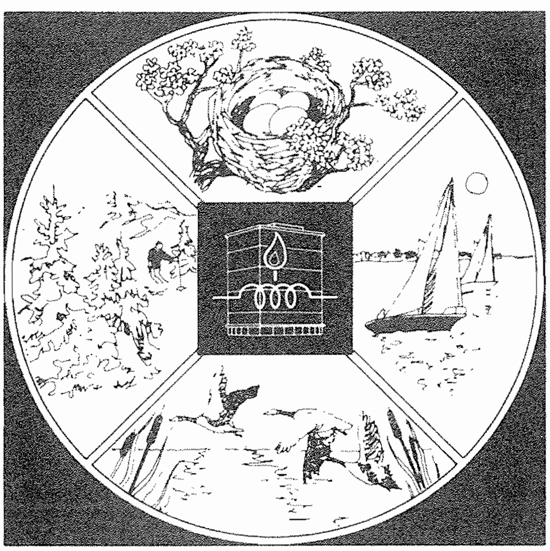
MINNEAPOLIS RESIDENTIAL ENERGY CONSUMPTION

Final Report
November 1976

Department of Housing and Urban Development

Office of the Assistant Secretary for Policy Development and Research



ENERGY CONSERVATION

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HIT-650-8

FINAL REPORT

November 1976

Contract No. H-2280R

Office of the Assistant Secretary
for
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Department of
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ACKNOWLEDGEMENTS

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Harvey M. Bernstein
Taghi Alereza

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I. INTRODUCTION

This report on residential energy consumption in Minneapolis, Minnesota, 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 Minneapolis is the eighth 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 Minneapolis residences, on the computation of heating and cooling energy requirements in the typical residences, and on the energy consumption of thermally "improved" Minneapolis residences.

The most basic location-specific factor in determining heating and cooling energy consumption is climate, which, in Minneapolis is predominantly the continental type, for the city is situated very close to the geographical center of the North America continent. There are wide variations in temperature, ample summer rainfall, and scanty winter precipitation. In general, there exists a tendency to extremes in all climatic features. Disturbances originating in the northwestern United States and many which have their origin in the southwest migrate eastward near Minneapolis to be followed by cooler, sometimes much colder, polar airmasses from the northwest and north. This cyclonic control of climate gives Minneapolis changeable weather that is stimulating and invigorating. The temperature variation from season to season is quite large. It ranges from very warm (though confortable due to low daytime humidity) in summer to very cold in winter. The normal mean temperature for the winter months of December, January, and February is about 16°F, and for the summer months of June, July, and August, about 70°F. There were 36 consecutive days during January-February 1936 when the temperature was below zero, and 11 straight days in July 1948 when it was 90° or higher.

The Minneapolis weather year is characterized by 8159 heating degree days (base 65°F) and 585 cooling degree days (base 65°F). The yearly mean wind velocity is 10.6 mph, with a fastest recorded wind velocity of 92 mph, in July 1951. There are normally 98 clear days, 103 partly cloudy days, and 164 cloudy days per year in Minneapolis (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 Minneapolis'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 Minneapolis. Based on national weather records kept since 1935, 1957 was picked as being a typical weather year for the Minneapolis area. Heating and cooling energy requirements were determined similarly for modified versions of these Minneapolis characteristic residences, incorporating various structural and systems improvements.

To identify the current trends in housing in the Minneapolis 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 three bedroom rancher.
Townhouse:	A two story structure containing eight three bedroom apartments in a line.
Low-Rise:	A two story structure containing 24 two bedroom units.
High-Rise:	A 15 story structure containing 193 one bedroom units.

n 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., heat pumps replaced electric resistance heating units, and only commercially available insulation material was added to the structure.

The energy requirements for the Minneapolis residences were calculated for 1957 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 was 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 1957 Minneapolis weather year. This approach to the development of annual loads and primary energy consumption produced data for Minneapolis 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. As would be expected for the cold Minneapolis climate, the heating load was significantly higher than the cooling load for the single-family and townhouse. Due to increased internal heat generation, the low-rise and high-rise heating and cooling loads were similar in magnitude.

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 consumed 47 percent of the energy required by the characteristic building, corresponding to both the largest reduction and the largest consumption of any structure studied. Structural modifications reduced the heating load by almost 50 percent and slightly increased the cooling load. It should be noted that the improved single-family building consumed more than twice as much primary energy as any other building on a per unit basis. It also had the highest floor area-normalized primary energy requirement encountered (0.72 therm/sq ft).

The improved townhouse consumed 52 percent of the energy consumed by the characteristic building. As was the case in the single-family residence, large heating load reductions were realized at the expense of small cooling load increases. Efficiency improvements in the HVAC system were responsible for a significant part of the energy savings. The improved townhouse had the lowest floor area-normalized primary energy requirement (0.40 therm/sq ft) of any residence studied.

The improved low-rise building required 53 percent as much primary energy as did the characteristic residence. This modest improvement must be considered in light of the fact that characteristic low-rise was by far the most efficient building studied, requiring about one third as much primary energy as the single-family building on a per unit basis. The reason for this efficiency lies in part in the fact that the Minneapolis climate is such that heating is the main requirement, and low-rise buildings exhibit large amounts of internal heat generation. The apartments were unusually small in the low-rise building as well, giving an improved floor area-normalized primary energy consumption of 0.48 therm/sq ft, more than half the value of the single-family residence.

