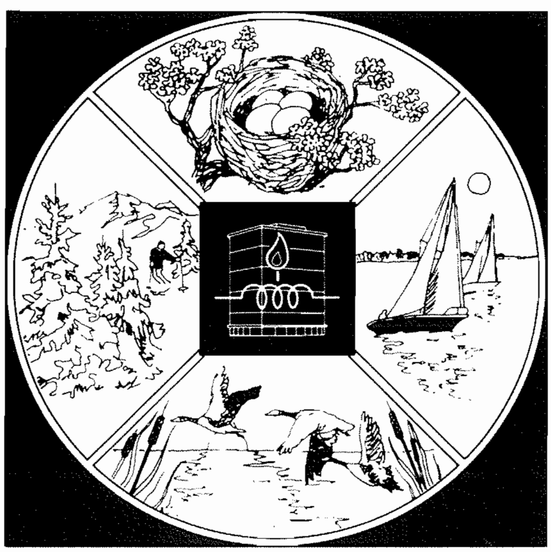
CHICAGO RESIDENTIAL ENERGY CONSUMPTION

Final Report
September 1976

Department of Housing and Urban Development

Office of the Assistant Secretary for Policy Development and Research



ENERGY CONSERVATION

CHICAGO RESIDENTIAL ENERGY CONSUMPTION

HIT-650-3

FINAL REPORT

September 1976

Contract No. H-2280R

Office of the Assistant Secretary
for
Policy Development & Research
Department of
Housing and Urban Development

HITTMAN ASSOCIATES, INC.
COLUMBIA, MARYLAND 21045

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock No. 023-000-00424-1

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States Government, nor any of its employees, nor any of its contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights.

ACKNOWLEDGEMENTS

This program was sponsored by the U.S. Department of Housing and Urban Development, with partial support from the U.S. Environmental Protection Agency. The suggestions, support, and guidance of Kenneth Credle and David Rosoff, Government Technical Representatives, are acknowledged with sincere thanks.

Thanks go also to members of the Hittman Associates, Inc., staff who contributed their ideas and efforts to the conduct of this work. Special mention must go to Barry K. Hinkle, Patrick M. McCarthy, and Kenneth R. Hall, who assisted in the characterization of residences and the preparation of computer input data; to Michael C. Miller and Kamran Bahrami, who contributed to the analysis of computer results; to James E. Reed and James E. Barber, who assisted in planning and writing the text; and Barbara White, for her assistance in preparing the manuscript.

The assistance of Housing Industry Dynamics, Inc., in providing survey data used in characterizing the low-rise residential structure is gratefully acknowledged. Finally, we wish to thank Arthur C. Johnson, of the National Association of Home Builders Research Foundation, Inc., for his review of the residential structure characterizations.

Harvey M. Bernstein
Taghi Alereza

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (CONTINUED)

I. INTRODUCTION

This report on residential energy consumption in Chicago, Illinois, is part of a continuing program devoted to the analysis of residential energy consumption in the United States. In initiating this research program in 1971, the U.S. Department of Housing and Urban Development (HUD) gave to the contractor, Hittman Associates, Inc., (HAI) the task of *"...identifying means for obtaining greater efficiencies in the utilization of energy in residences, in order to obtain lower per capita consumption without modification of existing life-styles."* Subsequent reports were published which dealt with the consumption and efficient use of energy in Baltimore/Washington area residences.*

In 1975, HAI was retained by HUD to perform detailed geographical analyses *"...to extend the previous results obtained for the Baltimore/Washington area to ten geographical locations in the United States."* The locations selected for these analyses were the following:

Atlanta, Georgia

Boston, Massachusetts

Chicago, Illinois

Denver, Colorado

Houston, Texas

Los Angeles, California

Miami, Florida

Minneapolis, Minnesota

San Francisco, California

St. Louis, Missouri

The boundaries for each geographical area were defined in accordance with the Federal Government's definition of standard metropolitan statistical areas (SMSA's). An SMSA

**See "Residential Energy Conservation (A Summary Report)," HUD-HAI-8, July 1974, and seven technical reports cited there.*

includes one central city and one or more contiguous counties that are metropolitan in character, as determined by the percentage of the labor force that is nonagricultural and by the amount of commuting between the county and the city. For each of these locations, it was sought (1) to identify and quantify the total heating and cooling energy requirements in typical single-family detached, single-family attached, low-rise multifamily, and high-rise multifamily dwellings; and (2) to evaluate the use of various technical innovations potentially capable of minimizing energy consumption in typical dwellings.

In conducting each of these city-specific studies, the following multi-step approach was taken:

> Identify the current trends in construction and design and the energy consumption patterns of residences in the area.
>
> Define characteristic single-family, townhouse, low-rise, and high-rise structures representing typical new structures in the area.
>
> Calculate the hourly, monthly, and annual energy requirements for heating and cooling each characteristic structure for the chosen weather year (a year selected after careful scrutiny to be typical for the location).
>
> Define improved single-family, townhouse, low-rise, and high-rise structures incorporating energy conserving modifications.
>
> Calculate the hourly, monthly, and annual energy requirements for heating and cooling the improved residences for the chosen weather year, and compare the results with those of the corresponding (unmodified) characteristic residences.

This report on energy consumption in Chicago is the third of ten city-specific reports to be issued in the detailed geographical analysis series. In addition to the summary and statement of conclusions to follow, the report includes chapters on the characterization of typical Chicago residences, on the computation of heating and cooling energy requirements in the typical residences, and on the energy consumption of thermally "improved" Chicago residences.

The most basic location-specific factor in determining heating and cooling energy consumption is climate. Chicago is in a region of frequently changeable weather. The climate is predominantly continental, ranging from relatively warm in summer to relatively cold in winter. However, the continentality is partially modified by Lake Michigan, and to a lesser extent by other Great Lakes. In late autumn and winter, airmasses that are initially very cold often reach the City only after being tempered by passage over one or more of the lakes. Similarly, in late spring and summer, airmasses reaching the City from the north, northeast, or east are cooler because of movement over the Great Lakes. Very low winter temperatures most often occur in air that flows southward to the west of Lake Superior before reaching the Chicago area. In summer the higher temperatures are with south or southwest flow and are therefore not influenced by the lakes, the only modifying effect being a local lake breeze. Strong south or southwest flow may overcome the lake breeze and cause high temperatures to extend over the entire City.

The Chicago weather year is characterized by 6127 heating degree days (base 65°F) and 925 cooling degree days (base 65°F). The yearly mean wind, velocity is 10.3 mph, with a fastest recorded wind velocity of 60 mph, in November 1952. There are normally 94 clear days, 102 partly cloudy days, and 169 cloudy days per year in Chicago (Ref. 1). Residential construction trends, discussed in Chapter III, have been influenced historically by the structural and thermal demands imposed by this climatic environment. Other factors, such as fuel and electricity prices, local income levels, and the ethnic backgrounds represented in Chicago's population have also influenced construction practices, and, therefore, heating and cooling energy consumption.

II. SUMMARY AND CONCLUSIONS

Heating and cooling energy requirements were determined by a time-response, multizone computer program for characteristic single-family, townhouse, low-rise, and high-rise residences in Chicago. Based on national weather records kept since 1935, 1951 was picked as being a typical weather year for the Chicago area. Heating and cooling energy requirements were determined similarly for modified versions of these Chicago characteristic residences, incorporating various structural and systems improvements.

To identify the current trends in housing in the Chicago area, a large data base was developed from information obtained from national and municipal government agencies and local builders. Using these data, parameters were identified for the design, construction, internal loads, and comfort control systems for the following characteristic structures:

Single-family: A two-story, four bedroom detached building.

Townhouse: A two-story structure containing eight three bedroom apartments in a row.

Low-Rise: A three-story building with 12 one bedroom, and 12 two bedroom units.

High-Rise: A 15-story building with 95 one bedroom and 95 two bedroom units.

In defining these parameters, good quality materials, components, and workmanship were assumed consistent with current practice and standards. The residences are typical of those occupied by middle-income residents, and, therefore, the kinds and use-rate of appliances and life-style patterns were assumed accordingly. The "modified" residences of each type were defined to incorporate structural and HVAC system improvements practical from a builder's or architect's viewpoint. That is, no radical changes were made; e.g., flue gas heat recovery units were added to gas furnaces and only commercially available insulation material was added to the structure.

The energy requirements for the Chicago residences were calculated for the 1951 weather year using a two-step process. In the first step, the hourly heating and cooling loads were calculated for each dwelling unit. Calculations were made using a computer program whose inputs included design and materials of the structure, building surroundings, internal thermal loads (lights, appliances, and occupants), hourly weather data, and pertinent astronomy of the sun. Included in this program was the calculation of heating and cooling loads (both sensible and latent) due to the infiltration of outside air. In the second step, the monthly and annual energy required to meet the heating and cooling loads were calculated using specific heating, cooling, and ventilation systems. The inputs to these calculations included the heating and cooling load data, equipment performance and energy requirements at full and partial loads, and the type of energy required. The computer model used was the existing Buildings Energy Analysis Model (BEAM) developed at Hittman Associates, Inc.

Hourly load calculations were performed for both heating and cooling, in each space-conditioned "zone" of the four types of residences, over each day of the 1951 Chicago weather year. This approach to the development of annual loads and primary energy consumption produced data for Chicago residences equivalent to some 54,000 different one-day, one-zone load profiles.

A summary of the calculated average annual heating and cooling loads, and primary energy consumption for dwelling units of each type considered, are shown in Table I. Heating loads were much greater than cooling loads in every residence except the low-rise, which had a larger cooling load. This was due to lack of ventilation (present in the high-rise) and a large amount of internal heat generation (characteristic of multifamily apartment buildings) in the low-rise structure.

