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ORIGINAL

MIAMI 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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MIAMI RESIDENTIAL ENERGY CONSUMPTION

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FINAL REPORT

November 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

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Harvey M. Bernstein
Taghi Alereza

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I. INTRODUCTION

This report on residential energy consumption in Miami, Florida, 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 Miami is the seventh 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 Miami residences, on the computation of heating and cooling energy requirements in the typical residences, and on the energy consumption of thermally "improved" Miami residences.

The most basic location-specific factor determining heating and cooling energy consumption is climate. The climate of Miami is essentially subtropical marine, featured by a long, warm summer, with abundant rainfall, followed by a mild, dry winter. The marine influence is evidenced by the low daily range of temperature and the rapid warming of cold airmasses which pass to the east of the State. Located as it is, the Miami area is subject to winds from the east or southeast about half the time, which tend to keep the average daily range of temperature (difference between maximum and minimum) around 10°F. The Miami weather year is characterized by 206 heating degree days (base 65°F) and 4038 cooling degree days (base 65°F). The yearly mean wind velocity is 9.1 mph, with a fastest recorded wind velocity of 74 mph, in August 1964. There are normally 77 clear days, 170 partly coudy days, and 118 cloudy days per year in Miami (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 Miami'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 Miami. Based on national weather records kept since 1935, 1960 was picked as being a typical weather year for the Miami area. Heating and cooling energy requirements were determined similarly for modified versions of these Miami characteristic residences, incorporating various structural and systems improvements.

To identify the current trends in housing in the Miami 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 four story structure containing 16 one bedroom and 16 two bedroom units.
High-Rise:	A 10 story structure containing 150 two bedroom and 58 one 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., heat pumps replaced electric resistance heating units, and only commercially available insulation material was added to the structure.

The energy requirements for the Miami residences were calculated for the 1960 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 1960 Miami weather year. This approach to the development of annual loads and primary energy consumption produced data for Miami 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 warm Miami climate, the cooling loads for all four residences were significantly larger than the heating loads.

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 Miami single-family residence consumed 41 percent of the primary energy required by the characteristic building. This reduction was due to a substantially decreased cooling load brought about by installing reflective glass and shading the south face during summer months, as well as substituting an electric heat pump for the existing electric resistance heating and electric air conditioning. The structure had a floor area-normalized primary energy requirement of 0.67 therm/sq ft, owing almost exclusively to cooling, as would be expected for the warm Miami climate.

The improved townhouse consumed 49 percent of the primary energy consumed by the characteristic townhouse. This reduction was brought about through improvements similar to those for the single-family residence, although the cooling load was not reduced as much as in the single-family residence. The townhouse had the lowest floor area-normalized primary energy requirement of any residence studied, 0.58 therm/sq ft.

The improved low-rise consumed half the primary energy consumed by the characteristic structure. This energy savings was due primarily to a more efficient heating and cooling system. The low-rise had the lowest energy consumption on a per unit basis, and floor area-normalized primary energy requirement of 0.59 therm/sq ft, nearly as low as that of the townhouse.

The improved high-rise consumed 46 percent of the energy required by the characteristic building. The characteristic building was not extremely efficient, using more energy than all but the single-family building, but improvements were limited by two features inherent in high-rise structures: large amounts of required mechanical ventilation and large non-apartment sections of floor space such as halls and lobbies. The floor area-normalized primary energy requirement for the high-rise was 0.73 therm/sq ft, the largest of any residence studied.