The improved high-rise residence achieved only a 34 percent reduction in energy required, a consumption level of 66 percent that of the characteristic building. Two factors tend to limit the improvements possible in high-rise energy consumption, those being (1) large volumes of required ventilation air and (2) large amounts of non-apartment floor space such as halls and lobbies. The floor area-normalized primary energy requirement for the improved high-rise was 0.56 therm/ sq ft, higher than both the townhouse and the low-rise.

TABLE I. SUMMARY OF ANNUAL HEATING AND COOLING LOADS AND PRIMARY ENERGY REQUIREMENTS FOR THE MINNEAPOLIS 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	1410.9	712.3	499.9	223.4	178.0	135.8	160.3	105.2
Cooling load per average unit, therms	91.1	154.0	111.1	160.3	119.0	120.2	152.4	151.3
Primary energy consumption per average unit, therms*	2224.0	1053.3 (53)	882.0	466.3 (48)	795.0	420.8 (47)	665.9	438.6 (34)
Primary energy consumption per sq ft of floor area, therms	1.52	0.72	0.77	0.40	0.92	0.48	0.86	0.56

**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:*

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

TABLE II. SUMMARY OF STRUCTURAL AND SYSTEM MODIFICATIONS MADE IN IMPROVED RESIDENCES

	Glass[1] Reduction in North Face (%)	Glass[1] Reduction in South Face (%)	Addition of Weather Stripping	Addition of Storm Windows or Double Glazing	Revised Wall Insulation R Value	Revised Ceiling Insulation R Value	Revised Floor U Value	Improved Gas/Oil Furnace Efficiency	Substitution of Heat Pump for Electric Resistance Heating	Use of Heat Recovery Systems	Improved Cooling System C.O.P.
Single-Family	50	9	*	Exist	17	27	0.08	*		*	*
Town-house	50	7	*	Exist	17	27	0.08	*		*	*
Low-Rise	See note 1		*	Exist	17	27	0.1 Exists		*		*
High-Rise	See note 1		*	Exist	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 MINNEAPOLIS

Typical, or characteristic, new residential buildings for the Minneapolis 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, 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 Minneapolis 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 Minneapolis 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.

The trend in the Minneapolis area does not follow the national one. In 1970, 64.7 percent of the total stock of residential buildings was single-family units; and in 1973, 70.4 percent of the housing starts authorized by permit were in single-family dwellings.

In this context, the term "single-family residence" refers to the completely detached single-family house. Approximately 9700 such houses were built in the Minneapolis 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 Minneapolis area builders were responsible for the construction of 641 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 Minneapolis 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 Minneapolis 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

TABLE III. STRUCTURAL CHARACTERISTICS FOR TYPICAL SINGLE-FAMILY RESIDENCE - MINNEAPOLIS AREA

STRUCTURAL PARAMETERS:	
Basic House Design	3-Bedroom rancher
Foundation	Full basement
Garage/carport	2-Car garage
Floor area, ft^2	1457
Construction	Wood frame, 2x4 studs 16" on ctr
Exterior walls:	
Outside surface	1/2" hardboard siding
Sheathing	1/2" fiberboard sheathing
Insulation	3 1/2" fiberglass batts
Inside surface	1/2" gypsumboard
Ceiling insulation	Asphalt shingles, 1/2" plywood sheathing, air space, 6" fiberglass loose-fill insulation, 1/2" gypsumboard
Roof	Gable
Windows:	
Type	Wood casement
Glazing	Single with storm sash
Area, ft^2	145
Exterior doors:	
Type	Wood with storm doors
Number	Two
Total area, ft^2	40
Patio door(s):	
Type	Aluminum, sliding
Glazing	Double
Area, ft^2	40
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 (2030 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	1957

