. These ratios are about 10% to 20% lower for the small building. Use of a variable air volume HVAC system instead of a multizone system reduces the mean ratios about 10% to 15%. This is due to the peak cooling loads being about the same for the two systems.

The lower electrical load factor for the variable air volume systems is reflected in the energy costs. Buildings having these HVAC systems have lower electrical energy costs but have about the same electrical demand costs. There are opportunities for lowering demand costs by using energy storage techniques, cogeneration, or alternative energy supplies. These options should be investigated further.

Reducing the internal loads results in lower energy use and costs. One of the most effective ways to reduce electricity use and cost is to reduce the lighting. In this investigation, reducing the lighting from 3 W/ft^2 to 1.6 W/ft^2 results in a reduction of about 4 $kWh/ft^2/yr$. This is about a 20% reduction in the electrical use, on the average. Most of this reduction is due to direct reduction of the lighting energy since the coefficient of performance of the selected air conditioning equipment is in the range of 2.5 to 3. In many cases there is additional heating demand, but its cost is lower than the savings from the reduced electricity consumption.

Work in the immediate future should be directed toward analyzing different HVAC options and control strategies for a single building located in a single city. This analysis could then be expanded for the same building located in other cities. It is suggested that the large building be selected for this study, since the additional cost to analyze this building compared to the medium-size building is negligible.

7. REFERENCES

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APPENDIX A

APPENDIX A

DOE-2.1B Program Input Files

The DOE-2.1B program input files for the buildings investigated in this analysis are listed in Tables A.1, A.2, and A.3. These files are for the small office building, medium office building, and the large office building, respectively.

To facilitate the handling of multiple computer runs, the buildings and parameters were cataloged in terms of configuration numbers (Fig. 2.1). These are nine digit numbers, with each digit being a code number for a selected parameter values. The meanings of the code numbers for the first eight digits of the configuration number are given in Table 2.2. (The ninth digit of the configuration number was not used.)

The DOE-2.1B program files, given in Tables A.1, A.2, and A.3, incorporate multiple statements for the different parameter values used in this investigation. The statements start with the symbol, $, which is the convention used in the DOE-2.1B program for commenting statements so that they do not become part of the input data. For each building configuration, selected for analysis, the comment symbol, $, was removed from the beginning of the statements required to be part of the input data for that configuration. The line numbers of the input data statements invoked this way for the different parameter code numbers are listed in Table A.4. Abbreviated values of the parameters are listed in this table for the reader's convenience.

Included in the input files are design day weather data used to size the HVAC equipment for the buildings. These data are listed in Lines 79 through 98 in Table A.1, Lines 81 through 100 in Table A.2, and Lines 80 through 99 in Table A.3. The first set of data is for

Chicago, IL, the second set of data is for Ft. Worth, TX, and third set of data is for Miami, FL. The data were selected from design weather data presented in the American Society of Heating, Refrigerating, and Air Conditioning Engineers' 1981 Handbook of Fundamentals and from the data listed in the TRY weather data. Some engineering judgement was required in selecting the design day weather data.

Table A.1. DOE-2.1B Input File for Small Office Building

```
INPUT LOADS ..

TITLE LINE-1 * G *
      LINE-2 *1-STORY OFFICE BLDG.*
$      LINE-3 *CHICAGO*                   ..
$      LINE-3 *FT WORTH*                  ..
$      LINE-3 *MIAMI*                     ..

$ FREE INTERPRETATION OF DOE-2 1-STORY OFFICE BUILDING FILE
$ LISTED IN PNL-4870-12

$ INPUT FILE USED CUSTOM WEIGHTING FACTORS
$ TO GIVE A BETTER SIMULATION OF BUILDING MASS AND HVAC SYSTEM
$ PERFORMANCE.  EACH BAY ON ALL FOUR EXPOSURES IS TREATED
$ AS A SEPARATE ZONE.  THERE ARE 2 BAYS EXPOSED TO EACH ORIENTATION,
$ EACH BAY HAVING 25 FT EXPOSURE.

$ ONE STORY STRUCTURE STEEL FRAME WITH CARPETED, CONCRETE FLOORS
$             AND ROOF.  12 FT FLOOR TO ROOF HEIGHT,
$             9FT CEILING, AND SINGLE RETURN AIR CEILING PLENUM ARE
$             DEFINED.

$ CURTAIN WALL  USING CODE-WORDS FROM DOE-2 LIBRARY (REFERENCE MANUAL,
$             PART 2) AND STARTING WITH OUTSIDE AND WORKING INWARD;
$             LIGHTWEIGHT PRECAST CONCRETE (CC24);  6 IN. AIRSPACE (AL31);
$             5/8 IN. GYPSUM BOARD FINISH (GP02).
$             FOR INSULATED WALLS, ADD R-11 MINERAL WOOL INSULATION
$             (IN02 BETWEEN CC24 AND AL31).

$ ROOF        ROOF GRAVEL (RG01); BUILTUP ROOFING (BR01); 1 IN. ROOF
$             INSUL (IN76); 4 IN. CONCRETE (CC03); METAL DECK (AS01).
$             FOR INSULATED ROOFS, ADD 3 IN. EXPANDED POLYSTYRENE
$             INSULATION (IN36 BETWEEN IN76 AND CC03)

$ WINDOWS     30% OF EXTERNAL WALL AREA GLAZED
$             GLAZING 1/4 IN. CLEAR GLASS - SINGLE PANE.
$             FOR INSULATED BUILDINGS, CHANGE GLAZING TO
$             DOUBLE PANE TINTED GLASS FOR CHICAGO (G-T-C 7)
$             SINGLE PANE TINTED GLASS FOR FT. WORTH AND MIAMI (G-T-C 10).

$ INTERIORS   CEILING IS SUSPENDED ACCOUSTIC TILE (AC02).
$             PARTITIONS ARE FRAME WALLS WITH GYPSUM BOARD ON EACH
$             SIDE (GP02, AL12, GP02).

$ SPACE LOADS  LIGHTING RECESSED FLUORESCENT AT 3 WATTS/SQFT.
$             OFFICE EQUIPMENT 1 WATTS/SQFT.
$             PEOPLE  100 SQFT/PERSON FOR PERIMETER SPACES
$                     200 SQFT/PERSON FOR CORE AREAS.
$             FOR LOW INTERNAL LOAD CASES, LIGHTING 1.6 WATTS/SQFT,
$             EQUIPMENT .5 WATTS/SQFT, PEOPLE 250 SQFT/PERSON IN
$             ALL AREAS.
$             INFILTRATION .6 AIR CHANGES/HR FOR PERIMETER AREAS WHEN
$             FANS ARE OFF - .2 AIR CHANGES/HR WHEN FANS ARE ON.

$ HVAC DESCRIPTIONS ARE TO BE FOUND WITH EACH INDIVIDUAL SYSTEM AND
$ PLANT INPUT.

DIAGNOSTIC CAUTIONS  ..
ABORT ERRORS         ..

$BUILDING-LOCATION  LAT 41.78  LON 87.75  ALT 610  T-Z 6
$         ATM-MOISTURE (.36,.32,.40,.53,.76,1.11,
$                       1.21,1.12,.88,.66,.43,.35)
$         ATM-TURBIDITY (.15,.18,.21,.18,.18,.19,
$                       .22,.16,.16,.14,.13,.15)          ..

```

```
$BUILDING-LOCATION  LAT 32.90  LON 97.30  ALT 538  T-Z 6
$          ATM-MOISTURE (.48,.51,.58,.80,1.06,1.32,
$                        1.48,1.46,1.28,.90,.65,.54)
$          ATM-TURBIDITY (.07,.12,.16,.16,.36,.35,
$                         .36,.53,.45,.23,.19,.21)  ..

$BUILDING-LOCATION  LAT 25.8  LON 80.27  ALT 7  T-Z 5
$          ATM-MOISTURE (.96,.95,1.00,1.10,1.31,1.64,
$                        1.69,1.74,1.77,1.50,1.16,1.10)
$          ATM-TURBIDITY (.19,.29,.30,.31,.36,.54,
$                         .51,.55,.40,.33,.31,.24)  ..

$ WINTER=DESIGN-DAY  DB-H 10  DB-L -4  H-H 15  H-L 8
$                    DP-H 0  DP-L -13  DH-H 15  DH-L 8
$                    W-S 12  W-D 13  C-A 5  C-T 2  CL .98  G-T 38    ..
$ SUMMER=DESIGN-DAY  DB-H 91  DB-L 71  H-H 16  H-L 6
$                    DP-H 68  DP-L 58  DH-H 16  DH-L 8
$                    W-S 12  W-D 11  C-A 0  C-T 2  CL .98  G-T 65  ..

$ WINTER=DESIGN-DAY  DB-H 50  DB-L 22  H-H 16  H-L 6
$                    DP-H 19  DP-L 16  DH-H 16  DH-L 8
$                    W-S 12  W-D 8  C-A 5  C-T 2  CL .95  G-T 60  ..
$ SUMMER=DESIGN-DAY  DB-H 100  DB-L 80  H-H 17  H-L 6
$                    DP-H 66  DP-L 65  DH-H 18  DH-L 6
$                    W-S 10  W-D 8  C-A 0  C-T 2  CL .95  G-T 80  ..

$ WINTER=DESIGN-DAY  DB-H 62  DB-L 47  H-H 17  H-L 6
$                    DP-H 55  DP-L 45  DH-H 18  DH-L 6
$                    W-S 10  W-D 5  C-A 5  C-T 2  CL .85  G-T 69  ..
$ SUMMER=DESIGN-DAY  DB-H 89  DB-L 80  H-H 15  H-L 6
$                    DP-H 76  DP-L 75  DH-H 16  DH-L 6
$                    W-S 12  W-D 6  C-A 0  C-T 2  CL .90  G-T 78  ..

$RUN-PERIOD  JAN  1 1974 THRU DEC 31 1974  ..
$RUN-PERIOD  JAN  1 1975 THRU DEC 31 1975  ..
$RUN-PERIOD  JAN  1 1964 THRU DEC 31 1964  ..

LOADS-REPORT  S (LS-F,LS-K)    ..

        $  SCHEDULES  $

OC1 D-SCH   (1,5) (.025)  (6,8) (.05,.1,.2)  (9,11) (.95)  (12,13) (.8,.5)
            (14,17) (.95)  (18,19) (.5,.3)  (20,22) (.1)  (23,24) (.025)  ..
OC2 D-SCH   (1,5) (.025)  (6,7) (.05)  (8,17) (.1)  (18) (.05)
            (19,24) (.025)  ..
OC3 D-SCH   (1,24) (.025)  ..
OCCUP SCH   THRU DEC 31 (WD) OC1  (SAT) OC2  (SUN,HOL) OC3  ..

LG1 D-SCH   (1,6) (.05)  (7,8) (.1,.3)  (9,17) (.9)  (18) (.5)
             (19,20) (.3)  (21,22) (.2)  (23,24) (.05)  ..
LG2 D-SCH   (1,6) (.05)  (7,8) (.1)  (9,12) (.3)  (13,17) (.15)
            (18,24) (.05)  ..
LG3 D-SCH   (1,24) (.05)  ..
LIGHTS SCH  THRU DEC 31  (WD) LG1  (SAT) LG2  (SUN,HOL) LG3  ..

INFIL SCH   THRU DEC 31  (WD)  (1,6) (1)  (7,18) (.33)  (19,24) (1)
            (WEH) (1,24) (1)  ..  $ MIRROR OF FAN SCH

DH1 D-SCH (1,7) (.025)  (8,24) (.15,.3,.35,.35,.55,.55,.5,.3,.3,.4,
                                .2,.2,.1,.15,.05,.025,.025)  ..
DH2 D-SCH (1,7) (.025)  (8,17) (.1,.1,.2,.15,.2,.15,.15,.1,.1,.1)
            (18,24) (.025)  ..
DHW SCH  THRU DEC 31  (WD) DH1  (SAT) DH2  (SUN,HOL) OC3  ..
PULL-SHADE SCH  THRU DEC 31  (ALL)  (1,24) (100)  ..
SHADE-MULT SCH  THRU DEC 31  (ALL)  (1,24) (.65)  ..

        $ MATERIAL NOT IN DOE-2 LIBRARY $

EARTH MAT  TH 2.50  COND .500  DENS 120  S-H .2  ..
```

```
          $  CONSTRUCTION  $

$WA1 LAYERS  MAT (CC24,AL31,GP02)  ..
$R1 LAYERS  MAT (RG01,BR01,IN72,CC03,AS01)  I-F-R .61  ..
$WA1 LAYERS  MAT (CC24,IN02,AL31,GP02)  ..
$R1 LAYERS  MAT (CC24,BR01,IN72,IN36,CC03,AS01)  I-F-R .61  ..
P1 LAYERS  MAT (GP01,AL21,GP01)  ..
FLRG LAYERS  MAT (EARTH,CC03,CP01)  I-F-R .61  ..
C1 LAYERS  MAT (AC02)  ..

B-WALL CONS  LA WA1  RO 5  ..  ROF CONS  LA R1  ..
PART CONS  LA P1  ..  AIR-LY CONS  U 1.5  ..
CEIL CONS  LA C1  ..  FLOOR-G CONS  LA FLRG  ..
$GLASS1 G-T  G-T-C 3  P 1  G-C 1.38  ..
$GLASS1 G-T  G-T-C 7  P 2  G-C .574  ..
$GLASS1 G-T  G-T-C 10  P 1  G-C 1.38  ..

SET-DEFAULT FOR EXTERIOR-WALL  CONS B-WALL  AZ 180  W 25  ..
SET-DEFAULT FOR WINDOW  G-T  GLASS1  X 3.5  Y 3  H 5  W 18
                        M-S-SCH PULL-SHADE  S-SCH SHADE-MULT  ..

          $  SPACE DESCRIPTION  $

OFFICE S-C  T (74)  F-W 0  I-M AIR-CHANGE  A-C .6
$            L-T REC-FLUOR-RV  L-SCH LIGHTS  L-W 3  L-T-S .8
$            L-T REC-FLUOR-RV  L-SCH LIGHTS  L-W 1.6  L-T-S .9
$            E-SCH LIGHTS  E-W 1  P-SCH OCCUP  P-H-G 450
$            E-SCH LIGHTS  E-W .5  P-SCH OCCUP  P-H-G 450
            DAY NO  I-SCH INFIL  ..

OFF-PLEN S-C  T (74)  Z-TYPE PLENUM  F-W 0
              I-M AIR-CHANGE  A-C .6  I-SCH INFIL  ..

$Z1 SPACE  S-C OFFICE  V 3600  A 400  N-O-P 2  A-C 0  ..
$Z1 SPACE  S-C OFFICE  V 3600  A 400  N-O-P 1.6  A-C 0  ..
    IN1 I-W  A 225  CONS PART  N-T Z2  ..
        I-W  LIKE IN1  N-T Z3  ..
        I-W  LIKE IN1  N-T Z4  ..  I-W  LIKE IN1  N-T Z5  ..
        I-W  A 9450  CONS CEIL  TILT 0  N-T PLEN  ..
        U-W  A 400  CONS FLOOR-G  TILT 180  U-EFF 0  ..

$Z2 SPACE  S-C OFFICE  A 262.5  V 2362.5  N-O-P 2.63  AZ -90  M 2  ..
$Z2 SPACE  S-C OFFICE  A 262.5  V 2362.5  N-O-P 1.05  AZ -90  M 2  ..
    WL1 E-W  H 9  ..  WI  ..
    IN2 I-W  A 125  CONS PART  I-W-TYPE ADIABATIC  ..
        I-W  LIKE IN2  ..
    FL1 U-W  A 262.5  CONS FLOOR-G  TILT 180  U-EFF .079  ..
    CL1 I-W  A 262.5  CONS CEIL  TILT 0  N-T PLEN  ..

Z3 SPACE  LIKE Z2  AZ 180  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        U-W  LIKE FL1  ..  I-W LIKE CL1  ..

Z4 SPACE  LIKE Z2  AZ 90  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        U-W  LIKE FL1  ..  I-W  LIKE CL1  ..

Z5 SPACE  LIKE Z2  AZ 0  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        U-W  LIKE FL1  ..  I-W  LIKE CL1  ..

PLEN SPACE  S-C OFF-PLEN  A 2500  V 6750  ..
    WL2 E-W  H 3  ..  E-W  LIKE WL2  AZ -90  ..
        E-W  LIKE WL2  AZ 90  ..  E-W  LIKE WL2  AZ 180  ..
        ROOF  H 50  W 50 CONS ROF  G-R 0  AZ 90  TILT 0  ..

B-R  H-W 3000  HW-SCH DHW  ..
```

```
        $  HOURLY REPORT  $
RPTSCH SCH  THRU DEC 31  (ALL)  (1,24)  (1)  ..
OUT-1 R-B  V-T BUILDING  V-L (40,41,44)  ..
HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1)  ..
END  ..
COMPUTE LOADS  ..
INPUT SYSTEMS  ..
$TITLE  LINE-4  *PMZS*  ..
$TITLE  LINE-4  *PVAVS*  ..
SYSTEMS-REPORT  V (SV-A)  S (SS-A,SS-B,SS-D,SS-H)  ..
FANSON1 SCH  THRU APR 15  (WD)  (1,6) (0)  (7,18) (1)  (19,24) (0)
                          (WEH) (1,24) (0)
             THRU OCT 15  (WD)  (1,6) (-1)  (7,18) (1)  (19,24) (-1)
                          (WEH) (1,24) (-1)
             THRU DEC 31  (WD)  (1,6) (0)  (7,18) (1)  (19,24) (0)
                          (WEH) (1,24) (0)  ..
HEAT-SETPT  SCH  THRU DEC 31  (WD)  (1,6) (55)  (7,18) (72)  (19,24) (55)
                              (WEH)  (1,24) (55)  ..
COOL-SETPT  SCH  THRU DEC 31  (WD)  (1,6) (90)  (7,18) (76)  (19,24) (90)
                              (WEH) (1,24) (90)  ..
ENV Z-C  D-H-T 72  D-C-T 76  H-T-SCH HEAT-SETPT  C-T-SCH COOL-SETPT  ..
Z1 Z  Z-C ENV  A-CFM 280  ..
$Z2 Z  Z-C ENV  A-CFM 630  ..
$Z2 Z  Z-C ENV  A-CFM 472.5  ..
Z3 Z  LIKE Z2  ..
Z4 Z  LIKE Z2  ..
Z5 Z  LIKE Z2  ..
PLEN Z  Z-TYPE PLENUM  S-O ADJUST-LOADS  D-H-T 72  D-C-T 76  ..
$SYS1 SYSTEM  S-TYPE PMZS  MAX-S-T 105  MIN-S-T 55  S-S 3.5  S-E .6
$SYS1 SYSTEM  S-TYPE PVAVS  MAX-S-T 105  MIN-S-T 55  S-S 3.5  S-E .6
$             F-C INLET  MIN-F-R .3   M-C-R .3
$             F-SCH FANSON1  N-C-C CYCLE-ON-ANY  M-O-A .2
$             F-SCH FANSON1  N-C-C CYCLE-ON-ANY  M-O-A .05
$             O-CTRL FIXED
$             O-CTRL TEMP  E-L-T 62
$             C-CAP 220000
$             C-CAP 240000
$             C-CAP 240000
$             C-CAP 165000
$             C-CAP 185000
$             C-CAP 180000
$             C-CAP 155000  R-D-T 25
$             C-CAP 200000  R-D-T 5
$             C-CAP 170000
$             C-CAP 130000  R-D-T 10
$             C-CAP 150000  R-D-T 10
$             C-CAP 140000
             H-S-T 105  HEAT-S HOT-WATER/SOLAR
             P-N (PLEN)  R-A-P PLENUM-ZONES
             Z-N (Z1,Z2,Z3,Z4,Z5,PLEN)  ..
        $  HOURLY REPORT  $
RPTSCH SCH  THRU DEC 31  (ALL)  (1,24)  (1)  ..
OUT-1 R-B  V-T SYS1  V-L (5,6,7,33,47)  ..
HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1)  ..
```

```
END  ..

COMPUTE SYSTEMS  ..

INPUT PLANT  ..

PLANT-REPORT  V (PV-A)  S (PS-A,PS-C,PS-D,BEPS)  ..

HW-HTR P-E  TYPE DHW-HEATER  SIZE .030  ..
$FURN P-E  TYPE FURNACE  SIZE .300  ..
$FURN P-E  TYPE FURNACE  SIZE .220  ..
$FURN P-E  TYPE FURNACE  SIZE .140  ..
$FURN P-E  TYPE FURNACE  SIZE .220  ..
$FURN P-E  TYPE FURNACE  SIZE .185  ..
$FURN P-E  TYPE FURNACE  SIZE .110  ..
$HWG P-E  TYPE HW-BOILER  SIZE .140  ..
$HWG P-E  TYPE HW-BOILER  SIZE .050  ..
$HWG P-E  TYPE HW-BOILER  SIZE .005  ..
$HWG P-E  TYPE HW-BOILER  SIZE .085  ..
$HWG P-E  TYPE HW-BOILER  SIZE .050  ..
$HWG P-E  TYPE HW-BOILER  SIZE .005  ..

$P-P  FURNACE-FUEL NATURAL-GAS  FURNACE-HIR 1.35  ..
$P-P  BOILER-FUEL NATURAL-GAS  HW-BOILER-HIR 1.33  ..

        $  HOURLY REPORT  $

RPTSCH SCH  THRU DEC 31  (ALL)  (1,24) (1)  ..

OUT-1 R-B  V-T PLANT  V-L (8,9,10,12)  ..

$OUT-2 R-B  V-T FURNACE  V-L (3)  ..
$OUT-2 R-B  V-T HW-BOILER  V-L (3)  ..

HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1,OUT-2)  ..

END  ..

COMPUTE PLANT  ..

STOP  ..
```