TABLE I. SUMMARY OF ANNUAL HEATING AND COOLING LOADS AND PRIMARY ENERGY REQUIREMENTS FOR THE MIAMI 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	86.2	39.8	23.1	12.7	13.0	2.6	10.8	5.9
Cooling load per average unit, therms	1325.5	859.0	794.3	586.4	541.6	404.8	751.6	593.8
Primary energy consumption per average unit, therms*	2787.0	1156.0 (59)	1589.0	772.1 (51)	1064.3	525.8 (50)	1866.3	867.7 (54)
Primary energy consumption per sq ft of floor area, therms	1.63	0.67	1.20	0.58	1.19	0.59	1.58	0.73

**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. ENERGY CONSERVATION MODIFICATIONS FOR CHARACTERISTIC MIAMI RESIDENCES

	Glass Reduction (%)	Addition of Weather Stripping	Use of Reflective Glass	Use of Exterior Shading Surfaces	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	Improved Cooling System C.O.P.
Single-Family	25	*	*	Shade South Face All Year	11	27	0.1		*	*
Town-house	25	*	*	Shade South Face All Year	11	27	0.1		*	*
Low-Rise	25	*	*		11	27	0.1 Exists	*		*
High-Rise	25	*	*		12	17	0.1 Exists			*

Change made in Characteristic Residence.

III. CHARACTERIZATION OF TYPICAL RESIDENTIAL STRUCTURES IN MIAMI

Typical, or characteristic, new residential buildings for the Miami 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 Miami 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 Miami 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 Miami metropolitan area, this trend is even more pronounced. The total residential housing stock for the SMSA, as of 1970, was comprised of 56.4 percent single-family dwellings; while in 1973, only 23.7 percent of the housing starts authorized by permit were in single-family units.

In this context, the term "single-family residence" refers to the completely detached single-family house. Approximately 8300 such houses were built in the Miami 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 Miami area builders were responsible for the construction of 281 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 Miami 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 Miami 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 - MIAMI AREA

STRUCTURAL PARAMETERS:

Basic House Design	3-Bedroom Rancher
Foundation	Slab-on-Grade (No Insulation)
Garage/carport	2-Car garage
Floor area, ft^2	1705
Construction	Solid Masonry
Exterior walls:	
Outside surface	Stucco Finish
Sheathing	8" Concrete Block
Insulation	Air Space
Inside surface	1/2" Gypsumboard
Ceiling insulation	Built Up Roof, 1/2" Plywood Sheathing, Air Space, 4" Fiberglass Loose-Fill insulation, 1/2" Gypsumboard
Roof	Gable
Windows:	
Type	Aluminum Awning
Glazing	Single
Area, ft^2	150
Exterior doors:	
Type	Wood
Number	Two
Total area, ft^2	40
Patio door(s):	
Type	Aluminum, Sliding
Glazing	Single
Area, ft^2	40
Orientation	South

ENERGY CONSUMPTION PARAMETERS:*

Energy consuming equipment:	
Heating system	Electric, forced air
Cooling system	Electric, central
Hot water heater	Electric (9317 Kw-hr/year)
Cooking range/oven	Electric (2340 Kw-hr/year)
Clothes dryer	Electric (2637 Kw-hr/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	1960