The energy conserving modifications made for the single-family, townhouse, low-rise, and high-rise structures are summarized in Table II. Both structural and comfort control system modifications were made. The following paragraphs discuss the energy savings realized in each type of residence.

The improved single-family residence required significantly less in-structure and primary energy than the characteristic residence. Structural modifications including added weatherstripping and insulation resulted in a major heating load reduction and a small cooling load increase, the net change being a large total annual load reduction. As shown in Table I, the improved single-family residence consumed 48 percent less primary energy than the characteristic building (the largest reduction of any residence studied), resulting in a floor area-normalized energy requirement of 0.54 therm/sq ft.

Primary energy savings in the improved townhouse was 43 percent. The townhouse consumed less energy as a result of both heating and cooling load reductions, as well as an improved comfort control system. The floor area-normalized energy requirement was 0.38 therm/sq ft.

The improved low-rise consumed 41 percent less primary energy than the characteristic structure. This is a very impressive savings considering the fact that the characteristic low-rise was by far the most efficient structure analyzed, with a per unit energy consumption of less than half that of any other residence. The improved low-rise, through added insulation and more efficient heating and cooling systems, had a floor area-normalized primary energy consumption of 0.27 therm/sq ft, the lowest of all residences.

The improved high-rise exhibited the smallest primary energy savings, a modest 38 percent. However, on a per unit basis, the structure was significantly more efficient than the single-family residence. There are two limiting factors in attempting to achieve a small floor area-normalized energy requirement in high-rise buildings: (1) building codes require large amounts of forced ventilation and (2) present architectural designs demand large amounts of floor area to be used for halls, stairwells, and lobbies. As a result, the improved high-rise had a floor area-normalized primary energy requirement of 0.52 therm/sq ft, nearly that of the single-family residence.

TABLE I. SUMMARY OF ANNUAL HEATING AND COOLING LOADS AND PRIMARY ENERGY REQUIREMENTS FOR THE CHICAGO CHARACTERISTIC AND IMPROVED RESIDENCES

	Single-Family		Townhouse		Low-Rise		High-Rise	
	Characteristic	Improved	Characteristic	Improved	Characteristic	Improved	Characteristic	Improved
Heating load per average unit, therms	998.8	554.2	392.5	263.2	115.8	80.0	295.9	183.8
Cooling load per average unit, therms	178.0	218.3	176.6	164.7	144.7	145.8	185.0	178.5
Primary energy consumption per average unit, therms*	1755.8	918.4 (48)	871.7	499.6 (43)	388.5	229.1 (41)	949.2	584.0 (38)
Primary energy consumption per sq ft of floor area, therms	1.03	0.54	0.66	0.38	0.46	0.27	1.09	0.52

*Percent reduction in primary energy consumption per average dwelling unit is given in parentheses. Number in parentheses for each residence type is found with the relationship:

$$\text{Percent reduction} = \frac{(\text{Energy consumption, characteristic})-(\text{energy consumption, modified})}{\text{Energy consumption, characteristic}} \times 100.$$

**Floor area includes halls, lobbies, and stairwells in high-rise buildings.

TABLE II. ENERGY CONSERVATION MODIFICATIONS FOR CHARACTERISTIC CHICAGO RESIDENCES

	Glass[1] Reduction in North Face (%)	Glass[1] Reduction in South Face (%)	Addition of Weather Stripping	Revised Wall Insulation R Value	Revised Ceiling Insulation R Value	Revised Floor U Value	Improved Gas/Oil Furnace Efficiency	Use of Heat Recovery System	Improved Cooling System C.O.P.
Single-Family	44		*	17	27	0.8	*	*	*
Town-house	50	9	*	17	27	0.1 Exists	*	*	*
Low-Rise	See Note 1		*	17	27	0.1 Exists	*	*	*
High-Rise	See Note 1		*	12	17	0.1 Exists	*	*	*

[1] *Total glass reduction for all buildings equals 25 percent.*

* *Change made in Characteristic Residence.*

III. CHARACTERIZATION OF TYPICAL RESIDENTIAL STRUCTURES IN CHICAGO

Typical, or characteristic, new residential buildings for the Chicago area were synthesized following the methodology of previous HAI Residential Energy Consumption studies for the U.S. Department of Housing and Urban Development. Four such typical residences were developed, including a single-family (detached) house, a townhouse, a low-rise apartment building, and a high-rise apartment building.

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

Structural parameters such as construction details, dimensions, and materials used.

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

Whereas specific life-styles were not prescribed for the residents of the characteristic residences, a certain number of life-style parameters were imposed, by necessity, for the analyses. Examples of life-style parameters that were identified include:

Thermostat set points

Relative humidity set points

Type and number of appliances

Daily profile of appliance usage

Usage of ventilation fans

Most of these parameters were defined for average conditions; no attempt was made to modify the parameters to allow for variations caused by weekends or holidays, vacations, entertaining of large groups, difference in age or affluence of the residents, etc. Occupancy loads were, however, adjusted for weekends. In consideration of the sizes and quality of the characteristic residences, and of the appliances included in these residences, it can be assumed that the residences would be occupied by individuals or families in the middle income group. It should also be recognized that the life-style of any given resident (in a real case) could vary greatly from the average conditions defined for these analyses, and that variations in occupant life-style can affect the buildings' energy consumption in a non-negligible way.

With respect to ventilation air, the single-family, townhouse, and low-rise apartment structures were defined as having no mechanical ventilation equipment, whereas the high-rise apartment structure had ventilation air supplied to, and only to, the halls. The normal rate of air infiltration through the structures, augmented by kitchen and bathroom fans, was more than sufficient to meet the physiological and esthetic requirements of both the townhouse and low-rise units. The windows of the respective characteristic residences were defined as remaining closed during periods of heating and cooling. However, allowances were made for daily opening of entrance doors in accordance with each residence's population.

Current trends in Chicago area housing were identified by contacting a large number of area builders and acquiring data for a large number of residential buildings constructed in that area. Based on this informal sampling, and data provided by the Department of Housing and Urban Development, compatible sets of building parameters were synthesized to represent complete residential structures typical of the Chicago area. This chapter describes relevant structural and energy parameters, and their selected values for the four typical residential structures thus characterized.

A. Single-Family Residences

The single-family (detached) residence is still the most prevalent form of housing in the U.S. In 1973, some 64 percent of the existing stock of year-round dwelling units nationwide were in single-family buildings (Ref. 2). Recent demographic trends, combined with costs of building materials, land, and financing, however, have begun to diminish the domination which the single-family home has held. In 1973, only 55 percent of the dwelling units started nationwide were in single-family residences.

In the Chicago SMSA, this trend is not being followed for the simple reason that the multifamily residences have been popular for some time. In 1970, the total stock of housing units was comprised of 46.6 percent single-family units, and in 1973, 45.5 percent of the starts were in single-family residences.

In this context, the term "single-family residence" refers to the completely detached single-family house. Approximately 20,900 such houses were built in the Chicago metropolitan area in 1973 (based on building permits issued).

Quantitative data for design and structural features of single-family residences was obtained from the National Survey of Builder Practices (Ref. 3). This survey included over 1600 builders nationwide, who were responsible for the construction of approximately 84,000 single-family homes in 1973. Information was gathered on construction details, building materials used, heating and cooling equipment, and appliances used. The Chicago area builders were responsible for the construction of 613 homes in the area during 1975.

Other sources from which single-family housing data were obtained included a recent study of the potential for solar heating and cooling of buildings (Refs. 4, 5), which specified typical residential structures in various U.S. regions. Some building parameters, such as window area, for which published regional data was not available, were specified by recourse to HAI's statistical analyses of Baltimore/Washington area construction and standard civil engineering and construction handbooks (Refs. 6, 7, and 8). Compatibility among building elements was carefully preserved. Typical appliance mixes and electricity consumption levels were taken from the previous work by HAI for single-family housing in the Baltimore/Washington area.

On the basis of the data obtained for single-family residences in the Chicago area, structural and energy consumption parameters for a typical single-family residence were defined as in Table III. Figure 1 shows the floor plan for the typical Chicago single-family residence. This internal floor plan was not itself critical to the energy analyses performed, since the single-family house was treated as a unit shell in heat transfer calculations.

B. Townhouse Residences

General trends in the housing market over the last several years, especially in large metropolitan areas, indicate that the construction of single-family detached housing units is declining rapidly. In the nation, the portion of private housing starts which were for single-family detached residences has decreased steadily, from 79.5 percent in 1960, to 65.4 percent in 1965, to 56.8 percent in 1970, to 55.4 percent in 1973. These trends indicate that, in the future, construction of townhouse and multifamily residences will dominate in large urban areas.

TABLE III. STRUCTURAL AND ENERGY CONSUMPTION PARAMETERS FOR TYPICAL SINGLE-FAMILY RESIDENCE IN THE CHICAGO AREA

STRUCTURAL PARAMETERS:	
Basic House Design	4-Bedroom, Two Story, 9 ft stories
Foundation	Full Basement
Garage/carport	2-Car Garage
Floor area, ft^2	1700 Square Ft
Construction	Wood Frame, 2x4 Studs 16" on ctr.
Exterior walls:	
Outside surface	Brick Veneer
Sheathing	1/2" Insulation Board
Insulation	3 1/2" Fiberglass Batts
Inside surface	1/2" Gypsumboard
Ceiling insulation	Asphalt Shingles, 1/2" Plywood Sheathing, Air Space, 6" Fiber-glass Loose-Fill Insulation, 1/2" Gypsumboard
Roof	Gable
Windows:	
Type	Wood Casement
Glazing	Single With Storm Sash
Area, ft^2	180 Sq Ft
Exterior doors:	
Type	Wood Frame
Number	Two
Total area, ft^2	40 Sq Ft Per Door
Patio door(s):	
Type	Aluminum, Sliding
Glazing	Double
Area, ft^2	35 Sq Ft
Orientation	South

ENERGY CONSUMPTION PARAMETERS:*	
Energy consuming equipment:	
Heating system	Gas, Forced Air
Cooling system	Electric, Forced Air
Hot water heater	Gas (270 Therms/year)
Cooking range/oven	Gas (90 Therms/year)
Clothes dryer	Gas (90 Therms/year)
Refrigerator/freezer	Electric (1830 Kw-hr/year)
Lights	Electric-Incandescent (2020 Kw-hr/Year)
Color TV	Electric (500 Kw-hr/Year)
Furnace fan	Electric (394 Kw-hr/Year)
Dishwasher	Electric (363 Kw-hr/Year)
Clothes washer	Electric (103 Kw-hr/Year)
Iron	Electric (144 Kw-hr/Year)
Coffee maker	Electric (106 Kw-hr/Year)
Miscellaneous	Electric (1200 Kw-hr/Year)
HEATING/COOLING LOAD PARAMETERS:	
Dwelling facing	North
People per unit	Two adults, two children
Weather year	1951

* Figures shown in parentheses represent energy input to structure for each appliance (based on data in Reference 10).