Table A.2. DOE-2.1B Input File for Medium Office Building

```
INPUT LOADS ..

TITLE LINE-1 *  G  *
      LINE-2 *3-STORY OFFICE BLDG.*
$      LINE-3 *CHICAGO*                    ..
$      LINE-3 *FT WORTH*                   ..
$      LINE-3 *MIAMI*                      ..

$ FREE INTERPRETATION OF DOE-2 3-STORY OFFICE BUILDING FILE
$ LISTED IN PNL-4870-15

$ INPUT FILE USED CUSTOM WEIGHTING FACTORS
$ TO GIVE A BETTER SIMULATION OF BUILDING MASS AND HVAC SYSTEM
$ PERFORMANCE.  EACH BAY ON ALL FOUR EXPOSURES IS TREATED
$ AS A SEPARATE ZONE.  THERE ARE 7 BAYS PER FLOOR ON THE EAST AND WEST,
$ EACH HAVING 23.57 FT EXPOSURE;  AND 4 BAYS PER FLOOR ON THE NORTH
$ AND SOUTH, EACH HAVING 25 FT EXPOSURE.

$ STRUCTURE  STEEL FRAME WITH CARPETED, CONCRETE FLOORS AND ROOF.
$            3 OCCUPIED STORIES, 12 FT FLOOR TO FLOOR HEIGHT
$            9FT CEILINGS, RETURN AIR CEILING PLENUMS ARE DEFINED;
$            5 FOR THE TOP FLOOR, 5 FOR THE MIDDLE FLOOR, AND
$            5 FOR THE BOTTOM PLOOR

$ CURTAIN WALL  USING CODE-WORDS FROM DOE-2 LIBRARY (REFERENCE MANUAL,
$            PART 2) AND STARTING WITH OUTSIDE AND WORKING INWARD;
$            LIGHTWEIGHT PRECAST CONCRETE (CC24);  6 IN. AIRSPACE (AL31);
$            5/8 IN. GYPSUM BOARD FINISH (GP02).
$            FOR INSULATED WALLS, ADD R-11 MINERAL WOOL INSULATION
$            (IN02 BETWEEN CC24 AND AL 31).

$ ROOF       ROOF GRAVEL (RG01); BUILTUP ROOFING (BR01); 1 IN. ROOF
$            INSUL (IN76); 4 IN. CONCRETE (CC03); METAL DECK (AS01).
$            FOR INSULATED ROOFS, ADD 3 IN. EXPANDED POLYSTYRENE
$            INSULATION (IN36 BETWEEN IN76 AND CC03)

$ WINDOWS    30% OF EXTERNAL WALL AREA GLAZED
$            GLAZING 1/4 IN. CLEAR GLASS - SINGLE PANE.
$            FOR INSULATED BUILDINGS, CHANGE GLAZING TO
$            DOUBLE PANE TINTED GLASS FOR CHICAGO (G-T-C 7)
$            SINGLE PANE TINTED GLASS FOR FT. WORTH AND MIAMI (G-T-C 10).

$ INTERIORS  CEILINGS ARE SUSPENDED ACCOUSTIC TILE (AC02).
$            PARTITIONS ARE FRAME WALLS WITH GYPSUM BOARD ON EACH
$            SIDE (GP02, AL12, GP02).

$ SPACE LOADS  LIGHTING RECESSED FLUORESCENT AT 3 WATTS/SQFT.
$            OFFICE EQUIPMENT 1 WATTS/SQFT.
$            PEOPLE   100 SQFT/PERSON FOR PERIMETER SPACES
$                     200 SQFT/PERSON FOR CORE AREAS.
$            FOR LOW INTERNAL LOAD CASES, LIGHTING 1.6 WATTS/SQFT,
$            EQUIPMENT .5 WATTS/SQFT, PEOPLE 250 SQFT/PERSON IN
$            ALL AREAS.
$            INFILTRATION .6 AIR CHANGES/HR FOR PERIMETER AREAS WHEN
$            FANS ARE OFF - .2 AIR CHANGES/HR WHEN FANS ARE ON.

$ HVAC DESCRIPTIONS ARE TO BE FOUND WITH EACH INDIVIDUAL SYSTEM AND
$ PLANT INPUT.

DIAGNOSTIC CAUTIONS  ..
ABORT ERRORS         ..

$BUILDING-LOCATION  LAT 41.78  LON 87.75  ALT 610  T-Z 6
$         ATM-MOISTURE (.36,.32,.40,.53,.76,1.11,
$                       1.21,1.12,.88,.66,.43,.35)
$         ATM-TURBIDITY (.15,.18,.21,.18,.18,.19,
```

```
$                      .22,.16,.16,.14,.13,.15)          ..

$BUILDING-LOCATION  LAT 32.90  LON 97.30  ALT 538  T-Z 6
$        ATM-MOISTURE (.48,.51,.58,.80,1.06,1.32,
$                     1.48,1.46,1.28,.90,.65,.54)
$        ATM-TURBIDITY (.07,.12,.16,.16,.36,.35,
$                      .36,.53,.45,.23,.19,.21)  ..

$BUILDING-LOCATION  LAT 25.8  LON 80.27  ALT 7  T-Z 5
$        ATM-MOISTURE (.96,.95,1.00,1.10,1.31,1.64,
$                     1.69,1.74,1.77,1.50,1.16,1.10)
$        ATM-TURBIDITY (.19,.29,.30,.31,.36,.54,
$                      .51,.55,.40,.33,.31,.24)  ..

$ WINTER=DESIGN-DAY  DB-H 10  DB-L -4  H-H 15  H-L 8
$                    DP-H 0  DP-L -13  DH-H 15  DH-L 8
$                    W-S 12  W-D 13  C-A 5  C-T 2  CL .98  G-T 38   ..
$ SUMMER=DESIGN-DAY  DB-H 91  DB-L 71  H-H 16  H-L 6
$                    DP-H 68  DP-L 58  DH-H 16  DH-L 8
$                    W-S 12  W-D 11  C-A 0  C-T 2  CL .98  G-T 65  ..

$ WINTER=DESIGN-DAY  DB-H 50  DB-L 22  H-H 16  H-L 6
$                    DP-H 19  DP-L 16  DH-H 16  DH-L 8
$                    W-S 12  W-D 8  C-A 5  C-T 2  CL .95  G-T 60  ..
$ SUMMER=DESIGN-DAY  DB-H 100  DB-L 80  H-H 17  H-L 6
$                    DP-H 66  DP-L 65  DH-H 18  DH-L 6
$                    W-S 10  W-D 8  C-A 0  C-T 2  CL .95  G-T 80  ..

$ WINTER=DESIGN-DAY  DB-H 62  DB-L 47  H-H 17  H-L 6
$                    DP-H 55  DP-L 45  DH-H 18  DH-L 6
$                    W-S 10  W-D 5  C-A 5  C-T 2  CL .85  G-T 69  ..
$ SUMMER=DESIGN-DAY  DB-H 89  DB-L 80  H-H 15  H-L 6
$                    DP-H 76  DP-L 75  DH-H 16  DH-L 6
$                    W-S 12  W-D 6  C-A 0  C-T 2  CL .90  G-T 78  ..

$RUN-PERIOD  JAN  1 1974 THRU DEC 31 1974  ..
$RUN-PERIOD  JAN  1 1975 THRU DEC 31 1975  ..
$RUN-PERIOD  JAN  1 1964 THRU DEC 31 1964  ..

LOADS-REPORT  S (LS-F,LS-K)    ..

        $  SCHEDULES  $

OC1 D-SCH  (1,5) (.025)  (6,8) (.05,.1,.2)  (9,11) (.95)  (12,13) (.8,.5)
           (14,17) (.95)  (18,19) (.5,.3)  (20,22) (.1)  (23,24) (.025)  ..
OC2 D-SCH  (1,5) (.025)  (6,7) (.05)  (8,17) (.1)  (18) (.05)
           (19,24) (.025)  ..
OC3 D-SCH  (1,24) (.025)  ..
OCCUP SCH  THRU DEC 31 (WD) OC1  (SAT) OC2  (SUN,HOL) OC3  ..

LG1 D-SCH  (1,6) (.05)  (7,8) (.1,.3)  (9,17) (.9)  (18) (.5)
            (19,20) (.3)  (21,22) (.2)  (23,24) (.05)  ..
LG2 D-SCH  (1,6) (.05)  (7,8) (.1)  (9,12) (.3)  (13,17) (.15)
           (18,24) (.05)  ..
LG3 D-SCH  (1,24) (.05)  ..
LIGHTS SCH  THRU DEC 31  (WD) LG1  (SAT) LG2  (SUN,HOL) LG3  ..

INFIL SCH  THRU DEC 31  (WD)  (1,6) (1)  (7,18) (.33)  (19,24) (1)
           (WEH) (1,24) (1)  ..  $ MIRROR OF FAN SCH

DH1 D-SCH (1,7) (.025)  (8,24) (.15,.3,.35,.35,.55,.55,.5,.3,.3,.4,
                         .2,.2,.1,.15,.05,.025,.025)  ..
DH2 D-SCH (1,7) (.025)  (8,17) (.1,.1,.2,.15,.2,.15,.15,.1,.1,.1)
           (18,24) (.025)  ..
DHW SCH  THRU DEC 31  (WD) DH1  (SAT) DH2  (SUN,HOL) OC3  ..

EL1 D-SCH  (1,5) (.025)  (6,20) (.05,.05,.35,.7,.45,.35,.45,.5,.5,
                          .35,.35,.45,.6,.2,.1)  (21,24) (.025)  ..
EL2 D-SCH  (1,5) (.025)  (6,17) (.05,.05,.15,.15,.2,.2,.25,.2,.15,.1,.05,.05)
           (18,24) (.025)  ..
```

```
ELEV SCH  THRU DEC 31  (WD) EL1  (SAT) EL2  (SUN,HOL) OC3  ..

PULL-SHADE SCH  THRU DEC 31  (ALL)  (1,24) (100)  ..
SHADE-MULT SCH  THRU DEC 31  (ALL)  (1,24) (.65)  ..

        $ MATERIAL NOT IN DOE-2 LIBRARY $

EARTH MAT  TH 2.50  COND .500  DENS 120  S-H .2  ..

        $  CONSTRUCTION  $

$WA1 LAYERS  MAT (CC24,AL31,GP02)  ..
$R1 LAYERS  MAT (RG01,BR01,IN72,CC03,AS01)  I-F-R .61  ..
$WA1 LAYERS  MAT (CC24,IN02,AL31,GP02)  ..
$R1 LAYERS  MAT (RG01,BR01,IN72,IN36,CC03,AS01)  I-F-R .61  ..
P1 LAYERS  MAT (GP01,AL21,GP01)  ..
FLRG LAYERS  MAT (EARTH,CC03,CP01)  I-F-R .61  ..
FLRB LAYERS  MAT (CC03,CC01)  ..
FLRA LAYERS  MAT (CP01,CC03)  ..
C1 LAYERS  MAT (AC02)  ..

B-WALL CONS  LA WA1  RO 5  ..  ROF CONS  LA R1  ..
PART CONS  LA P1  ..  AIR-LY CONS  U 1.5  ..
FLOOR CONS  LA FLRB  ..  FLOOR-G CONS  LA FLRG  ..
CEIL CONS  LA C1  ..  UNDER-S CONS  LA FLRA  ..
$GLASS1 G-T  G-T-C 3  P 1  G-C 1.38  ..
$GLASS1 G-T  G-T-C 7  P 2  G-C .574  ..
$GLASS1 G-T  G-T-C 10  P 1  G-C 1.38  ..

SET-DEFAULT FOR EXTERIOR-WALL  CONS B-WALL  AZ 180  ..
SET-DEFAULT FOR WINDOW  G-T  GLASS1  X 3.5  Y 3  H 5
                        M-S-SCH PULL-SHADE  S-SCH SHADE-MULT  ..

        $  SPACE DESCRIPTION  $

OFFICE S-C  T (74)  F-W 0  I-M AIR-CHANGE  A-C .6
$           L-T REC-FLUOR-RV  L-SCH LIGHTS  L-W 3  L-T-S .8
$           L-T REC-FLUOR-RV  L-SCH LIGHTS  L-W 1.6  L-T-S .9
$           E-SCH LIGHTS  E-W 1  P-SCH OCCUP  P-H-G 450
$           E-SCH LIGHTS  E-W .5  P-SCH OCCUP  P-H-G 450
           DAY NO  I-SCH INFIL  ..

OFF-PLEN S-C  T (74)  Z-TYPE PLENUM  F-W 0
             I-M AIR-CHANGE  A-C .6  I-SCH INFIL  ..

$RZ1 SPACE  S-C OFFICE  V 85050  A 9450  N-O-P 47.25  A-C 0  ..
$RZ1 SPACE  S-C OFFICE  V 85050  A 9450  N-O-P 37.8  A-C 0  ..
    IN1 I-W  A 225  CONS PART  N-T RZ2  ..
        I-W  LIKE IN1  N-T RZ3  ..
        I-W  LIKE IN1  N-T RZ4  ..  I-W  LIKE IN1  N-T RZ5  ..
    CL1 I-W  A 9450  CONS CEIL  TILT 0  N-T RP1  ..
    FL1 I-W  A 9450  CONS FLOOR  TILT 180  I-W-TYPE ADIABATIC  ..

$RZ2 SPACE  S-C OFFICE  A 321.4  V 2893  N-O-P 3.21  AZ -90  M 7  ..
$RZ2 SPACE  S-C OFFICE  A 321.4  V 2893  N-O-P 1.29  AZ -90  M 7  ..
    WL1 E-W  H 9  W 23.57  ..  WI  W 16.97  ..
    IN2 I-W  A 125  CONS PART  I-W-TYPE ADIABATIC  ..
        I-W  LIKE IN2  ..
    FL2 I-W  A 321.4  CONS FLOOR  TILT 180  I-W-TYPE ADIABATIC  ..
    CL2 I-W  A 321.4  CONS CEIL  TILT 0  N-T RP2  ..

$RZ3 SPACE  LIKE RZ2  A 318.7  V 2868  N-O-P 3.19  AZ 180  M 4  ..
$RZ3 SPACE  LIKE RZ2  A 318.7  V 2868  N-O-P 1.28  AZ 180  M 4  ..
    WL2 E-W  H 9  W 25  ..  WI  W 18  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
    FL3 I-W  LIKE FL2  A 318.7  ..
    CL3 I-W  LIKE CL2  A 318.7  N-T RP3  ..

RZ4 SPACE  LIKE RZ2  AZ 90  M 7  ..
        E-W  LIKE WL1  ..  WI  W 16.97  ..
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            I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
            I-W  LIKE FL2  ..  I-W  LIKE CL2  N-T RP4  ..

    RZ5 SPACE  LIKE RZ3  AZ 0  M 4  ..
            E-W  LIKE WL2  ..  WI  W 18  ..
            I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
            I-W  LIKE FL3  ..  I-W  LIKE CL3  N-T RP5  ..

    RP1 SPACE  S-C OFF-PLEN  A 9450  V 25515  A-C 0  ..
        IN3 I-W  A 364.5  CONS AIR-LY  N-T RP2  ..
        IN4 I-W  A 189  CONS AIR-LY  N-T RP3  ..
            I-W  LIKE IN3  N-T RP4  ..  I-W  LIKE IN4  N-T RP5  ..
            ROOF  H 70  W 135 CONS ROF  G-R 0  AZ 90  TILT 0  ..

    RP2 SPACE  AZ -90  S-C OFF-PLEN  A 2250  V 6075  ..
        WL3 E-W  H 3  W 165  ..
        RF1 ROOF  AZ 180  H 15  W 150  CONS ROF  G-R 0  TILT 0  ..

    RP3 SPACE  AZ 180  S-C OFF-PLEN  A 1275  V 3442.5  ..
        WL4 E-W  H 3  W 100  ..
        RF2 ROOF  AZ 180  H 15  W 85  CONS ROF  G-R 0  TILT 0  ..

    RP4 SPACE  LIKE RP2  AZ 90  ..
            E-W  LIKE WL3  ..  ROOF  LIKE RF1  ..

    RP5 SPACE  LIKE RP3  AZ 0  ..
            E-W  LIKE WL4  ..  ROOF  LIKE RF2  ..

    TZ1 SPACE  LIKE RZ1  ..
            I-W  LIKE IN1  N-T TZ2  ..  I-W  LIKE IN1  N-T TZ3  ..
            I-W  LIKE IN1  N-T TZ4  ..  I-W  LIKE IN1  N-T TZ5  ..
            I-W  LIKE CL1  N-T TP1  ..  I-W  LIKE FL1  ..

    TZ2 SPACE  LIKE RZ2  M 7  ..
            E-W  LIKE WL1  ..  WI  W 16.97  ..
            I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
            I-W  LIKE FL2  ..
        CL4 I-W  LIKE CL2  N-T TP2  ..

    TZ3 SPACE  LIKE RZ3  M 4  ..
            E-W  LIKE WL2  ..  WI  W 18  ..
            I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
            I-W  LIKE FL3  ..
        CL5 I-W  LIKE CL3  N-T TP3  ..

    TZ4 SPACE  LIKE RZ4  M 7  ..
            E-W  LIKE WL1  ..  WI  W 16.97  ..
            I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
            I-W  LIKE FL2  ..  I-W  LIKE CL4  N-T TP4  ..

    TZ5 SPACE  LIKE RZ5  M 4  ..
            E-W  LIKE WL2  ..  WI  W 18  ..
            I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
            I-W  LIKE FL3  ..  I-W  LIKE CL5  N-T TP5  ..

    TP1 SPACE  S-C OFF-PLEN  A 9450  V 25515  A-C 0  ..
            I-W  LIKE IN3  N-T TP2  ..  I-W  LIKE IN4  N-T TP3  ..
            I-W  LIKE IN3  N-T TP4  ..  I-W  LIKE IN4  N-T TP5  ..
        IN5 I-W  A 9450  CONS UNDER-S  I-W-TYPE ADIABATIC  TILT 0  ..

    TP2 SPACE  AZ -90  S-C OFF-PLEN  A 2250  V 6075  ..
            E-W  LIKE WL3  ..  I-W  LIKE IN5  A 2250  ..

    TP3 SPACE  AZ 180  S-C OFF-PLEN  A 1275  V 3442.5  ..
            E-W  LIKE WL4  ..  I-W  LIKE IN5  A 1275  ..

    TP4 SPACE  LIKE TP2  AZ 90  ..
            E-W  LIKE WL3  ..  I-W  LIKE IN5  A 2250  ..

    TP5 SPACE  LIKE TP3  AZ 0  ..
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```
         E-W  LIKE WL4  ..  I-W  LIKE IN5  A 1275  ..

FZ1 SPACE  LIKE RZ1  ..
         I-W  LIKE IN1  N-T FZ2  ..  I-W  LIKE IN1  N-T FZ3  ..
         I-W  LIKE IN1  N-T FZ3  ..  I-W  LIKE IN1  N-T FZ5  ..
         I-W  LIKE CL1  N-T FP1  ..
         U-W  A 9450  CONS FLOOR-G  TILT 180  U-EFF 0  ..

FZ2 SPACE  LIKE RZ2  M 7  ..
         E-W  LIKE WL1  ..  WI  W 16.97  ..
         I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
         I-W  LIKE CL2  N-T FP2  ..
     FL4 U-W  A 321.4  CONS FLOOR-G  TILT 180  U-EFF .079  ..

FZ3 SPACE  LIKE RZ3  M 4  ..
         E-W  LIKE WL2  ..  WI  W 18  ..
         I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
         I-W  LIKE CL3  N-T FP3  ..
     FL5 U-W  A 318.7  CONS FLOOR-G  TILT 180  U-EFF .079  ..

FZ4 SPACE  LIKE RZ4  M 7  ..
         E-W  LIKE WL1  ..  WI  W 16.97  ..
         I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
         I-W  LIKE CL2  N-T FP4  ..  U-W  LIKE FL4  ..

FZ5 SPACE  LIKE RZ5  M 4  ..
         E-W  LIKE WL2  ..  WI  W 18  ..
         I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
         I-W  LIKE CL3  N-T FP5  ..  U-W  LIKE FL5  ..

FP1 SPACE  S-C OFF-PLEN  A 9450  V 25515  A-C 0  ..
         I-W  LIKE IN3  N-T FP2  ..  I-W  LIKE IN4  N-T FP3  ..
         I-W  LIKE IN3  N-T FP4  ..  I-W  LIKE IN4  N-T FP5  ..
         I-W  LIKE IN5  ..

FP2  SPACE  LIKE TP2  ..
         E-W  LIKE WL3  ..  I-W  LIKE IN5  A 2250  ..

FP3  SPACE  LIKE TP3  ..
         E-W  LIKE WL4  ..  I-W  LIKE IN5  A 1275  ..

FP4  SPACE  LIKE TP4  ..
         E-W  LIKE WL3  ..  I-W  LIKE IN5  A 2250  ..

FP5  SPACE  LIKE TP5  ..
         E-W  LIKE WL4  ..  I-W  LIKE IN5  A 1275  ..

B-R  V-T-KW 18  V-T-SCH ELEV  H-W 25000  HW-SCH DHW  ..

         $  HOURLY REPORT  $

RPTSCH SCH  THRU DEC 31  (ALL)  (1,24) (1)  ..

OUT-1 R-B  V-T BUILDING  V-L (40,41,44,45)  ..

HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1)  ..

END  ..

COMPUTE LOADS  ..

INPUT SYSTEMS  ..
$TITLE   LINE-4  *PERIMETER MZS  -  CORE MZS*  ..
$TITLE   LINE-4  *PERIMETER VAVS  -  CORE VAVS*  ..

SYSTEMS-REPORT  V (SV-A)  S (SS-A,SS-B,SS-D,SS-H)  ..

FANSON1 SCH  THRU APR 15  (WD)  (1,6) (0)  (7,18) (1)  (19,24) (0)
                          (WEH) (1,24) (0)
             THRU OCT 15  (WD)  (1,6) (-1)  (7,18) (1)  (19,24) (-1)
```

```
                              (WEH)  (1,24) (-1)
                 THRU DEC 31  (WD)  (1,6) (0)  (7,18) (1)  (19,24) (0)
                              (WEH)  (1,24) (0)  ..

HEAT-SETPT  SCH  THRU DEC 31  (WD)  (1,6) (55)  (7,18) (72)  (19,24) (55)
                              (WEH)  (1,24) (55)  ..
COOL-SETPT  SCH  THRU DEC 31  (WD)  (1,6) (90)  (7,18) (76)  (19,24) (90)
                              (WEH)  (1,24) (90)  ..

ENV Z-C  D-H-T 72  D-C-T 76  H-T-SCH HEAT-SETPT  C-T-SCH COOL-SETPT  ..

RZ1 Z  Z-C ENV  A-CFM 6615  ..
$RZ2 Z  Z-C ENV  A-CFM 578.5  ..
$RZ3 Z  Z-C ENV  A-CFM 573.7  ..
$RZ2 Z  Z-C ENV  A-CFM 482.1  ..
$RZ3 Z  Z-C ENV  A-CFM 478.1  ..
RZ4 Z  LIKE RZ2  ..
RZ5 Z  LIKE RZ3  ..
TZ1 Z  LIKE RZ1  ..
TZ2 Z  LIKE RZ2  ..
TZ3 Z  LIKE RZ3  ..
TZ4 Z  LIKE RZ2  ..
TZ5 Z  LIKE RZ3  ..
FZ1 Z  LIKE RZ1  ..
FZ2 Z  LIKE RZ2  ..
FZ3 Z  LIKE RZ3  ..
FZ4 Z  LIKE RZ2  ..
FZ5 Z  LIKE RZ3  ..
RP1 Z  Z-TYPE PLENUM  D-H-T 72  D-C-T 76  ..
RP2 Z  LIKE RP1  ..
RP3 Z  LIKE RP1  ..
RP4 Z  LIKE RP1  ..
RP5 Z  LIKE RP1  ..
TP1 Z  LIKE RP1  ..
TP2 Z  LIKE RP1  ..
TP3 Z  LIKE RP1  ..
TP4 Z  LIKE RP1  ..
TP5 Z  LIKE RP1  ..
FP1 Z  LIKE RP1  ..
FP2 Z  LIKE RP1  ..
FP3 Z  LIKE RP1  ..
FP4 Z  LIKE RP1  ..
FP5 Z  LIKE RP1  ..

$SYS1 SYSTEM  S-TYPE MZS  MAX-S-T 72  MIN-S-T 55  S-S 4.5  S-E .6
$             H-S-T 72
$SYS1 SYSTEM  S-TYPE VAVS  MAX-S-T 72  MIN-S-T 55  S-S 6.5  S-E .65
$             H-S-T 72  F-C INLET  MIN-F-R .3  M-C-R .3
$             F-SCH FANSON1  M-O-A .2
$             F-SCH FANSON1  M-O-A .05
$             O-CTRL FIXED
$             O-CTRL TEMP  E-L-T 62
             P-N (RP1)  R-A-P PLENUM-ZONES  Z-N (RZ1,RP1)  ..

SYS2 SYSTEM  LIKE SYS1  P-N (TP1,FP1)  Z-N (TZ1,FZ1,TP1,FP1)  ..

SYS3 SYSTEM  LIKE SYS1  MAX-S-T 105  MIN-S-T 55  H-S-T 105
$             F-SCH FANSON1  N-C-C CYCLE-ON-ANY  M-O-A .2
$             F-SCH FANSON1  N-C-C CYCLE-ON-ANY  M-O-A .05
$             R-D-T 25
$             R-D-T 10
             P-N (RP2,TP2,FP2)  Z-N (RZ2,TZ2,FZ2,RP2,TP2,FP2)  ..

SYS4 SYSTEM  LIKE SYS3  P-N (RP3,TP3,FP3)  Z-N (RZ3,TZ3,FZ3,RP3,TP3,FP3)  ..

SYS5 SYSTEM  LIKE SYS3  P-N (RP4,TP4,FP4)  Z-N (RZ4,TZ4,FZ4,RP4,TP4,FP4)  ..

SYS6 SYSTEM  LIKE SYS3  P-N (RP5,TP5,FP5)  Z-N (RZ5,TZ5,FZ5,RP5,TP5,FP5)  ..

PA-1 P-A  S-N (SYS1,SYS2,SYS3,SYS4,SYS5,SYS6)  ..
```

```

        $   HOURLY REPORT   $

RPTSCH SCH  THRU DEC 31  (ALL)  (1,24) (1)  ..

OUT-1 R-B  V-T PA-1  V-L (1,2,7)  ..

HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1)  ..

END  ..

COMPUTE SYSTEMS  ..

INPUT PLANT  ..

PLANT-REPORT  V (PV-A)  S (PS-A,PS-C,PS-D,BEPS)  ..

$HWG P-E  TYPE HW-BOILER  SIZE 3.0  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.1  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.4  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 2.0  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.2  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.5  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 1.0  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.5  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.7  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 2.4  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 1.8  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.2  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 1.6  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.0  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.3  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 0.8  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.1  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.4  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 1.1  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.0  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.3  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 0.5  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.2  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.4  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 0.05  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.3  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.5  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 0.9  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 1.7  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.1  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 0.5  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 1.9  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.2  I-N 2  M-N-A 2  ..
$HWG P-E  TYPE HW-BOILER  SIZE 0.05  ..
$CHL P-E  TYPE HERM-REC-CHLR  SIZE 2.0  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 1.3  I-N 2  M-N-A 2  ..

PLANT-PARAMETERS  BOILER-FUEL NATURAL-GAS  ..

PA-1 P-A  ..

        $   HOURLY REPORT   $

RPTSCH SCH  THRU DEC 31  (ALL)  (1,24) (1)  ..

OUT-1 R-B  V-T PLANT  V-L (8,9,10,12)  ..
OUT-2 R-B  V-T HW-BOILER  V-L (3)  ..
OUT-3 R-B  V-T HERM-REC-CHLR  V-L (3)  ..
OUT-4 R-B  V-T COOLING-TWR  V-L (3)  ..

HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1,OUT-2,OUT-3,OUT-4)  ..

END  ..
```

```

      COMPUTE PLANT  ..

      STOP  ..
```

Table A.3. DOE-2.1B Input File for Large Office Building

```
INPUT LOADS  ..

TITLE LINE-1 *  G  *
      LINE-2 *10-STORY OFFICE BLDG.*
$       LINE-3 *CHICAGO*                    ..
$       LINE-3 *FT WORTH*                   ..
$       LINE-3 *MIAMI*                      ..

$ MODIFICATION OF DOE-2 SAMPLE 31-STORY OFFICE BUILDING FILE
$ IN THE DOE-2.1C SAMPLE RUN BOOK, LBL-8678, REV. 2.

$ INPUT FILE USED CUSTOM WEIGHTING FACTORS
$ TO GIVE A BETTER SIMULATION OF BUILDING MASS AND HVAC SYSTEM
$ PERFORMANCE.  EACH 25 FT WIDE BAY ON ALL FOUR EXPOSURES IS TREATED
$ AS A SEPARATE ZONE.  THERE ARE 8 BAYS PER FLOOR ON THE EAST AND WEST
$ EXPOSURES, AND 4 BAYS PER FLOOR ON THE NORTH AND SOUTH.

$ STRUCTURE  STEEL FRAME WITH CARPETED, CONCRETE FLOORS AND ROOF.
$            10 OCCUPIED STORIES, 12 FT FLOOR TO FLOOR HEIGHT
$            9FT CEILINGS, RETURN AIR CEILING PLENUMS ARE DEFINED;
$            5 FOR THE TOP FLOOR, 5 FOR THE TYPICAL FLOOR, AND
$            5 FOR THE BOTTOM FLOOR

$ CURTAIN WALL  USING CODE-WORDS FROM DOE-2 LIBRARY (REFERENCE MANUAL,
$            PART 2) AND STARTING WITH OUTSIDE AND WORKING INWARD;
$            LIGHTWEIGHT PRECAST CONCRETE (CC24);  6 IN. AIRSPACE (AL31);
$            5/8 IN. GYPSUM BOARD FINISH (GP02).
$            FOR INSULATED WALLS, ADD R-11 MINERAL WOOL INSULATION
$            (IN02 BETWEEN CC24 AND AL31).

$ ROOF       ROOF GRAVEL (RG01); BUILTUP ROOFING (BR01); 1 IN. ROOF
$            INSUL (IN76); 4 IN. CONCRETE (CC03); METAL DECK (AS01).
$            FOR INSULATED ROOFS, ADD 3 IN. EXPANDED POLYSTYRENE
$            INSULATION (IN36 BETWEEN IN76 AND CC03).

$ WINDOWS    30% OF EXTERNAL WALL AREA GLAZED
$            GLAZING 1/4 IN. CLEAR GLASS - SINGLE PANE.
$            FOR INSULATED BUILDINGS, CHANGE GLAZING TO
$            DOUBLE PANE TINTED GLASS FOR CHICAGO (G-T-C 7)
$            SINGLE PANE TINTED GLASS FOR FT. WORTH AND MIAMI (G-T-C 10).

$ INTERIORS  CEILINGS ARE SUSPENDED ACCOUSTIC TILE (AC02).
$            PARTITIONS ARE FRAME WALLS WITH GYPSUM BOARD ON EACH
$            SIDE (GP02, AL12, GP02).

$ SPACE LOADS  LIGHTING RECESSED FLUORESCENT AT 3 WATTS/SQFT.
$            OFFICE EQUIPMENT 1 WATTS/SQFT.
$            PEOPLE  100 SQFT/PERSON FOR PERIMETER SPACES
$                    200 SQFT/PERSON FOR CORE AREAS.
$            FOR LOW INTERNAL LOAD CASES, LIGHTING 1.6 WATTS/SQFT,
$            EQUIPMENT .5 WATTS/SQFT, PEOPLE 250 SQFT/PERSON IN
$            ALL AREAS.
$            INFILTRATION .6 AIR CHANGES/HR FOR PERIMETER AREAS WHEN
$            FANS ARE OFF - .2 AIR CHANGES/HR WHEN FANS ARE ON.

$ HVAC DESCRIPTIONS ARE TO BE FOUND WITH EACH INDIVIDUAL SYSTEM AND
$ PLANT INPUT.

DIAGNOSTIC CAUTIONS  ..
ABORT ERRORS         ..

$BUILDING-LOCATION  LAT 41.78  LON 87.75  ALT 610  T-Z 6
$        ATM-MOISTURE (.36,.32,.40,.53,.76,1.11,
$                      1.21,1.12,.88,.66,.43,.35)
$        ATM-TURBIDITY (.15,.18,.21,.18,.18,.19,
$                      .22,.16,.16,.14,.13,.15)         ..
```

```

$BUILDING-LOCATION  LAT 32.90  LON 97.30  ALT 538  T-Z 6
$         ATM-MOISTURE (.48,.51,.58,.80,1.06,1.32,
$                       1.48,1.46,1.28,.90,.65,.54)
$         ATM-TURBIDITY (.07,.12,.16,.16,.36,.35,
$                        .36,.53,.45,.23,.19,.21)  ..

$BUILDING-LOCATION  LAT 25.8  LON 80.27  ALT 7  T-Z 5
$         ATM-MOISTURE (.96,.95,1.00,1.10,1.31,1.64,
$                       1.69,1.74,1.77,1.50,1.16,1.10)
$         ATM-TURBIDITY (.19,.29,.30,.31,.36,.54,
$                        .51,.55,.40,.33,.31,.24)  ..

$ WINTER=DESIGN-DAY  DB-H 10  DB-L -4  H-H 15  H-L 8
$                    DP-H 0  DP-L -13  DH-H 15  DH-L 8
$                    W-S 12  W-D 13  C-A 5  C-T 2  CL .98  G-T 38    ..
$ SUMMER=DESIGN-DAY  DB-H 91  DB-L 71  H-H 16  H-L 6
$                    DP-H 68  DP-L 58  DH-H 16  DH-L 8
$                    W-S 12  W-D 11  C-A 0  C-T 2  CL .98  G-T 65  ..

$ WINTER=DESIGN-DAY  DB-H 50  DB-L 22  H-H 16  H-L 6
$                    DP-H 19  DP-L 16  DH-H 16  DH-L 8
$                    W-S 12  W-D 8  C-A 5  C-T 2  CL .95  G-T 60  ..
$ SUMMER=DESIGN-DAY  DB-H 100  DB-L 80  H-H 17  H-L 6
$                    DP-H 66  DP-L 65  DH-H 18  DH-L 6
$                    W-S 10  W-D 8  C-A 0  C-T 2  CL .95  G-T 80  ..

$ WINTER=DESIGN-DAY  DB-H 62  DB-L 47  H-H 17  H-L 6
$                    DP-H 55  DP-L 45  DH-H 18  DH-L 6
$                    W-S 10  W-D 5  C-A 5  C-T 2  CL .85  G-T 69  ..
$ SUMMER=DESIGN-DAY  DB-H 89  DB-L 80  H-H 15  H-L 6
$                    DP-H 76  DP-L 75  DH-H 16  DH-L 6
$                    W-S 12  W-D 6  C-A 0  C-T 2  CL .90  G-T 78  ..

$RUN-PERIOD  JAN  1 1974 THRU DEC 31 1974  ..
$RUN-PERIOD  JAN  1 1975 THRU DEC 31 1975  ..
$RUN-PERIOD  JAN  1 1964 THRU DEC 31 1964  ..

LOADS-REPORT  S (LS-F,LS-K)    ..

        $  SCHEDULES  $

OC1 D-SCH  (1,5) (.025)  (6,8) (.05,.1,.2)  (9,11) (.95)  (12,13) (.8,.5)
           (14,17) (.95)  (18,19) (.5,.3)  (20,22) (.1)  (23,24) (.025)  ..
OC2 D-SCH  (1,5) (.025)  (6,7) (.05)  (8,17) (.1)  (18) (.05)
           (19,24) (.025)  ..
OC3 D-SCH  (1,24) (.025)  ..
OCCUP SCH  THRU DEC 31 (WD) OC1  (SAT) OC2  (SUN,HOL) OC3  ..

LG1 D-SCH  (1,6) (.05)  (7,8) (.1,.3)  (9,17) (.9)  (18) (.5)
            (19,20) (.3)  (21,22) (.2)  (23,24) (.05)  ..
LG2 D-SCH  (1,6) (.05)  (7,8) (.1)  (9,12) (.3)  (13,17) (.15)
           (18,24) (.05)  ..
LG3 D-SCH  (1,24) (.05)  ..
LIGHTS SCH  THRU DEC 31  (WD) LG1  (SAT) LG2  (SUN,HOL) LG3  ..

INFIL SCH  THRU DEC 31  (WD)  (1,6) (1)  (7,18) (.33)  (19,24) (1)
                        (WEH)  (1,24) (1)  ..  $ MIRROR OF FAN SCH

DH1 D-SCH (1,7) (.025)  (8,24) (.15,.3,.35,.35,.55,.55,.5,.3,.3,.4,
                               .2,.2,.1,.15,.05,.025,.025)  ..
DH2 D-SCH (1,7) (.025)  (8,17) (.1,.1,.2,.15,.2,.15,.15,.1,.1,.1)
           (18,24) (.025)  ..
DHW SCH  THRU DEC 31  (WD) DH1  (SAT) DH2  (SUN,HOL) OC3  ..

EL1 D-SCH  (1,5) (.025)  (6,20) (.05,.05,.35,.7,.45,.35,.45,.5,.5,
                                .35,.35,.45,.6,.2,.1)  (21,24) (.025)  ..
EL2 D-SCH  (1,5) (.025)  (6,17) (.05,.05,.15,.15,.2,.2,.25,.2,.15,.1,.05,.05)
           (18,24) (.025)  ..
ELEV SCH  THRU DEC 31  (WD) EL1  (SAT) EL2  (SUN,HOL) OC3  ..
```

```
PULL-SHADE SCH  THRU DEC 31  (ALL)  (1,24) (100)  ..
SHADE-MULT SCH  THRU DEC 31  (ALL)  (1,24) (.65)  ..

        $ MATERIAL NOT IN DOE-2 LIBRARY $

EARTH MAT  TH 2.50  COND .500  DENS 120  S-H .2  ..

        $  CONSTRUCTION  $

$WA1 LAYERS  MAT (CC24,AL31,GP02)  ..
$R1 LAYERS  MAT (RG01,BR01,IN72,CC03,AS01)  I-F-R .61  ..
$WA1 LAYERS  MAT (CC24,IN02,AL31,GP02)  ..
$R1 LAYERS  MAT (RG01,BR01,IN72,IN36,CC03,AS01)  I-F-R .61  ..
P1 LAYERS  MAT (GP01,AL21,GP01)  ..
FLRG LAYERS  MAT (EARTH,CC03,CP01)  I-F-R .61  ..
FLRB LAYERS  MAT (CC03,CC01)  ..
FLRA LAYERS  MAT (CP01,CC03)  ..
C1 LAYERS  MAT (AC02)  ..

B-WALL CONS  LA WA1  RO 5  ..  ROF CONS  LA R1  ..
PART CONS  LA P1  ..  AIR-LY CONS  U 1.5  ..
FLOOR CONS  LA FLRB  ..  FLOOR-G CONS  LA FLRG  ..
CEIL CONS  LA C1  ..  UNDER-S CONS  LA FLRA  ..
$GLASS1 G-T  G-T-C 3  P 1  G-C 1.38  ..
$GLASS1 G-T  G-T-C 7  P 2  G-C .574  ..
$GLASS1 G-T  G-T-C 10  P 1  G-C 1.38  ..

SET-DEFAULT FOR EXTERIOR-WALL  CONS B-WALL  AZ 180  ..
SET-DEFAULT FOR WINDOW  G-T  GLASS1  X 3.5  Y 3  H 5  W 18
                        M-S-SCH PULL-SHADE  S-SCH SHADE-MULT  ..

        $  SPACE DESCRIPTION  $

OFFICE S-C  T (74)  F-W 0  I-M AIR-CHANGE  A-C .6
$             L-T REC-FLUOR-RV  L-SCH LIGHTS  L-W 3  L-T-S .8
$             L-T REC-FLUOR-RV  L-SCH LIGHTS  L-W 1.6  L-T-S .9
$             E-SCH LIGHTS  E-W 1  P-SCH OCCUP  P-H-G 450
$             E-SCH LIGHTS  E-W .5  P-SCH OCCUP  P-H-G 450
             DAY NO  I-SCH INFIL  ..

OFF-PLEN S-C  T (74)  Z-TYPE PLENUM  F-W 0
               I-M AIR-CHANGE  A-C .6  I-SCH INFIL  ..

$RZ1 SPACE  S-C OFFICE  V 107100  A 11900  N-O-P 59.5  A-C 0  ..
$RZ1 SPACE  S-C OFFICE  V 107100  A 11900  N-O-P 47.6  A-C 0  ..
    IN1 I-W  A 225  CONS PART  N-T RZ2  ..
        I-W  LIKE IN1  N-T RZ3  ..
        I-W  LIKE IN1  N-T RZ4  ..  I-W  LIKE IN1  N-T RZ5  ..
    CL1 I-W  A 11900  CONS CEIL  TILT 0  N-T RP1  ..
    FL1 I-W  A 11900  CONS FLOOR  TILT 180  I-W-TYPE ADIABATIC  ..

$RZ2 SPACE  S-C OFFICE  A 346.8  V 3121  N-O-P 3.47  AZ -90  M 8  ..
$RZ2 SPACE  S-C OFFICE  A 346.8  V 3121  N-O-P 1.39  AZ -90  M 8  ..
    WL1 E-W  H 9  W 25  ..  WI  ..
    IN2 I-W  A 125  CONS PART  I-W-TYPE ADIABATIC  ..
        I-W  LIKE IN2  ..
    FL2 I-W  A 346.8  CONS FLOOR  TILT 180  I-W-TYPE ADIABATIC  ..
    CL2 I-W  A 346.8  CONS CEIL  TILT 0  N-T RP2  ..

$RZ3 SPACE  S-C OFFICE  A 318.7  V 2868  N-O-P 3.19  AZ 180  M 4  ..
$RZ3 SPACE  S-C OFFICE  A 318.7  V 2868  N-O-P 1.27  AZ 180  M 4  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
    FL3 I-W  LIKE FL2  A 318.7  ..
    CL3 I-W  LIKE CL2  A 318.7  N-T RP3  ..

RZ4 SPACE  LIKE RZ2  AZ 90  M 8  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
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```
        I-W  LIKE FL2  ..  I-W  LIKE CL2  N-T RP4  ..

RZ5 SPACE  LIKE RZ3  AZ 0  M 4  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE FL3  ..  I-W  LIKE CL3  N-T RP5  ..

RP1 SPACE  S-C OFF-PLEN  A 11900  V 32130  A-C 0  ..
    IN3 I-W  A 459  CONS AIR-LY  N-T RP2  ..
    IN4 I-W  A 189  CONS AIR-LY  N-T RP3  ..
        I-W  LIKE IN3  N-T RP4  ..  I-W  LIKE IN4  N-T RP5  ..
        ROOF  H 70  W 170  CONS ROF  G-R 0  AZ 90  TILT 0  ..

RP2 SPACE  AZ -90  S-C OFF-PLEN  A 2775  V 7493  ..
    WL2 E-W  H 3  W 200  ..
    RF1 ROOF  AZ 180  H 15  W 185  CONS ROF  G-R 0  TILT 0  ..

RP3 SPACE  AZ 180  S-C OFF-PLEN  A 1275  V 3442.5  ..
    WL3 E-W  H 3  W 100  ..
    RF2 ROOF  AZ 180  H 15  W 85  CONS ROF  G-R 0  TILT 0  ..

RP4 SPACE  LIKE RP2  AZ 90  ..
        E-W  LIKE WL2  ..  ROOF  LIKE RF1  ..

RP5 SPACE  LIKE RP3  AZ 0  ..
        E-W  LIKE WL3  ..  ROOF  LIKE RF2  ..

TZ1 SPACE  LIKE RZ1  F-M=8  ..
        I-W  LIKE IN1  N-T TZ2  ..  I-W  LIKE IN1  N-T TZ3  ..
        I-W  LIKE IN1  N-T TZ4  ..  I-W  LIKE IN1  N-T TZ5  ..
        I-W  LIKE CL1  N-T TP1  ..  I-W  LIKE FL1  ..

TZ2 SPACE  LIKE RZ2  F-M 8  M 8  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE FL2  ..
    CL4 I-W  LIKE CL2  N-T TP2  ..

TZ3 SPACE  LIKE RZ3  F-M 8  M 4  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE FL3  ..
    CL5 I-W  LIKE CL3  N-T TP3  ..

TZ4 SPACE  LIKE RZ4  F-M 8  M 8  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE FL2  ..  I-W  LIKE CL4  N-T TP4  ..

TZ5 SPACE  LIKE RZ5  F-M 8  M 4  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE FL3  ..  I-W  LIKE CL5  N-T TP5  ..

TP1 SPACE  S-C OFF-PLEN  A 11900  V 32130  A-C 0  F-M 8  ..
        I-W  LIKE IN3  N-T TP2  ..  I-W  LIKE IN4  N-T TP3  ..
        I-W  LIKE IN3  N-T TP4  ..  I-W  LIKE IN4  N-T TP5  ..
    IN5 I-W  A 11900  CONS UNDER-S  I-W-TYPE ADIABATIC  TILT 0  ..

TP2 SPACE  AZ -90  S-C OFF-PLEN  A 2775  V 7493  F-M 8  ..
        E-W  LIKE WL2  ..  I-W  LIKE IN5  A 2775  ..

TP3 SPACE  AZ 180  S-C OFF-PLEN  A 1275  V 3442.5  F-M 8  ..
        E-W  LIKE WL3  ..  I-W  LIKE IN5  A 1275  ..

TP4 SPACE  LIKE TP2  AZ 90  ..
        E-W  LIKE WL2  ..  I-W  LIKE IN5  A 2775  ..

TP5 SPACE  LIKE TP3  AZ 0  ..
        E-W  LIKE WL3  ..  I-W  LIKE IN5  A 1275  ..
```

```

FZ1 SPACE  LIKE RZ1  ..
        I-W  LIKE IN1  N-T FZ2  ..  I-W  LIKE IN1  N-T FZ3  ..
        I-W  LIKE IN1  N-T FZ3  ..  I-W  LIKE IN1  N-T FZ5  ..
        I-W  LIKE CL1  N-T FP1  ..
        U-W  A 11900  CONS FLOOR-G  TILT 180  U-EFF 0  ..

FZ2 SPACE  LIKE RZ2  M 8  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE CL2  N-T FP2  ..
    FL4 U-W  A 346.8  CONS FLOOR-G  TILT 180  U-EFF .079  ..

FZ3 SPACE  LIKE RZ3  M 4  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE CL3  N-T FP3  ..
    FL5 U-W  A 318.7  CONS FLOOR-G  TILT 180  U-EFF .079  ..

FZ4 SPACE  LIKE RZ4  M 8  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE CL2  N-T FP4  ..  U-W  LIKE FL4  ..

FZ5 SPACE  LIKE RZ5  M 4  ..
        E-W  LIKE WL1  ..  WI  ..
        I-W  LIKE IN2  ..  I-W  LIKE IN2  ..
        I-W  LIKE CL3  N-T FP5  ..  U-W  LIKE FL5  ..

FP1 SPACE  S-C OFF-PLEN  A 11900  V 32130  A-C 0  ..
        I-W  LIKE IN3  N-T FP2  ..  I-W  LIKE IN4  N-T FP3  ..
        I-W  LIKE IN3  N-T FP4  ..  I-W  LIKE IN4  N-T FP5  ..
        I-W  LIKE IN5  ..

FP2  SPACE  LIKE TP2  F-M 1  ..
        E-W  LIKE WL2  ..  I-W  LIKE IN5  A 2775  ..

FP3  SPACE  LIKE TP3  F-M 1  ..
        E-W  LIKE WL3  ..  I-W  LIKE IN5  A 1275  ..

FP4  SPACE  LIKE TP4  F-M 1  ..
        E-W  LIKE WL2  ..  I-W  LIKE IN5  A 2775  ..

FP5  SPACE  LIKE TP5  F-M 1  ..
        E-W  LIKE WL3  ..  I-W  LIKE IN5  A 1275  ..

B-R  V-T-KW 25  V-T-SCH ELEV  H-W 100000  HW-SCH DHW  ..

        $   HOURLY REPORT  $

RPTSCH SCH  THRU DEC 31  (ALL)  (1,24) (1)  ..

OUT-1 R-B  V-T BUILDING  V-L (40,41,44,45)  ..

HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1)  ..

END  ..

COMPUTE LOADS  ..

INPUT SYSTEMS  ..
$TITLE   LINE-4  *PERIMETER MZS  -  CORE MZS*  ..
$TITLE   LINE-4  *PERIMETER VAVS  -  CORE VAVS*  ..

SYSTEMS-REPORT  V (SV-A)  S (SS-A,SS-B,SS-D,SS-H)  ..

FANSON1 SCH  THRU APR 15  (WD)  (1,6) (0)  (7,18) (1)  (19,24) (0)
                          (WEH) (1,24) (0)
             THRU OCT 15  (WD)  (1,6) (-1)  (7,18) (1)  (19,24) (-1)
                          (WEH) (1,24) (-1)
```

```
              THRU DEC 31  (WD)  (1,6) (0)  (7,18) (1)  (19,24) (0)
                           (WEH)  (1,24) (0)  ..
HEAT-SETPT  SCH  THRU DEC 31  (WD)  (1,6) (55)  (7,18) (72)  (19,24) (55)
                              (WEH)  (1,24) (55)  ..
COOL-SETPT  SCH  THRU DEC 31  (WD)  (1,6) (90)  (7,18) (76)  (19,24) (90)
                              (WEH)  (1,24) (90)  ..
ENV Z-C  D-H-T 72  D-C-T 76  H-T-SCH HEAT-SETPT  C-T-SCH COOL-SETPT  ..
RZ1 Z  Z-C ENV  A-CFM 8330  ..
$RZ2 Z  Z-C ENV  A-CFM 589.6  ..
$RZ3 Z  Z-C ENV  A-CFM 541.8  ..
$RZ2 Z  Z-C ENV  A-CFM 485.5  ..
$RZ3 Z  Z-C ENV  A-CFM 446.2  ..
RZ4 Z  LIKE RZ2  ..
RZ5 Z  LIKE RZ3  ..
TZ1 Z  LIKE RZ1  ..
TZ2 Z  LIKE RZ2  ..
TZ3 Z  LIKE RZ3  ..
TZ4 Z  LIKE RZ2  ..
TZ5 Z  LIKE RZ3  ..
FZ1 Z  LIKE RZ1  ..
FZ2 Z  LIKE RZ2  ..
FZ3 Z  LIKE RZ3  ..
FZ4 Z  LIKE RZ2  ..
FZ5 Z  LIKE RZ3  ..
RP1 Z  Z-TYPE PLENUM  D-H-T 72  D-C-T 76  ..
RP2 Z  LIKE RP1  ..
RP3 Z  LIKE RP1  ..
RP4 Z  LIKE RP1  ..
RP5 Z  LIKE RP1  ..
TP1 Z  LIKE RP1  ..
TP2 Z  LIKE RP1  ..
TP3 Z  LIKE RP1  ..
TP4 Z  LIKE RP1  ..
TP5 Z  LIKE RP1  ..
FP1 Z  LIKE RP1  ..
FP2 Z  LIKE RP1  ..
FP3 Z  LIKE RP1  ..
FP4 Z  LIKE RP1  ..
FP5 Z  LIKE RP1  ..
$SYS1 SYSTEM  S-TYPE MZS  MAX-S-T 72  MIN-S-T 55  S-S 4.5  S-E .6
$              H-S-T 72
$SYS1 SYSTEM  S-TYPE VAVS  MAX-S-T 72  MIN-S-T 55  S-S 6.5  S-E .65
$              H-S-T 72  F-C INLET  MIN-F-R .3  M-C-R .3
$              F-SCH FANSON1  M-O-A .2
$              F-SCH FANSON1  M-O-A .05
$              O-CTRL FIXED
$              O-CTRL TEMP  E-L-T 62
              R-A-P PLENUM-ZONES  P-N (RP1)  Z-N (RZ1,RP1)  ..
SYS2 SYSTEM  LIKE SYS1  P-N (TP1,FP1)  Z-N (TZ1,FZ1,TP1,FP1)  ..
$SYS3 SYSTEM  LIKE SYS1  MAX-S-T 105  MIN-S-T 55  H-S-T 105
$SYS3 SYSTEM  S-TYPE VAVS  MAX-S-T 105  MIN-S-T 55  S-S 6.5  S-E .65
$              H-S-T 105  F-C INLET  MIN-F-R .3  M-C-R .3
$              F-SCH FANSON1  N-C-C CYCLE-ON-ANY  M-O-A .2
$              F-SCH FANSON1  N-C-C CYCLE-ON-ANY  M-O-A .05
$              O-CTRL FIXED
$              O-CTRL TEMP  E-L-T 62
$              R-D-T 30
$              R-D-T 10
              R-A-P PLENUM-ZONES  P-N (TP2,RP2,FP2)
              Z-N (TZ2,RZ2,FZ2,TP2,RP2,FP2)  ..
SYS4 SYSTEM  LIKE SYS3  P-N (TP3,RP3,FP3)  Z-N (TZ3,RZ3,FZ3,RP3,TP3,FP3)  ..
SYS5 SYSTEM  LIKE SYS3  P-N (TP4,RP4,FP4)  Z-N (TZ4,RZ4,FZ4,RP4,TP4,FP4)  ..
```

```

SYS6 SYSTEM  LIKE SYS3  P-N (TP5,RP5,FP5)  Z-N (TZ5,RZ5,FZ5,RP5,TP5,FP5)  ..

PA-1 P-A  S-N (SYS1,SYS2,SYS3,SYS4,SYS5,SYS6)  ..

        $  HOURLY REPORT   $

RPTSCH SCH  THRU DEC 31  (ALL)  (1,24) (1)  ..

OUT-1 R-B  V-T PA-1  V-L (1,2,7)  ..

HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1)  ..

END  ..

COMPUTE SYSTEMS  ..

INPUT PLANT  ..


PLANT-REPORT  V (PV-A)  S (PS-A,PS-C,PS-D,BEPS)  ..

$HWG P-E  TYPE HW-BOILER  SIZE 10.5  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 8.   ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.4  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 6.6  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 8.3  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.5  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 3.4  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 9.2  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.8  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 8.2  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 6.9  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.1  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 5.8  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 7.4  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.2  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 2.9  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 8.0  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.4  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 4.5  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 7.8  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.4  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 1.8  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 8.4  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.6  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 0.1  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 8.7  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.7  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 3.0  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 6.7  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.1  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 1.5  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 7.2  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.2  I-N 4  M-N-A 4  ..
$HWG P-E  TYPE HW-BOILER  SIZE 0.1  ..
$CHL P-E  TYPE HERM-CENT-CHLR  SIZE 7.6  ..
$CTW P-E  TYPE COOLING-TWR  SIZE 2.3  I-N 4  M-N-A 4  ..

PLANT-PARAMETERS  BOILER-FUEL NATURAL-GAS  ..

PA-1 P-A  ..

        $  HOURLY REPORT   $

RPTSCH SCH  THRU DEC 31  (ALL)  (1,24) (1)  ..

OUT-1 R-B  V-T PLANT  V-L (8,9,10,12)  ..
OUT-2 R-B  V-T HW-BOILER  V-L (3)  ..
OUT-3 R-B  V-T HERM-CENT-CHLR  V-L (3)  ..
```

```
OUT-4 R-B  V-T COOLING-TWR  V-L (3)  ..

HR-RPT H-R  R-SCH RPTSCH  R-B (OUT-1,OUT-2,OUT-3,OUT-4)  ..

END  ..

COMPUTE PLANT  ..

STOP  ..
```