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

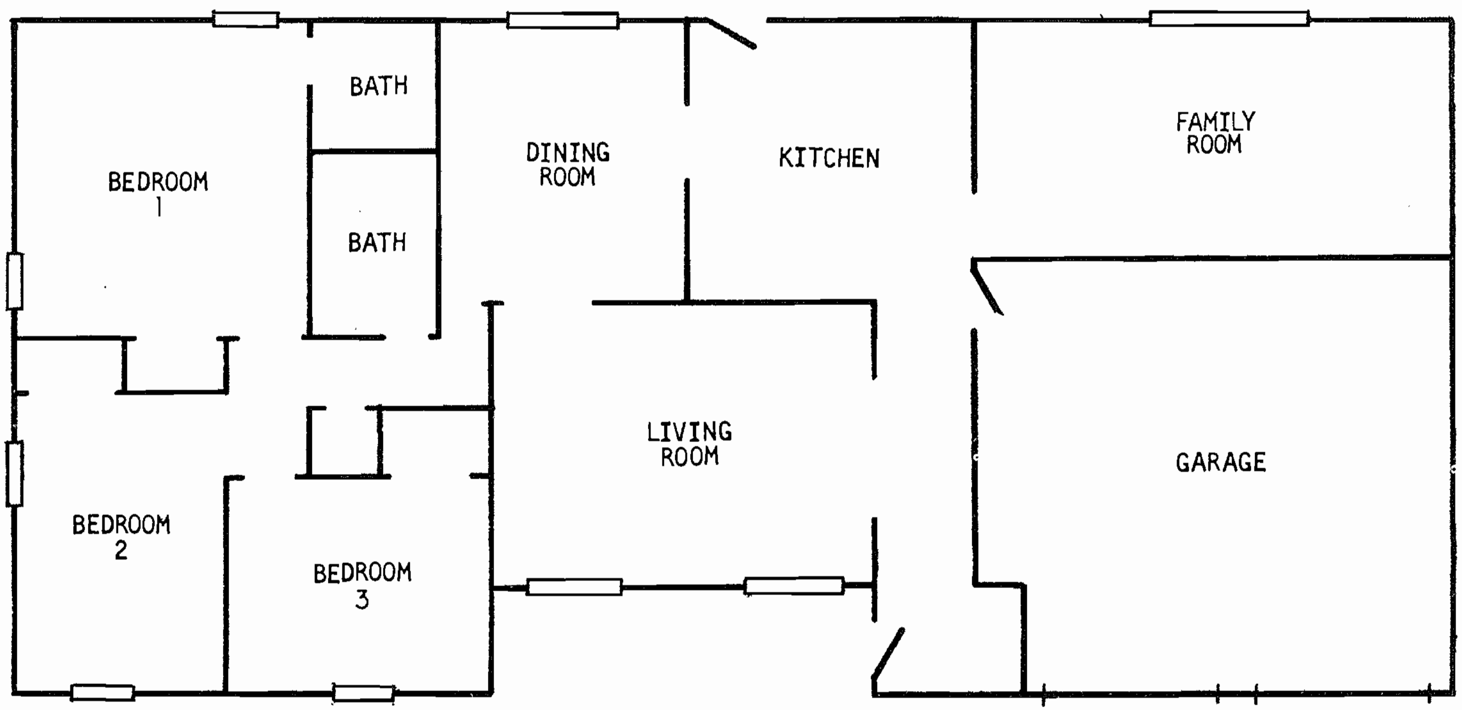

Figure 1. Floor Plan for the Characteristic Single-Family House in Minneapolis

1970, to 55.4 percent in 1973. These trends indicate that, in the future, construction of townhouse and multi-family residences will dominate in large urban areas.

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 Minneapolis area sub-sample included 3 contractors who together were responsible for the construction of 413 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 Minneapolis area townhouse residence are presented in Table IV. The floor plan for the typical Minneapolis 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 Minneapolis area, approximately 3200 multifamily dwelling units were constructed in 1974, and of these, approximately 2800 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 Minneapolis area are applicable.

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

GENERAL PARAMETERS:		
Arrangement	Rectangular structure, eight townhouse units in a row	
Basic design	Two-story, three-bedroom	
Foundation	Full basement	
DIMENSIONAL PARAMETERS:		
(Areas are per townhouse unit, not per floor level)	Intermediate Units	End Units
Floor area, ft^2	1150	1150
Exterior wall area, ft^2	617	1080
Window glass area, ft^2	110	134
Patio door, ft^2	N/A	N/A
Exterior door(s), ft^2	40	40
Roof area, per unit, ft^2	575	575
Story height, ft	9	9

CONSTRUCTION PARAMETERS:	
Construction type	Wood frame, 2x4 studs 16" on ctr
Exterior walls:	
Siding	3/8" plywood
Sheathing	1/2" nail base insulation board
Insulation	3 1/2" fiberglass batt insulation
Inside surface	1/2" Gypsumboard
Interior walls:	1/2" gypsumboard, 2x4 studs 16" on ctr, 1/2" gypsumboard
Roof	Gable
Exterior door(s)	Wood, two
Windows Glazing	Single
Windows Frames	Sliding, aluminum
Patio door: Glazing, Frames	N/A
Roof composition	Asphalt shingles, 1/2" plywood, air space, 6" fiberglass 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 Therms/year)
Clothes dryer	Gas (90 Therms/year)
Refrigerator/freezer	Electric (1830 Kw-hr/year)
Lights	Electric-incandescent (1370 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	1957