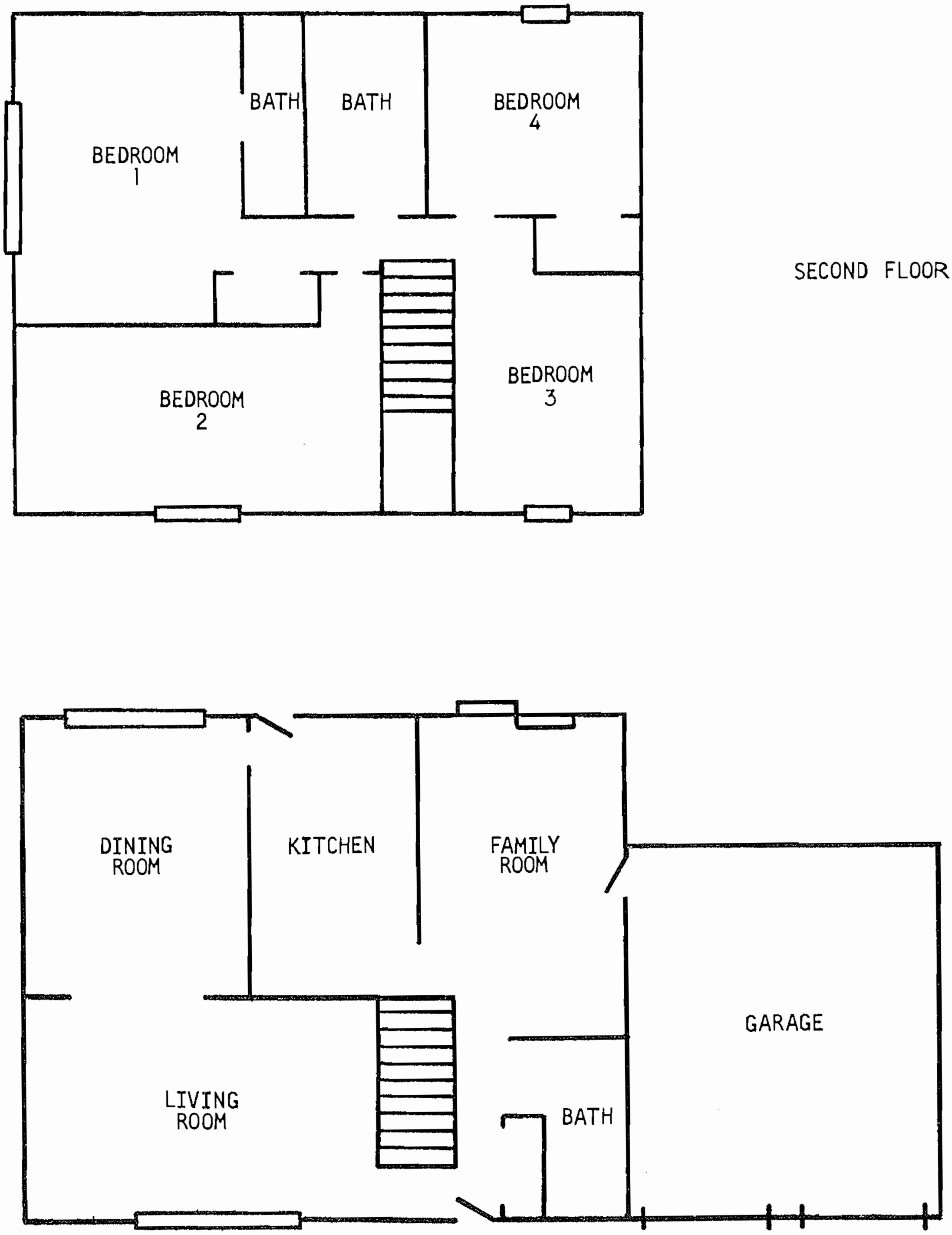


Figure 1. Floor Plan for the Characteristic Single-Family House in Chicago

For the townhouse residences, the primary source of data was the same as for the single-family residences; the National Survey of Builder Practices (Ref. 3). Of the 84,000 housing units constructed nationally by surveyed builders, 19 percent, or approximately 16,000 units, were townhouses, The Chicago area sub-sample included 9 contractors who together were responsible for the construction of 917 townhouse units in 1973.

In addition to the builder practices survey, the earlier data collection and townhouse specification done by HAI, under contract to HUD (Ref. 10) for the Baltimore/Washington area, was used for reference. Other sources included standard engineering and construction handbooks (Refs. 6, 7). Compatibility among building elements was carefully preserved.

The structural and energy consumption parameters for the typical Chicago area townhouse residence are presented in Table IV. The floor plan for the typical Chicago townhouse is presented in Figure 2.

C Low-Rise Residences

Generally speaking, the low-rise multifamily residence is one which does not require mechanical elevation. The low-rise building may contain either for-rent or for-sale dwelling units, though the for-rent variety is most common. In the United States, there were approximately 256,000 low-rise dwelling units constructed in 1974 (Ref. 11). In the Chicago area, approximately 10,000 multifamily dwelling units were constructed in 1974, and of these, approximately 7000 units were contained in low-rise buildings (Ref. 11). While historical data on the growth of low-rise housing was not specifically obtained, the historic growth patterns of multifamily housing in the Chicago area are applicable.

The primary source of data used for the specification of low-rise building components was a very recent nationwide survey (Ref. 12) of builders who had built single-family, townhouse, and lowrise residences in the past year. This survey was performed from May 1975 to September 1975, and covered only dwelling units built during 1974. The survey was responded to by about 9000 builders, who had built approximately 200,000 dwelling units in 1974. Based on government figures of approximately 1,300,000 dwelling units built in 1974, this represents a composite sampling rate of approximately 14 percent nationwide. The city-specific response rates for low-rise buildings for

TABLE IV. STRUCTURAL AND ENERGY CONSUMPTION PARAMETERS FOR TYPICAL TOWNHOUSE RESIDENCE IN THE CHICAGO AREA

Parameter	Value	
GENERAL PARAMETERS:		
Arrangement	Rectangular Structure, Eight Town House Units in a Row	
Basic design	2-Story, 3 Bedroom	
Foundation	Slab-on-Grade with Perimeter Insulation	
DIMENSIONAL PARAMETERS:		
(Areas are per townhouse unit, not per floor level)	Intermediate Units	End Units
Floor area, ft^2	1320	1320
Interior wall area, ft^2	623	1193
Window glass area, ft^2	77	101
Exterior door(s), ft^2	20	20
Roof area, per unit, ft^2	660	660
Story height, ft	9	9
CONSTRUCTION PARAMETERS:		
Construction type	Wood Frame, 2x4 Studs 16" on ctr	
Exterior walls:		
Siding	Brick Veneer	
Sheathing	1/2" Insulation Board	
Insulation	3 1/2" Fiberglass Batts	
Inside surface	1/2" Gypsumboard	
Interior walls:	1/2" Gypsumboard 2x4 Studs 16" on ctr 1/2" Gypsumboard	
Roof	Gable	
Exterior door(s)	Front-Steel	
Windows Glazing	Double	
Windows Frames	Sliding, Aluminum	
Patio door:	None	
Roof composition	Asphalt shingles; 1/2" Plywood sheathing, Air space, 6" Loose Fill Insulation, 1/2" Gypsumboard	
ENERGY CONSUMPTION PARAMETERS:*		
Heating system	Forced Air, Gas	
Cooling system	Forced Air, Electric	
Hot water heater	Gas, (270 Therms/Year)	
Cooking range	Gas, (90 Therm/Year)	
Clothes dryer	Gas, (90 Therms/Year)	
Refrigerator/freezer	Electric (1830 Kw-hr/Year)	
Lights	Electric-Incandescent (1570 Kw-hr/Year)	
Color TV	Electric (500 Kw-hr/Year)	
Furnace fan	Electric (394 Kw-hr/Year)	
Dishwasher	Electric (363 Kw-hr/Year)	
Clothes washer	Electric (103 Kw-hr/Year)	
Iron	Electric (144 Kw-hr/Year)	
Coffee maker	Electric (106 Kw-hr/Year)	
Miscellaneous	Electric (1200 Kw-hr/Year)	
HEATING/COOLING LOAD PARAMETERS:		
Dwelling facing	North	
People per unit	Two Adults, Two Children	
Typical weather year	1951	
Patio Door Facing:	South	

* Figures shown in parentheses represent energy input to structure for each appliance (based on data in Reference 10).

Figure 2. Floor Plan for Characteristic Townhouse

the ten cities represented in this study vary considerably, from five percent in Los Angeles to 48 percent in Miami. Eight of the ten cities had response rates of at least 14 percent for low-rise buildings.