Table A.4. Line numbers in DOE-2.1B input files invoked by parmeter configuration numbers.

Parameter number	Parameter value	Small office building	Medium office building	Large office building
Building size				
A1* = 0	2,500 sq ft	Table A.1		
= 1	49,500 sq ft		Table A.2	
= 2	200,000 sq ft			Table A.3
Location				
A2 = 0	Chicago, IL	5,61-65,100	5,63-67,102	5,63-66,101
= 1	Ft. Worth, TX	6,62-71,101	6,69-73,103	6,68-72,102
= 2	Miami, FL	7,73-77,102	7,75,79,104	7,74-78,103
HVAC system				
A3 = 0	MZS	221,248,300, 309	339,391-392	338,390-391, 402
= 1	VAVS	222,249-250 301,310	340,393-394	339,392-393, 403-404
HVAC economizer				
A4 = 0	No economizer	253	397	396,407
= 1	Economizer	254	398	397,408
Minimum ventilation				
A5 = 0	20%	251	359,404	394,405
= 1	5%	252	396,406	396,406
Lighting power				
A6 = 0	3 W/sq ft	161	173	172
= 1	1.6 sq ft	162	174	173
Occupancy and equipment				
A7 = 0	High	163,170,178	175,182,190, 198	174,181,189, 197
= 1	Low	164,171,179	176,183,191, 199	175,182,190, 198

Table A.4. (continued)

Parameter number	Parameter value	Small office building	Medium office building	Large office building
Envelope construction and glazing				
A8 = 0	Normal	139-140,150, 241	148-149,162, 359-360	147-148,161, 358-359
= 1	Energy efficient	141,142,242	150-151, 361-362	149-150, 360-361
Parameter combinations				
A8 = 1 and A2 = 0		151	163	162
= 1		152	164	163
= 2		152	164	163
A3 = 0, A8 = 0,				
and A2 = 0		255,287	434-436	439-441
= 1		256,288	437-439	442-444
= 2		257,289	440-442	445-447
A3 = 0, A8 = 1,				
and A2 = 0		258,290	443-445	448-450
= 1		259,291	446-448	451-453
= 2		260,292	449-451	454-456
A3 = 1, A8 = 0,				
and A2 = 0		261,293	406,452-454	409,457-459
= 1		262,294	407,455-457	410,460-462
= 2		263,295	458-460	463-465
A3 = 1, A8 =1,				
and A2 = 0		264,296	407,461-463	410,466-468
= 1		265,297	407,464-466	410,469-470
= 2		266,298	467-469	472-474

*A1, etc., stands for digit 1, etc., in the configuration identifier.

APPENDIX B

APPENDIX B

Annual End-Use Energy Data and Cost Summaries

Summaries of the building end-use energy and costs that were calculated using the DOE-2.1B program are listed in Tables B.1, B.2, and B.3. A total of 106 calculation runs were made, the first 96 being specified for the fractional factorial design that is addressed in Appendix C.

The data in the tables are presented on a per square foot basis in order to compare the values for the different size buildings. The heating and cooling energy values are the totals for the building which, in addition to the heat added to or extracted from the conditioned spaces, include the HVAC systems' circulating water loop heat gains or losses and the domestic hot water system energy requirements. The peak heating and cooling values are the peak rates that heat is added to or extracted from the conditioned spaces.

Each run is identified by the nine digit configuration identifier, in addition to the run number. This identifier, discussed in Sect. 2.2, specifies the values of the parameters for each DOE-2.1B run. For the convenience of the reader, the meanings of the digits in the configuration identifier are listed below.

Digit	Value	Parameter Value
Floor Area		
1	0	2500 sq ft (small building)
	1	49500 sq ft (medium building)
	2	200000 sq ft (large building)
Location		
2	0	Chicago, IL
	1	Ft. Worth, TX
	2	Miami, FL
HVAC System		
3	0	Multizone (low efficiency)
	1	Variable air volume (high efficiency)
HVAC Economizer		
4	0	No economizer
	1	Economizer (62 F temperature limit)
Minimum Ventilation		
5	0	20%
	1	5%

Lighting		
6	0	3 W/sq ft
	1	1.6 W/sq ft
Occupancy and Equipment		
7	0	10 people/1000 sq ft in perimeter areas 5 people/1000 sq ft in core areas 1 W/sq ft equipment
	1	4 people/1000 sq ft, 0.5 W/sq ft equipment
Envelope Construction		
8	0	Normal
	1	Energy efficient
Spare		
9		

The data are presented in graphical format in Figs. B.1 through B.5. Included are bar graphs for

1. Annual heating-cooling loads,
2. Annual energy use,
3. Annual average to peak energy use,
4. Annual electric energy end-use, and
5. Annual energy costs.

Plots are presented for each building size-location combination. In each of these graphs, the bars are labeled on abscissa using the last seven digits of the building configuration number.

To interpret the graphical data, it is suggested that copies of the figures be made, and that the copies be laid out on a 3 x 3 matrix for the three building sizes and the three locations. The influence of these two parameters can be more readily visualized using this procedure.

Table B.1. Summary of DOE-2.1B runs for small office building.

Run #	BLH loV dcA g C	EVL ceg ont ntg	OIS cnp /sa E r q e	Annual heating energy, KBtu/sqft	Annual cooling energy, KBtu/sqft	Peak heating energy, Btuh/sqft	Peak cooling energy, Btuh/sqft	Annual electric usage, kWh/sqft	Average to peak electric usage	Annual ntrl gas usage, kBtu/sqft	Average to peak ntrl gas usage	Annual electric cost, $/sqft	Annual ntrl gas cost, $/sqft
1	000	000	000	107.72	85.01	101.04	80.22	28.48	0.247	170.08	0.139	2.893	0.874
2	001	111	000	54.52	30.76	30.76	49.70	15.20	0.195	92.56	0.231	1.632	0.491
3	000	110	100	126.40	51.38	101.75	73.98	22.80	0.225	195.72	0.159	2.367	1.001
4	001	001	100	81.04	33.92	52.00	64.14	14.20	0.172	127.80	0.206	1.576	1.665
5	000	011	010	61.04	70.79	54.82	50.78	20.88	0.281	100.12	0.145	2.064	0.528
6	001	100	010	32.00	28.32	29.44	48.32	17.24	0.205	53.20	0.149	1.831	0.296
7	000	101	110	92.84	39.52	80.08	55.46	15.36	0.201	143.96	0.150	1.664	0.745
8	001	010	110	18.92	29.45	12.62	35.07	16.24	0.226	35.32	0.197	1.672	0.207
9	010	011	000	51.92	121.11	65.38	84.45	27.68	0.270	86.12	0.107	2.590	0.463
10	011	100	000	11.16	86.06	20.84	82.03	24.28	0.200	20.36	0.082	2.474	0.137
11	010	101	100	71.96	109.55	88.72	89.16	23.96	0.221	113.28	0.108	2.404	0.597
12	011	010	100	7.56	71.83	10.60	62.96	22.08	0.209	15.64	0.109	2.196	0.113
13	010	000	010	38.68	101.62	61.82	63.98	27.24	0.268	65.96	0.088	2.569	0.363
14	011	111	010	9.16	46.20	8.08	42.90	15.52	0.212	18.28	0.157	1.505	0.126
15	010	110	110	53.60	72.58	64.27	57.51	22.84	0.259	86.48	0.111	2.204	0.464
16	011	001	110	13.04	54.76	17.94	53.11	14.72	0.196	23.68	0.107	1.452	0.153
17	020	001	010	24.04	129.71	40.04	63.15	25.24	0.288	42.68	0.088	2.226	0.300
18	021	110	010	1.56	77.67	0.00	45.31	22.64	0.276	5.32	0.482	2.002	0.097
19	020	111	110	30.32	101.92	53.28	55.86	21.96	0.300	51.52	0.097	1.943	0.348
20	021	000	110	1.56	93.21	2.97	56.27	22.12	0.262	5.32	0.154	1.957	0.097
21	020	010	000	24.56	157.11	48.59	81.80	34.40	0.312	44.28	0.075	3.013	0.309
22	021	101	000	1.60	129.48	6.02	75.31	23.80	0.246	5.36	0.140	2.103	0.098
23	020	100	100	27.96	180.02	67.94	85.26	34.32	0.292	48.92	0.073	3.008	0.334
24	021	011	100	1.56	93.35	0.00	57.07	19.88	0.248	5.32	0.482	1.762	0.097
25	021	000	010	1.56	100.23	2.70	59.44	24.16	0.266	5.32	0.160	2.132	0.097
26	020	111	010	26.56	106.54	52.59	56.35	23.68	0.303	46.20	0.088	2.089	0.319
27	021	110	110	1.56	70.01	0.00	41.95	20.56	0.269	5.32	0.482	1.821	0.097
28	020	001	110	27.68	125.16	40.69	63.12	23.56	0.286	47.84	0.097	2.081	0.358
29	021	011	000	1.56	100.45	0.00	59.55	21.92	0.253	5.32	0.482	1.940	0.097
30	020	100	000	24.88	184.43	67.28	85.14	36.00	0.294	44.44	0.066	3.153	0.309
31	021	101	100	1.60	123.72	6.31	73.71	21.84	0.240	5.36	0.140	1.933	0.098
32	020	010	100	27.72	152.37	49.18	82.10	32.72	0.311	48.84	0.082	2.866	0.333
100	010	000	000	50.48	134.64	77.38	89.59	32.28	0.257	83.60	0.090	3.036	0.450
101	020	000	000	23.56	186.33	54.98	85.14	36.28	0.296	42.72	0.065	3.175	0.300

Table B.2. Summary of DOE-2.1B runs for medium office building.

Run #	BLH loV dcA g C	EVL ceg ont ntg	OIS cnp /sa E r q e	Annual heating energy, KBtu/sqft	Annual cooling energy, KBtu/sqft	Peak heating energy, Btuh/sqft	Peak cooling energy, Btuh/sqft	Annual electric usage, kWh/sqft	Average to peak electric usage	Annual ntrl gas usage, kBtu/sqft	Average to peak ntrl gas usage	Annual electric cost, $/sqft	Annual ntrl gas cost, $/sqft
33	100	011	000	30.83	48.39	34.41	36.23	18.80	0.319	49.50	0.119	1.891	0.247
34	101	100	000	18.53	27.66	19.47	41.33	17.79	0.235	27.67	0.126	1.965	0.139
35	100	101	100	57.48	27.77	49.90	39.75	14.56	0.245	85.15	0.150	1.604	0.423
36	101	010	100	13.60	33.45	10.17	30.85	17.83	0.277	21.55	0.169	1.864	0.108
37	100	000	010	23.06	44.03	33.43	35.43	20.83	0.293	36.70	0.094	2.163	0.183
38	101	111	010	5.48	18.46	4.10	23.86	12.28	0.248	8.96	0.150	1.735	0.046
39	100	110	110	39.26	25.23	33.12	31.24	17.09	0.276	58.60	0.151	1.838	0.292
40	101	001	110	12.64	19.51	13.47	27.22	11.32	0.240	19.67	0.126	1.284	0.099
41	110	001	010	16.70	59.57	26.15	37.55	17.82	0.289	26.01	0.087	1.418	0.131
42	111	110	010	2.31	43.34	2.22	32.07	18.85	0.269	3.77	0.106	1.539	0.020
43	110	111	110	27.97	41.39	31.17	32.21	14.64	0.282	39.84	0.115	1.194	0.199
44	111	000	110	3.15	48.19	7.91	36.63	17.91	0.264	5.01	0.055	1.462	0.027
45	110	010	000	13.62	73.75	24.15	41.08	23.47	0.315	21.80	0.075	1.808	0.110
46	111	101	000	4.23	52.27	9.73	44.20	16.08	0.234	6.58	0.061	1.369	0.034
47	110	100	100	27.87	62.66	38.57	45.29	20.78	0.277	40.11	0.094	1.693	0.201
48	111	011	100	3.72	44.27	3.52	32.41	14.42	0.256	6.03	0.127	1.174	0.032
49	111	000	010	2.69	53.46	7.84	39.09	19.88	0.268	4.28	0.047	1.619	0.023
50	110	111	010	25.94	44.37	32.37	32.68	16.23	0.285	36.95	0.104	1.318	0.185
51	111	110	110	2.70	38.48	2.22	28.97	16.94	0.269	4.42	0.123	1.381	0.024
52	110	001	110	18.66	56.57	26.41	37.12	16.26	0.286	28.94	0.096	1.296	0.145
53	111	011	000	3.26	49.50	3.36	35.34	16.31	0.258	5.29	0.115	1.327	0.028
54	110	100	000	26.10	65.60	38.35	45.85	22.36	0.281	37.62	0.088	1.813	0.188
55	111	101	100	4.80	48.42	9.84	41.31	14.30	0.230	7.45	0.068	1.223	0.039
56	110	010	100	15.20	69.42	24.36	40.49	21.80	0.313	24.31	0.083	1.683	0.122
57	120	000	000	6.42	104.80	18.52	48.22	26.15	0.317	10.26	0.049	2.152	0.059
58	121	111	000	0.66	64.91	0.00	35.11	17.85	0.281	1.07	0.276	1.511	0.009
59	120	110	100	8.91	82.95	28.92	39.92	23.14	0.323	13.74	0.053	1.895	0.078
60	121	001	100	0.66	76.56	0.99	43.19	17.23	0.271	1.07	0.097	1.471	0.009
61	120	011	010	8.55	67.75	11.83	32.10	18.47	0.321	13.68	0.099	1.519	0.078
62	121	100	010	0.66	78.29	0.24	41.42	22.25	0.294	1.07	0.276	1.868	0.009
63	120	101	110	11.53	76.25	25.61	39.19	17.77	0.305	17.71	0.086	1.484	0.099
64	121	010	110	0.66	57.03	0.00	28.56	19.04	0.302	1.07	0.276	1.585	0.009
102	100	000	000	35.58	48.56	48.37	41.43	22.66	0.294	55.91	0.101	2.309	0.278
103	110	000	000	16.07	76.03	31.82	45.85	23.66	0.298	25.19	0.069	1.860	0.127
106	111	000	000	3.37	62.63	9.56	47.80	21.29	0.261	5.25	0.049	1.751	0.028

Table B.3. Summary of DOE-2.1B runs for large office building.

Run #	BLH loV dcA g C	EVL ceg ont ntg	OIS cnp /sa E r q e	Annual heating energy, KBtu/sqft	Annual cooling energy, KBtu/sqft	Peak heating energy, Btuh/sqft	Peak cooling energy, Btuh/sqft	Annual electric usage, kWh/sqft	Average to peak electric usage	Annual ntrl gas usage, kBtu/sqft	Average to peak ntrl gas usage	Annual electric cost, $/sqft	Annual ntrl gas cost, $/sqft
65	200	001	010	22.57	38.27	30.19	32.69	14.98	0.299	35.54	0.102	1.470	0.176
66	201	110	010	3.08	24.34	2.96	29.53	15.61	0.261	5.04	0.118	1.606	0.025
67	200	111	110	38.58	21.45	32.05	28.55	11.64	0.283	56.18	0.153	1.187	0.279
68	201	000	110	7.54	26.69	11.92	32.29	14.78	0.260	11.68	0.085	1.519	0.058
69	200	010	000	21.87	56.99	25.70	35.35	20.97	0.339	35.28	0.111	1.976	0.175
70	201	101	000	18.31	23.50	18.65	35.93	12.30	0.232	27.41	0.129	1.297	0.136
71	200	100	100	47.23	29.31	41.48	37.80	16.95	0.270	69.60	0.147	1.718	0.345
72	201	011	100	13.93	28.97	8.69	25.97	12.51	0.304	22.00	0.195	1.202	0.109
73	201	000	010	6.36	31.57	11.77	35.01	16.64	0.263	9.86	0.073	1.707	0.049
74	200	111	010	35.97	23.11	31.33	29.06	13.09	0.284	52.72	0.146	1.332	0.261
75	201	110	110	3.69	21.19	2.99	26.62	13.97	0.264	6.04	0.139	1.433	0.030
76	200	001	110	24.80	36.94	30.56	32.08	13.54	0.302	38.87	0.110	1.324	0.193
77	201	011	000	12.43	32.99	8.67	28.62	14.14	0.296	19.67	0.174	1.367	0.098
78	200	100	000	44.79	31.07	41.33	39.25	18.43	0.273	66.34	0.140	1.865	0.329
79	201	101	100	20.17	21.19	18.74	33.18	10.77	0.233	30.13	0.141	1.136	0.150
80	200	010	100	23.76	53.15	25.77	34.72	19.46	0.341	38.29	0.120	1.827	0.190
81	210	000	000	13.31	73.55	27.43	43.02	20.95	0.302	20.75	0.067	1.622	0.103
82	211	111	000	2.86	42.77	2.44	33.57	13.59	0.255	4.63	0.127	1.110	0.023
83	210	110	100	24.70	52.43	32.69	37.72	17.88	0.301	34.86	0.097	1.403	0.173
84	211	001	100	4.03	48.08	8.66	38.96	12.72	0.243	6.28	0.065	1.042	0.544
85	210	011	010	12.15	53.54	16.83	30.51	15.04	0.318	19.47	0.096	1.148	0.097
86	211	100	010	2.31	49.66	6.95	38.42	17.70	0.268	3.63	0.046	1.432	0.689
87	210	101	110	25.38	45.58	31.36	34.85	13.06	0.277	35.86	0.105	1.052	0.176
88	211	010	110	2.20	44.90	1.94	28.52	16.04	0.291	3.57	0.118	1.274	0.018
89	220	011	000	6.63	76.54	13.26	36.90	16.97	0.324	10.60	0.069	1.381	0.058
90	221	100	000	0.65	91.24	0.37	47.91	21.42	0.293	0.99	0.224	1.792	0.006
91	220	101	100	9.28	86.16	27.40	43.41	16.26	0.297	14.20	0.065	1.346	0.078
92	221	010	100	0.65	69.21	0.00	35.63	18.28	0.291	0.99	0.297	1.519	0.006
93	220	000	010	4.86	85.59	12.47	38.62	20.84	0.313	7.79	0.055	1.712	0.043
94	221	111	010	0.65	51.00	0.00	26.01	13.73	0.301	0.99	0.297	1.136	0.006
95	220	110	110	7.57	66.01	23.12	31.01	18.22	0.328	14.17	0.077	1.483	0.064
96	221	001	110	0.65	59.46	0.31	32.49	12.73	0.282	0.99	0.250	1.068	0.006
97	200	000	100	31.33	45.56	40.06	37.81	19.24	0.306	49.03	0.106	1.847	0.243
98	211	100	000	2.81	58.34	8.33	45.45	18.85	0.262	4.41	0.047	1.539	0.022
99	220	010	010	4.68	72.85	9.83	31.76	19.93	0.331	7.54	0.065	1.616	0.042
104	200	000	000	29.19	47.93	40.00	39.26	20.74	0.307	45.82	0.100	1.995	0.227
105	220	000	000	5.13	100.13	15.58	45.35	22.43	0.312	8.19	0.047	1.840	0.045

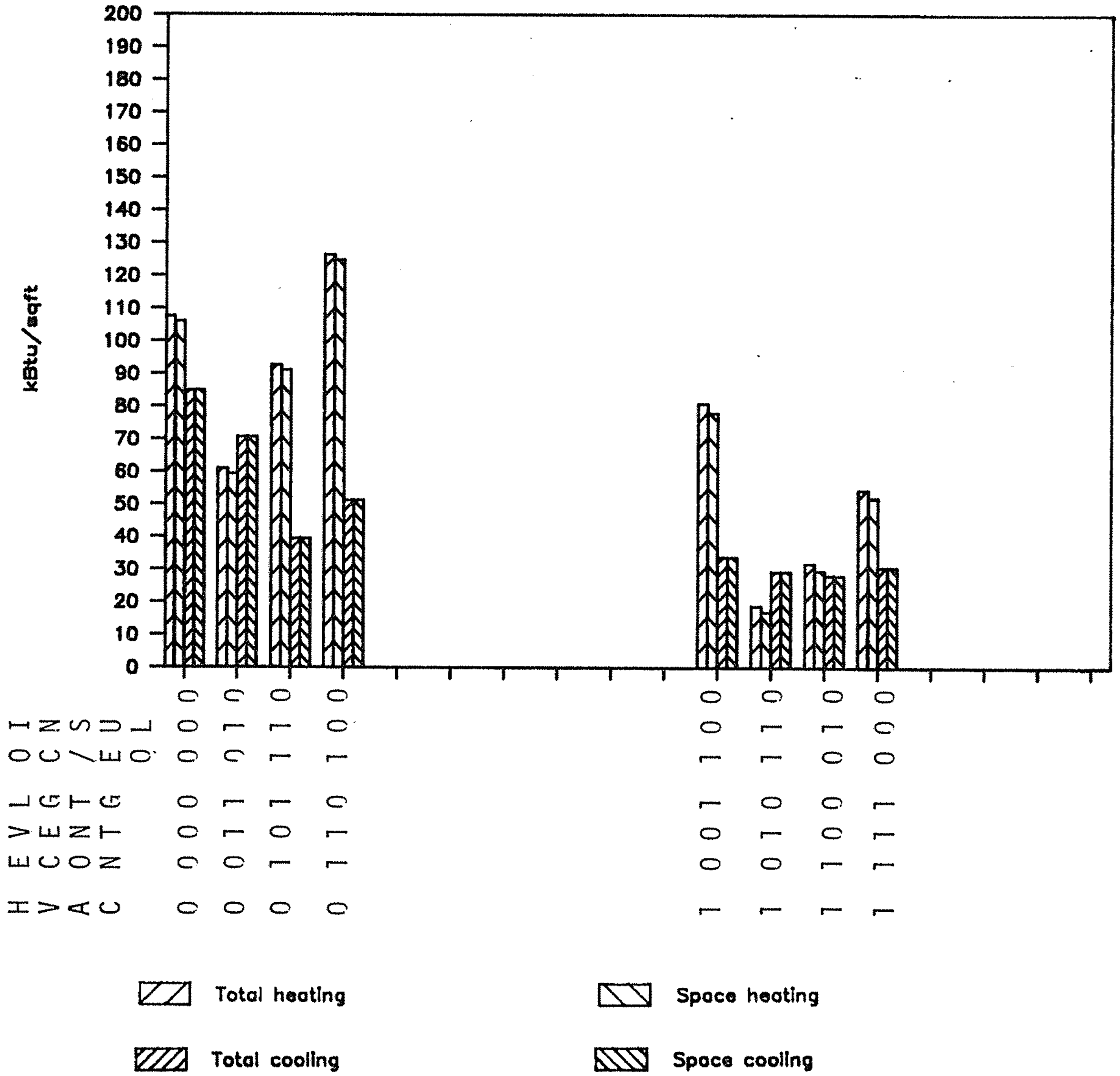

Fig. B.1(a). Annual heating-cooling loads, small building, Chicago.

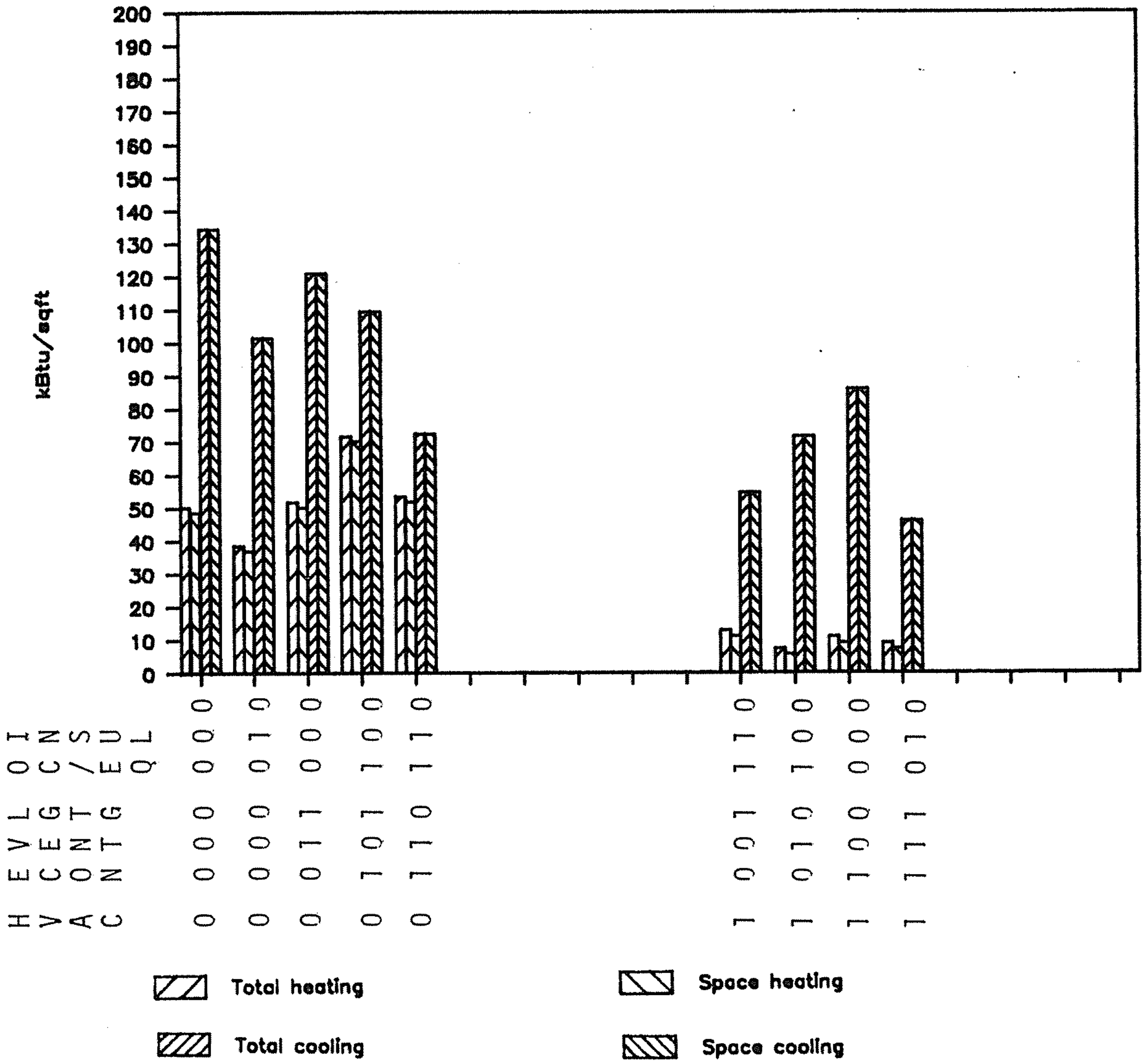

Fig. B.1(b). Annual heating-cooling loads, small building, Fort Worth.

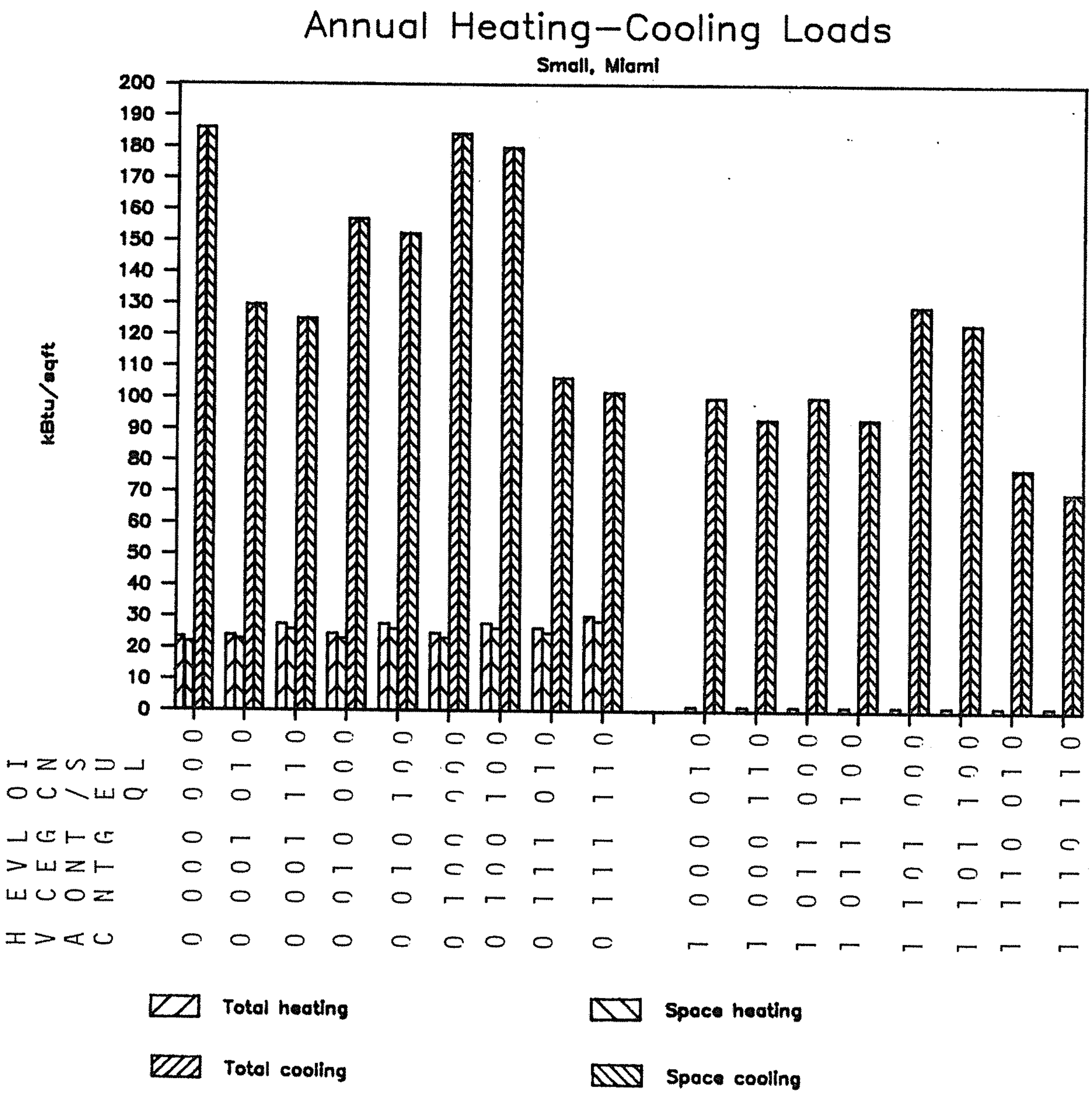

Fig. B.1(c). Annual heating-cooling loads, small building, Miami.