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

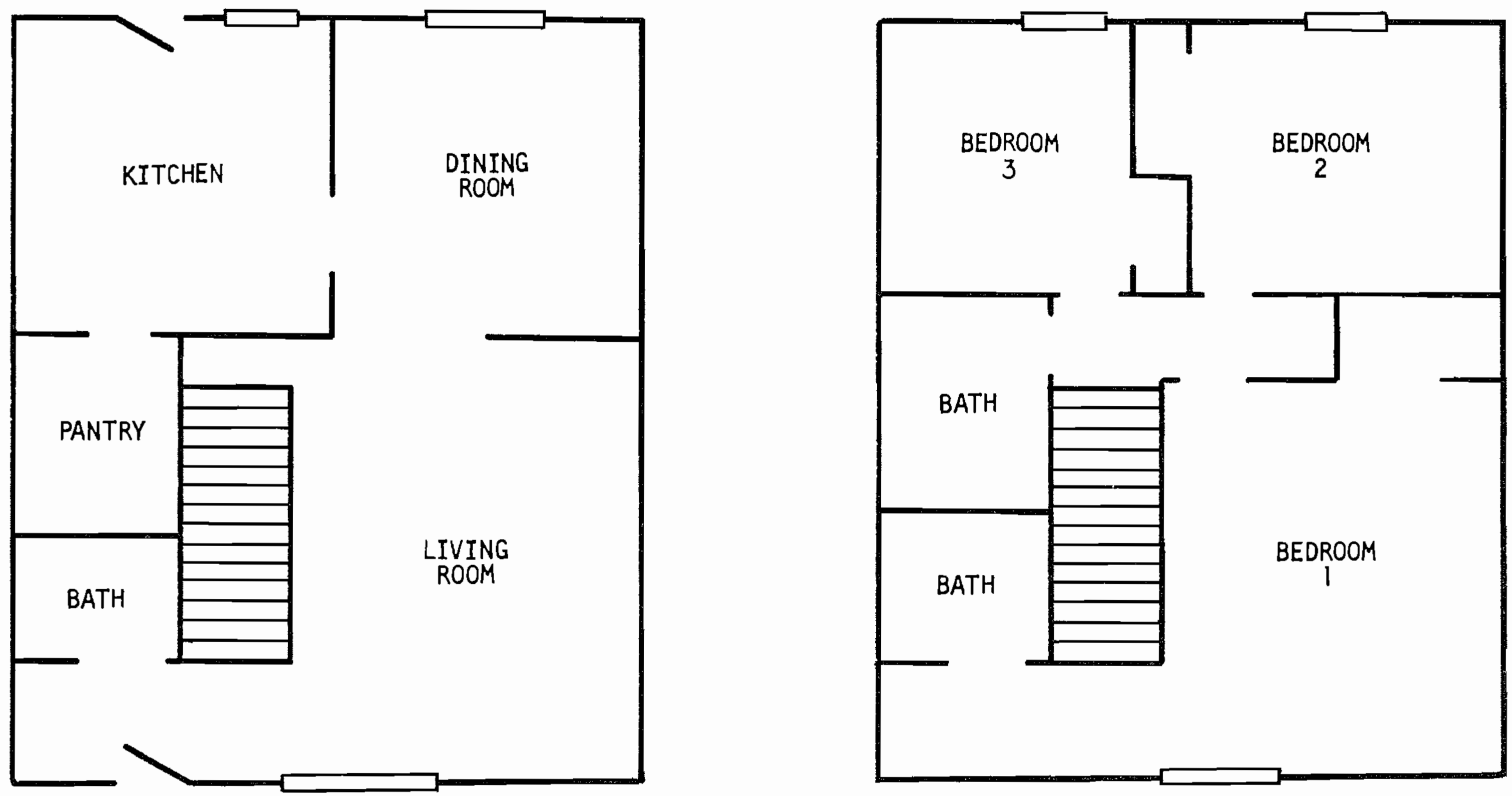

FIGURE 2. FLOOR PLAN FOR CHARACTERISTIC TOWNHOUSE RESIDENCE

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 low-rise 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 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 Minneapolis metropolitan area, approximately 2880 low-rise units were built in 1974. Builders responding to this survey were responsible for 1106 of those units, giving a 38 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.

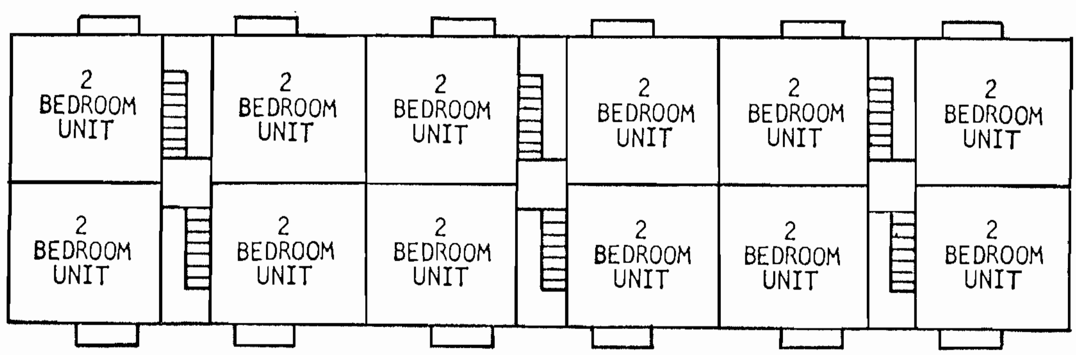

Figure 3. Floor Plan for Characteristic Low-Rise Structure

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

GENERAL PARAMETERS:		
Arrangement	Eight units around each enclosed stairwell. Three enclosed stairwells per building.	
Number of stories	Two	
Apartments	Twenty-four two-bedroom	
DIMENSIONAL PARAMETERS:		
	Interior Units	End Units
Floor area, ft^2	864	864
Exterior wall area, ft^2	243	486
Window glass, ft^2	45	45
Door(s), steel, ft^2	20	20
Patio/balcony door(s)	N/A	N/A
Roof area, ft^2	864	864
Story height, ft	9	9
CONSTRUCTION PARAMETERS:		
Construction type	Wood frame, 2x4 studs 16" on ctr	
Foundation	Slab-on-grade	
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" on ctr, 1/2" gypsumboard	
Roof	Gable	
Entrance doors, per unit	One, wood frame	
Windows and patio doors per unit:		
Glazing	Single	
Frames	Aluminum, storm sash	

Ceiling composition	Asphalt shingles, 1/2" plywood, air space, 10" fiberglass loose fill insulation, 1/2" gypsumboard
ENERGY CONSUMPTION PARAMETERS:*	
Electric metering	Individual (per apartment)
Equipment in each structure:	
Hot water heater	Electric
Clothes washers	Electric
Clothes dryers	Electric
Equipment in each apartment:	
Heating system	Baseboard, electric
Cooling system	Individual unit, electric
Cooking range/oven	Electric (2000 Kw-hr/year)
Refrigerator	Electric (1400 Kw-hr/year)
Dishwasher	Electric (280 Kw-hr/year)
Lights	Electric (1240 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, one child
Typical weather year	1957

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

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

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.