In the Chicago metropolitan area, approximately 7000 low-rise units were built in 1974. Builders responding to this survey were responsible for 1278 of those units, giving an 18 percent sampling rate. In addition to this survey, HAI's previous low-rise data acquisition work for HUD (Ref. 13), wherein a similar specification was done for the Baltimore/Washington area, was consulted as a reference. Judgements based on previous experience were made where necessary to ensure compatibility among building elements.

The structural and energy use characteristics for the low-rise residence are presented in Table V. Figure 3 shows the arrangement and floor plan of the units within the building.

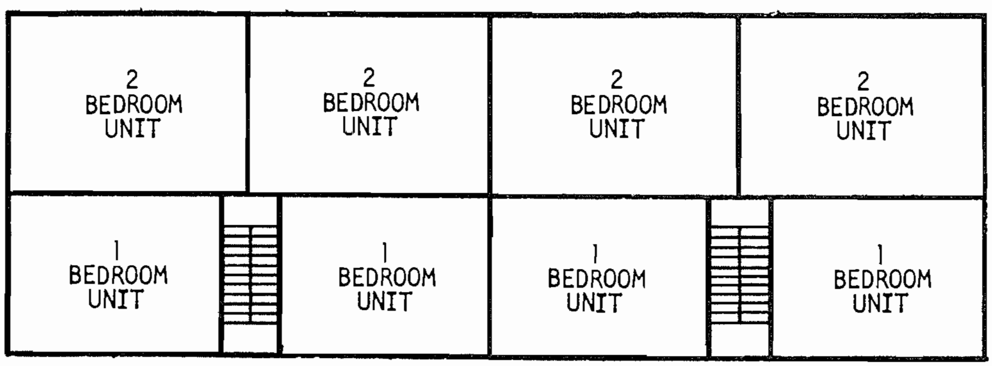


Figure 3. Floor Plan for Characteristic Low-Rise Structure

D. High-Rise Buildings

High-rise residences are defined as residential structures having more than four stories. They typically have mechanical elevation. High-rise buildings have traditionally been renter-occupied, but recent years have shown an increasing tendency towards owner-occupied, or condominium, units in many of the U.S. central cities.

TABLE V. STRUCTURAL AND ENERGY CONSUMPTION PARAMETERS FOR TYPICAL LOW-RISE RESIDENCE IN THE CHICAGO AREA

GENERAL PARAMETERS:		
Arrangement	Twelve units around enclosed stairwell. Two enclosed stairwells per building.	
Number of stories	Three	
Apartments	24 (Twelve 1-Bedroom Units) (Twelve 2-Bedroom Units)	
DIMENSIONAL PARAMETERS:		
	Interior Units	End Units
Floor area, ft^2	700[1], 986[2]	700[1], 986[2]
Exterior wall area, ft^2	428[1], 263[2]	615[1], 509[2]
Window glass, ft^2	40[1], 56[2]	40[1], 56[2]
Door(s), steel, ft^2	20	20
Patio/balcony door(s),	NA	NA
Roof area, ft^2	700[1], 986[2]	700[1], 986[2]
Story height, ft	9	9
CONSTRUCTION PARAMETERS:		
Construction type	Wood Frame, 2x4 Studs 16" on ctr	
Foundation	Slab-on-Grade with perimeter insulation	
Exterior walls:		
Siding	Brick Veneer	
Sheathing	1/2" Insulation Board	
Insulation	3 1/2" Fiberglass Batt Insulation	
Inside surface	1/2" Gypsumboard	
Interior Walls:	1/2" Gypsumboard 2x3 Studs 16" ctr 1/2" Gypsumboard	
Roof	Gable	
Entrance doors, per unit	One	
Windows and patio doors per unit:		
Glazing	Double	
Frames	Single Hung	

Ceiling composition	Asphalt Shingles, 1/2" Plywood Air Space, 6" Loose Fill Fiberglass Insulation, 1/2" Gypsumboard
ENETRY CONSUMPTION PARAMETERS:*	
Electric metering	Individual (per apartment)
Equipment in each structure:	
Central heating system	Individual forced air furnaces, gas
Hot water heater	Individual unit, gas
Clothes washers	Electric
Clothes dryers	Gas
Equipment in each apartment:	
Cooling system	Individual Unit, Electric
Cooking range/oven	Gas (68 Therms/year)
Refrigerator	Electric (1400 Kw-hr/year)
Dishwasher	Electric (280 Kw-hr/year)
Lights	Electric (1000[1], 1410[2] Kw-hr/year)
TV	Electric (400 Kw-hr/year)
Misc. appliances**	Electric (1100 Kw-hr/year)
HEATING/COOLING LOAD PARAMETERS:	
Dwelling facing	North
People per unit	Two Adults[1], Two Adults & One Child[2]
Typical weather year	1951

* Figures shown in parentheses represent energy input to structure for each appliance (based

** Includes disposal, iron, coffee maker, etc.

1 One-bedroom apartment

2 Two-bedroom apartment

In the Chicago area, approximately 10,000 multifamily dwelling units were constructed in 1974. Of these, approximately 3000 dwelling units were in buildings which were of the high-rise type (Ref. 11). These estimates were not disaggregated by type of occupant (owner or renter).

The data acquisition for high-rise buildings was accomplished entirely by telephone communication with builders, architects, and engineering consultants in each of the ten cities studied. Sources were asked if their opinions on the characteristics of high-rise buildings in their city could be considered representative of the majority of such buildings in their city. Sufficient contacts were made to establish and verify a complete picture of high-rise residential building construction for the area. Compatibility among building components selected for each city was carefully preserved during the analysis.

Three general observations on high-rise residential construction have been made from this informal sampling:

(1) Most cities have both condo (condominium, or owner-occupied) and rental units. Rental units include both private sector and public sector buildings (low-income or elderly housing).

(2) The major differences between high-rise rental and high-rise condo units were in size and utilities. Condo units tended to be larger, both in number of rooms and number of square feet, than rental units. Condo units also tended to have unitary heating and cooling equipment, whereas rental units tended to employ central equipment.

(3) High-rise residential buildings showed marked city-specific homogeneity in construction details, but were heterogeneous in facade, trim, geometry, and other surface features related to appearance.

It was concluded, especially for high-cost rental and condominium units, that the variety in appearance but not construction detail was attributable to the marketing needs of the developer. The potential high-rise occupant's purchase decision criteria, while bounded broadly by cost considerations, seem actually more related to considerations of status, uniqueness, etc.

In the Chicago area, the typical high-rise structure was a 15 story building, comprised of 95 one bedroom and 95 two bedroom rental units. Table VI provides structural and energy consumption parameters for the typical high-rise building in Chicago. Figure 4 shows the typical high-rise floor plan.

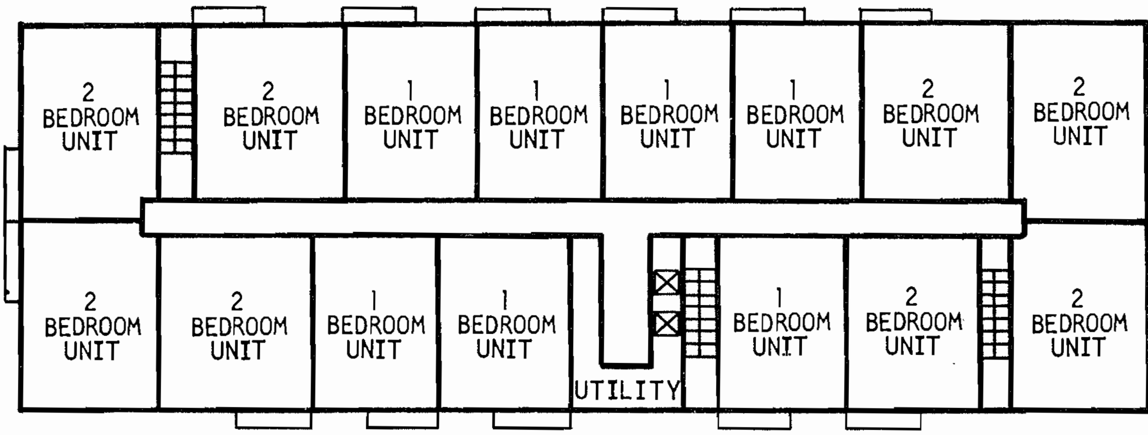


Figure 4. Floor Plan for Characteristic High-Rise Structure

TABLE VI. STRUCTURAL AND ENERGY CONSUMPTION PARAMETERS FOR TYPICAL HIGH-RISE RESIDENCE IN THE CHICAGO AREA

GENERAL PARAMETERS:

Arrangement	Rectangular structure, central hall on each floor, two stairwells, two elevators
Number of stories	15
Basement	Underground Garage
Apartments	First floor: 7 1-Bdrm. condominium units; 7 2-Bdrm. condominium units Other floors: 7 1-Bdrm. condominium units; 7 2-bdrm. condominium units — Total 210 Units

DIMENSIONAL PARAMETERS:

	Interior Apartments	End Apartments	Halls & Lobbies	Stairwells & Elevators	Utility Rooms
Floor area, ft^2	812 (1-br)	960	1905 (ff)*	632	812 (ff)*
	957 (2-br)		1242 (of)**		663 (of)**
Exterior wall area, ft^2	175 (1-br)	470		160 (ff)*	280 (ff)*
	225 (2-br)			160 (of)**	330 (of)**
Roof area, ft^2	812 (1-br)	960	2585	632	495
	957 (2-br)				
Window glass, ft^2	105 (1-br)	150	167 (ff)*		
	105 (2-br)				
Entrance doors, ft^2	20	20	20	20	20
Story height, ft	10	10	10	10	10

CONSTRUCTION PARAMETERS:

Frame	Reinforced Concrete
Floors and roof deck	
Exterior walls:	
Siding	4" Concrete
Sheathing	1" Rigid Insulation
Insulation	Air Space
Inside surface	1/2" Gypsumboard
Roof	Built-up; Felt-Bitumen Composition, 1 1/2" rigid insulation, 2" Concrete Deck, Air Gap, 1/2" Gypsumboard
Entrance doors:	
Apartments	Metal, one per unit
Lobby	Steel, four
Staircases	Metal, three
Windows:	
Glazing	Double
Frames	Sliders, Aluminum

ENERGY CONSUMPTION PARAMETERS:***

Electric metering	Master (per structure)
Equipment in each structure:	
Central cooling system	Electric
Hot water heater	Gas
Clothes washers	Electric
Clothes dryers	Gas
Elevators	Electric
Lights, signal system, miscellaneous appliances	Electric
Equipment in each apartment:	
Heating system	Forced Air, Gas
Cooking range	Electric (2000 Kw-hr/year)
Refrigerator	Electric (1400 Kw-hr/year)
Dishwasher	Electric (280 Kw-hr/year)
Lights:	
1-bedroom unit	Electric (1160 Kw-hr/year)
2-bedroom unit	Electric (1370 Kw-hr/year)
TV	Electric (400 Kw-hr/year)
Miscellaneous	Electric (1100 Kw-hr/year)

HEATING/COOLING LOAD PARAMETERS:

Dwelling facing	North
People per apartment:	
1-bedroom	Two Adults
2-bedroom	Two Adults, One Child
Typical weather year	

* ff = first floor

** of = other floors

*** Data shown in parentheses represents energy input to structure for each appliance. Data based on Reference 10.

IV. COMPUTATION OF HEATING AND COOLING ENERGY REQUIREMENTS

Annual heating and cooling loads and resultant energy requirements were calculated for each of the four characteristic residences defined in Chapter III for the Chicago area. To determine the heating and cooling loads, or heat delivery/removal requirements, for each residence, a time-response computer program was used. This computer program included subroutines for computing hourly load contributions throughout the year due to conduction, convection, air infiltration, radiation, and internal heat gain. Annual HVAC energy requirements were calculated from monthly heating and cooling loads by applying system and auxiliary component efficiencies and coefficients of performance appropriate for each characteristic residence. The computer program calculation procedures, and the results of these calculations, are discussed in the following sections.

A. Description of the Computer Program Used for Load Calculations

The Load Calculating Sub-Program (LCSP) of the Buildings Energy Analysis Model (BEAM) was developed at Hittman Associates, Inc., as a revised form of the original U.S. Postal Service program. The Load Calculation Sub-Program is a complex of heat transfer, environmental, and geometric subroutines which compute the heating and cooling loads for each space* at each hour. The input to the LCSP structure is the building surroundings, local weather, and the pertinent astronomy of the sun. The output consists of hourly weather and psychrometric data, sensible loads, latent loads, lighting loads (if applicable), and equipment and lighting power consumption for each space.

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

**Such a space is defined as a room or a group of rooms which are treated as a single load module by the LCSP.*

1. <u>Hourly Weather Data</u>

Weather tapes of past years are available for enough weather stations throughout the United States so that a tape is likely to be available for a station near the site of any building being considered. The Load Sub-Program uses weather tapes to realistically simulate the changing meteorological conditions to which the building is continuously exposed. The data read from the weather tape and a brief summary of the uses to which they are put are listed below:

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

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

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

(d) Wind direction (used in computing infiltration rate)

(e) Barometric pressure (used in computing density of air)

(f) Cloud type and amount (used in computing heat gain and heat loss by radiation between the building and the sky)

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

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

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

(b) Direct normal intensity

(c) Brightness of sky and ground

(d) Re-radiation to sky

(e) Shadows cast upon the surface

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

3. Infiltration Support Program

The mathematical model of this computer program is basically a mass flow balance network. Major components are exterior walls, walls of vertical shafts, floors, leakage areas in the major separations which are lumped together and represented by orifice areas, and ventilation systems.

The value of outside absolute pressure is taken as normal atmospheric pressure. Outside air pressures at other levels depend on the density of outside air and on wind pressure (depending on wind speed and direction). Inside pressures on the floor at various levels are interrelated by the weight of the column of inside air between levels and the pressure drop across the intervening floors. Inside pressures in the shaft at various levels are interrelated only by the weight of the column of shaft air, assuming no frictional pressure drop in the vertical shaft. The flows through the orifices are computed at hourly intervals.

The program is designed to permit variation in the number of floors and shafts, size of orifice areas, and pressurization levels induced by mechanical ventilation.

B. Calculation of Heating and Cooling Loads and Energy Requirements

The annual heating and cooling loads and subsequent energy requirements for the four characteristic residences in the Chicago area were calculated for the 1951 Chicago weather year. The method used for making the calculations was a two step process. First, hourly heating and cooling loads were calculated for each space in each of the characteristic residences using the LCSP program described previously. Appropriate structural properties and design data for each respective residential building type in the Chicago area, as well as daily internal load profiles for lights, appliances, and occupants in the area, were all prepared as input to the LCSP. In the second step, the energy required to meet the heating and cooling loads was calculated. These calculations required the various system capacities, efficiencies and performance characteristics for the type of heating, cooling and ventilation system characterized for each of the four residences.

1. Heating and Cooling Load Calculations

The structural parameters and floor plan configurations defined for each characteristic house in Chapter III were used in formulating inputs to the load calculating computer program. Detailed performance parameters were defined as shown in Tables VII, VIII, IX and X, including total U values for the walls, roof, floors, and doors; material conductivities, densities, specific heats; and R values as appropriate.

Internal load profiles for lights, appliances, and occupants were taken from Reference 12. These profiles were varied for weekdays and weekends throughout the year. A constant thermostat set point of 72°F was established for both the heating and cooling season. All loads tending to decrease the internal temperature were defined as heating loads, and all loads tending to increase the internal temperature were cooling loads. For example, cold air infiltrating from outside the heating space would contribute as a heating load, whereas an internal load would contribute as a cooling load. In calculating the loads, it was assumed that all windows in the residences remained closed throughout the year.

Monthly and annual heating and cooling loads for the four characteristic structures are shown in Table XI. Annual loads per average dwelling unit for the single-family, townhouse, low-rise, and high-rise characteristic structures are also given. It should be noted that, in subsequent calculations of energy requirements, it was assumed that very small loads occurring during some months would not be met by the buildings' HVAC systems.*

The percentage of heating and cooling loads due to the infiltration of outside air through windows, doors, and walls, as well as mechanical ventilation, is shown below for each residential building type. These percentages represent the portion of the total annual loads for the entire building which can be attributed to air infiltration.

**For example, a small cooling load in January (caused by internal heat gain) would not be met by the air-conditioning system, but rather by opening the building's windows.*

TABLE VII. CHICAGO CHARACTERISTIC SINGLE-FAMILY RESIDENCE STRUCTURAL PARAMETERS

Components	"U" Value (Btu/hr-ft^2-°F)	Thickness (ft)	Conductivity (Btu/hr-ft-°F)	Density (lb/ft^3)	Specific Heat (Btu/lb-°F)	"R" Value (hr-ft^2-°F/Btu)
Wall						
Brick Veneer		0.333	0.757	130.	0.22	
Insulation Board	0.076	0.042	0.032	18.	0.31	
3-1/2" Batt Insulation		0.292	0.0265	3.	0.18	
Gypsumboard		0.042	0.093	50.	0.26	
Roof						
Asphalt Shingles		0.042	0.096	99.	0.26	
Wood Sheathing	0.048	0.042	0.065	34.	0.29	
Air Space		-----	-----	----	----	0.96
Loose Fill Insulation		0.500	0.0274	10.	0.18	
Gypsumboard		0.042	0.093	50.	0.26	
Door						
Wood Frame	0.67					
Floor						
Full Concrete Basement	0.24					

TABLE VIII. CHICAGO CHARACTERISTIC TOWNHOUSE RESIDENCE STRUCTURAL PARAMETERS

Components	"U" Value (Btu/hr-ft^2-°F)	Thickness (ft)	Conductivity (Btu/hr-ft-°F)	Density (lb/ft^3)	Specific Heat (Btu/lb-°F)	"R" Value (hr-ft^2-°F/Btu)
Wall						
Brick Veneer		0.333	0.757	130.	0.22	
Fiberboard Sheathing	0.076	0.042	0.032	18.	0.31	
3-1/2" Batt Insulation.		0.292	0.0265	3.	0.18	
Gypsumboard		0.042	0.093	50.	0.26	
Roof						
Asphalt Shingles		0.042	0.096	99.	0.26	
Wood Sheathing		0.042	0.065	34.	0.29	
Air Space	0.048	-----	------	-----	----	0.96
Loose Fill Insulation		0.500	0.0274	10.	0.18	
Gypsumboard		0.042	0.093	50.	0.26	
Door						
Steel	0.56					
Floor						
Concrete Slab	0.10					

TABLE IX. CHICAGO CHARACTERISTIC LOW-RISE RESIDENCE STRUCTURAL PARAMETERS

Components	"U" Value (Btu/hr-ft^2-°F)	Thickness (ft)	Conductivity (Btu/hr-ft-°F)	Density (lb/ft^3)	Specific Heat (Btu/lb-°F)	"R" Value (hr-ft^2-°F/Btu)
Wall						
Brick Veneer		0.333	0.757	130.	0.22	
Insulation Board	0.076	0.042	0.032	18.	0.31	
3-1/2" Batt Insulation		0.292	0.0265	3.	0.18	
Gypsumboard		0.042	0.093	50.	0.26	
Roof						
Asphalt Shingles		0.042	0.096	99.	0.26	
Wood Sheathing		0.042	0.005	34.	0.29	
Air Space		-----	-----	-----	----	0.96
Loose Fill Insulation	0.048	0.500	0.0274	10.	0.18	
Gypsumboard		0.042	0.093	50.	0.26	
Door						
Steel	0.35					
Floor						
Concrete Slab	0.10					