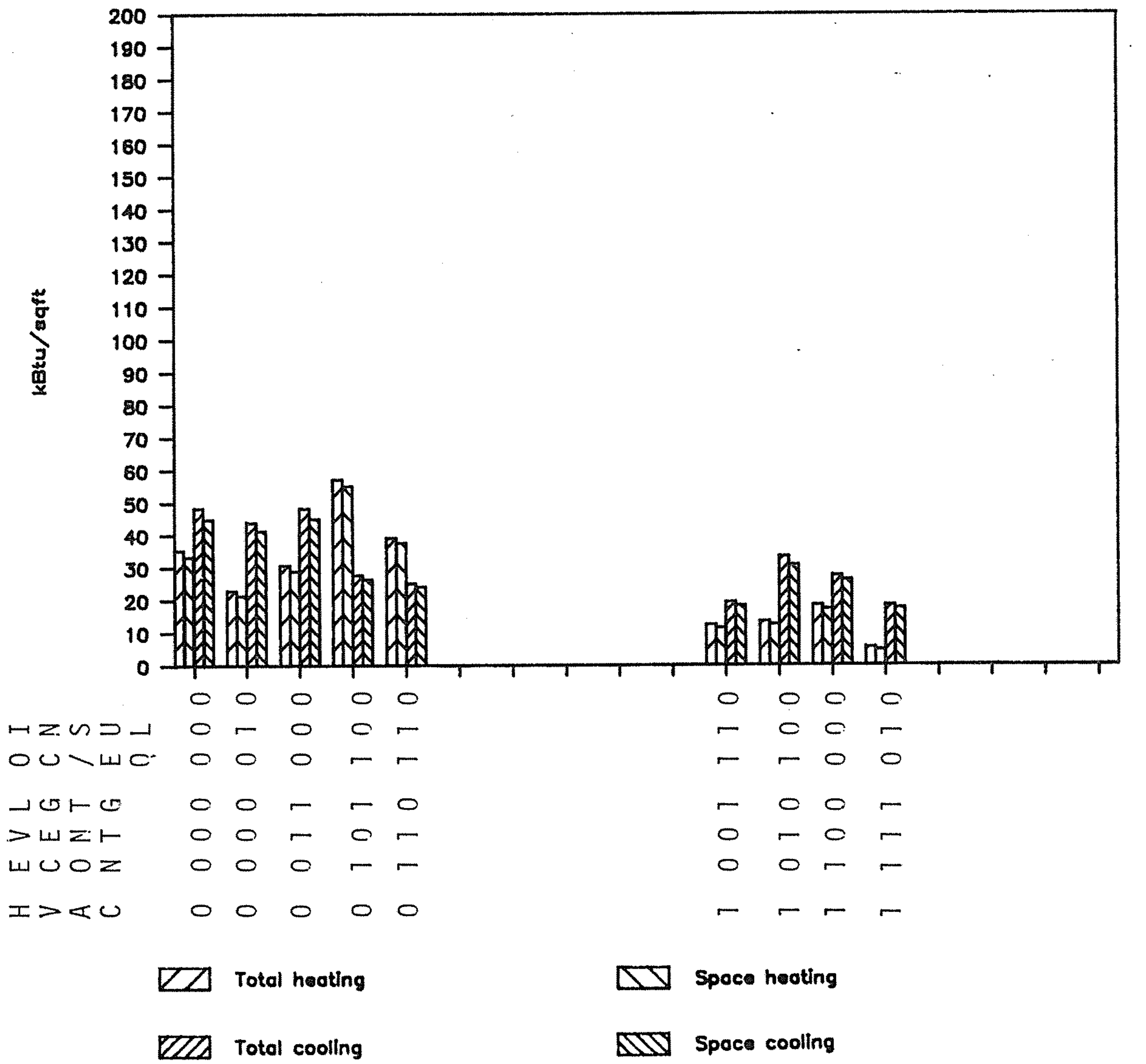

Fig. B.1(d). Annual heating-cooling loads, medium building, Chicago.

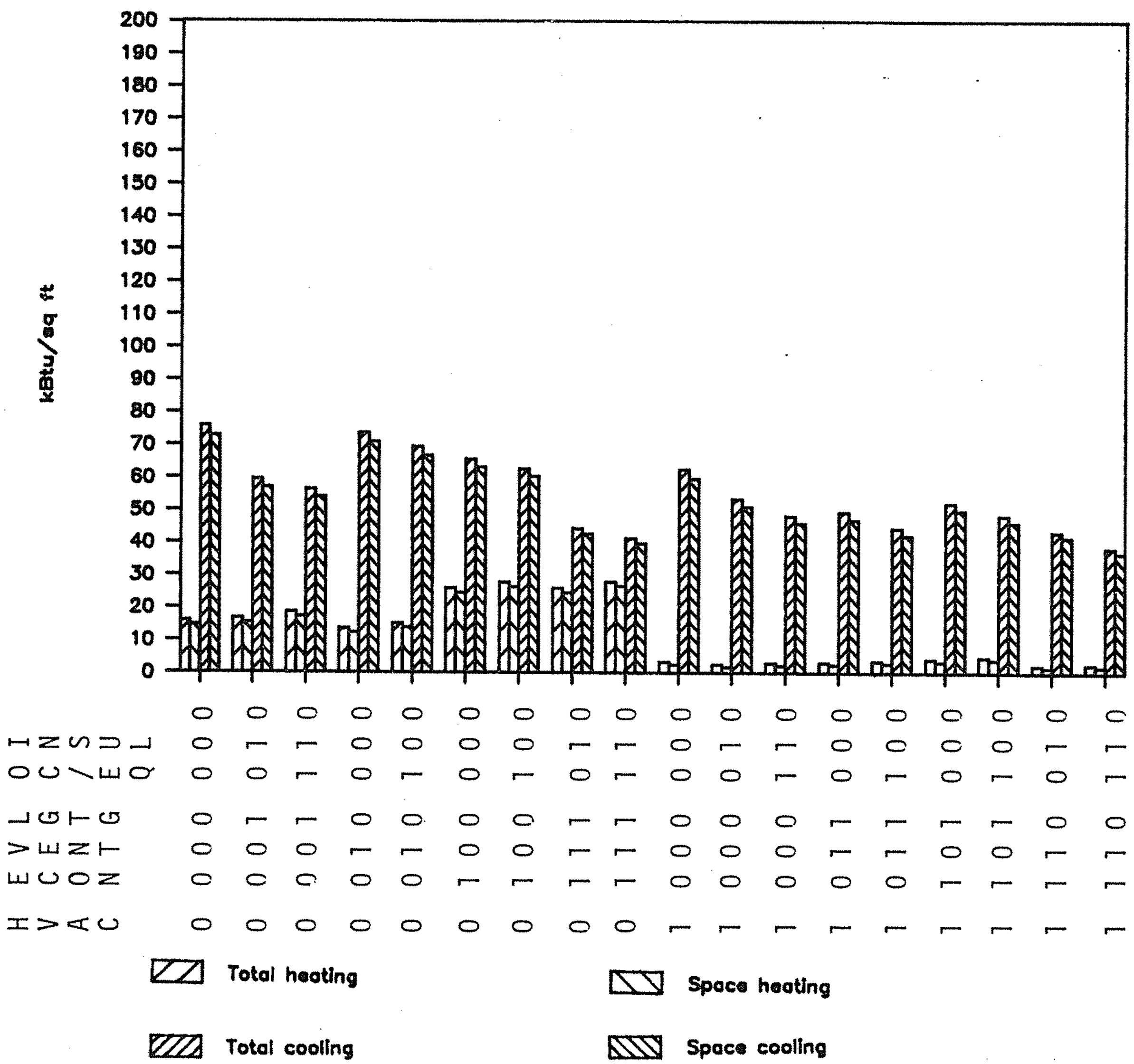

Fig. B.1(e). Annual heating-cooling loads, medium building, Fort Worth.

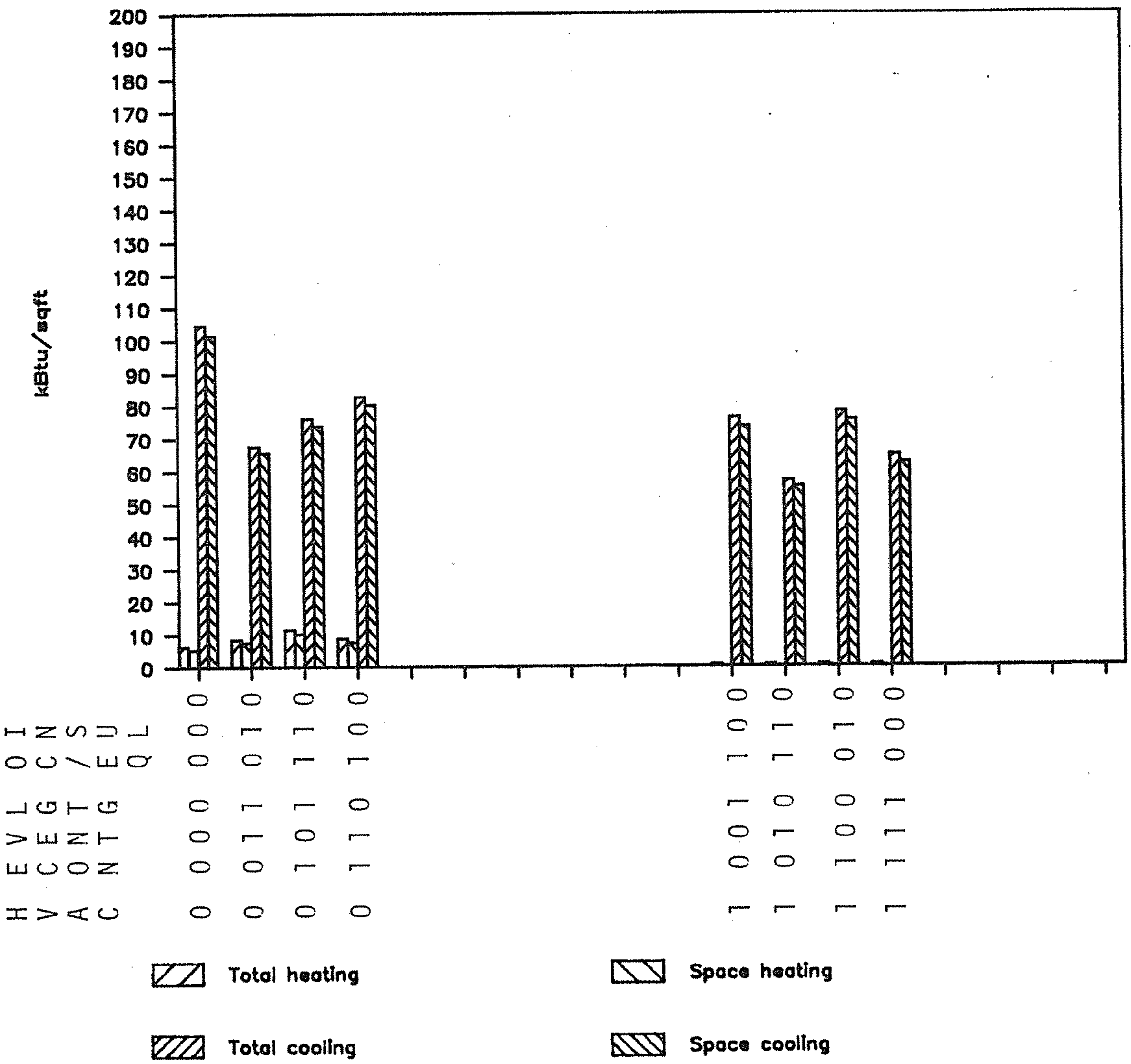

Fig. B.1(f). Annual heating-cooling loads, medium building, Miami.

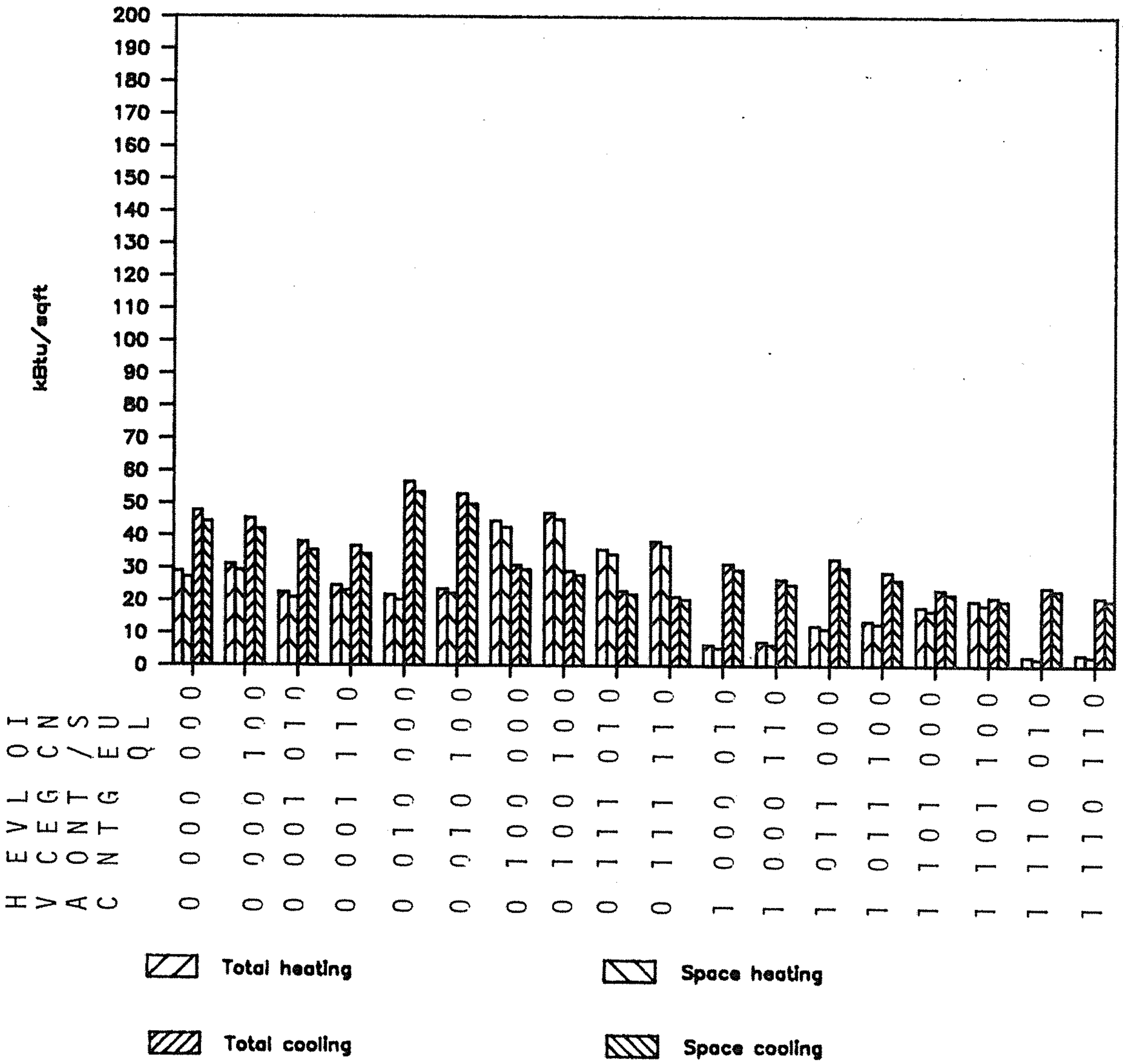

Fig. B.1(g). Annual heating-cooling loads, large building, Chicago.

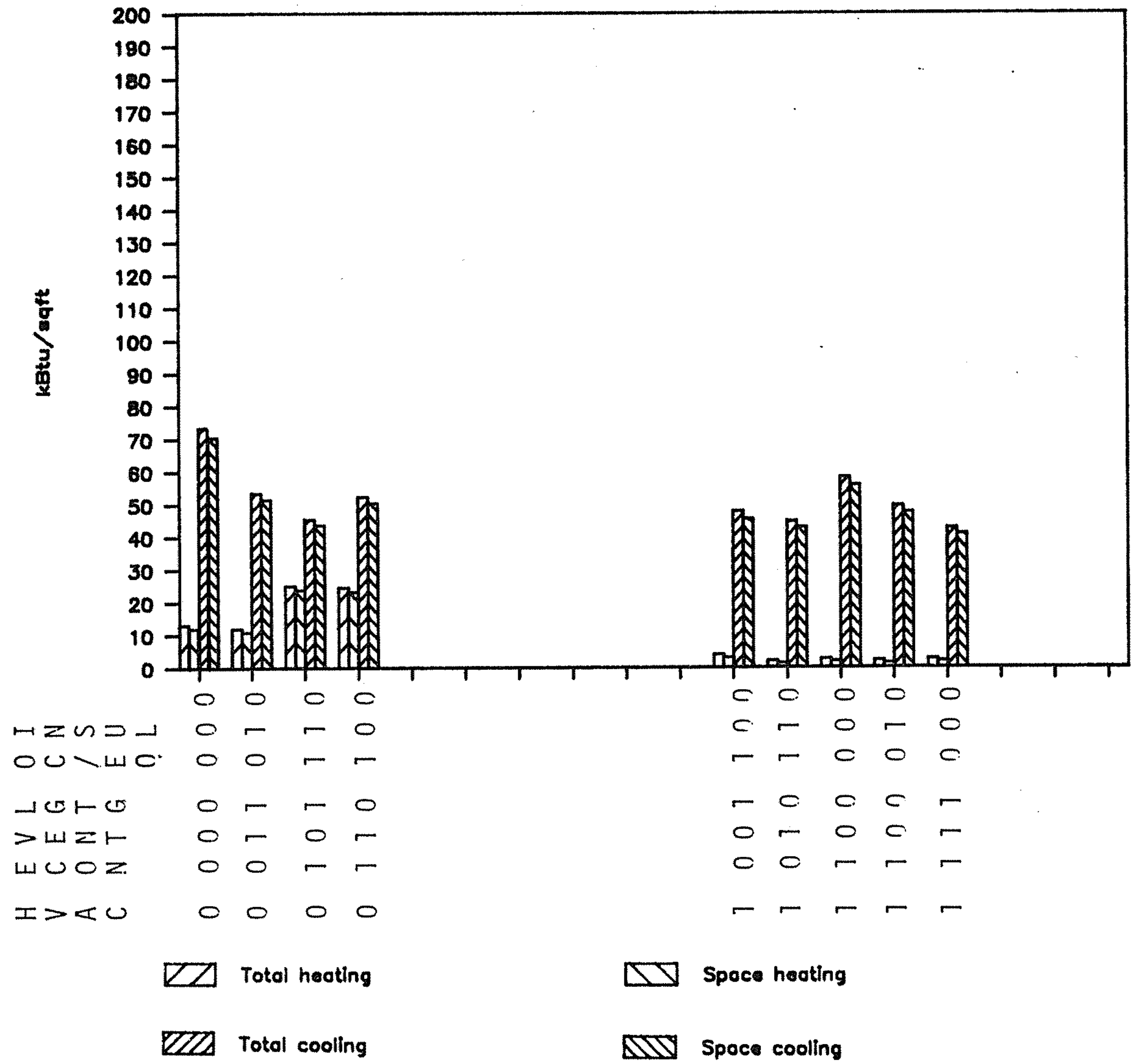

Fig. B.1(h). Annual heating-cooling loads, large building, Fort Worth.

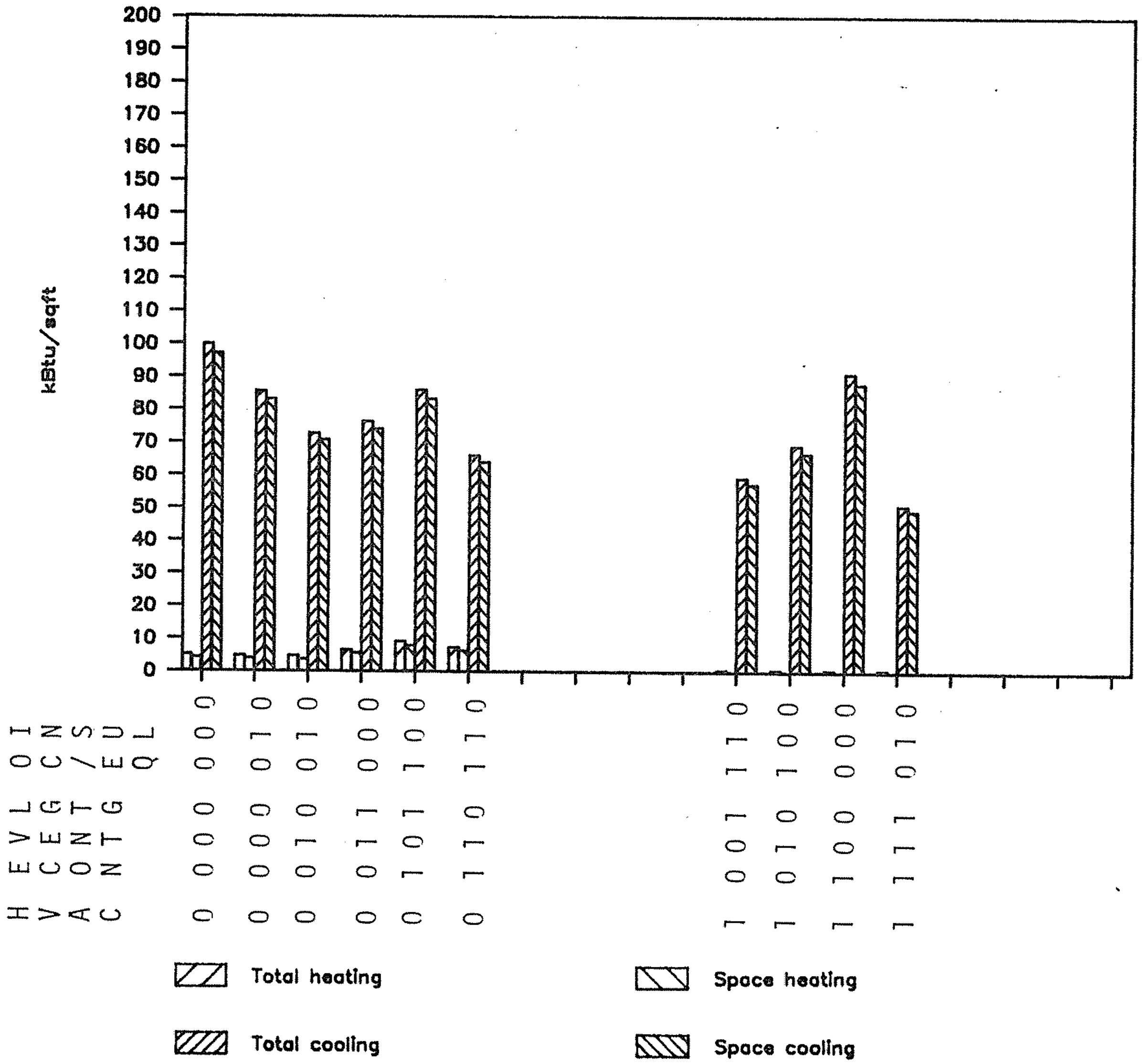

Fig. B.1(i). Annual heating-cooling loads, large building, Miami.

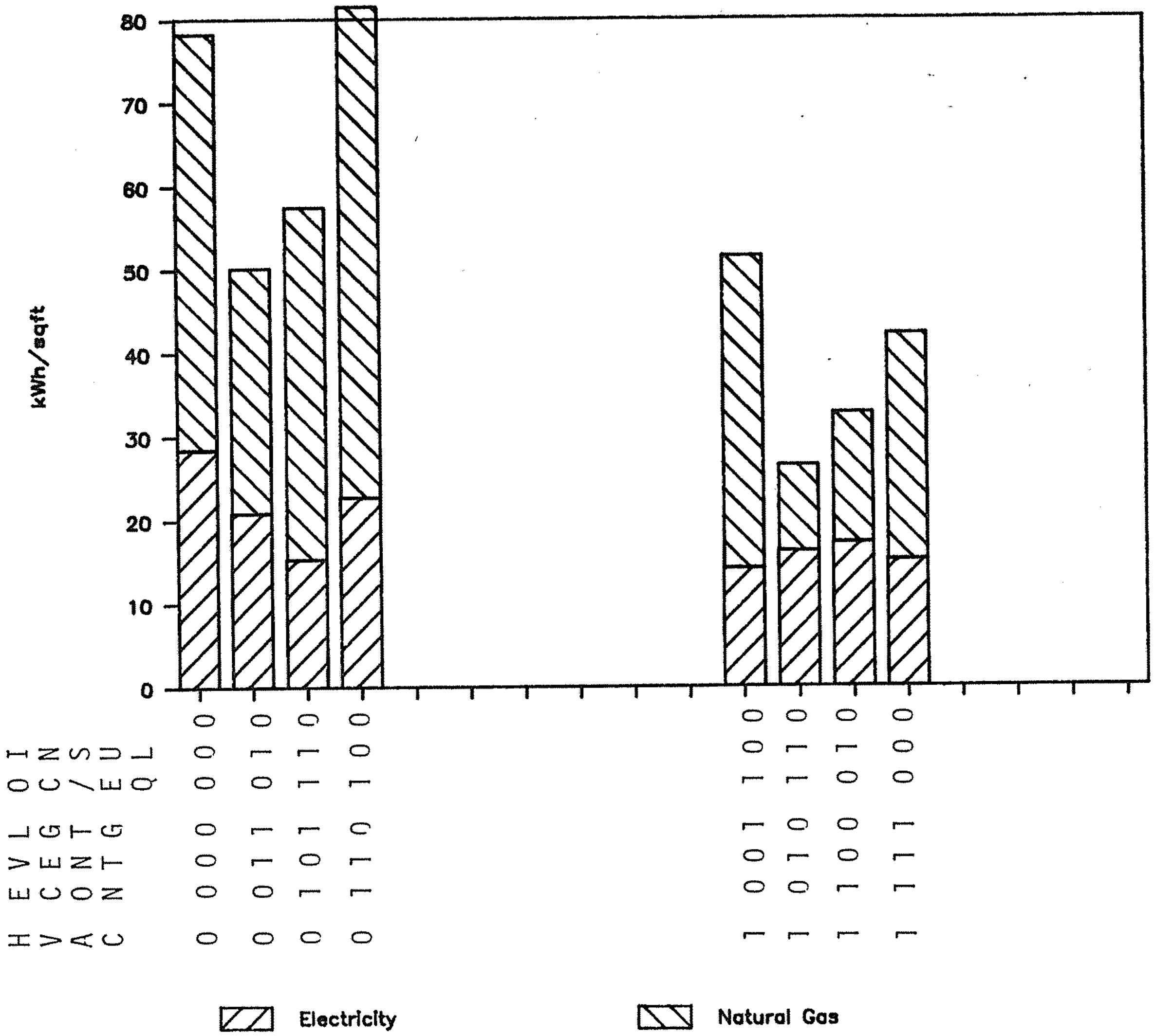

Fig. B.2(a). Annual energy use, small building, Chicago.

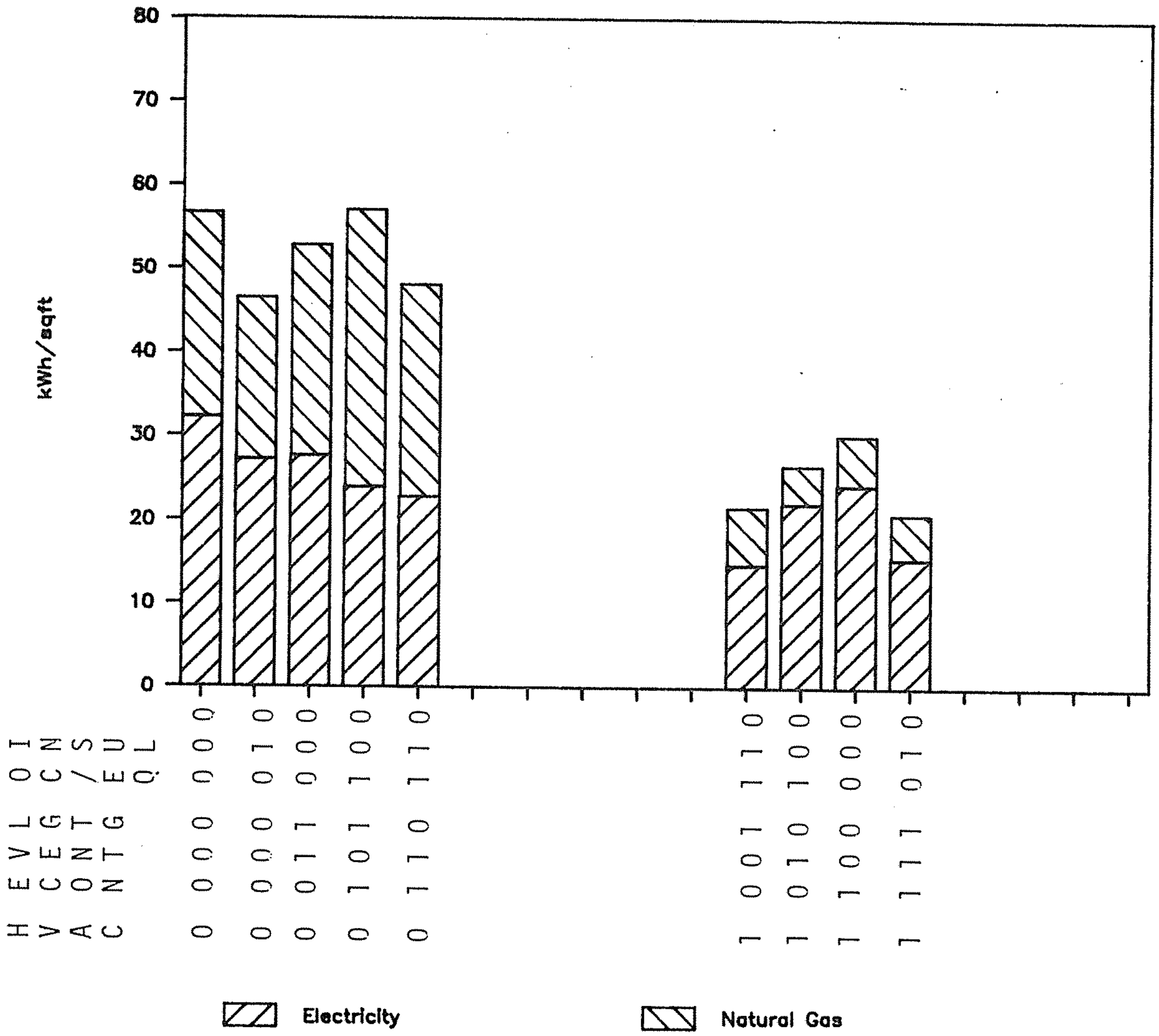

Fig. B.2(b). Annual energy use, small building, Fort Worth.

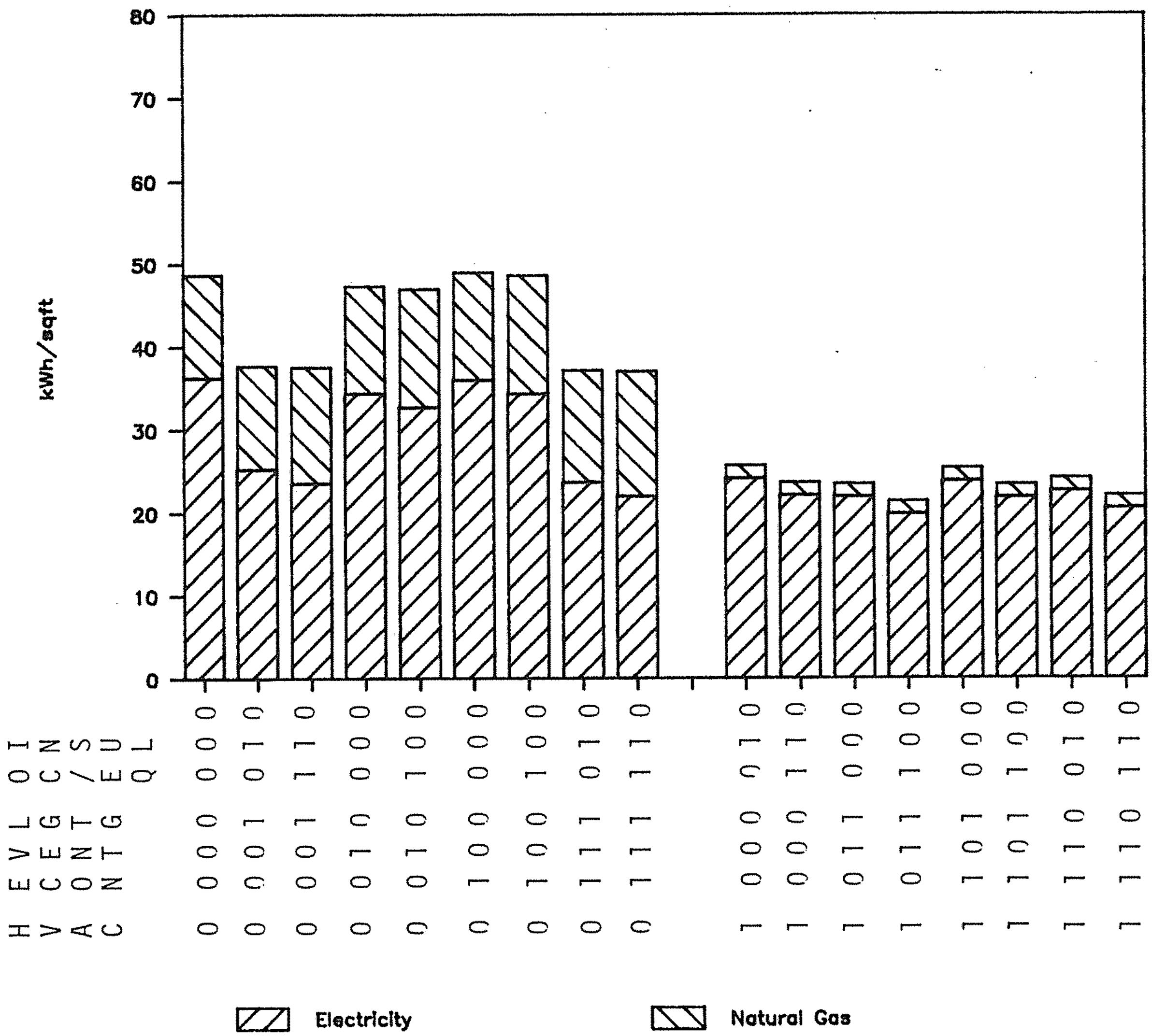

Fig. B.2(c). Annual energy use, small building, Miami.