In the Minneapolis area, approximately 3200 multifamily dwelling units were constructed in 1974. Of these, approximately 320 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 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 condominum 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 Minneapolis area, the typical high-rise structure was a 15 story building, comprised of 193 one bedroom rental units. Table VI provides structural and energy consumption parameters for the typical high-rise building in Minneapolis. Figure 4 shows the typical high-rise floor plan.

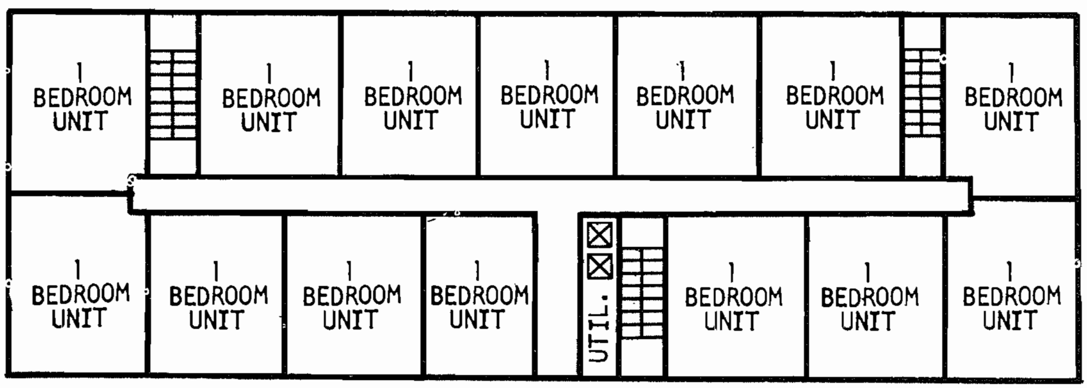

Figure 4. Floor Plan for Characteristic High-Rise Structure

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

GENERAL PARAMETERS:

Arrangement	Rectangular structure, central hall on each floor, three stairwells, two elevators
Number of stories	Fifteen
Basement	None
Apartments	First Floor: Eleven one-bedroom Other Floors: Thirteen one-bedroom — Total 193

DIMENSIONAL PARAMETERS:

	Interior Apartments	End Apartments	Halls & Lobbies	Stairwells & Elevators	Utility Rooms
Floor area, ft^2	594	600	1566 (ff)* 918 (of)**	728	1108 (ff)* 568 (of)**
Exterior wall area, ft^2	175	428		180 (ff)* 240 (of)**	440 (ff)* 240 (of)**
Roof area, ft^2	594	600	918	728	568
Window glass, ft^2	45	72	147 (ff)*		
Entrance doors, ft^2	20	20	20	20	
Story height, ft	10	10	10	10	10

CONSTRUCTION PARAMETERS:

Frame	Reinforced Concrete
Floors and roof deck	6" concrete deck
Exterior walls:	
Siding	4" brick veneer
Sheathing	4" block
Insulation	1" rigid insulation
Inside surface	1/2" gypsumboard
Roof	Flat, built-up roofing, 2" rigid insulation, air gap, 1/2" gypsumboard
Entrance doors:	
Apartments	One, metal
Lobby	Four, glass
Staircases	Three, steel
Windows:	
Glazing	Double
Frames	Sliding, aluminum

ENERGY CONSUMPTION PARAMETERS:***

Gas and Electric metering	Master (per structure)
Equipment in each structure:	
Heating system	Hot water, gas
Hot water heater	Gas
Clothes washers	Electric
Clothes dryers	Gas
Elevators	Electric
Lights, signal system, miscellaneous appliances	Electric
Equipment in each apartment:	
Cooling system	Electric
Cooking range	Electric (2000 Kw-hr/year)
Refrigerator	Electric (1400 Kw-hr/year)
Dishwasher	Electric (280 Kw-hr/year)
Lights	Electric (860 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:	Two adults
Typical weather year	1957

* 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 Minneapolis 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. Hourly Weather Data

Weather tapes of past years are available for enough weather stations throughout the United States so that a tape is likely to be available for a station near the site of any building being considered. The Load 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. Hourly Solar Radiation Data

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 the 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 Minneapolis area were calculated for the 1957 Minneapolis 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 Minneapolis 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 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 percentages 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 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. MINNEAPOLIS 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						
Hardboard Siding		0.042	0.085	48.	0.45	---
Fiberboard Sheathing	0.076	0.042	0.032	18.	0.31	---
3-½" 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	---
Plywood Sheathing		0.042	0.065	34.	0.29	---
Air Space	0.048	---	---	---	---	0.96
Loose Fill Insulation		0.50	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. MINNEAPOLIS 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	0.074					
Plywood		0.052	0.065	34.	0.29	---
Insulation Board		0.042	0.032	18.	0.31	---
3½" Batt Insulation		0.292	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Roof	0.048					
Asphalt Shingles		0.042	0.096	99.	0.26	---
Wood Sheathing		0.042	0.065	34.	0.29	---
Air Space		---	---	---	---	0.96
Loose Fill Insulation		0.50	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 IX. MINNEAPOLIS CHARACTERISITC 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	0.076	0.333	0.757	130.	0.22	---
Gypsumboard		0.042	0.032	18.	0.31	---
3½" Batt Insulation		0.292	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Roof						
Asphalt Singles	0.031	0.042	0.096	99.	0.26	---
Plywood Sheathing		0.042	0.065	34.	0.29	---
Air Gap		---	---	---	---	0.96
Loose Fill Insulation		0.833	0.0274	10.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Door						
Wood Frame	0.50	---	---	---	---	---
Floor						
Concrete Slab	0.10	---	---	---	---	---