TABLE X. CHICAGO CHARACTERISTIC HIGH-RISE RESIDENCE STRUCTURAL PARAMETERS

Components	"U" Value (Btu/hr-ft^2-°F)	Thickness (ft)	Conductivity (Btu/hr-ft-°F)	Density (lb/ft^3)	Specific Heat (Btu/lb-°F)	"R" Value (hr-ft^2-°F/Btu)
Wall	0.206					
Precast Concrete		0.333	0.54	144.	0.16	
Rigid Insulation		0.083	----	-----	----	0.278
Air Gap		-----	----	-----	----	1.01
Gypsumboard		0.042	0.093	50.	0.26	
Roof	0.160					
Built Up Roof		0.031	0.094	70.	0.35	
1-1/2" Rigid Insulation		-----	-----	-----	----	4.17
2" Concrete Deck		0.167	0.54	144.	0.16	
Air Gap		-----	-----	-----	----	0.96
Gypsumboard		0.042	0.093	50.	0.26	
Floor	0.450					
Concrete Slab		0.500	0.54	144.	0.16	
Carpet/Padding		0.065	0.050	10.	0.34	

TABLE XI. HEATING AND COOLING LOADS FOR CHARACTERISTIC CHICAGO RESIDENTIAL STRUCTURES - LOADS ARE GIVEN IN THERMS

Month	Single-Family		Townhouse		Multifamily Low-Rise		Multifamily High-Rise	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
January	187.9	0.0	665.2	0.0	621.9	20.6	13019.1	6.5
February	169.9	0.0	580.9	0.0	546.4	34.4	10833.4	34.1
March	146.9	0.0	457.4	2.5	407.6	63.7	8562.5	184.4
April	88.8	1.7	216.9	27.0	179.7	151.2	4289.5	1046.0
May	35.7	13.2	77.1	141.9	55.5	396.3	1094.6	4684.9
June	11.6	23.2	12.5	222.0	7.4	512.9	203.4	6532.3
July	2.1	53.6	0.6	361.6	0.0	697.1	15.3	9902.3
August	2.0	51.2	0.9	333.1	0.0	665.6	29.8	8732.2
September	13.2	21.9	20.6	207.8	7.4	491.5	577.2	4584.0
October	39.9	13.2	102.5	115.7	52.6	337.2	2378.6	2892.9
November	131.3	0.0	444.8	0.1	372.1	53.4	9173.2	116.5
December	166.9	0.0	560.7	0.9	528.7	48.8	11981.2	148.9
Annual Load	998.2	178.0	3140.1	1412.6	2779.3	3472.7	62157.8	38865.0
Annual Load per Dwelling Unit	998.2	178.0	392.5	176.6	115.8	144.7	295.9	185.0

PERCENTAGE OF TOTAL ANNUAL HEATING AND COOLING LOADS ATTRIBUTED TO AIR INFILTRATION

	Heating Load	Cooling Load
Single-Family	42	22
Townhouse	60	12
Low-Rise	62	0
High-Rise	61	10

In order to better compare infiltration loads among the four building types, the annual infiltration loads on a per square foot basis are also presented.

TOTAL ANNUAL HEATING AND COOLING INFILTRATION LOADS PER UNIT FLOOR AREA (THERM/SQ FT)

	Heating Load	Cooling Load
Single-Family	0.25	0.02
Townhouse	0.10	0.01
Low-Rise	0.08	0.00
High-Rise	0.16	0.07

These infiltration loads relate fairly closely to a ratio of building exterior opening area (exterior windows and doors) to building floor area. The single-family structure exhibits the highest exterior opening area to floor area and correspondingly has a high infiltration load per unit floor area. Similarily, the exterior opening area ratio is progressively lower in the townhouse structure and the low-rise structure, with correspondingly decreasing unit floor area infiltration loads. Due to the partial pressurization caused by forced ventilation and higher stack effect, this comparison is not quite valid for the high-rise structure.

2. Calculated Energy Consumption for Heating and Cooling the Characteristic Residences

The energy consumption required to heat, cool, and ventilate the characteristic residences were determined using the previously calculated heating and cooling loads. The heating, cooling, and ventilation equipment used in the residences are described below. For the computation of energy required for cooling, cooling loads were discarded if they occurred in the cold weather period between September 20 and May 10, since the simple expediency of opening windows (for entry of cooler outside air) would be a more practical method of meeting these cooling requirements. For both heating and cooling, the thermostat was set at 72°F, a thirty-one percent electricity conversion/transmission efficiency, and three percent gas pipeline losses, were assumed for conversion of units of in-structure energy to units of primary energy.

a. Single-Family Detached

Heating - gas fired furnace, forced air system; loads not met between May 20 and September 20; efficiency = 0.7

Cooling - central, electric, forced air system; loads not met between September 20 and May 20; C.O.P. = 1.7

b. Townhouse

Heating - gas fired furnace, forced air system; loads not met between May 16 and September 20; efficiency = 0.7

cooling - central, electric, forced air system; loads not met between September 20 and May 20; C.O.P. = 1.7

c. Low-Rise

Heating - individual gas fired furnaces, forced air system; loads not met between May 10 and September 20; efficiency = 0.7

Cooling - individual electric units; loads not met between September 20 and May 10; C.O.P. = 1.7

d. High-Rise

Heating - central gas fired furnace, hot water system; loads not met between May 10 and September 20; efficiency = 0.7

Cooling - electric window units; loads not met between September 20 and May 10; C.O.P. = 1.5

Detailed analyses of the energy consumed for heating and cooling of the Chicago characteristic single-family, townhouse, low-rise, and high-rise residences are shown in Tables XII, XIII, XIV, and XV, respectively. The following data are presented for each residence:

(a) Monthly and annual energy consumption of each major component of the heating, cooling, and ventilation system

(b) Monthly and annual consumption of primary* gas and electric energy used for heating, cooling, and ventilation

(c) Annual average in-structure energy consumption per apartment for each major component of the heating, cooling, and ventilation system

(d) Annual average in-structure energy consumption per square foot of total floor area for each major component of the system

(e) Annual primary energy required per apartment

(f) Annual primary energy required per square foot of total floor area

Annual in-structure and primary energy requirements for the characteristic residences are compared in Table XVI. Comparisons were made for both in-structure and primary energy consumptions based on "per unit," "per square foot of floor area," and "per occupant" consumptions. It should be noted that each basis for comparison normalizes all parameters such as apartment size, number of occupants, and external wall area per unit. When comparing the primary energy consumptions of the residences, the "per unit" consumption for the single-family was the highest, and the low-rise's consumption was the lowest. The ratios of

**Primary energy is defined as the input energy to generation plants or gas distribution centers; electrical generation was assumed to require 10,910 Btu/Kw-hr consumed within the structure (31 percent thermal efficiency) and gas distribution was assumed to be 97 percent efficient.*

TABLE XII. HEATING AND COOLING ENERGY CONSUMPTION IN THE CHICAGO CHARACTERISTIC SINGLE-FAMILY RESIDENCE

	Energy Consumption in Therms			Primary Energy in Therms		
Month	Heating	Cooling	Total*	Gas	Electric	Total*
January	268.4	0.0	268.4	276.7	0.0	276.7
February	242.7	0.0	242.7	250.2	0.0	250.2
March	209.8	0.0	209.8	216.3	0.0	216.3
April	126.8	0.0	126.8	130.7	0.0	130.7
May	51.0	7.7	58.7	52.6	24.8	77.4
June	0.0	13.6	13.6	0.0	43.9	43.9
July	0.0	31.5	31.5	0.0	101.6	101.6
August	0.0	30.1	30.1	0.0	97.0	97.0
September	18.8	12.9	31.7	19.4	41.6	61.0
October	57.0	0.0	57.0	58.7	0.0	58.7
November	187.6	0.0	187.6	193.4	0.0	193.4
December	241.3	0.0	241.3	248.7	0.0	248.7
Annual Consumption	1403.4	95.8	1499.2	1446.8	309.0	1755.8
Average Annual Consumption Per Square Foot	0.82	0.05	0.88	0.85	0.18	1.03

Electric energy consumed by furnace fan was negligible compared to total energy consumption so it was not considered.

TABLE XIII. HEATING AND COOLING ENERGY CONSUMPTION IN THE CHICAGO CHARACTERISTIC TOWNHOUSE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total*	Gas	Electric	Total*
January	950.3	0.0	950.3	979.6	0.0	979.6
February	829.8	0.0	829.8	855.4	0.0	855.4
March	653.4	0.0	653.4	673.6	0.0	673.6
April	309.8	0.0	309.8	319.4	0.0	319.4
May	79.3	83.5	152.8	81.7	269.3	351.0
June	0.0	130.6	130.6	0.0	421.3	421.3
July	0.0	212.7	212.7	0.0	686.1	686.1
August	0.0	195.9	195.9	0.0	631.9	631.9
September	29.4	122.2	151.6	30.3	394.2	424.5
October	146.4	0.0	146.4	150.9	0.0	150.9
November	635.4	0.0	635.4	655.0	0.0	655.0
December	801.0	0.0	801.0	825.7	0.0	825.7
Annual Consumption	4434.8	744.9	5179.7	4571.6	2402.8	6974.4
Average Annual Consumption Per Unit	554.3	93.1	647.4	571.4	300.3	871.7
Average Annual Consumption Per Square Foot	0.42	0.07	0.49	0.43	0.23	0.66

Electric energy consumed by furnace fan was negligible compared to total energy consumption so it was not considered.