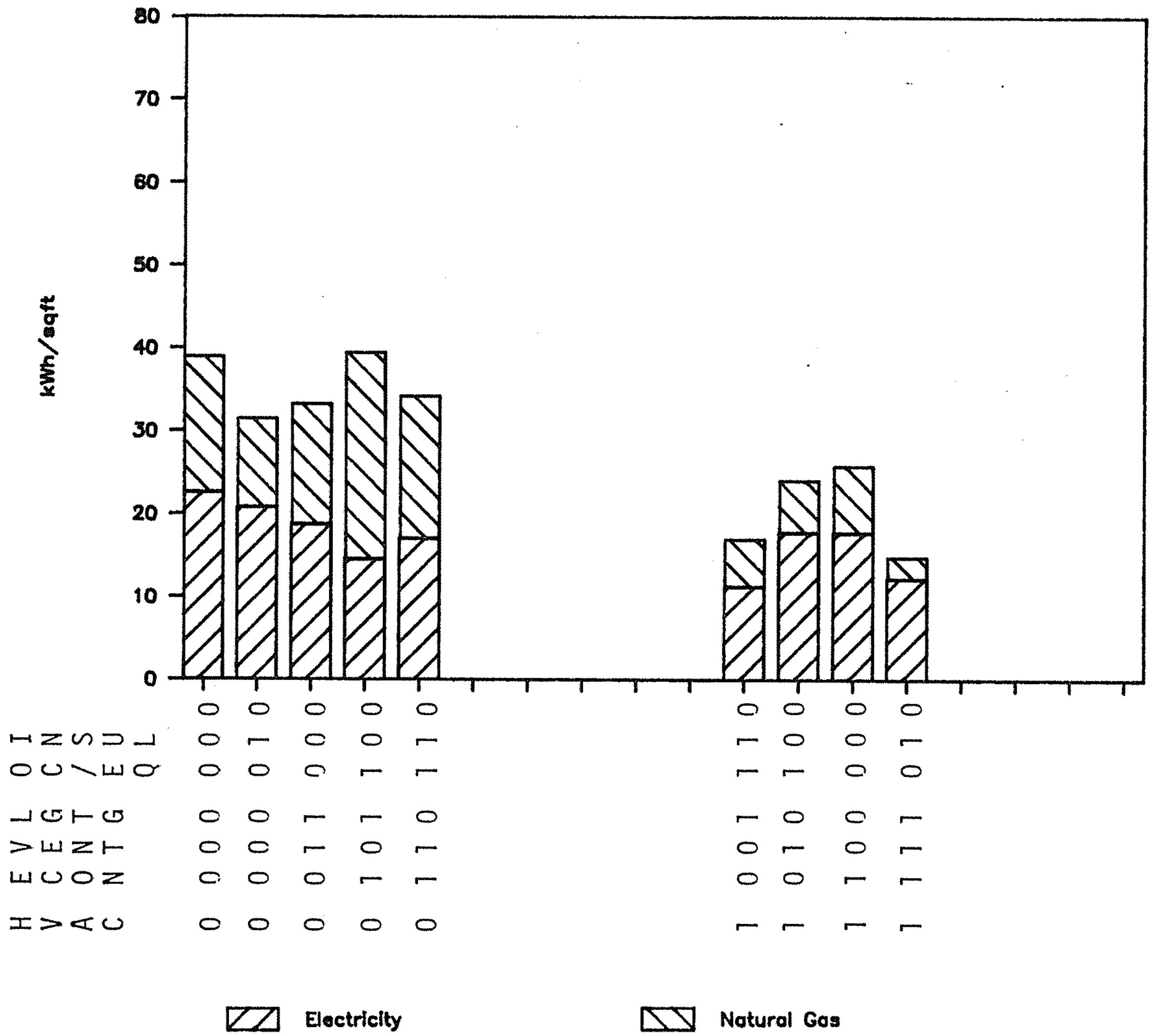

Fig. B.2(d). Annual energy use, medium building, Chicago.

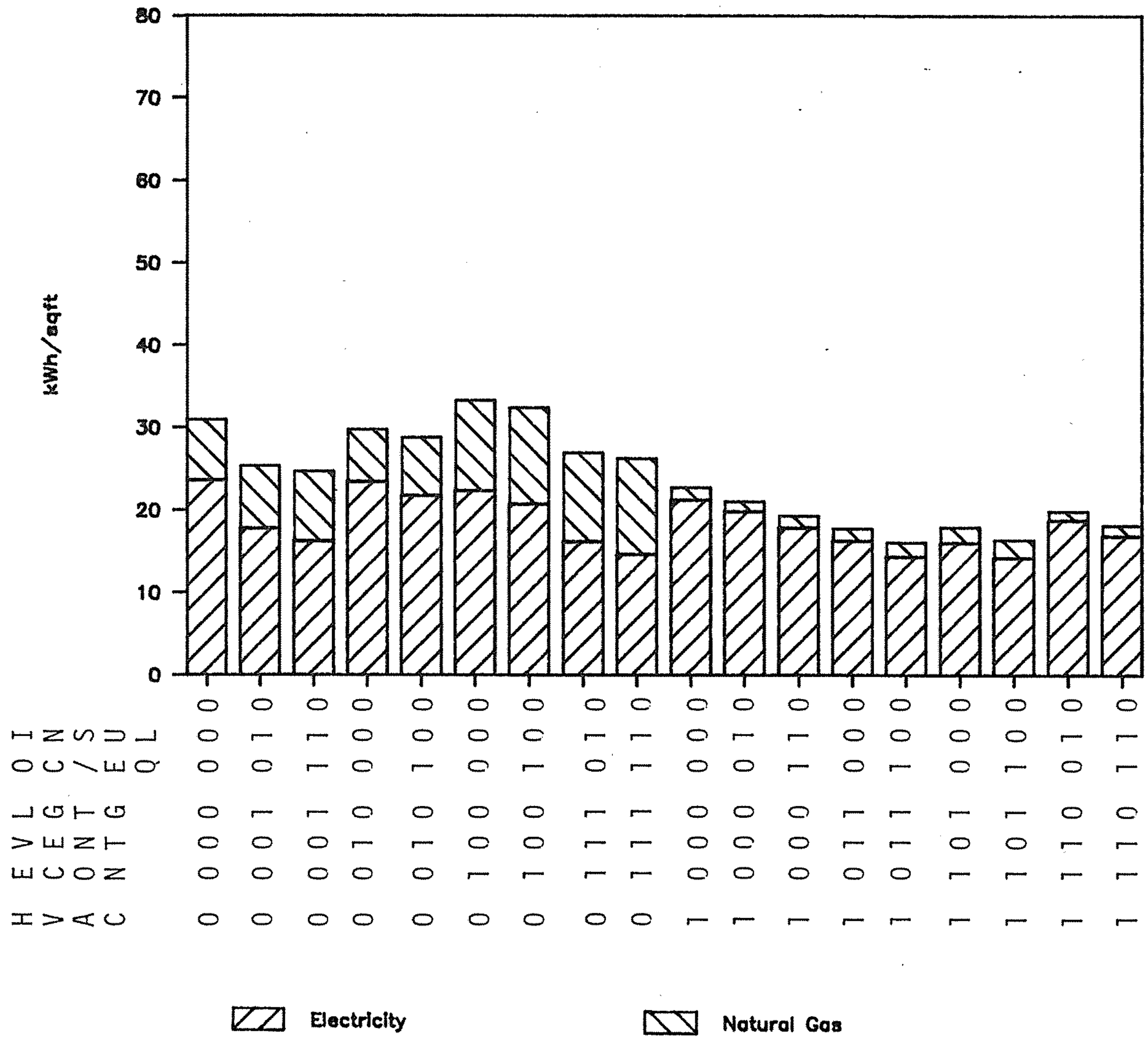

Fig. B.2(e). Annual energy use, medium building, Fort Worth.

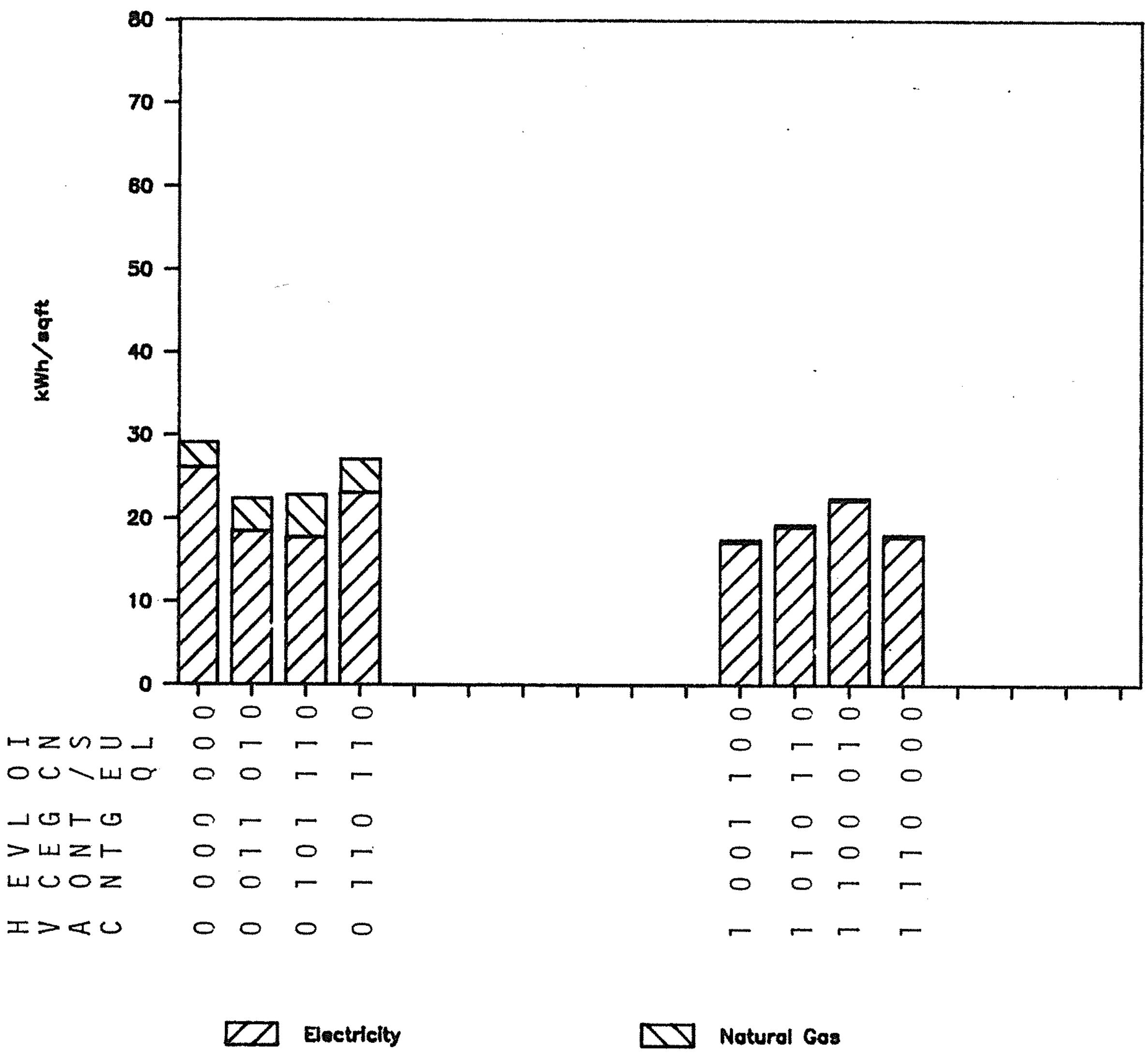

Fig. B.2(f). Annual energy use, medium building, Miami.

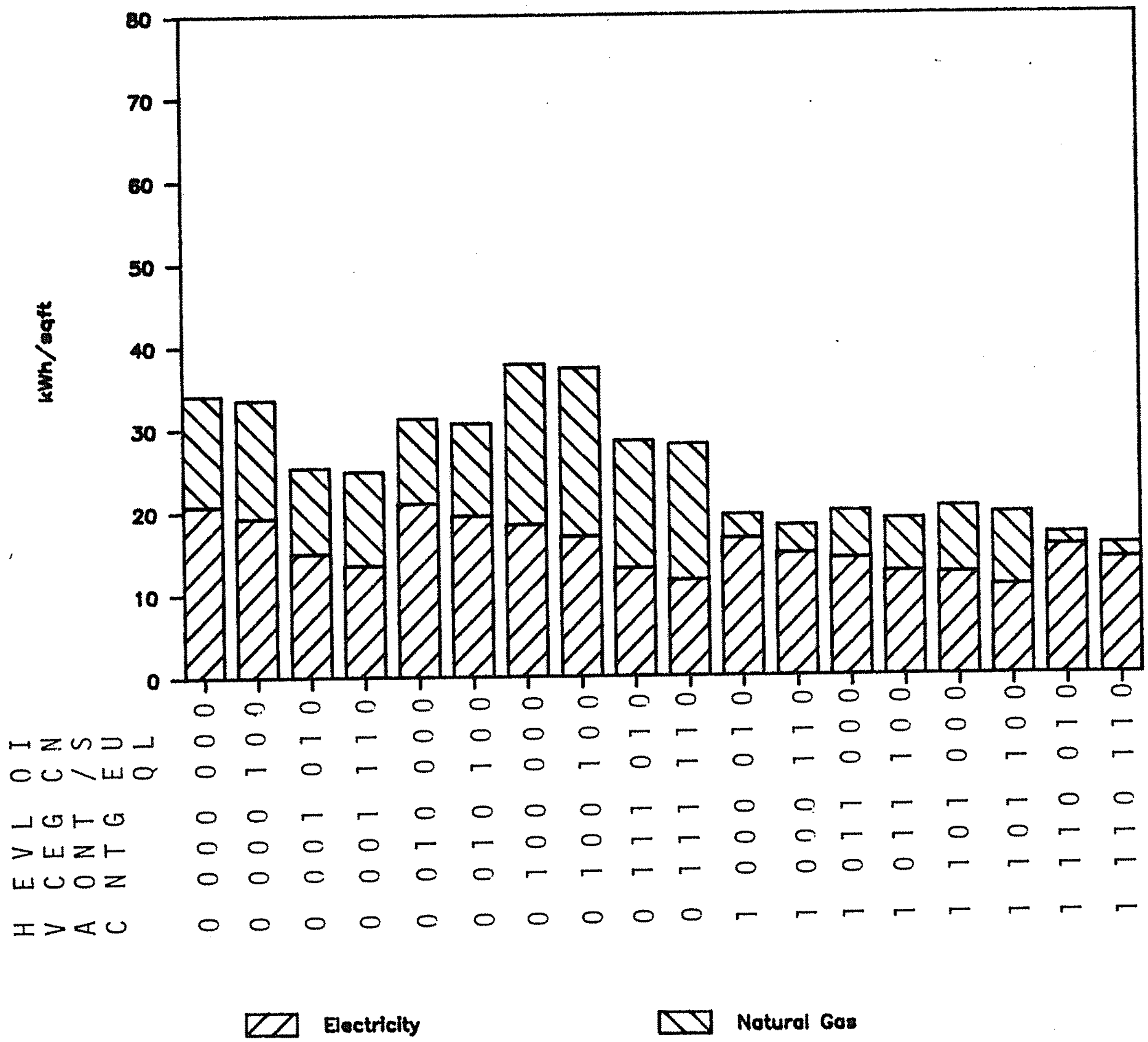

Fig. B.2(g). Annual energy use, large building, Chicago.

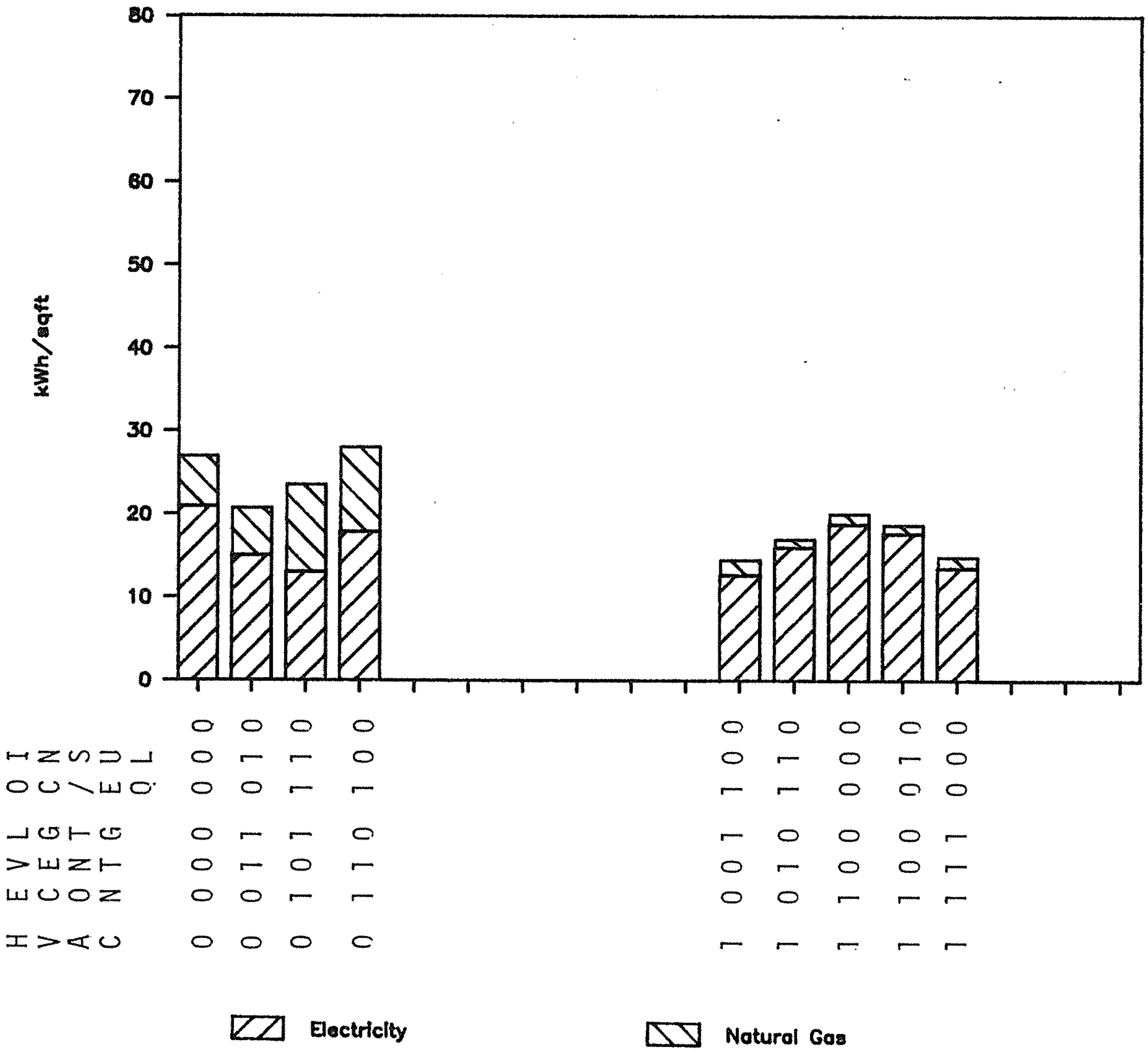

Fig. B.2(h). Annual energy use, large building, Fort Worth.

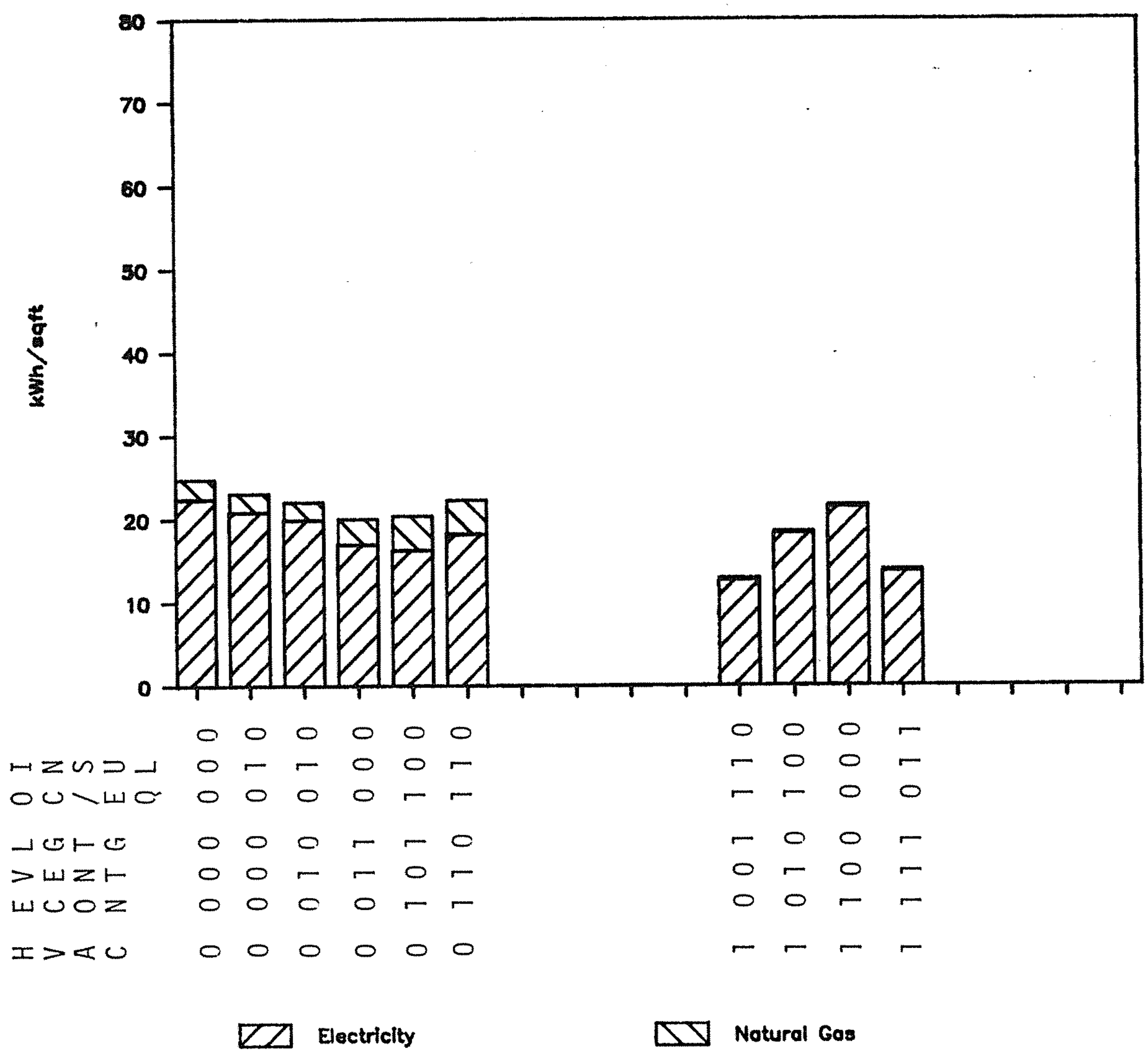

Fig. B.2(i). Annual energy use, large building, Miami.

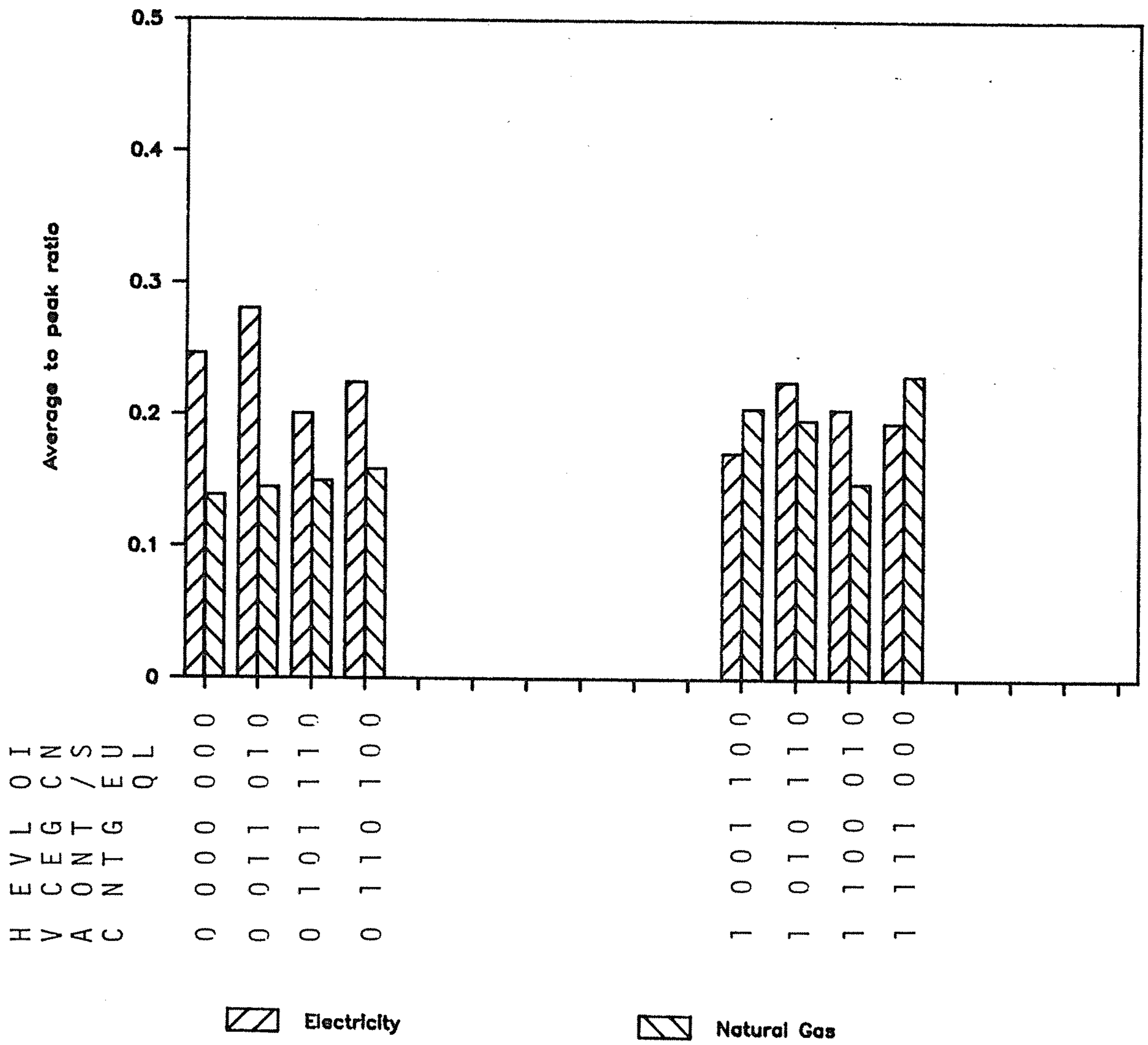

Fig. B.3(a). Annual average to peak energy use, small building, Chicago.

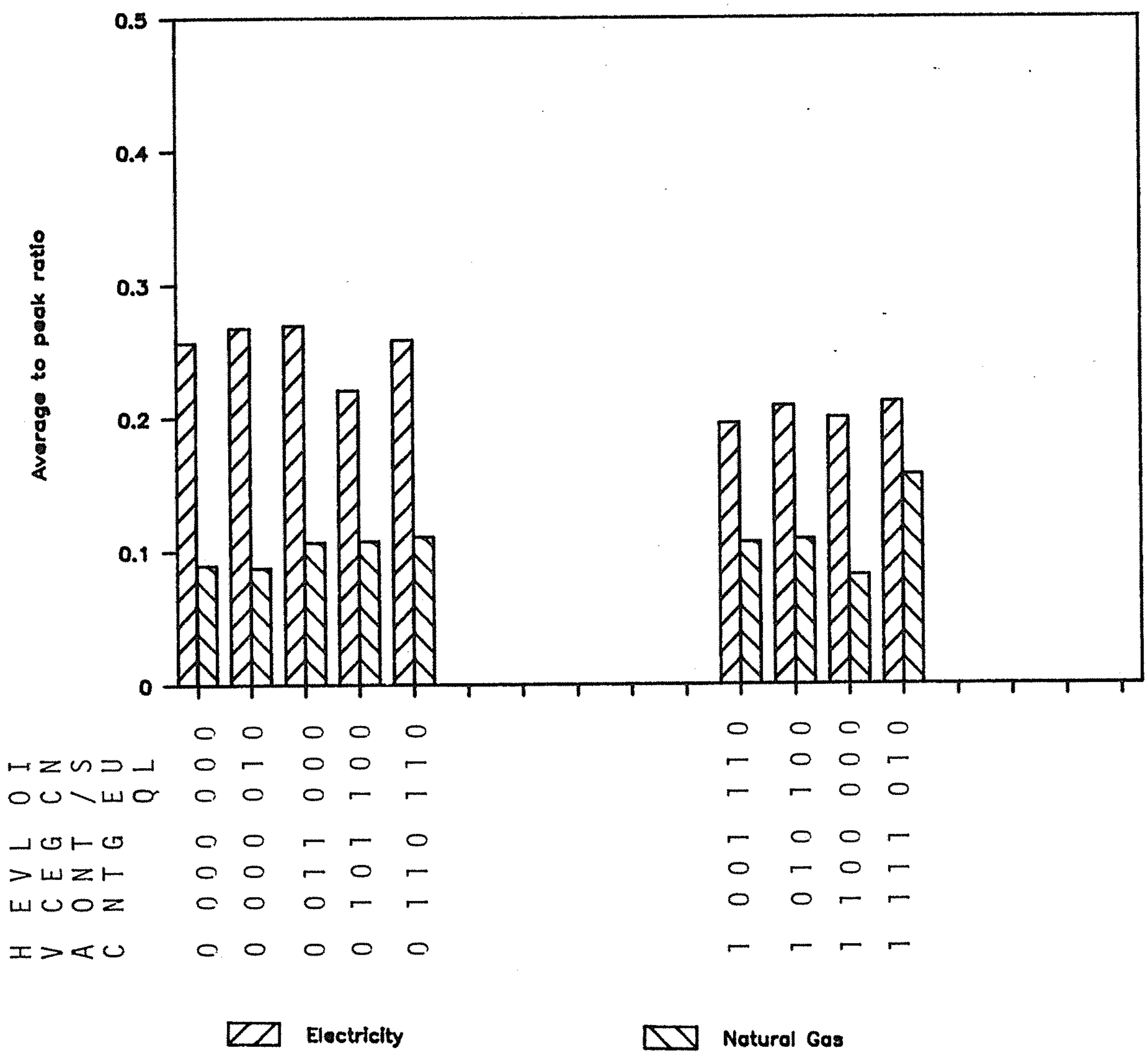

Fig. B.3(b). Annual average to peak energy use, small building, Fort Worth.

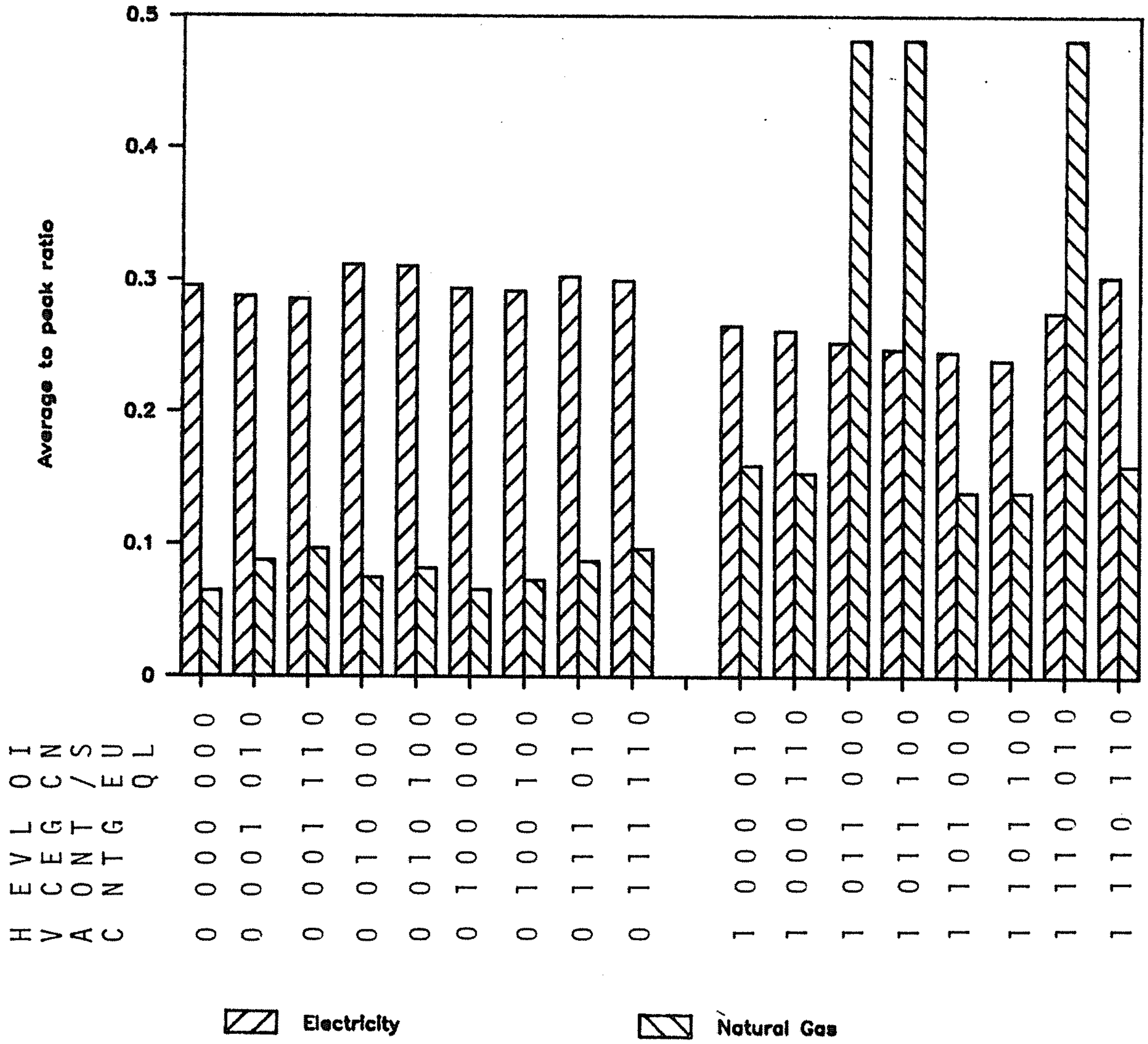

Fig. B.3(c). Annual average to peak energy use, small building, Miami.