TABLE X. MINNEAPOLIS 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	0.209					
Brick Veneer		0.333	0.757	130.	0.22	---
Concrete Block		0.667	0.60	82.	0.2	---
Rigid Insulation		0.083	---	---	---	2.78
Gypsumboard		0.042	0.093	50.	0.26	---
Roof	0.121					
Built-up Roof		0.031	0.094	70.	0.35	---
2" Rigid Insulation		---	---	---	---	4.17
6" Concrete Deck		0.500	0.54	144.	0.16	---
Air Gap		---	---	---	---	0.96
Gypsumboard		0.042	0.093	50.	0.26	---
Floor						
Concrete Slab	0.10	---	---	---	---	---

TABLE XI. HEATING AND COOLING LOADS FOR CHARACTERISTIC MINNEAPOLIS RESIDENTAL 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	271.2	0.0	853.5	0.0	1087.5	1.0	8267.9	1.9
February	218.6	0.0	671.2	0.0	779.5	6.7	5515.7	18.9
March	199.3	0.0	584.9	0.0	616.3	29.1	4158.5	192.2
April	128.8	0.0	340.1	14.2	314.9	143.5	1829.9	1537.2
May	95.7	0.0	208.2	16.4	145.0	228.1	531.9	2481.0
June	35.5	3.4	42.5	101.3	14.8	437.6	58.5	4971.9
July	4.9	42.3	0.6	335.8	0.0	776.1	12.4	8758.8
August	5.6	37.5	2.3	291.1	0.0	681.4	16.7	6701.2
September	30.0	7.2	48.0	109.1	17.9	368.0	219.8	3253.2
October	74.3	0.7	177.7	21.2	129.2	157.0	1131.6	1318.4
November	155.4	0.0	478.2	0.0	494.5	18.6	3757.0	132.1
December	191.6	0.0	591.8	0.0	672.5	9.5	5447.8	40.9
Annual Load	1410.9	91.1	3999.0	889.1	4272.1	2856.6	30947.7	29407.7
Annual Load Per Unit	1410.9	91.1	499.9	111.1	178.0	119.0	160.3	152.4

for each residential building type. These percentages represent the portions of the total annual loads for the entire building which can be attributed to air infiltration.

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

	Heating Load	Cooling Load
Single-Family	34	38
Townhouse	36	18
Low-Rise	52	4
High-Rise	94*	4

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	0.33	0.02
Townhouse	0.15	0.02
Low-Rise	0.10	0.01
High-Rise	0.19	0.01

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 the higher stack effect, this comparison is not quite valid for the high-rise structure.

**This figure includes ventilation-related infiltration and reflects the fact that the warming internal heat gain is nearly balanced by the cooling skin load.*

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

The energy consumptions 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 both heating and cooling, the thermostat was assumed to be 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 July 1 and September 1;
efficiency = 0.7

Cooling - central, electric, forced air system;
loads not met between September 1 and July 1;
C.O.P. = 1.7

b. Townhouse

Heating - gas fired furnace, forced air system;
loads not met between June 15 and September 15;
efficiency = 0.7

Cooling - central, electric, forced air system;
loads not met between September 15 and June 15;
C.O.P. = 1.7

c. Low-Rise

Heating - individual electric baseboard radiation systems;
loads not met between May 15 and September 25;
efficiency = 1.0

Cooling - electric window units;
loads not met between September 25 and May 15;
C.O.P. = 1.5

d. <u>High-Rise</u>

Heating - central gas fired furnace, forced 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;
efficiency = 1.5

Detailed analyses of the energy consumed for heating and cooling of the Minneapolis 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

**Primary energy is defined as the input energy to generation plants or gas distribution centers; electric 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 MINNEAPOLIS CHARACTERISTIC SINGLE-FAMILY RESIDENCE

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS		
Month	Heating	Cooling	Total*	Gas	Electric	Total*
January	387	0	387	399	0	399
February	312	0	312	321	0	321
March	284	0	284	292	0	292
April	184	0	184	189	0	189
May	136	0	136	140	0	140
June	50	2	52	51	6	57
July	0	25	32	0	80	80
August	0	22	30	0	71	71
September	42	4	46	43	13	56
October	106	0	106	109	0	109
November	222	0	222	229	0	229
December	273	0	273	281	0	281
Annual Consumption	1996	53	2049	2054	170	2224
Average Annual Consumption Per Square Foot	1.37	0.03	1.40	1.40	0.11	1.52

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 MINNEAPOLIS CHARACTERISTIC TOWNHOUSE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total*	Gas	Electric	Total*
January	1218	0	1218	1256	0	1256
February	958	0	958	987	0	987
March	585	0	585	603	0	603
April	340	0	340	350	0	350
May	297	0	297	306	0	306
June	60	59	119	62	190	252
July	0	197	197	0	635	635
August	0	171	171	0	551	551
September	68	64	132	70	206	276
October	254	0	254	262	0	262
November	683	0	683	704	0	704
December	845	0	845	871	0	871
Annual Consumption	5308	491	5799	5471	1582	7053
Average Annual Consumption Per Unit	663	61	725	683	198	882
Average Annual Consumption Per Square Foot	0.57	0.05	0.63	0.59	0.17	0.77

Electric energy consumed by the furnace fan was negligible compared to total energy consumption and was not considered.