TABLE XIV. HEATING AND COOLING ENERGY CONSUMPTION IN THE CHICAGO CHARACTERISTIC LOW-RISE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total *	Gas	Electric	Total *
January	888.4	0.0	888.4	915.9	0.0	915.9
February	780.5	0.0	780.5	804.6	0.0	804.6
March	582.3	0.0	582.3	600.3	0.0	600.3
April	256.7	0.0	256.7	264.6	0.0	264.6
May	79.3	233.1	312.4	81.7	751.9	833.6
June	0.0	301.7	301.7	0.0	973.2	973.2
July	0.0	410.0	410.0	0.0	1322.6	1322.6
August	0.0	391.5	391.5	0.0	1262.9	1262.9
September	10.6	289.1	299.7	10.9	932.6	943.5
October	75.1	0.0	75.1	77.4	0.0	77.4
November	531.6	0.0	531.6	548.0	0.0	548.0
December	755.3	0.0	755.3	778.6	0.0	778.6
Annual Consumption	3960.5	1625.4	5585.9	4082.0	5243.2	9325.2
Average Annual Consumption Per Unit	165.0	67.7	232.7	170.0	218.4	388.5
Average Annual Consumption Per Square Foot	0.19	0.08	0.27	0.20	0.26	0.46

**Electric energy consumed by furnace fan was negligible compared to total energy consumption so it was not considered.*

TABLE XV. HEATING AND COOLING ENERGY CONSUMPTION IN THE CHICAGO CHARACTERISTIC HIGH-RISE

Month	Energy Consumption in Therms				Primary Energy in Therms		
	Heating	Cooling	Fans	Total	Gas	Electric	Total
January	18589.7	0.0	1386.6	19985.3	19173.9	4472.9	23646.8
February	15476.3	0.0	1160.6	16636.9	15954.4	3743.9	19698.8
March	12232.1	0.0	1179.3	13411.4	12610.4	3804.2	16414.6
April	6127.8	0.0	823.0	6950.8	6317.3	2654.8	8972.1
May	1563.7	3123.2	611.3	5298.2	1612.0	12046.8	13658.8
June	0.0	4354.8	504.0	4858.8	0.0	15673.5	15673.5
July	0.0	6601.5	520.8	7122.3	0.0	22975.1	22975.1
August	0.0	5821.4	520.8	6342.2	0.0	20458.7	20458.7
September	824.6	3056.0	579.9	4460.5	850.1	11728.7	12578.8
October	3398.0	0.0	761.6	4159.6	3503.0	2456.8	5959.8
November	13104.6	0.0	1168.8	14273.4	13509.9	3770.3	17280.2
December	17116.0	0.0	1138.3	18454.3	17696.9	4317.0	22013.9
Annual Consumption	88441.8	22956.9	10555.0	121953.7	19228.4	108102.7	199331.1
Average Annual Consumption Per Unit	421.1	109.3	50.2	580.7	434.4	514.8	949.2
Average Annual Consumption Per Square Foot*	0.37	0.09	0.04	0.51	0.50	0.59	1.09

Halls, lobbies and stairwells included.

TABLE XVI. COMPARISON OF THE ENERGY REQUIREMENTS FOR HEATING AND COOLING THE CHARACTERISTIC CHICAGO RESIDENCES

Residence Type	In-Structure Energy Consumption in Therms			Primary Energy Consumption in Therms		
	Per Unit	Per Sq Ft of Floor Area	Per Occupant	Per Unit	Per Sq Ft of Floor Area	Per Occupant
Single-Family	1499	0.88	374	1755	1.03	439
Townhouse	647	0.49	161	871	0.66	217
Low-Rise	232	0.27	93	388	0.45	155
High-Rise	580	0.51	232	879	0.78	351

floor areas* for individual units in the single-family, town house, low-rise, and high-rise were 1.00, 0.77, 0.49, and 0.73, whereas the corresponding ratios for "per unit" primary energy consumption were 1.00, 0.50, 0.22, and 0.50. The dissimilarity of the above two groups of ratios shows that the differences in energy consumption "per unit" cannot be attributed only to differences in floor area.

When comparing the energy consumption of the Chicago residences on the basis of floor area, the single-family detached had the the greatest consumption of both in-structure and primary energy, and the low-rise had the least. The high-rise consumed less in-structure and more primary energy than the townhouse. This change is due to the fact that the high-rise used a larger proportion of electricity compared to fossil fuel, and large energy losses are associated with electricity generation.

When comparing the primary energy consumption of the residences on the basis of number of occupants, the low-rise had the lowest and the single-family had the highest consumption. The number of occupants for the various residences were defined as four per single-family unit, four per townhouse, two and one-half** per low-rise apartment, and two and one-half per high-rise apartment. The above occupancy density was assumed as reasonable based on the number of bedrooms per residence. Any change in the above occupancy densities could have a marked effect on the relative consumption of energy per occupant.

**In the high-rise residence, the hall, lobby, and stairwell floor areas were assigned in equal portions to each dwelling unit.*

***This figure is an average based on the total number of occupants and dwelling units in each building.*

V. ENERGY CONSUMPTION OF IMPROVED CHICAGO RESIDENCES

Heating and cooling loads and energy consumptions were calculated for improved versions of the single-family detached, townhouse, low-rise, and high-rise structures. The basis for selection of improvements was that they must provide reduction of primary energy consumed for heating, cooling, and ventilation; be currently technically feasible; and not restrict the life-styles of the residents. Improvements considered for inclusion in the improved residences included structural modifications and changes in the comfort control systems.

A. Definition of Improved Residences

The improved residences included changes designed to reduce energy consumption attributed to windows, walls, roofs, floors, infiltration, direct solar radiation, heating systems, cooling systems, and ventilation systems.

1. Structural Modifications

The structural modifications selected for the improved versions of the characteristic single-family, townhouse, low-rise, and high-rise were as follows:

(a) 25 percent reduction of window area

(b) Addition of weatherstripping to reduce infiltration

(c) Increase the thermal resistance ("R" value) of the ground floor, walls and roof insulation as follows:

	Ground Floor	Walls	Roof
Single-family	11	17	27
Townhouse	11	17	27
Low-Rise	11	17	27
High-Rise	11	12	17

All other structural, design, and internal load parameters previously defined for the characteristic residences remained unchanged.

2. System Modifications

The system modifications selected for the improved versions of the characteristic residences were as follows: add a heat recovery device to the furnace and improve its efficiency, and increase the cooling system C.O.P. The improved efficiencies and C.O.P.s are listed below.

(a) Improved Single-Family Detached

Heating efficiency = 0.83

Cooling C.O.P. = 2.7

(b) Improved Townhouse

Heating efficiency = 0.83

Cooling C.O.P. = 2.7

(c) Improved Low-Rise

Heating efficiency = 0.83

Cooling C.O.P. = 2.7

(d) Improved High-Rise

Heating efficiency = 0.78

Cooling C.O.P. = 2.5

These improvements were summarized in table form in Table II.

B. Calculation of Loads and Energy Consumption of Improved Residences

The computation methods used for evaluating the modified residences were the same as those used for calculating the loads and energy consumption of the characteristic residences; that is, the hourly loads and energy consumption were calculated for the full weather year using the computer program described in Chapter III, and the only changes in the computations were those required to model the respective modifications.

Monthly and annual heating and cooling loads for the modified single-family, townhouse, low-rise, and high-rise structures are delineated in Table XVII. Annual loads are also given for the average dwelling unit within each type of structure. Comparison of these modified structure loads with the loads for the characteristic structures taken from Table XI reveals that the modified Chicago structures generally have achieved lower heating loads only at the cost of higher cooling loads. As will be discussed, however, annual energy consumption in the modified residences was dramatically lower than in the characteristic residences.

Detailed energy consumption data for heating and cooling the modified Chicago structures are shown in Tables XVIII, XIX, XX, and XXI. These analyses included computation of monthly and annual in-structure energy consumption for heating, cooling, and ancillaries; monthly and annual primary energy consumption by type of energy; annual energy consumption per average dwelling unit; and annual average energy consumption per unit floor area.

Annual in-structure and primary energy consumption for the modified residences are compared in Table XXII. Useful comparisons may also be drawn between these results and the analogous results for the Chicago characteristic residences, shown previously in Table XVI.

Comparison of the primary energy consumption of the improved Chicago residences (Table XXII), shows the following:

(1) In terms of primary energy used per dwelling unit, the low-rise units used the least, followed by the townhouse, high-rise, and single-family, in that order.

(2) In terms of primary energy per unit floor area, the low-rise used the least energy, followed by

TABLE XVII. HEATING AND COOLING LOADS FOR IMPROVED CHICAGO RESIDENTIAL STRUCTURES - LOADS ARE GIVEN IN THERMS

Month	Single-Family		Townhouse		Multifamily Low-Rise		Multifamily High-Rise	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
January	114.9	0.0	463.5	0.0	436.9	41.2	8,447.7	28.5
February	99.2	0.0	409.4	0.0	393.7	58.5	6,951.0	95.4
March	79.9	0.4	312.7	3.3	287.0	95.8	5,245.6	321.0
April	41.2	4.1	136.6	27.4	126.5	200.5	2,373.4	1,266.6
May	12.2	22.8	47.8	127.7	40.5	345.1	568.6	4,562.5
June	2.5	35.0	5.5	202.8	4.6	495.7	101.1	6,171.3
July	0.2	57.9	0.0	318.1	0.0	652.4	7.2	8,856.2
August	0.3	53.1	0.1	306.5	0.0	627.8	11.2	8,046.1
September	4.6	28.2	8.6	207.4	2.7	490.7	279.9	4,627.1
October	18.4	16.7	53.2	119.1	25.8	334.8	1,245.8	3,024.3
November	76.5	0.0	292.6	2.0	242.6	83.5	5,678.8	244.0
December	104.3	0.1	375.6	3.4	360.7	74.8	7,684.4	256.6
Annual Load	554.2	218.3	2105.6	1317.7	1921.0	3500.8	38,594.1	37,499.6
Annual Load per Dwelling Unit	554.2	218.3	263.2	164.7	80.0	145.8	183.3	178.5

TABLE XVIII. HEATING AND COOLING ENERGY CONSUMPTION IN THE CHICAGO IMPROVED SINGLE-FAMILY RESIDENCE

	Energy Consumption in Therms			Primary Energy in Therms		
Month	Heating	Cooling	Total*	Gas	Electric	Total*
January	138.4	0.0	138.4	142.7	0.0	142.7
February	119.5	0.0	119.5	123.2	0.0	123.2
March	96.2	0.0	96.2	99.1	0.0	99.1
April	49.6	0.0	49.6	51.1	0.0	51.1
May	14.7	8.4	23.1	15.1	27.0	42.1
June	0.0	12.9	12.9	0.0	41.6	41.6
July	0.0	21.4	21.4	0.0	69.0	69.0
August	0.0	19.6	19.6	0.0	63.2	63.2
September	5.5	10.4	15.9	5.7	33.5	39.2
October	22.1	0.0	22.1	22.8	0.0	22.8
November	92.1	0.0	92.1	94.9	0.0	94.9
December	125.6	0.0	125.6	129.5	0.0	129.5
Annual Consumption	663.7	72.7	736.4	684.1	234.3	918.4
Average Annual Consumption Per Square Foot	0.39	0.04	0.43	0.40	0.14	0.54

Electric energy consumed by furnace fan was negligible compared to total energy consumption so it was not considered.