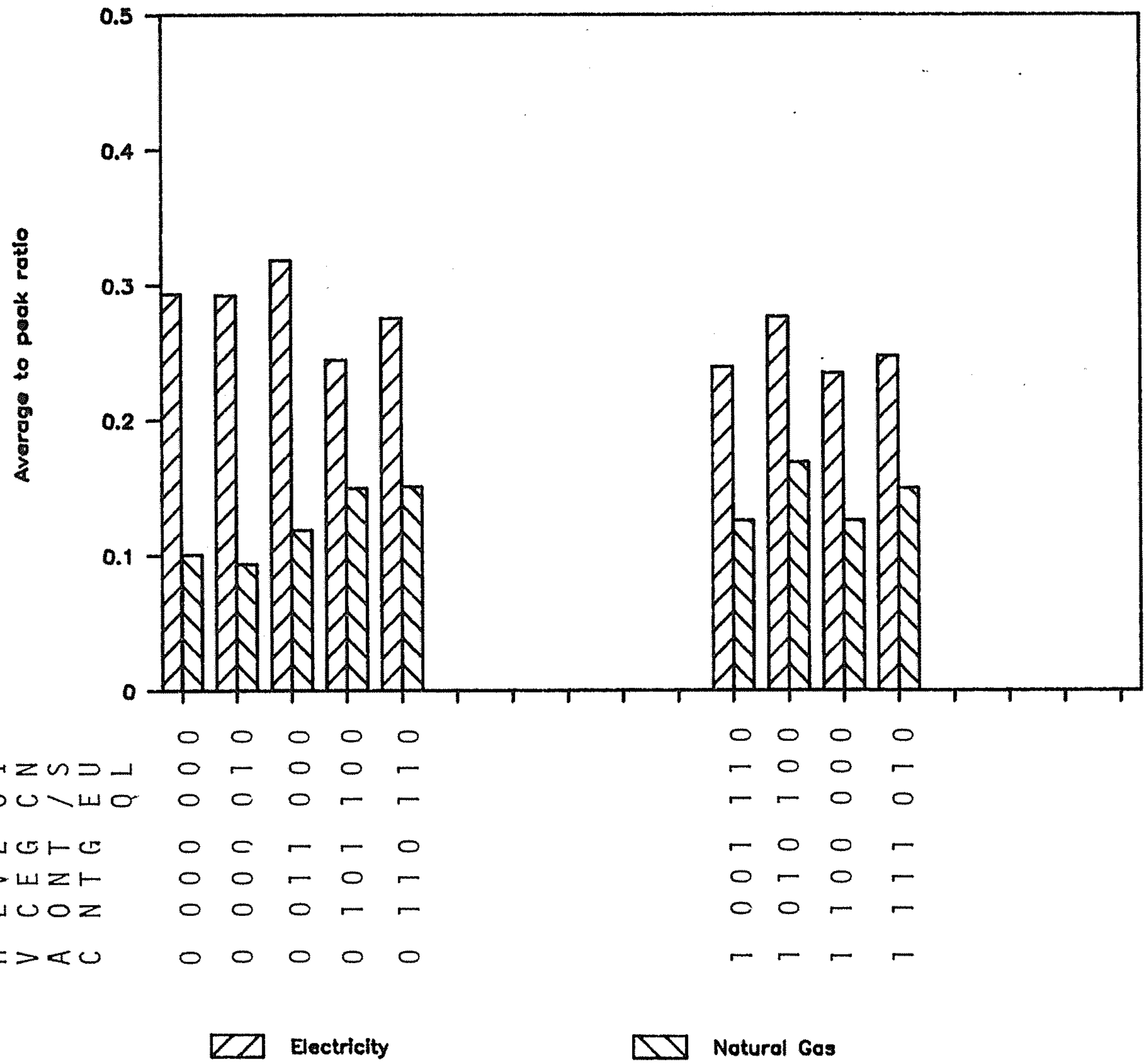

Fig. B.3(d). Annual average to peak energy use, medium building, Chicago.

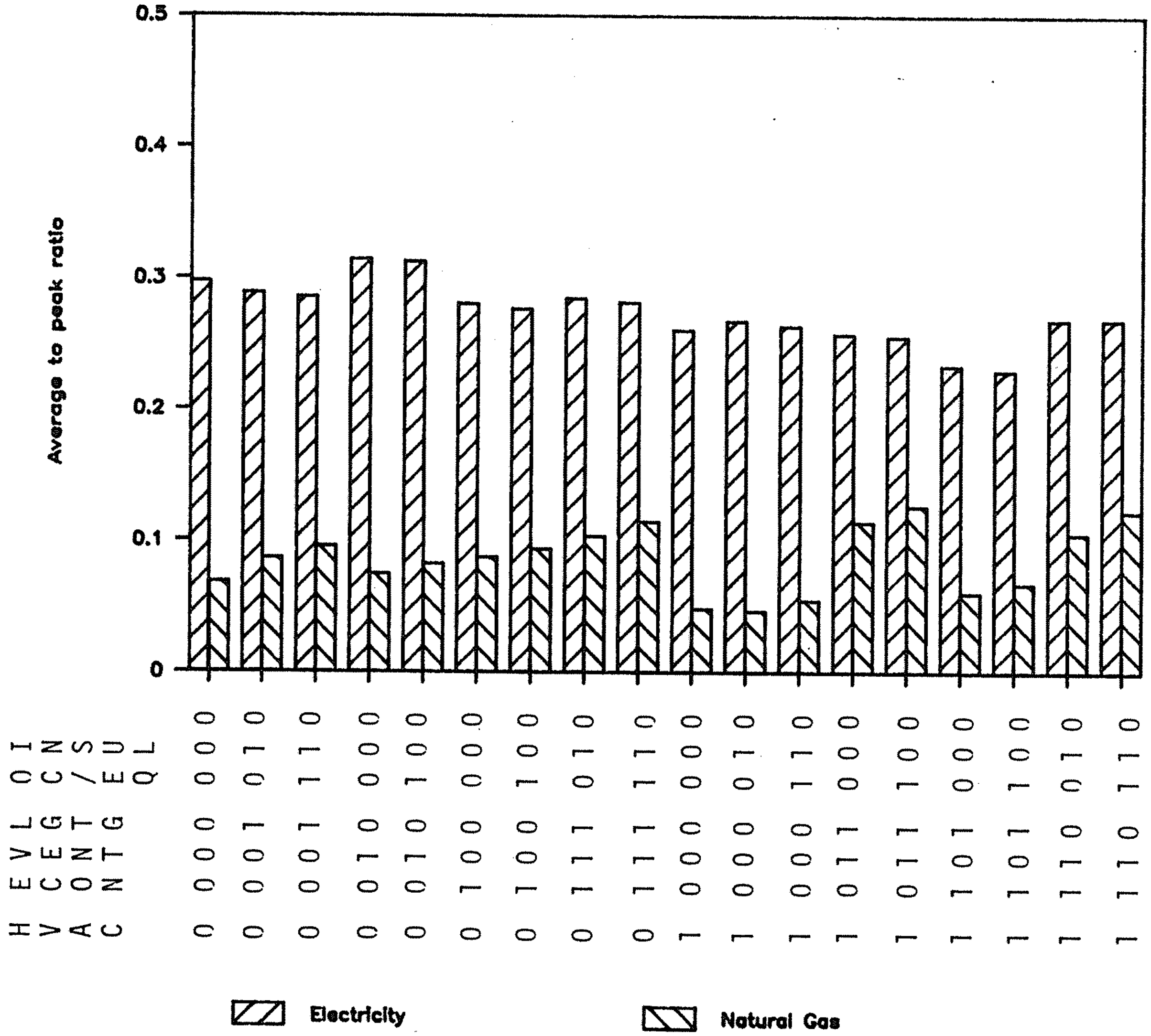

Fig. B.3(e). Annual average to peak energy use, medium building, Fort Worth.

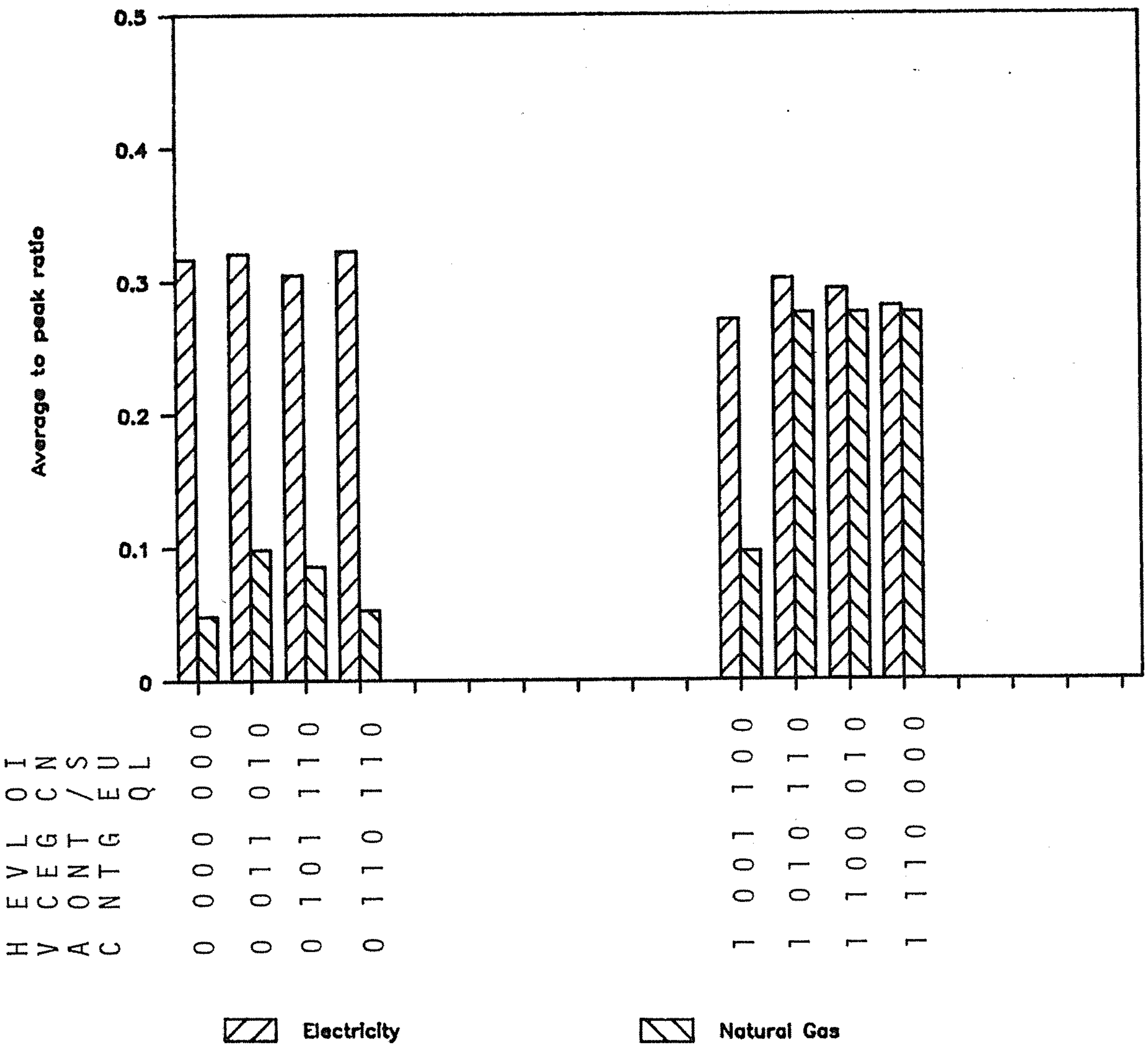

Fig. B.3(f). Annual average to peak energy use, medium building, Miami.

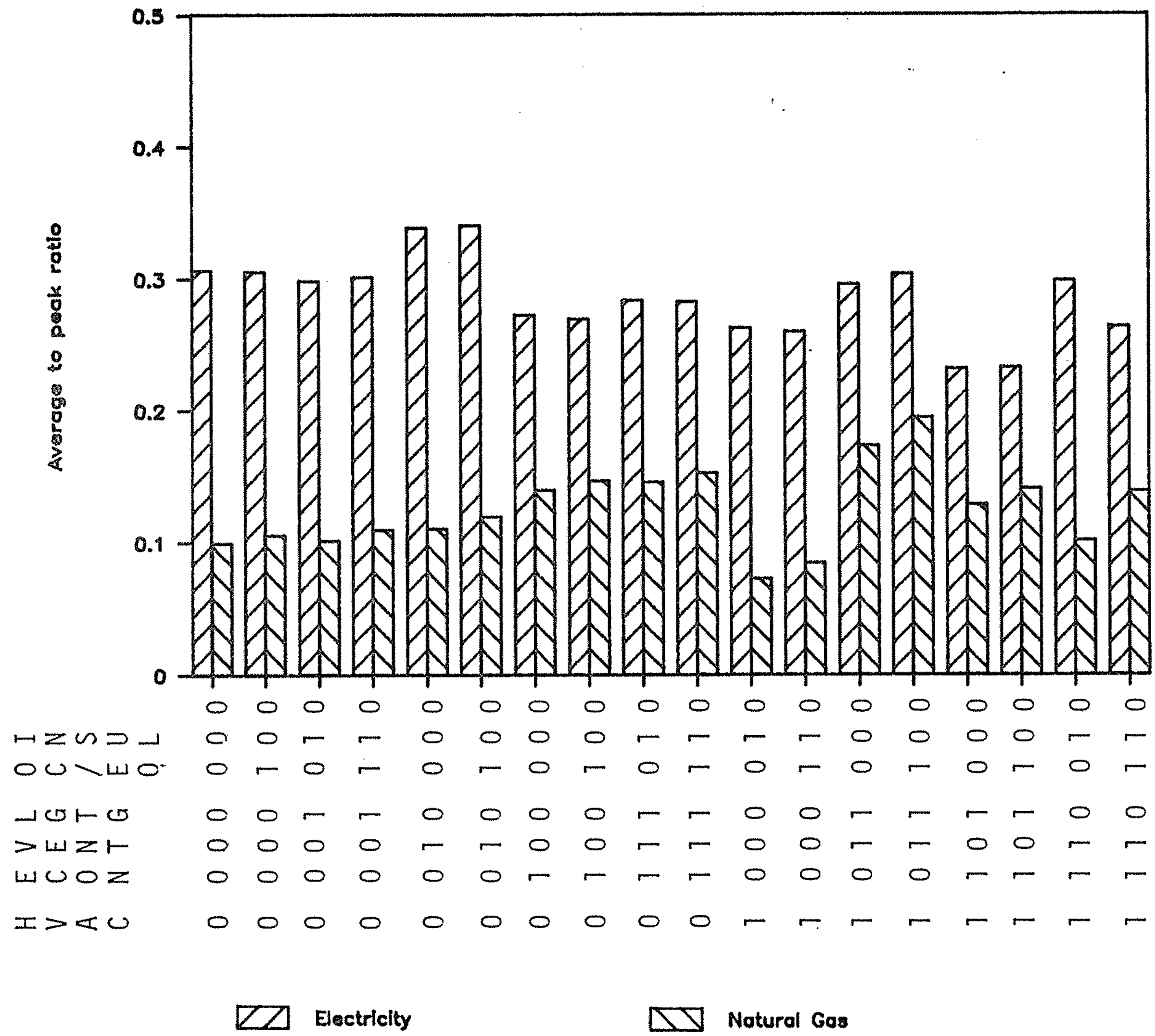

Fig. B.3(g). Annual average to peak energy use, large building, Chicago.

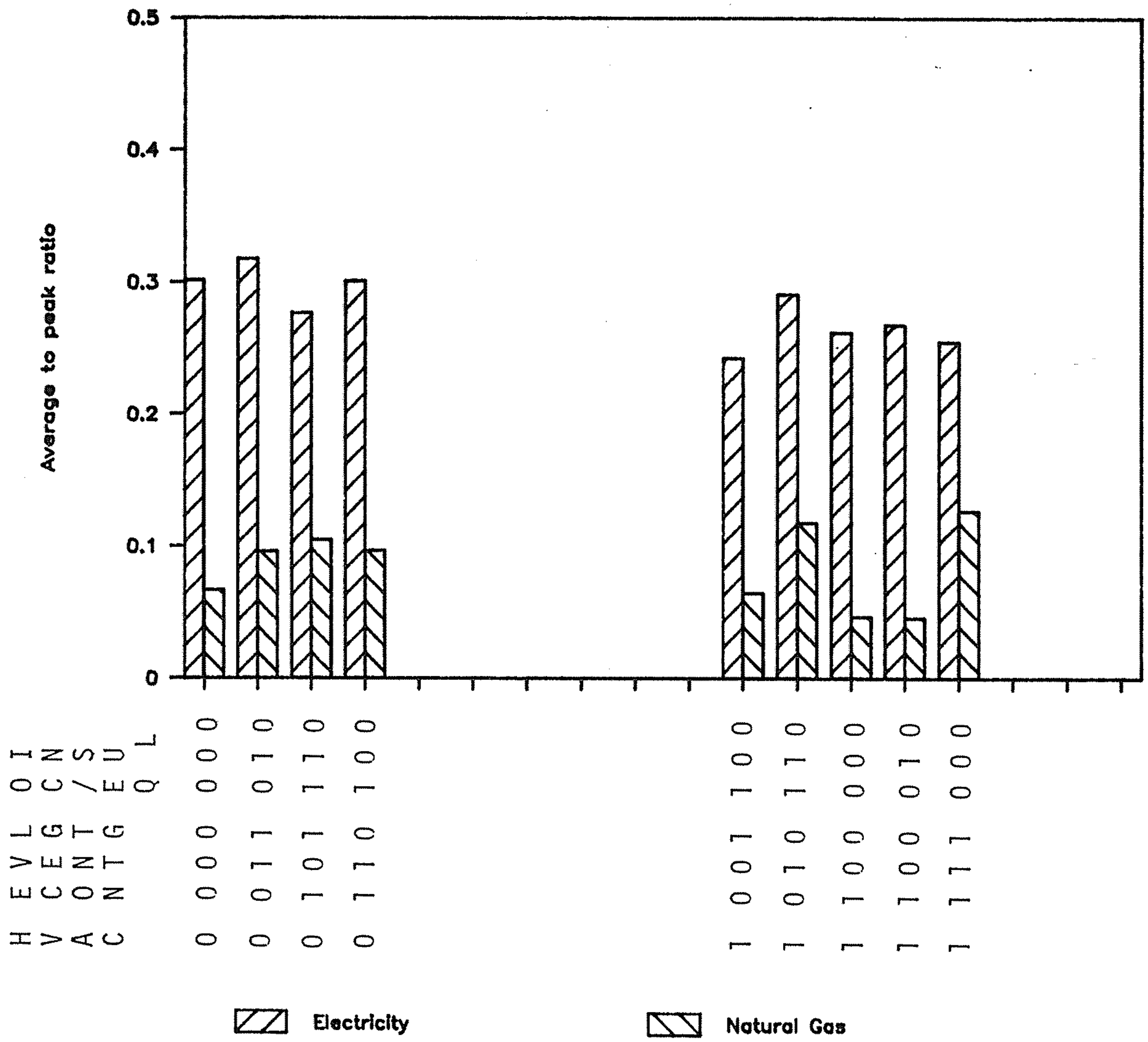

Fig. B.3(h). Annual average to peak energy use, large building, Fort Worth.

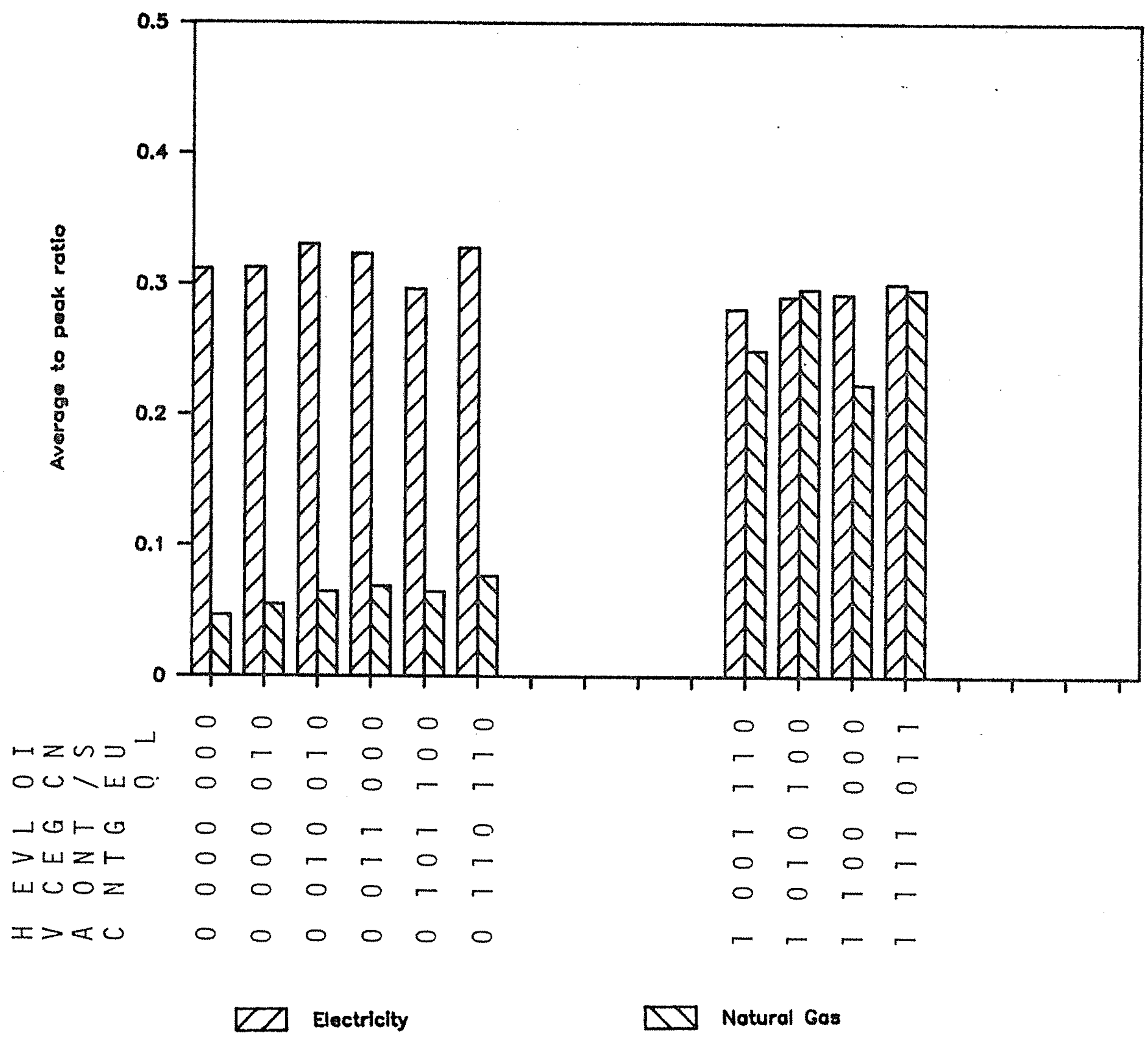

Fig. B.3(i). Annual average to peak energy use, large building, Miami.

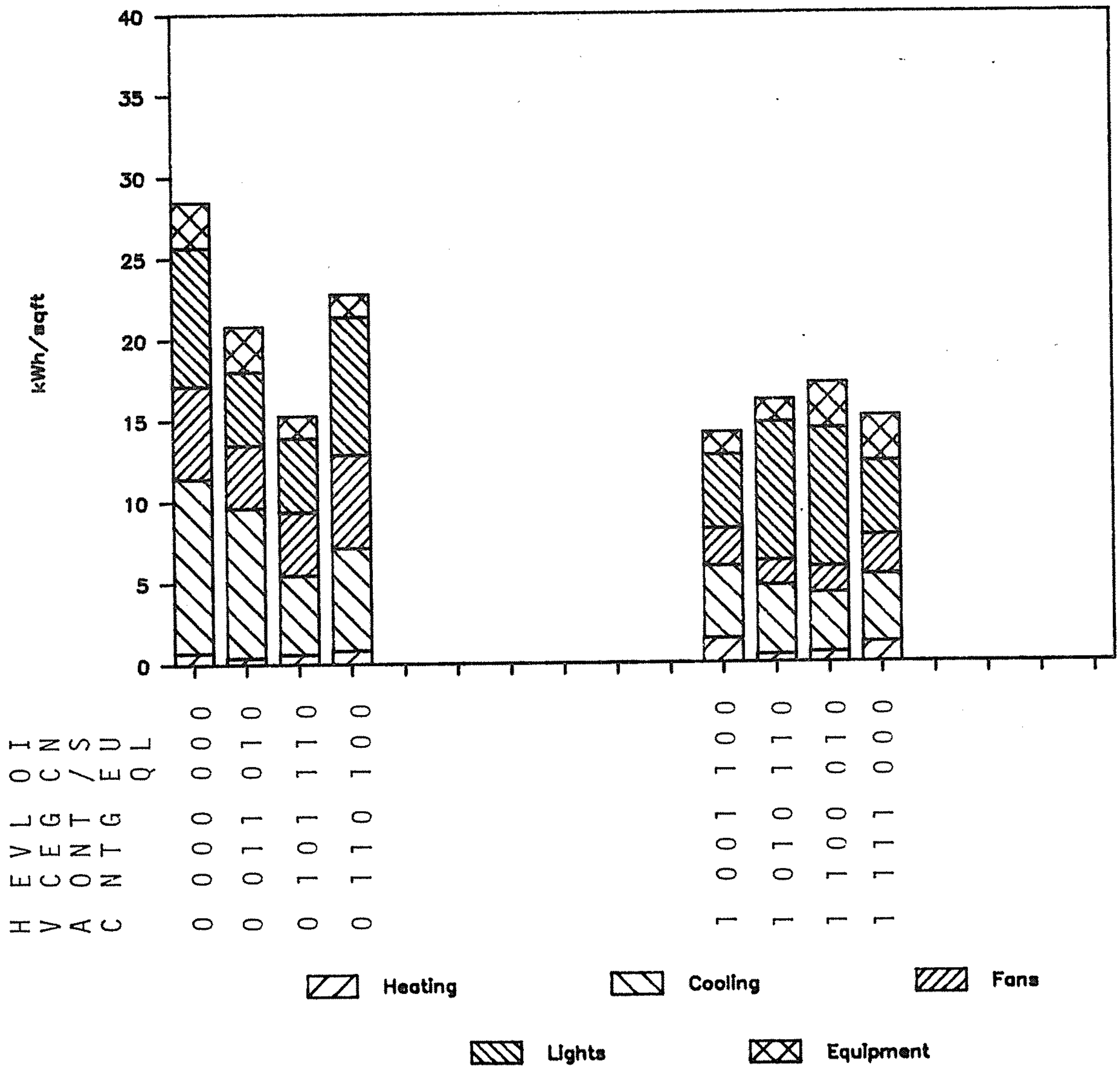

Fig. B.4(a). Annual electricity use, small building, Chicago.

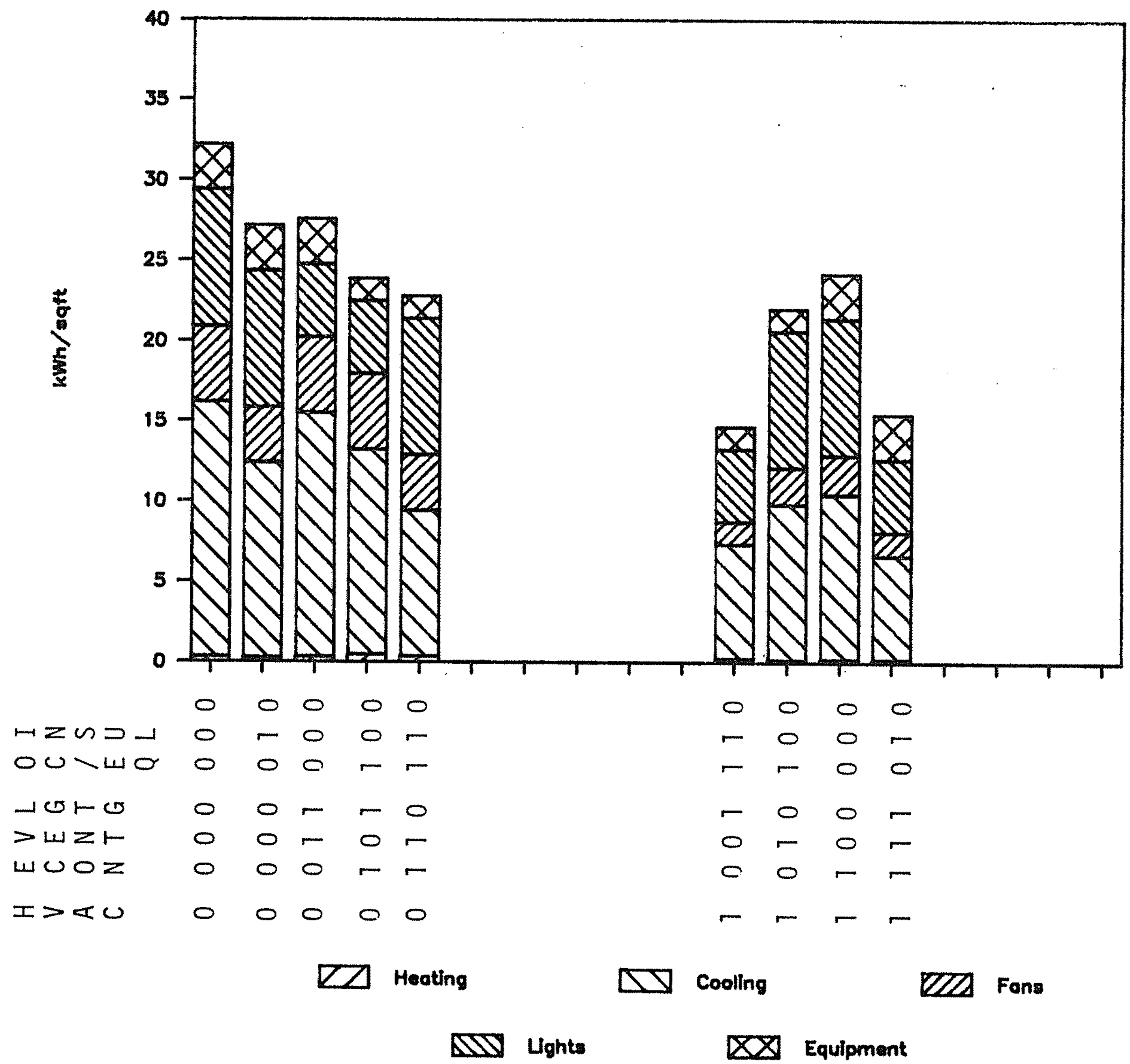

Fig. B.4(b). Annual electricity use, small building, Fort Worth.

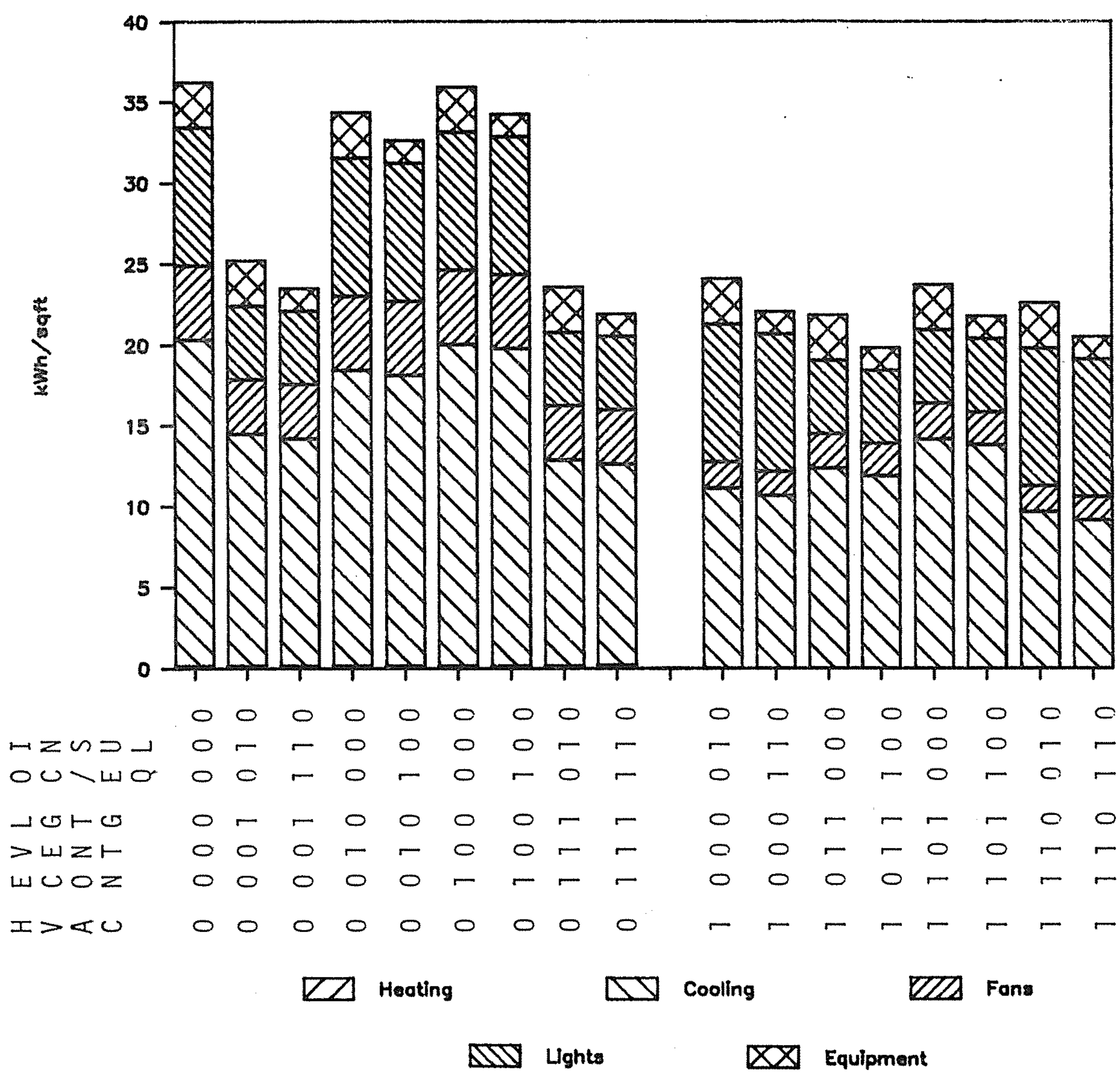

Fig. B.4(c). Annual electricity use, small building, Miami.

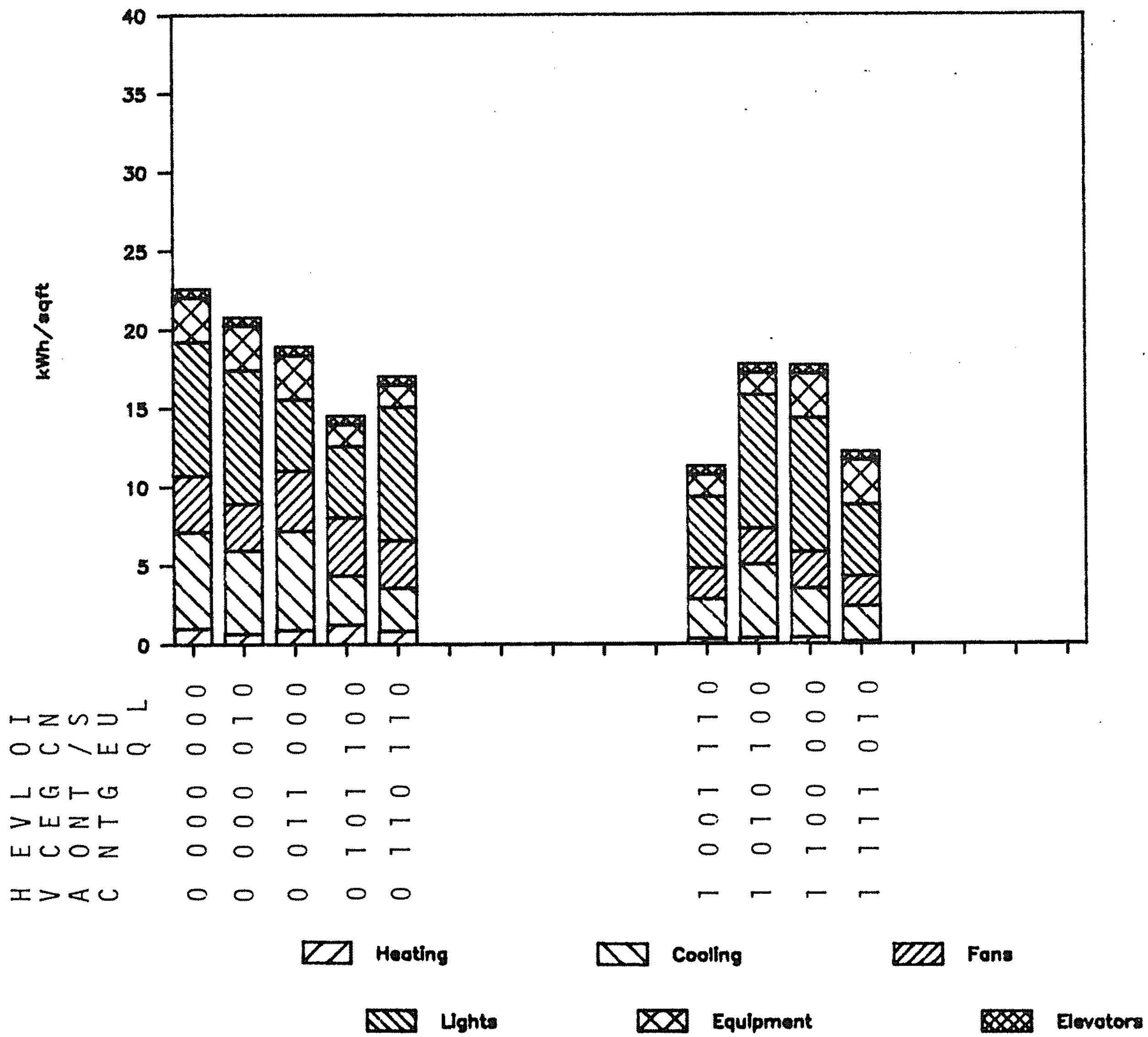

Fig. B.4(d). Annual electricity use, medium building, Chicago.