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

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS
Month	Heating	Cooling	Total*	Total*
January	1087	0	1087	3508
February	779	0	779	2514
March	616	0	616	1987
April	314	0	314	1015
May	145	152	297	958
June	0	291	291	939
July	0	517	517	1669
August	0	454	454	1465
September	17	245	263	849
October	129	0	129	416
November	494	0	494	1595
December	672	0	672	2169
Annual Consumption	4258	1660	5918	19088
Average Annual Consumption Per Unit	177	69	247	795
Average Annual Consumption Per Sq. Ft.	0.20	0.08	0.28	0.92

* *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 MINNEAPOLIS CHARACTERISTIC HIGH-RISE

Month	Energy Consumption in Therms				Primary Energy in Therms		
	Heating	Cooling	Fans	Total	Gas	Electric	Total
January	11811.3	0.0	1071.3	12882.6	12176.6	3455.8	15632.4
February	7879.6	0.0	861.4	[illegible]741.0	8123.3	2778.7	10902.0
March	5940.7	0.0	895.6	6836.3	6124.4	2889.0	9013.4
April	2614.1	0.0	654.7	3268.8	2694.9	2111.9	4806.8
May	759.8	1654.0	549.8	2963.6	783.3	7109.0	7892.3
June	0.0	3314.6	463.2	3777.8	0.0	12186.4	12186.4
July	0.0	5839.2	478.6	6317.8	0.0	20380.0	20380.0
August	0.0	4467.4	478.6	4946.0	0.0	15954.8	15954.8
September	314.0	2168.8	575.6	3008.4	323.7	8691.6	9015.3
October	1616.6	0.0	646.6	2263.2	1666.6	2085.8	3752.4
November	5367.1	0.0	734.4	6101.5	5533.0	2369.0	7902.0
December	7782.6	0.0	950.8	8733.4	[illegible]023.3	3067.0	11090.3
Annual Consumption	44085.8	17444.0	8310.6	69840.4	45449.3	83079.0	128528.3
Average Annual Consumption Per Unit	228.4	90.4	43.0	361.8	235.5	430.4	665.9
Average Annual Consumption Per Square Foot*	0.29	0.11	0.05	0.46	0.30	0.55	0.86

Halls, lobbies and stairwells included.

TABLE XVI. COMPARISON OF THE ENERGY REQUIREMENTS FOR HEATING AND COOLING THE CHARACTERISTIC MINNEAPOLIS 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	2049	1.40	512	2224	1.52	556
Townhouse	725	0.63	181	882	0.77	220
Low-Rise	247	0.28	82	795	0.92	265
High-Rise	362	0.46	181	666	0.86	333

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 floor areas* for individual units for the single-family, townhouse, low-rise, and high-rise were 1.00, 0.80, 0.59, and 0.53, whereas the corresponding ratios for "per unit" primary energy consumption were 1.00, 0.40, 0.36, and 0.30. 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 energy consumption on the basis of floor areas, the single-family residence consumed the most in-structure and primary energy, while the low-rise consumed the least in-structure and the townhouse the least primary energy. This change in relative amounts of consumption is due to the fact that the low-rise consumed more electricity as opposed to fossil fuel than did the townhouse.

When comparing the primary energy consumption of the residences on the basis of number of occupants, the townhouse had the lowest and the single-family had the highest consumption per occupant. The number of occupants for the various residences were defined as four per single-family unit, four per townhouse, three per low-rise apartment, and two 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 low-rise and high-rise residences, the hall, lobby and stairwell floor areas were assigned in equal portions to each dwelling unit.*

V. ENERGY CONSUMPTION OF IMPROVED MINNEAPOLIS 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:

(a) Improved Single-Family Detached

Heating - improved gas furnace efficiency, added flue gas heat recovery device, efficiency = 0.83

Cooling - improved cooling C.O.P. of 2.7

(b) Improved Townhouse

Heating - improved gas furnace efficiency, added flue gas heat recovery device, efficiency = 0.83

Cooling - improved cooling C.O.P. of 2.7

(c) Improved Low-Rise

Heating - substitution of electric heat pump for existing electric resistance heating, C.O.P. = 1.5

Cooling - heat pump, C.O.P. = 2.5

(d) Improved High-Rise

Heating - improved furnace efficiency, flue gas heat recovery device added, efficiency = 0.78

Cooling - improved C.O.P. of 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 Minneapolis 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 Minneapolis 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 Minneapolis characteristic residences, shown previously in Table XVI.

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

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

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

Month	Single-Family		Townhouse		Multifamily Low-Rise		Multifamily High-Rise	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
January	164.2	0.0	471.1	0.0	846.8	1.1	5033.6	7.4
February	120.0	0.0	326.5	0.0	608.7	12.9	3888.6	59.9
March	100.8	0.0	248.5	4.4	479.4	46.4	2821.1	323.7
April	54.7	3.8	118.9	59.9	247.0	154.4	1195.0	1660.0
May	29.8	4.7	37.8	87.1	121.6	240.9	332.3	2677.4
June	5.3	19.7	1.5	208.4	10.5	426.7	48.9	4807.7
July	0.1	60.3	0.0	368.8	0.0	712.6	13.3	8018.2
August	0.8	46.9	0.0	314.3	0.0	653.1	11.1	6306.6
September	9.9	15.7	8.4	169.3	7.8	385.4	105.6	3322.6
October	32.4	2.9	54.3	67.2	78.6	190.4	632.6	1635.7
November	84.2	0.0	222.1	2.0	359.3	34.0	2461.3	279.8
December	110.1	0.0	298.4	1.2	499.0	18.6	3763.2	105.3
Annual Load	712.3	154.0	1787.5	1282.6	3258.7	2885.5	20306.6	29204.3
Annual Load per Dwelling Unit	712.3	154.0	223.4	160.3	135.8	120.2	105.2	151.3