TABLE XIX. HEATING AND COOLING ENERGY CONSUMPTION IN THE CHICAGO IMPROVED TOWNHOUSE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total	Gas	Electric	Total
January	558.4	0.0	558.4	575.7	0.0	575.7
February	493.2	0.0	493.2	508.4	0.0	508.4
March	376.7	0.0	376.7	388.3	0.0	388.3
April	164.6	0.0	164.6	169.7	0.0	169.7
May	57.6	47.3	104.9	59.4	152.6	212.0
June	0.0	75.1	75.1	0.0	242.2	242.2
July	0.0	117.8	117.8	0.0	380.0	380.0
August	0.0	113.5	113.5	0.0	366.1	366.1
September	10.3	76.8	87.1	10.6	247.7	258.3
October	64.0	0.0	64.0	66.0	0.0	66.0
November	325.5	0.0	352.5	363.4	0.0	363.4
December	452.5	0.0	452.5	466.5	0.0	466.5
Annual Consumption	2529.8	430.5	2960.3	2608.0	1388.6	3996.6
Average Annual Consumption Per Unit	316.2	53.8	370.0	326.0	173.6	499.6
Average Annual Consumption Per Square Foot	0.24	0.04	0.28	0.24	0.13	0.38

**Electric energy consumed by furnace fan was negligible compared to total energy consumption so it was not considered.*

TABLE XX. HEATING AND COOLING ENERGY CONSUMPTION IN THE CHICAGO IMPROVED LOW-RISE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total	Gas	Electric	Total
January	526.4	0.0	526.4	542.7	0.0	524.7
February	474.3	0.0	474.3	488.9	0.0	488.9
March	345.8	0.0	345.8	356.5	0.0	356.5
April	152.4	0.0	152.4	157.1	0.0	157.1
May	48.8	127.8	176.6	50.3	4.2.2	462.5
June	0.0	183.6	183.6	0.0	592.2	592.2
July	0.0	241.6	241.6	0.0	779.3	779.3
August	0.0	232.5	232.5	0.0	750.0	750.0
September	3.2	181.7	184.9	3.3	586.1	589.4
October	31.0	0.0	31.0	32.0	0.0	32.0
November	292.3	0.0	292.3	301.3	0.0	301.3
December	434.6	0.0	434.6	448.0	0.0	448.0
Annual Consumption	2308.8	967.2	3276.0	2380.1	3119.8	5499.9
Average Annual Consumption Per Unit	96.2	40.3	136.5	99.2	129.9	229.1
Average Annual Consumption Per Square Foot	0.11	0.05	0.16	0.12	0.15	0.27

* *Electric energy consumed by furnace fan was negligible compared to total energy consumption so it was not considered*

TABLE XXI. HEATING AND COOLING ENERGY CONSUMPTION IN THE CHICAGO IMPROVED HIGH-RISE

Month	Energy Consumption in Therms				Primary Energy in Therms		
	Heating	Cooling	Fans	Total	Gas	Electric	Total
January	10,830.4	0.0	1,133.7	11,964.1	11,165.3	3,657.0	14,822.3
February	8,911.5	0.0	967.6	1,879.1	9,187.1	3,121.3	12,308.4
March	6,725.1	0.0	1,000.1	7,725.2	6,933.0	3,226.1	10,159.1
April	3,042.8	0.0	725.8	3,768.6	3,136.9	2,341.3	5,478.2
May	728.9	1,825.0	547.7	3,151.6	751.4	7,815.1	8,566.5
June	0.0	2,468.5	504.0	2,972.5	0.0	9,588.7	9,588.7
July	0.0	3,542.5	520.8	4,663.3	0.0	13,107.4	13,107.4
August	0.0	3,218.4	520.8	3,739.2	0.0	12,061.9	12,061.9
September	358.8	1,850.8	572.6	2,782.2	369.9	7,817.4	8,187.3
October	1,597.1	0.0	720.9	2,318.0	1,646.5	2,325.5	3,972.0
November	7,280.5	0.0	985.3	8,265.8	7,505.6	3,178.4	10,684.0
December	9,851.8	0.0	1,101.9	10,953.7	10,156.5	3,554.5	13,711.0
Annual Consumption	49,326.9	12,905.2	1,351.2	71,583.3	50,852.2	71,794.6	122,646.3
Average Annual Consumption Per Unit	234.9	61.4	44.5	340.9	242.1	341.9	584.0
Average Annual Consumption Per Square Foot	0.20	0.05	0.04	0.30	0.21	0.30	0.52

TABLE XXII. COMPARISON OF THE ENERGY REQUIREMENTS FOR HEATING AND COOLING THE IMPROVED CHICAGO RESIDENCES

Residence Type	In-Structure Energy Consumption in Therms			Primary Energy Consumption in Therms		
	Per Unit	Per Sq Ft of Floor Area*	Per Occupant	Per Unit	Per Sq Ft of Floor Area *	Per Occupant
Single-Family	736	0.43	184	918	0.54	230
Townhouse	370	0.28	93	499	0.38	125
Low-Rise	137	0.16	55	229	0.27	92
High-Rise	341	0.30	136	584	0.52	234

*Floor area includes halls, stairwells and lobbies in multifamily dwellings.

the townhouse, then by the high-rise and finally by the single-family (at twice the energy use per unit floor area that was used by the low-rise).

(3) In terms of primary energy per occupant, the low-rise (two and one-half occupants) again used the least energy, followed by the townhouse (four occupants), the single-family (four occupants) and the high-rise (two and one-half occupants), in that order. As previously stated, however, these figures are highly dependent on the number of occupants assumed per dwelling unit and are limited in usefulness as a metric for comparison.

VI. REFERENCES

1. "Local Climatological Data; Chicago, Illinois," National Oceanic and Atmospheric Administration, National Climatic Center, Ashville, NC, 1974.

2. "Annual Survey of Housing," HUD/DOC, 1974.

3. "Builder Practices: A National Survey of Characteristics and Construction Practices for All Types of One-Family Houses," NAHB Research Foundation, Inc., Rockville, MD, prepared for the National Association of Home Builders, Washington, DC, February 1974.

4. "Solar Heating and Cooling of Buildings, Volume II," Westinghouse Electric Corporation, Special Energy Systems, Baltimore, MD, prepared for the National Science Foundation, Washington, DC, May 1974.

5. "Solar Heating and Cooling of Buildings, Volume III," General Electric Corporation, Space Division, Valley Forge, Pennsylvania, prepared for the National Science Foundation, Washington, DC, May 1974.

6. Standard Handbook for Civil Engineers, F.S. Merritt, ed., McGraw-Hill Book Co., New York, NY, 1968.

7. Building Construction Handbook, F.S. Merrit, ed., McGraw-Hill Book Co., New York, NY, 1958.

8. "Residential Energy Consumption - Single-Family Housing Final Report," Report No. HUD-HAI-2, Hittman Associates, Inc., Columbia, MD, prepared for the U.S. Department of Housing and Urban Development, Contract No. H-1654, March 1973.

9. Statistical Abstract of the United States, 1974, U.S. Department of Commerce, Social and Economic Statistics Administration Bureau of the Census, U.S. Government Printing Office, Washington, DC, 1974.

10. "Residential Energy Conservation Summary Report," Report No. HUD-HAI-8, prepared for the Office of Policy Development and Research, U.S. Department of Housing and Urban Development, Contract No. H-1654, by Hittman Associates, Inc., Columbia, MD, July 1974.

11. Private communication, Mr. Donald F. Spear, NAHB Research Foundation, Inc., Rockville, MD, December 3, 1975.

12. Survey of Builder Practices for Single-Family, Townhouse, and Low-Rise Residences (unpublished), by NAHB Research Foundation Inc., Rockville, MD, prepared for Housing Industry Dynamics, Inc., Philadelphia, PA, 1975.

13. "Residential Energy Consumption - Multifamily Housing Data Acquisition," Report No. HUD-HAI-3, Hittman Associates, Inc., Prepared for the U.S. Department of Housing and Urban Development, Contract No. H-1654, October 1972.

14. "Residential Energy Consumption Multifamily Housing - Final Report," Report No. HUD-HAI-4, prepared for the Office of Policy Development and Research, U.S. Department of Housing and Urban Development, Contract No. H-1654, by Hittman Associates, Inc., June 1974.

*U.S. GOVERNMENT PRINTING OFFICE : 1978 0-254-420/6768

U.S. DEPARTMENT OF HOUSING
AND URBAN DEVELOPMENT
WASHINGTON, D.C. 20410

January 1978
HUD-PDR-250-4

Chicago