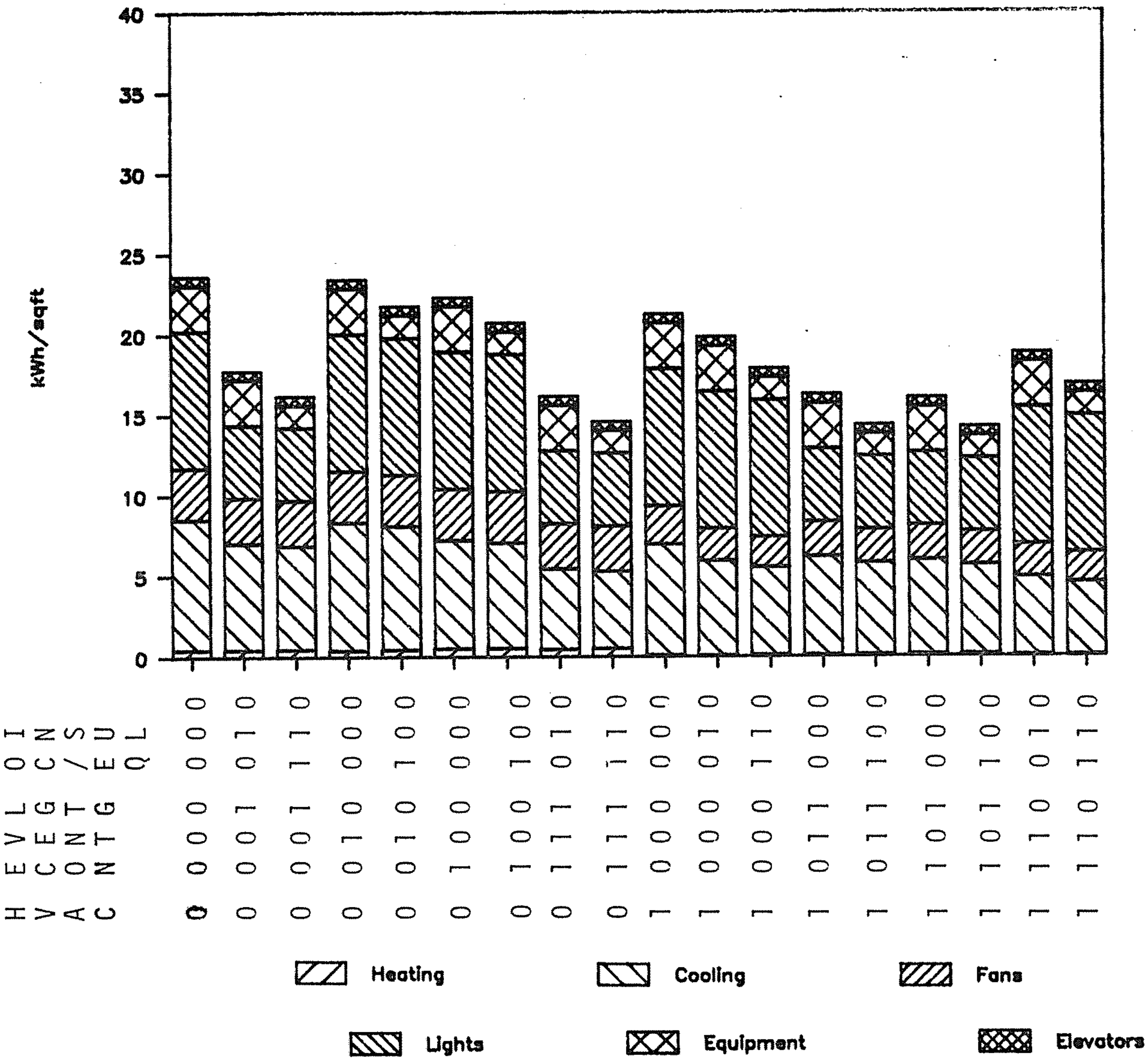

Fig. B.4(e). Annual electricity use, medium building, Fort Worth.

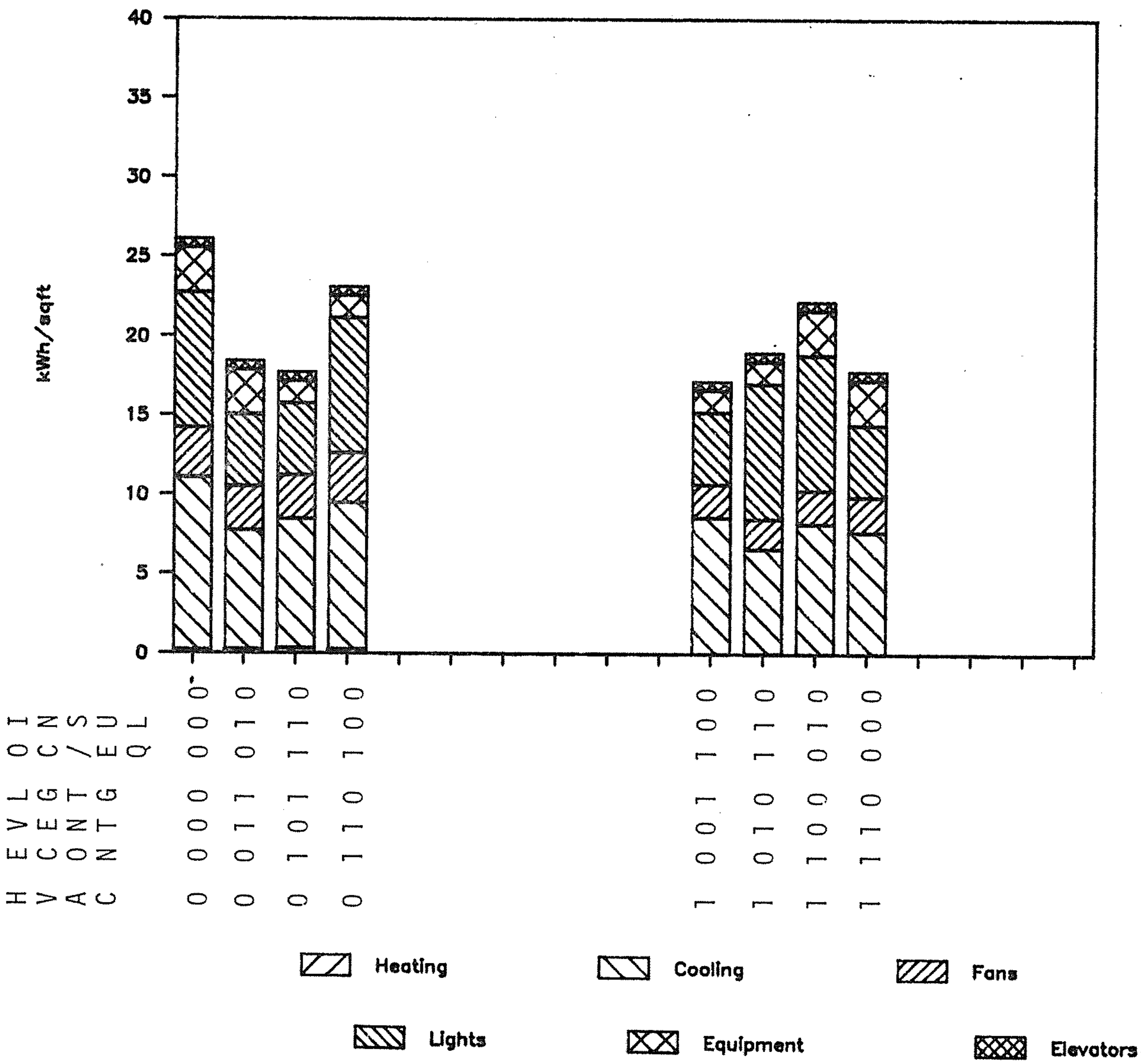

Fig. B.4(f). Annual electricity use, medium building, Miami.

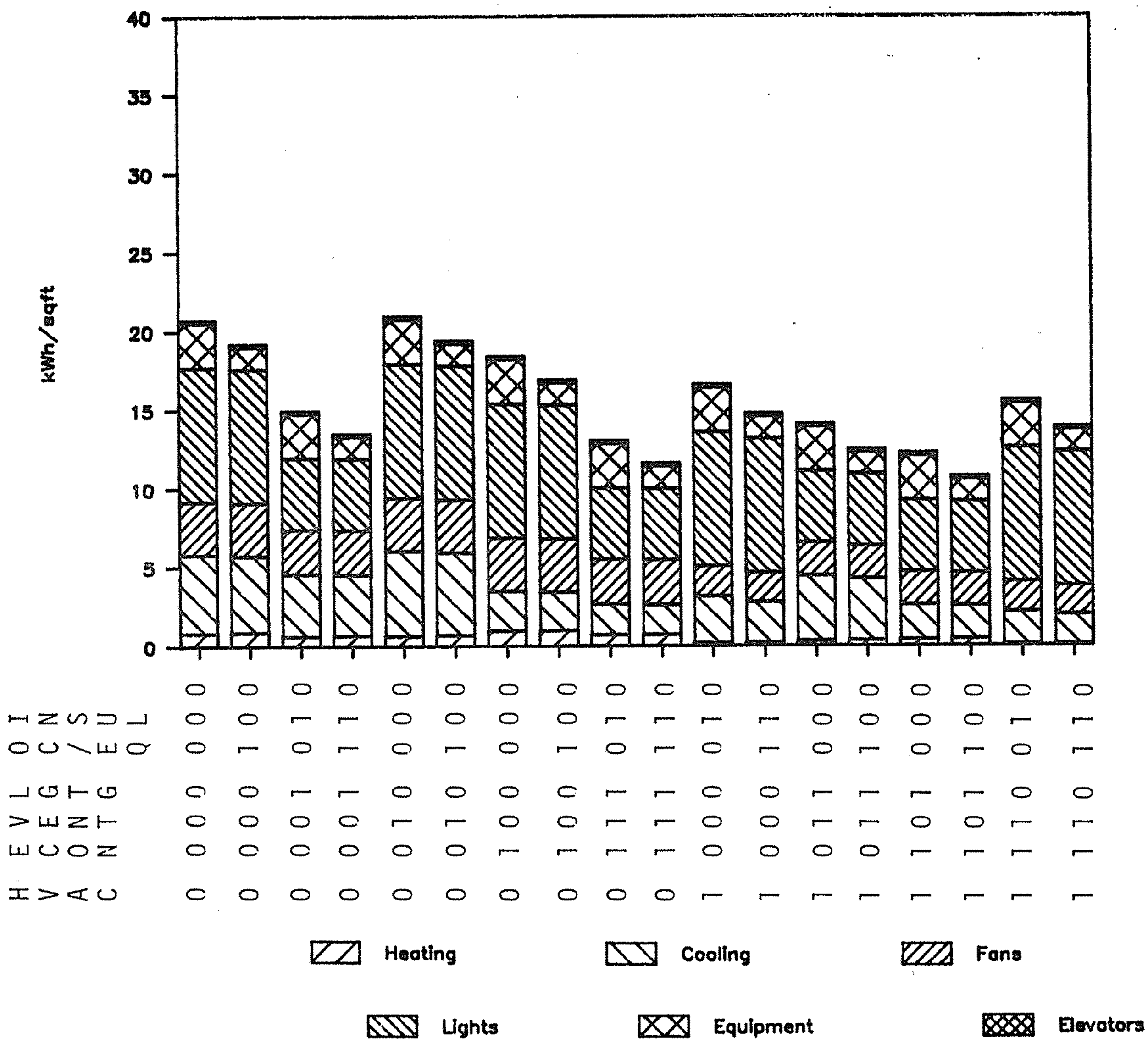

Fig. B.4(g). Annual electricity use, large building, Chicago.

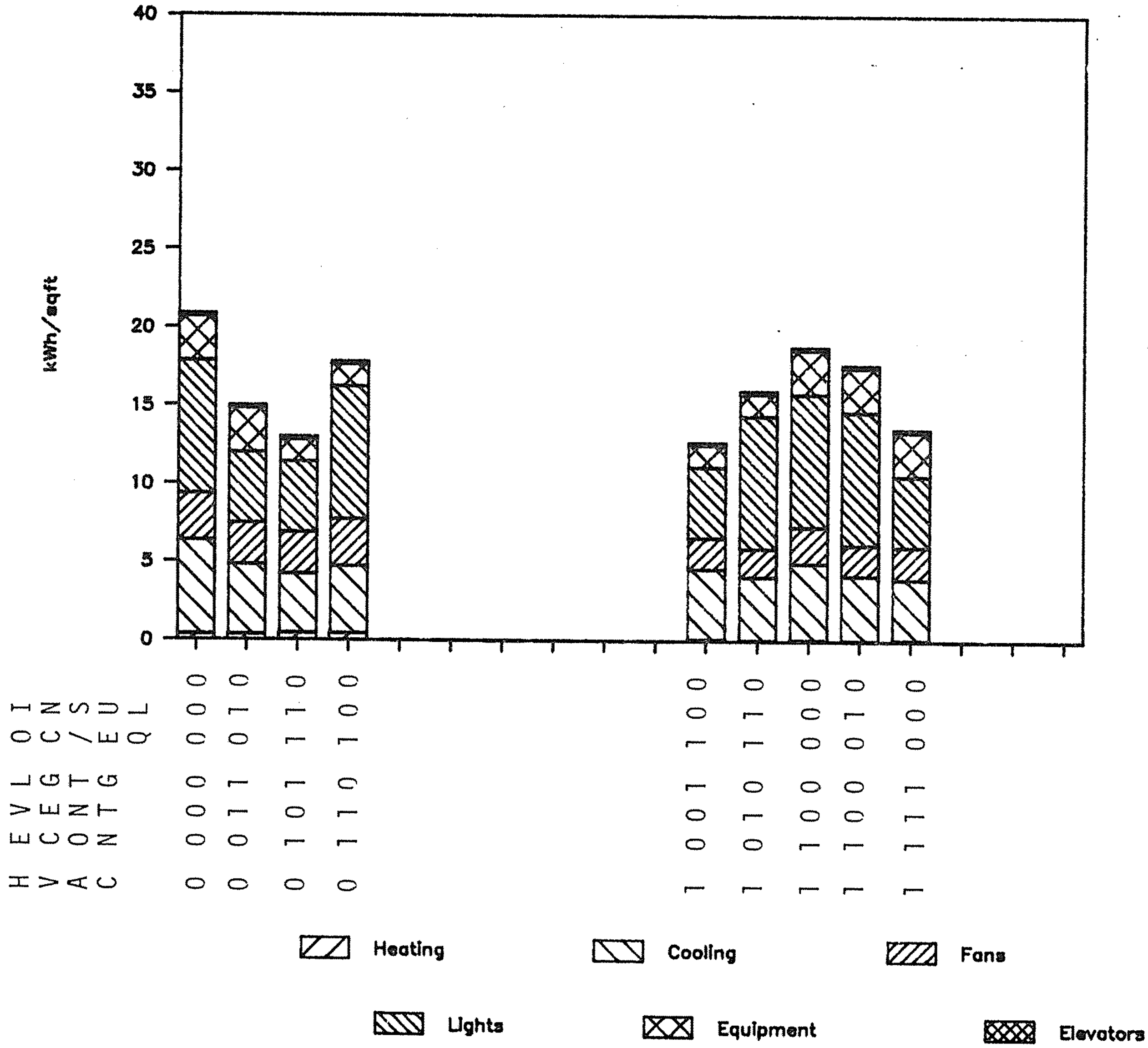

Fig. B.4(h). Annual electricity use, large building, Fort Worth.

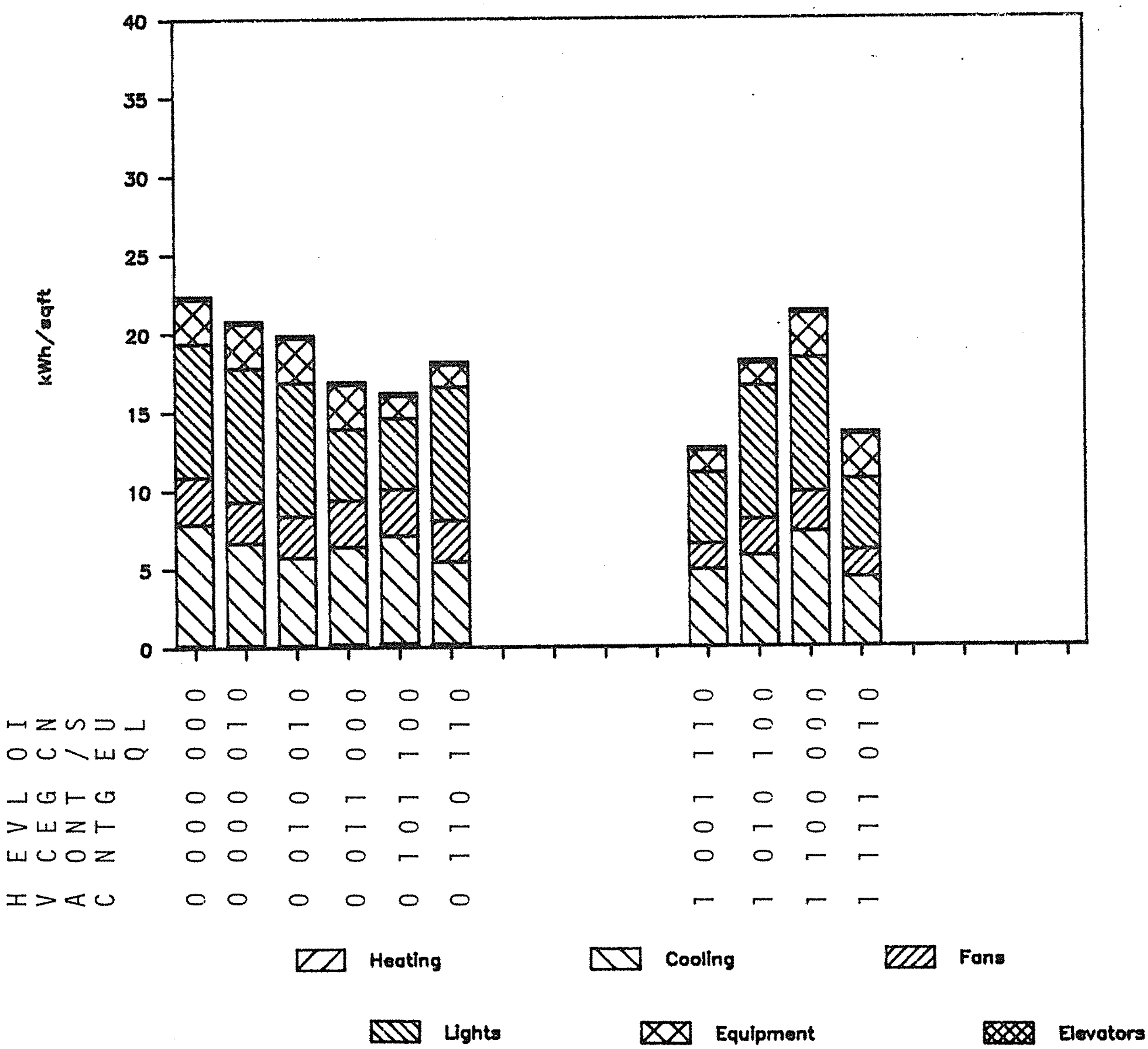

Fig. B.4(i). Annual electricity use, large building, Miami.

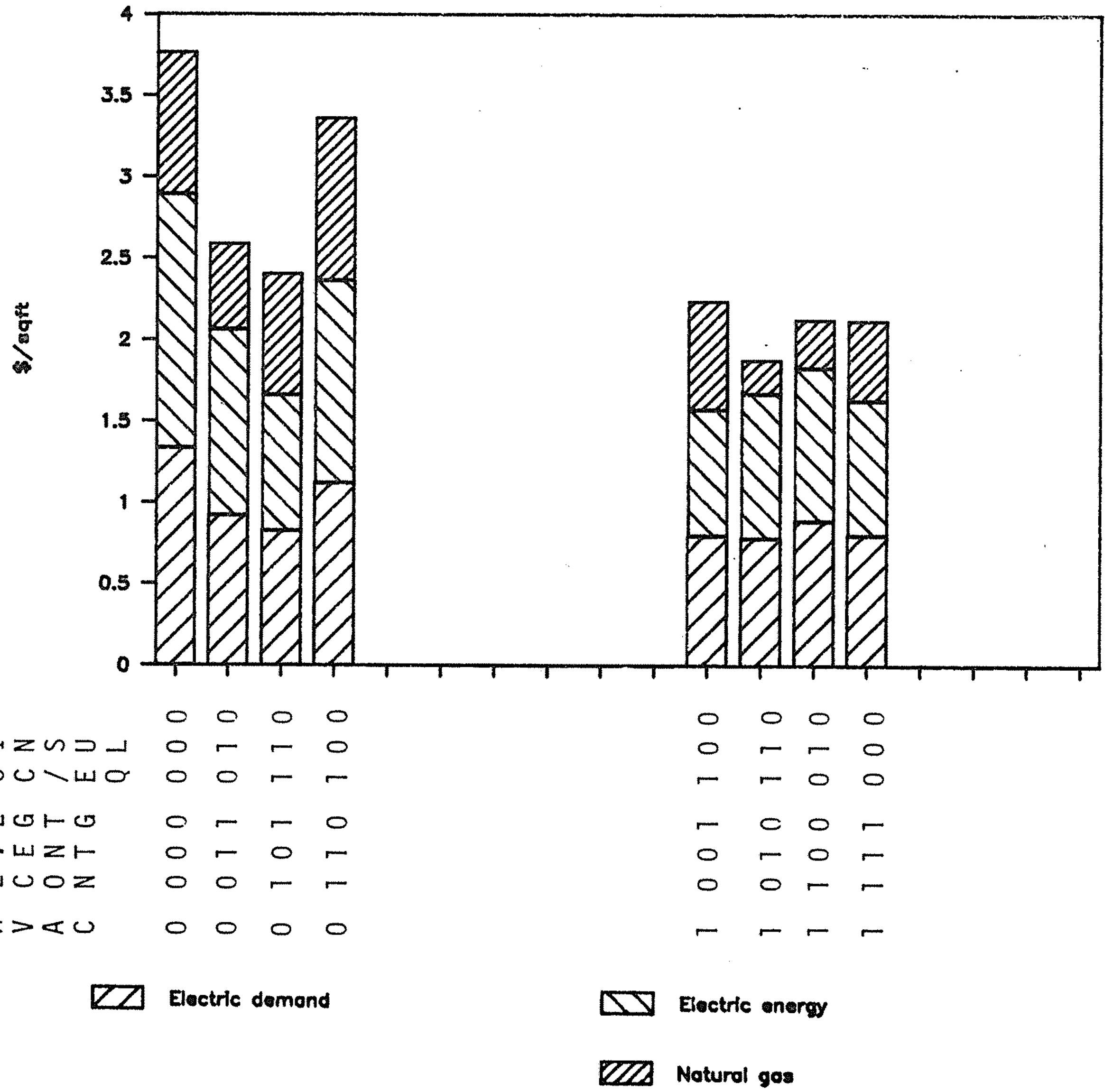

Fig. B.5(a). Annual energy costs, small building, Chicago.

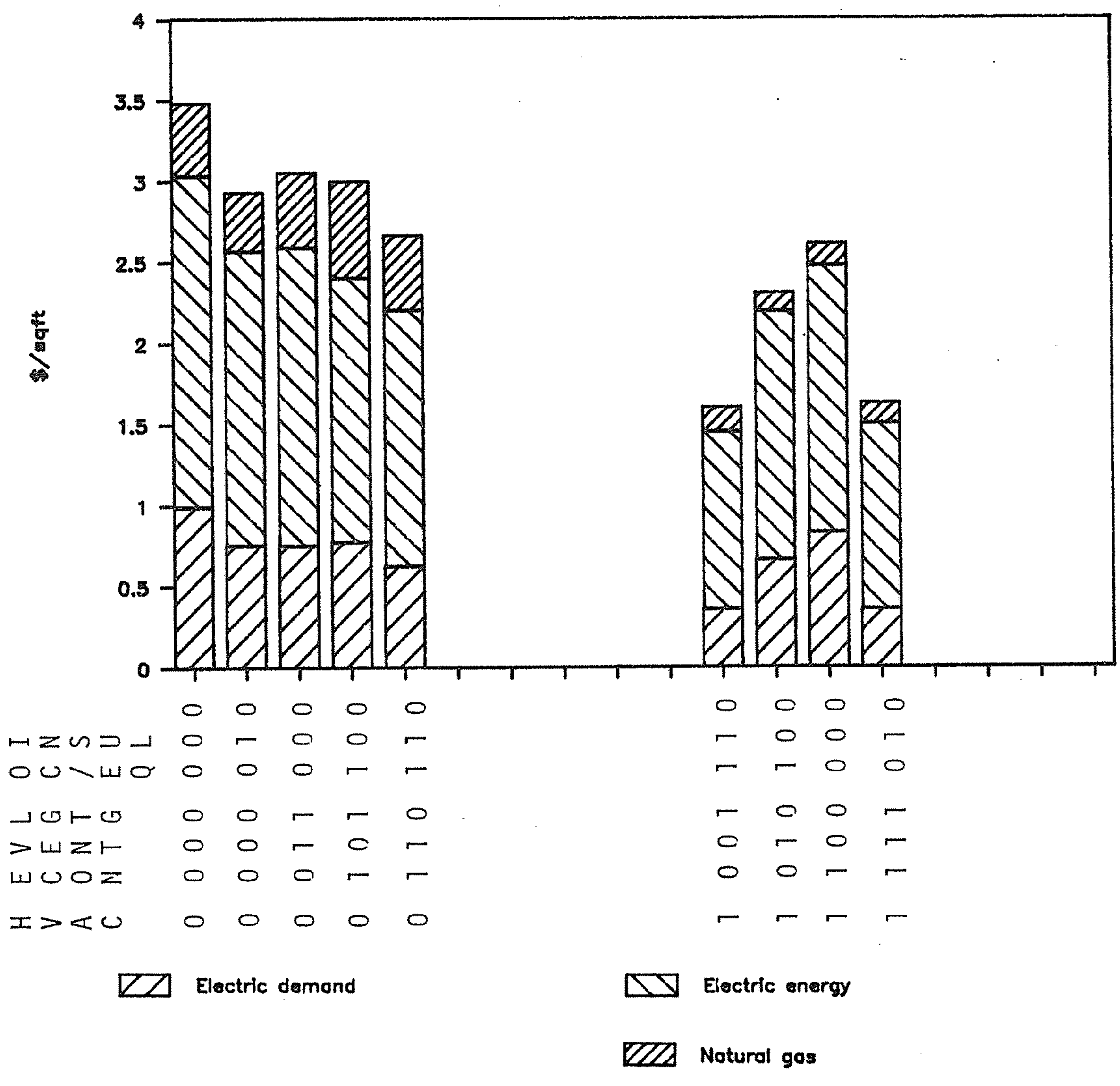

Fig. B.5(b). Annual energy costs, small building, Fort Worth.

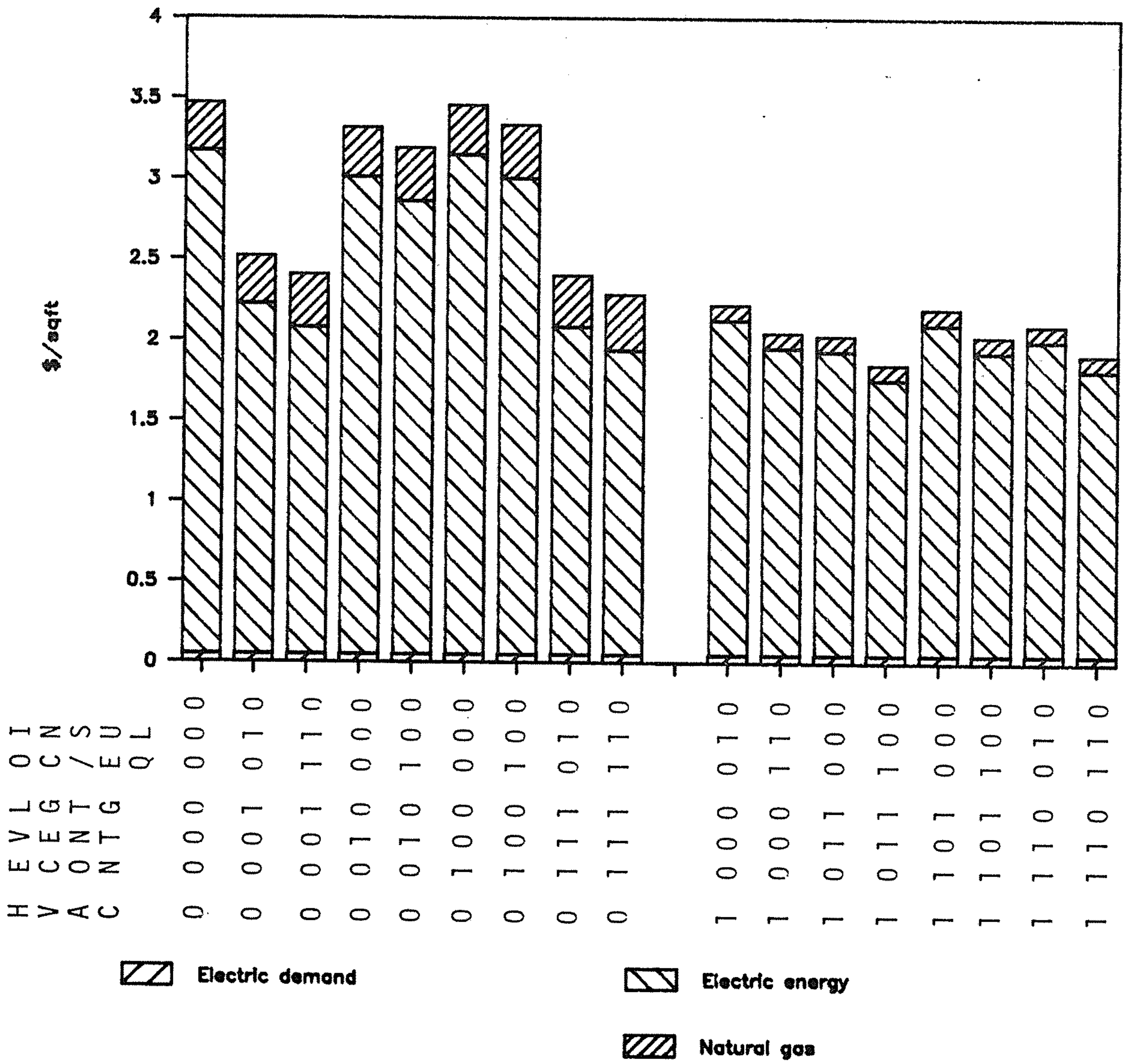

Fig. B.5(c). Annual energy costs, small building, Miami.

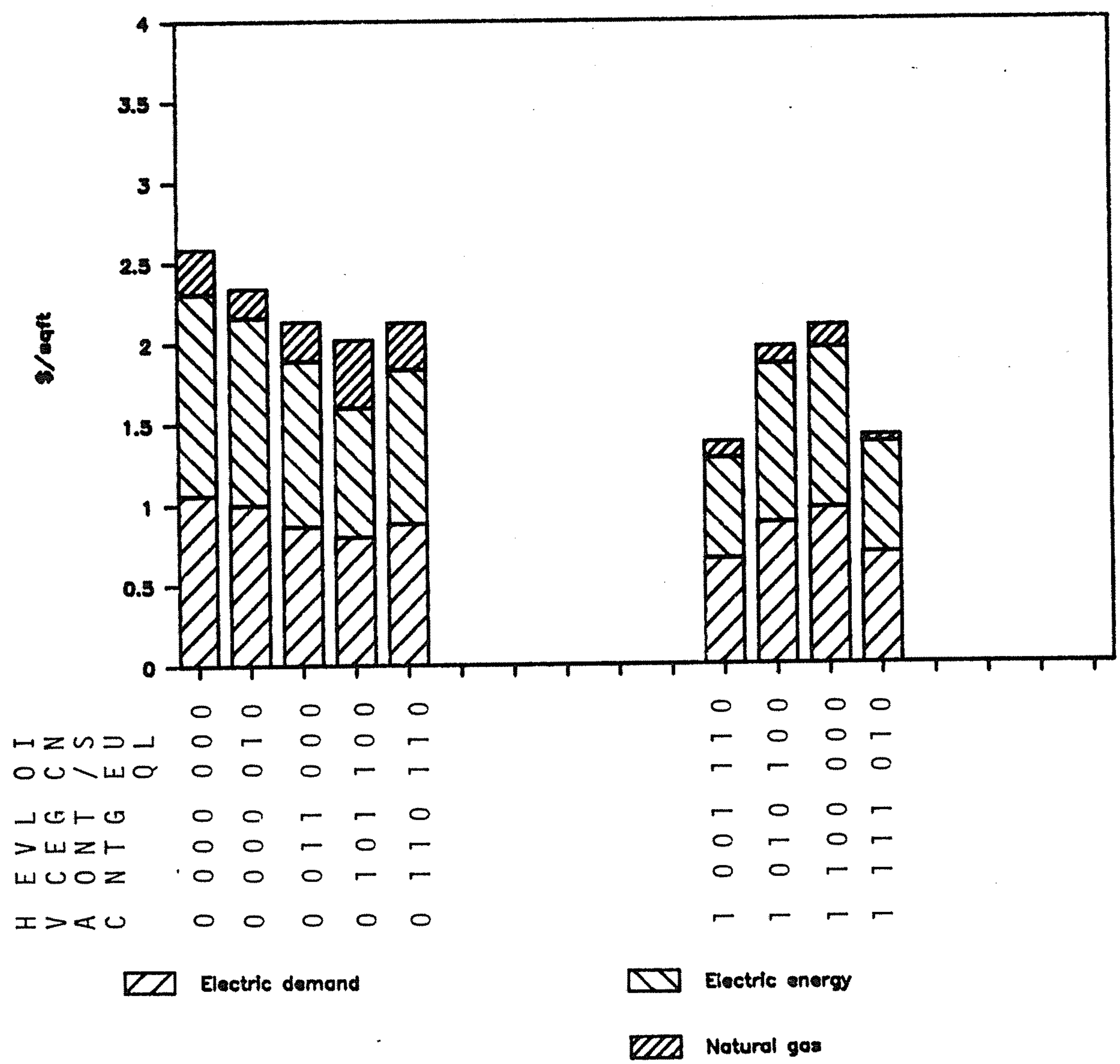

Fig. B.5(d). Annual energy costs, medium building, Chicago.