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

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS		
Month	Heating	Cooling	Total*	Gas	Electric	Total*
January	197.8	0.0	197.8	203.9	0.0	203.9
February	144.6	0.0	144.6	149.0	0.0	149.0
March	121.4	0.0	121.4	125.1	0.0	125.1
April	65.9	0.0	65.9	67.9	0.0	67.9
May	35.9	0.0	35.9	37.0	0.0	37.0
June	6.4	7.3	13.7	6.6	23.5	30.1
July	0.0	22.3	22.3	0.0	71.9	71.9
August	0.0	17.4	17.4	0.0	56.1	56.1
September	11.9	5.8	17.7	12.2	18.7	30.9
October	39.0	0.0	39.0	40.2	0.0	40.2
November	101.4	0.0	101.4	104.5	0.0	104.5
December	132.6	0.0	132.6	136.7	0.0	136.7
Annual Consumption	856.9	52.8	909.7	883.1	170.2	1053.3
Average Annual Consumption Per Square Foot	0.58	0.03	0.62	0.60	0.11	0.72

**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 MINNEAPOLIS IMPROVED TOWNHOUSE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total*	Gas	Electric	Total*
January	567.6	0.0	567.6	585.1	0.0	585.1
February	393.4	0.0	393.4	405.5	0.0	405.5
March	299.4	0.0	299.4	308.6	0.0	308.6
April	143.2	22.2	165.4	147.6	71.6	219.2
May	45.5	32.2	77.7	46.9	103.9	150.8
June	0.0	77.2	77.2	0.0	249.0	249.0
July	0.0	136.6	136.6	0.0	440.6	440.6
August	0.0	116.4	116.4	0.0	375.5	375.5
September	0.0	62.7	62.7	0.0	202.2	202.2
October	65.4	24.9	90.3	67.4	80.3	147.7
November	267.6	0.0	267.6	275.9	0.0	275.9
December	359.5	0.0	359.5	370.6	0.0	370.6
Annual Consumption	2141.6	472.2	2613.8	2207.6	1523.1	3730.7
Average Annual Consumption Per Unit	267.7	59.0	326.7	275.9	190.4	466.3
Average Annual Consumption Per Square Foot	0.73	0.05	0.28	0.24	0.16	0.40

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

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

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS
Month	Heating	Cooling	Total*	Total*
January	564.4	0.0	564.4	1820.9
February	405.8	0.0	405.8	1309.0
March	319.6	0.0	319.6	1030.9
April	164.6	0.0	164.6	530.9
May	81.0	96.3	177.3	571.9
June	0.0	170.7	170.7	550.7
July	0.0	288.6	288.6	930.9
August	0.0	261.2	261.2	842.6
September	0.0	154.1	154.1	497.2
October	52.4	0.0	52.4	169.0
November	239.5	0.0	239.5	772.6
December	332.6	0.0	332.6	1072.9
Annual Consumption	2160.0	971.0	3131.0	10099.5
Average Annual Consumption Per Unit	90.0	40.4	130.4	420.8
Average Annual Consumption Per Sq Ft	0.10	0.04	0.15	0.48

***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 MINNEAPOLIS IMPROVED HIGH-RISE

Month	Energy Consumption in Therms				Primary Energy in Therms		
	Heating	Cooling	Fans	Total	Gas	Electric	Total
January	6453.3	0.0	911.0	7364.3	6652.9	2938.7	9591.6
February	4985.4	0.0	783.2	5768.6	5139.6	2526.4	7666.0
March	3616.8	0.0	826.1	4442.9	3728.6	2664.8	6393.4
April	1532.0	0.0	623.3	2155.3	1579.4	2010.6	3590.0
May	426.0	1070.9	534.8	2041.7	439.1	5211.9	5651.0
June	0.0	1923.0	463.2	2386.2	0.0	7697.4	7697.4
July	0.0	3207.3	478.6	3685.9	0.0	11890.0	11890.0
August	0.0	2522.6	478.6	3001.2	0.0	9681.3	9681.3
September	135.4	1329.0	523.0	1987.0	139.2	5974.2	6113.4
October	811.0	0.0	622.5	1433.5	836.0	2008.0	2844.0
November	3155.5	0.0	786.1	3941.6	3253.0	2535.8	5788.8
December	4824.6	0.C	862.3	5686.9	4973.8	2781.6	7755.4
Annual Consumption	25940.0	10052.8	7902.7	43895.5	26741.6	57920.7	84662.3
Average Annual Consumption Per Unit	134.4	52.0	40.9	227.4	138.5	300.1	438.6
Average Annual Consumption Per Square Foot*	0.17	0.07	0.05	0.29	0.17	0.39	0.56

**Halls, lobbies and stairwells included.*

TABLE XXII. COMPARISON OF THE ENERGY REQUIREMENTS FOR HEATING AND COOLING THE IMPROVED MINNEAPOLIS 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	911	0.62	228	1059	0.72	265
Townhouse	327	0.28	81	466	0.40	112
Low-Rise	131	0.15	44	421	0.48	141
High-Rise	227	0.29	114	439	0.56	220

(2) In terms of primary energy per unit floor area, the townhouse used the least energy, followed by the low-rise, then by the high-rise and finally by the single-family (at almost twice the energy use per unit floor area of that used by the townhouse).

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

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