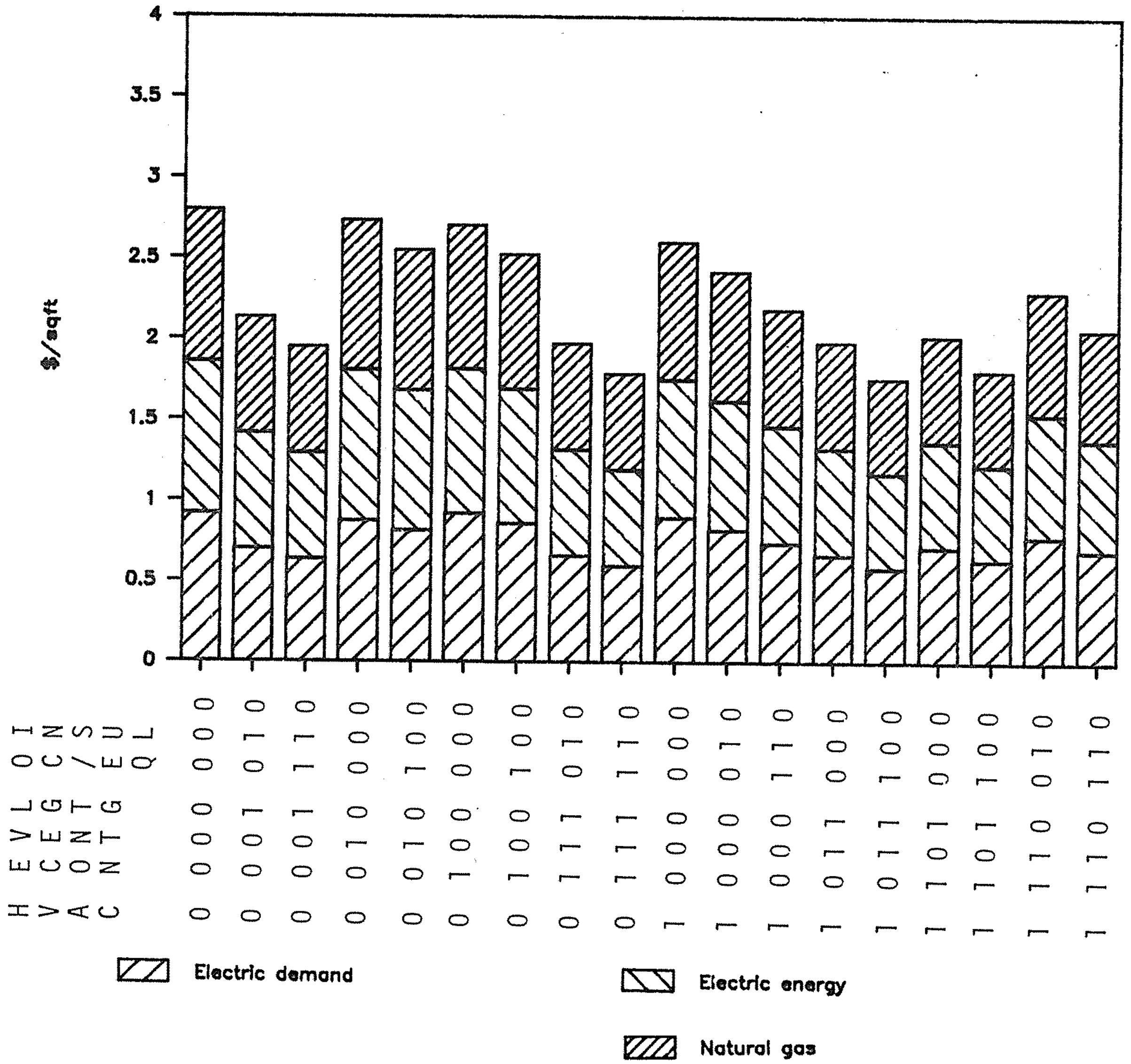

Fig. B.5(e). Annual energy costs, medium building, Fort Worth.

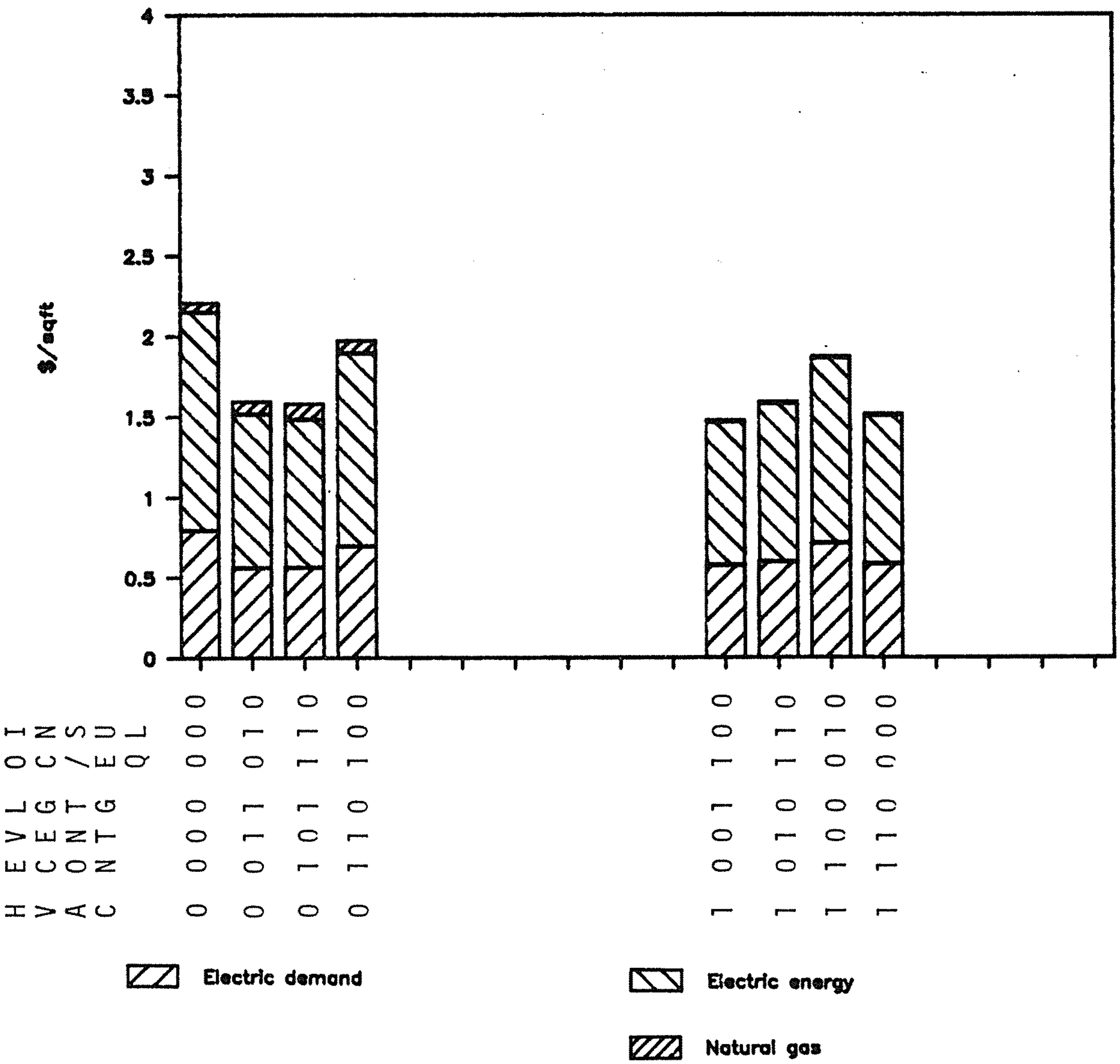

Fig. B.5(f). Annual energy costs, medium building, Miami.

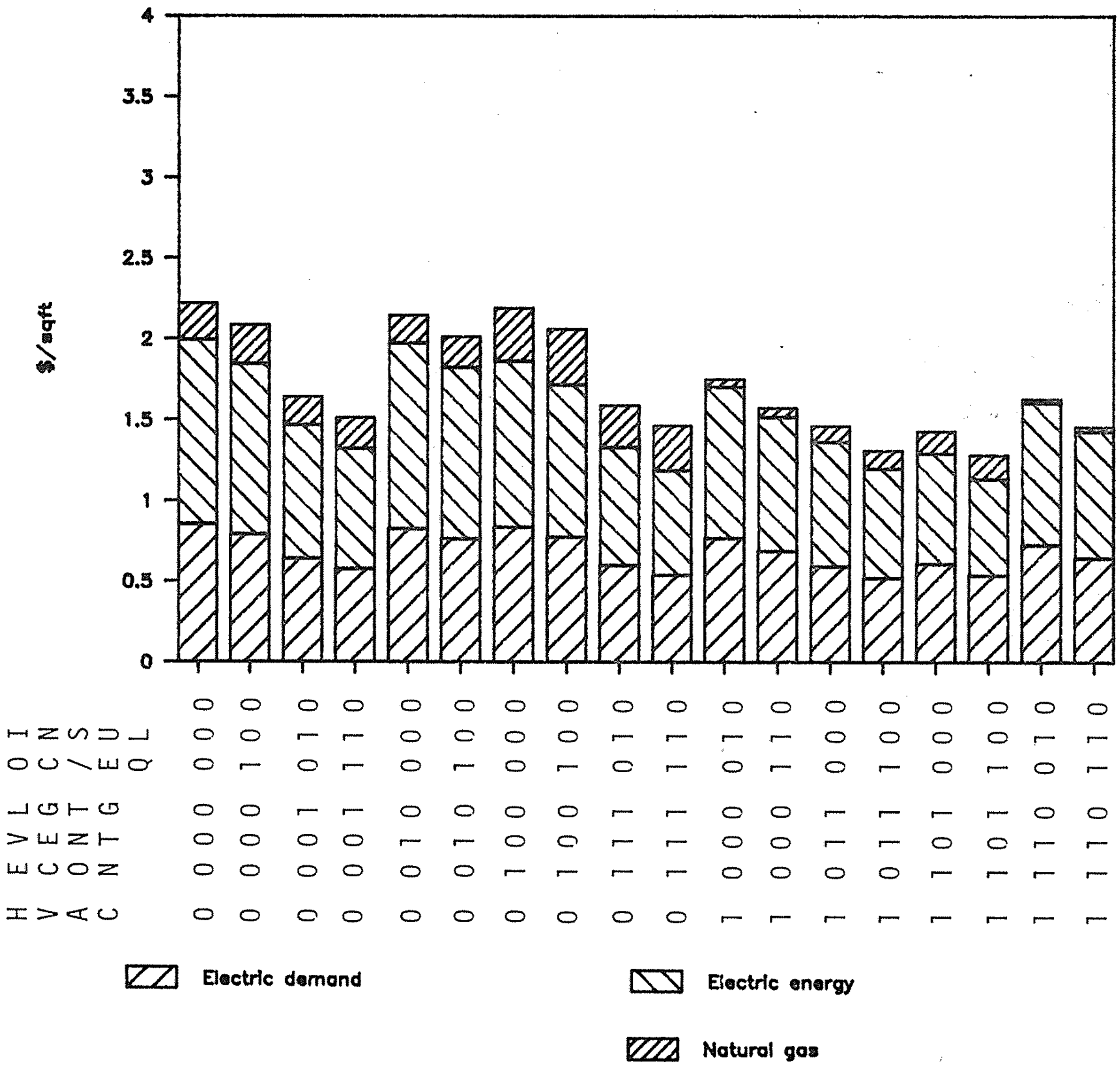

Fig. B.5(g). Annual energy costs, large building, Chicago.

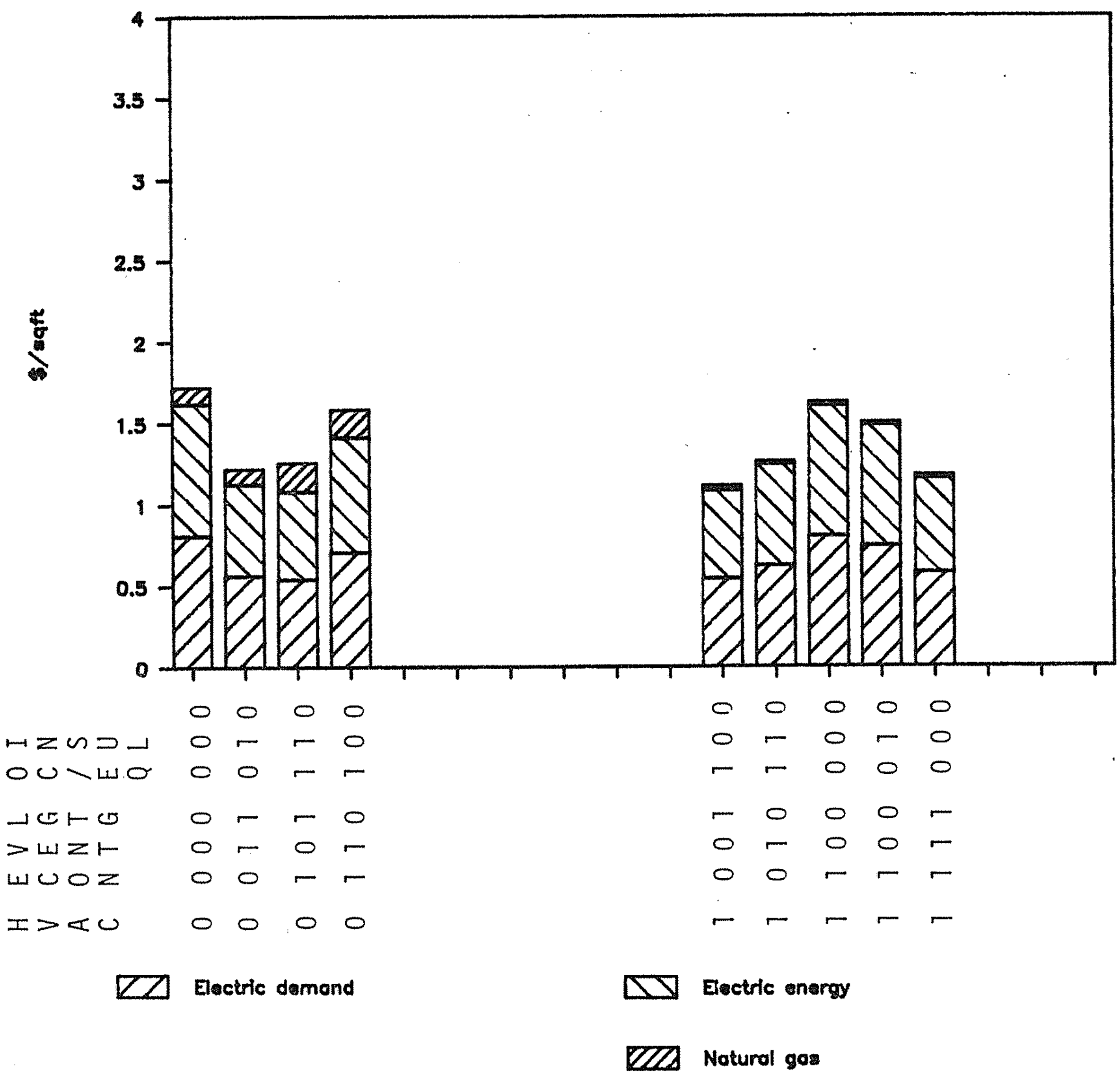

Fig. B.5(h). Annual energy costs, large building, Fort Worth.

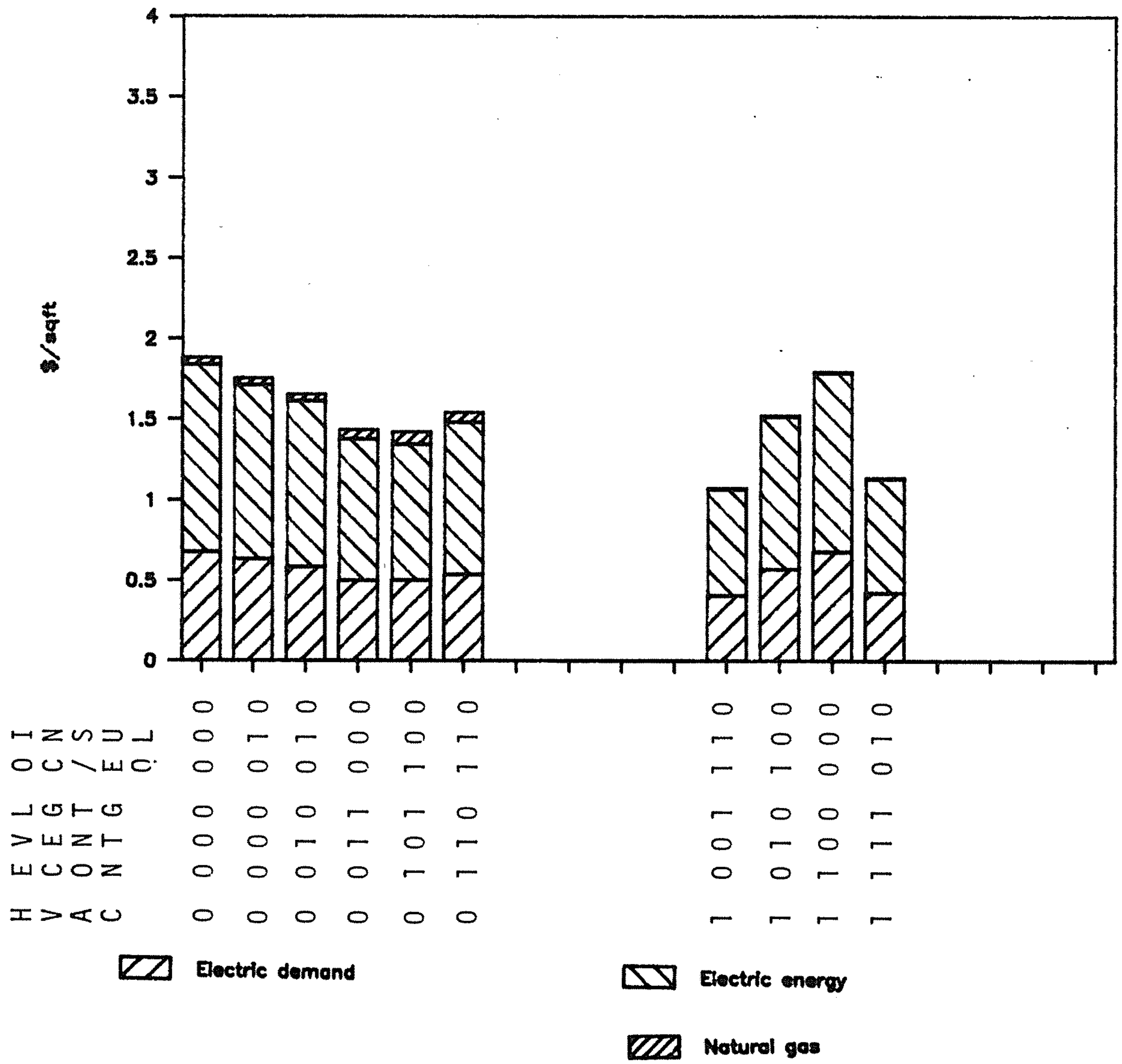

Fig. B.5(i). Annual energy costs, large building, Miami.

APPENDIX C

APPENDIX C

Fractional Factorial Design Analysis

C.1 Fractional Factorial Design

The fractional factorial design was used to study the impact of the eight independent parameters on the building loads. Two of the parameters, the building size and the building location could be set at three different levels. The remaining six parameters, the use of an economizer, minimum ventilation rate, lighting power, occupant density/equipment power, and building insulation/glazing type, could be set at two different levels.

A total of 96 runs was specified for this analysis. This is a one-sixth fraction of the $3^2 \times 2^6 = 576$ runs required for a full analysis examining all levels of the main effects and all levels of interactions. The specific buildings and parameters selected in this investigation are listed in Appendix B. These combinations of parameters were chosen from a collection of factorial designs developed by Conner and Young.[1] These designs were constructed so that all the main effects and two-factor interactions were confounded with higher order effects and not with each other. The term confounded (or confused) means that the estimate of main effect is really estimating the sum of the average value of the main effect and the average values of the higher order interaction values that are confounded with it. If these higher order effects are negligible, as assumed here, the estimate of the effect is close to the main value.

The fractional factorial design is an empirical model procedure limited to the range of parameters investigated. It further has the limitations assuming that the difference of the effects between two adjacent parameter levels is linear and the higher order interaction effects are negligible. Because of these assumptions, the design should be used with an understanding of the physical model to interpret the results correctly.

C.2 Estimate of the Main Effects

The ranking of the importance of the individual parameters on the building loads was estimated using the sum-of-squares-for-error drop procedure. In this procedure, the data are correlated using a linear combination of all the main parameters plus all the two input interaction terms. The sum of squares for error (SSE), defined as the sum of the squares of the residuals between the data and the regression, are then calculated. This procedure is then repeated for the same parameters and interactions except the parameter being evaluated plus its interaction terms. The sum of squares of the

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[1] W. S. Conner and S. Young, <u>Fractional Factorial Designs for Experiments with Factors at Two and Three Levels</u>, National Bureau of Standards, Applied Mathematics Series, 58, 1961.

residuals for the second regression is called the sum-of-squares-for-error for the reduced model (SSER). The difference between the two sums is called the sum-of-squares drop,

$$\text{SSDROP} = \text{SSER} - \text{SSE}.$$

For this investigation, the linear model has 54 terms. The first two parameters each have three levels, and each parameter needs two terms in the model to describe its effect. In general if a parameter has k levels, it would need (k-1) terms in the model to describe its effect. The combined effect of these (k-1) terms quantifies the combined effect of the parameters on the load. The 54 term model is made up of 10 terms to account for the main parameters (two terms for each three-level parameter and one term for each two-level parameter), 43 two-parameter interaction terms (four terms to account for the interactions between the two three-level parameters, 24 terms to account for the interactions between the three-level parameters and the two-level parameters, and 15 terms to account for the interactions between the two-level parameters), and one intercept term.

The effect of any parameter or two-parameter interaction is simply the contribution to the model of the set of terms that describe that parameter or its interaction. The impact of a parameter is estimated by calculating the changes in the fit of the model when the parameter is omitted. If the loads predicted by the linear model are not changed when omitting the parameter and its interactions, that parameter has no effect on the loads. If the parameter has no effect on the loads, the expected value of SSDROP is $\rho\sigma^2$, where ρ is the number of terms in the model and σ^2 is the error variance.

Because two of the parameters have three-level inputs, the SSDROP values must be adjusted or else the three level parameters might be considered to be more important. Since the expected value of SSDROP is $\rho\sigma^2$ when the parameter has no effect, a natural adjustment is to subtract $\rho\sigma^2$ from the SSDROP values, and then compare the adjusted SSDROP values. For the two-level parameters, $\rho = 10$, and for the three-level parameters, $\rho = 18$. The ranking of the direct impact of the parameters, together with the adjusted SSDROP values, are listed in Table C.1.

C.3 Estimate of the Main Effects and Two-Level Interactions

The ranking of the direct impacts of the parameters plus the two-parameter interactions were estimated by two simple, but effective, methods. These are (1) calculating the range of the mean load values across the levels of the parameter or interaction, and (2) calculating the standard deviation of the mean values across the levels of the parameter or interaction. Ranking of importance of the parameters and the two-parameter interactions on the building heating loads, together with the values for the mean range statistics and standard deviations, are listed in Table C.2. Table C.3 is the same listing for the building cooling loads. The two methods generally give the same ranking orders, although there are some minor differences.

Table C.1. Ranking of impact of individual parameters on building loads using sum of squares for error drop minus $\rho\sigma^2$.

Rank	Annual Heating Parameter	Annual Heating Value	Peak Heating Parameter	Peak Heating Value	Annual Cooling Parameter	Annual Cooling Value	Peak Cooling Parameter	Peak Cooling Value
1	Loc	24848.2	Size	18961.9	Loc	51719.5	Size	16898.8
2	Size	21029.1	HVAC	18319.5	Size	28689.6	Ins/Glaz	3035.5
3	HVAC	10406.4	Loc	7307.1	HVAC	9475.5	HVAC	1415.2
4	Ins/Glaz	3068.4	Ins/Glaz	1683.5	Ins/GLaz	4922.6	Vent	944.5
5	Econ	1418.4	Econ	1041.5	Vent	3399.9	Loc	743.8
6	Vent	718.6	Vent	551.5	Econ	2277.9	Lights	152.3
7	Occ/Eqp	159.4	Lights	44.8	Lights	672.9	Occ/Eqp	35.2
8	Lights	18.2	Occ/Eqt	-46.7	Occ/Eqp	261.4	Econ	10.4

Table C.2. Ranking of individual parameters and two-parameter interactions on the building heating loads, as determined by the values of the range of means and by the values of the standard deviations.

	Annual heating, kBtu/sq ft				Peak heating, Btu/hr/sq ft			
	Range of means		Std. deviation		Range of means		Std. deviation	
Rank	Term	Value	Term	Value	Term	Value	Term	Value
1	Size x Loc	67.94	Size x Loc	20.91	Size x HVAC	58.90	HVAC	22.94
2	Loc x HVAC	48.78	Loc x HVAC	17.68	Size x Loc	48.19	Size x HVAC	22.25
3	Size x HVAC	46.13	Size x HVAC	16.86	Loc x HVAC	45.45	HVAC x Econ	19.29
4	Loc x Ins/Glaz	34.21	HVAC	16.50	HVAC x Ins/Glaz	38.82	HVAC x Ins/Glaz	19.13
5	Loc x Econ	31.18	HVAC x Econ	14.33	HVAC x Vent	38.81	HVAC x Vent	19.09
6	Loc x Occ/Eqp	30.41	HVAC x Ins/Glaz	13.92	HVAC x Econ	38.20	HVAC x Occ/Eqp	18.88
7	HVAC x Econ	29.54	HVAC x Occ/Eqp	13.88	HVAC x Lights	35.96	HVAC x Lights	18.85
8	Loc x Vent	29.47	HVAC x Lights	13.65	HVAC x Occ/Eqp	35.49	Loc x HVAC	18.68
9	HVAC x Ins/Glaz	29.38	HVAC x Vent	13.58	HVAC	32.45	Size x Loc	15.65
10	HVAC x Occ/Eqp	27.88	Loc	13.23	Size x Ins/Glaz	29.36	Size	12.23
11	Loc x Lights	27.55	Loc x Ins/Glaz	12.95	Size x Vent	28.58	Size x Ins/Glaz	11.70
12	Size x Ins/Glaz	26.58	Loc x Econ	12.40	Size x Econ	27.70	Size x Vent	11.51
13	HVAC x Lights	26.39	Loc x Occ/Eqp	12.17	Size x Occ/Eqp	24.87	Size x Econ	11.40
14	HVAC x Vent	26.15	Loc x Vent	12.06	Size x Lights	23.26	Size x Occ/Eqp	11.07
15	Loc	25.79	Loc x Lights	11.91	Lights x Ins/Glaz	22.06	Size x Lights	10.98
16	Size x Occ/Eqp	24.76	Size	10.97	Size	21.55	Econ x Occ/Eqp	10.17
17	Size x Econ	24.64	Size x Ins/Glaz	10.60	Loc x Ins/Glaz	20.16	Lights x Ins/Glaz	9.79
18	HVAC	23.34	Size x Econ	10.31	Loc x Vent	18.92	Loc x Ins/Glaz	6.89
19	Size x Vent	22.29	Size x Occ/Eqp	10.17	Loc x Econ	18.53	Loc x Vent	6.89
20	Size x Lights	21.60	Size x Vent	9.94	Loc x Occ/Eqp	15.71	Loc x Econ	6.53
21	Size	19.38	Size x Lights	9.88	Loc x Lights	14.16	Loc	6.35
22	Econ x Occ/Eqp	18.27	Econ x Occ/Eqp	8.37	Econ x Occ/Eqp	13.32	Loc x Occ/Eqp	5.92
23	Lights x Ins/Glaz	16.82	Lights x Ins/Glaz	7.25	Vent x Ins/Glaz	12.73	Loc x Lights	5.75
24	Occ/Eq x Ins/Glaz	16.58	Econ x Ins/Glaz	4.82	Loc	12.59	Vent x Ins/Glaz	5.50
25	Econ x Ins/Glaz	11.79	Occ/Eq x Ins/Glaz	4.37	Econ x Ins/Glaz	12.12	Econ x Ins/Glaz	5.20
26	Vent x Ins/Glaz	9.03	Ins/Glaz	4.27	Econ x Vent	12.12	Econ x Vent	4.97
27	Econ x Vent	8.56	Vent x Ins/Glaz	4.22	Occ/Eq x Ins/Glaz	9.42	Ins/Glaz	4.50
28	Econ x Lights	7.95	Econ	4.07	Vent x Occ/Eqp	9.42	Vent	4.50
29	Vent x Occ/Eqp	7.35	Econ x Vent	3.72	Vent x Lights	7.21	Occ/Eq x Ins/Glaz	4.08
30	Lights x Occ/Eqp	6.73	Econ x Lights	3.57	Econ x Lights	6.60	Vent x Occ/Eqp	4.08
31	Ins/Glaz	6.04	Occ x Eqp	3.21	Lights x Occ/Eqp	6.52	Econ	4.07
32	Econ	5.75	Vent x Occ/Eqp	3.17	Ins/Glaz	6.37	Vent x Lights	3.71
33	Vent x Lights	5.00	Lights x Occ/Eqp	3.13	Vent	6.37	Econ x Lights	3.36
34	Occ/Eqp	4.54	Vent x Lights	2.20	Econ	5.75	Lights x Occ/Eqp	2.72
35	Vent	2.81	Vent	1.99	Occ/Eqp	2.16	Occ/Eqp	2.16
36	Lights	2.19	Lights	1.55	Lights	0.85	Lights	0.60

Table C.3. Ranking of individual parameters and two-parameter interactions on the building cooling loads, as determined by the values of the range of means and by the values of the standard deviations.

	Annual cooling, kBtu/sq ft				Peak cooling, Btu/hr/sq ft			
	Range of means		Std. deviation		Range of means		Std. deviation	
Rank	Term	Value	Term	Value	Term	Value	Term	Value
1	Size x Loc	89.77	Loc	31.31	Size x Ins/Glaz	42.52	Size	16.29
2	Loc x HVAC	84.46	Loc x HVAC	30.46	Size x HVAC	37.48	Size x Ins/Glaz	16.24
3	Loc x Ins/Glaz	79.65	Loc x Ins/Glaz	29.83	Size x Vent	37.47	Size x HVAC	15.27
4	Loc x Vent	73.75	Loc x Vent	29.01	Size x Loc	34.72	Size x Vent	15.19
5	Loc x Lights	70.92	Loc x Econ	28.64	Size x Lights	32.42	Size x Lights	14.65
6	Loc x Econ	70.39	Size x Loc	28.58	Size x Occ/Eqp	30.92	Size x Occ/Eqp	14.60
7	Size x Econ	70.13	Loc x Lights	28.52	Size x Econ	29.74	Size x Econ	14.57
8	Loc x Occ/Eqp	69.16	Loc x Occ/Eqp	28.42	Size	29.41	Size x Loc	14.11
9	Size x Ins/Glaz	64.45	Size x HVAC	25.77	Loc x Ins/Glaz	23.56	Loc x Ins/Glaz	8.29
10	Loc	62.65	Size	24.71	Loc x Vent	20.36	Ins/Glaz	7.73
11	Size x Vent	55.39	Size x Ins/Glaz	24.29	Loc x HVAC	19.65	Vent x Ins/Glaz	7.71
12	Size x Lights	53.23	Size x Vent	22.77	Vent x Ins/Glaz	18.60	HVAC x Ins/Glaz	7.41
13	Size x Occ/Eqp	52.80	Size x Lights	22.47	HVAC x Ins/Glaz	17.41	Loc x Vent	7.04
14	Size x Econ	52.51	Size x Econ	22.43	HVAC x Vent	14.14	Lights x Ins/Glaz	6.75
15	Size	45.68	Size x Occ/Eqp	22.43	Lights x Ins/Glaz	14.03	Loc x HVAC	6.66
16	HVAC x Ins/Glaz	36.25	HVAC x Ins/Glaz	15.20	Loc x Occ/Eqp	13.96	Econ x Ins/Glaz	6.64
17	HVAC x Vent	28.92	HVAC	14.42	Econ x Vent	13.41	Occ/Eq x Ins/Glaz	6.38
18	HVAC x Lights	27.77	HVAC x Lights	13.22	Loc x Econ	12.89	Loc	6.27
19	HVAC x Econ	27.20	HVAC x Econ	12.93	Loc	12.52	HVAC x Vent	5.98
20	HVAC x Occ/Eqp	26.97	HVAC x Vent	12.77	Occ/Eq x Ins/Glaz	12.51	Loc x Lights	5.83
21	Lights x Ins/Glaz	26.43	HVAC x Occ/Eqp	12.52	Loc x Lights	12.45	Loc x Occ/Eqp	5.68
22	Vent x Ins/Glaz	24.38	Lights x Ins/Glaz	11.80	Econ x Ins/Glaz	11.46	Loc x Econ	5.62
23	Econ x Ins/Glaz	22.67	Ins/Glaz	11.21	Ins/Glaz	10.93	Econ x Vent	5.54
24	Occ/Eq x Ins/Gaz	22.43	Vent x Ins/Glaz	10.50	HVAC x Lights	10.45	Vent	5.42
25	HVAC	20.39	Econ x Ins/Glaz	10.33	Vent x Lights	10.44	Vent x Lights	4.71
26	Econ x Vent	19.96	Occ/Eq x Ins/Gaz	9.91	Vent x Occ/Eqp	9.23	HVAC x Lights	4.67
27	Econ x Occ/Eqp	16.47	Econ x Vent	9.13	HVAC x Occ/Eqp	8.05	HVAC	4.58
28	Vent x Lights	15.91	Econ x Occ/Eqp	7.81	Vent	7.66	Vent x Occ/Eqp	4.57
29	Ins/Glaz	15.86	Vent x Lights	6.69	HVAC x Econ	7.63	HVAC x Occ/Eqp	3.90
30	Vent x Occ/Eqp	15.10	Vent x Occ/Eqp	6.43	Lights x Occ/Eqp	6.89	HVAC x Econ	3.81
31	Econ x Lights	14.17	Lights x Occ/Eqp	6.16	HVAC	6.48	Lights x Occ/Eqp	3.00
32	Lights x Occ/Eqp	13.95	Vent	6.03	Econ x Occ/Eqp	4.93	Econ x Occ/Eqp	2.16
33	Vent	8.53	Econ x Lights	5.80	Econ x Lights	3.30	Lights	1.96
34	Lights	7.37	Lights	5.22	Lights	2.77	Econ x Lights	1.63
35	Econ	6.81	Econ	4.81	Occ/Eqp	1.57	Occ/Eqp	1.11
36	Occ/Eqp	6.58	Occ/Eqp	4.65	Econ	0.52	Econ	0.37

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