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

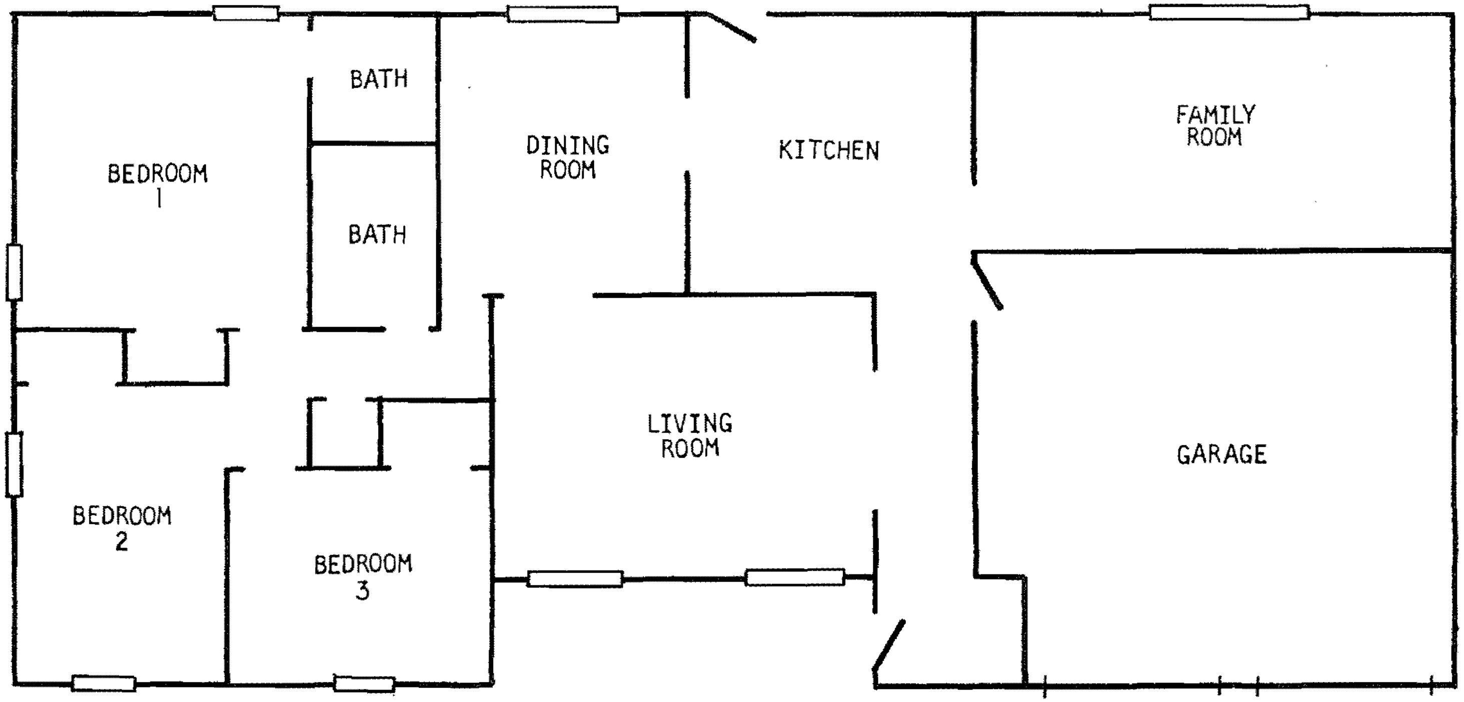

Figure 1. Floor Plan for the Characteristic Single-Family House in Miami

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 Miami area sub-sample included 10 contractors who together were responsible for the construction of 960 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 Miami area townhouse residence are presented in Table IV. The floor plan for the typical Miami 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 Miami area, approximately 13,000 multifamily dwelling units were constructed in 1974, and of these, approximately 9100 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 Miami area are applicable.

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

GENERAL PARAMETERS:

Arrangement	Rectangular structure, eight townhouse units in a row
Basic design	Two-story, three-bedroom
Foundation	Slab-on-grade

DIMENSIONAL PARAMETERS:

(Areas are per townhouse unit, not per floor level)	Intermediate Units	End Units
Floor area, ft^2	1320	1320
Exterior wall area, ft^2	529	1100
Window glass area, ft^2	129	153
Patio door, ft^2	40	40
Exterior door(s), ft^2	20	20
Roof area, per unit, ft^2	660	660
Story height, ft	9	9

CONSTRUCTION PARAMETERS:

Construction type	Masonry
Exterior walls:	
Siding	Stucco and Felt
Sheathing	8" concrete block
Insulation	Air space
Inside surface	1/2" gypsumboard
Interior walls:	1/2" gypsumboard, 2x4 studs 16" on ctr, 1/2" gypsumboard
Roof	Gable
Exterior door(s)	Steel, one
Windows Glazing	Single
Frames	Sliding, aluminum, no storm sash
Patio door:	
Glazing	Single
Frames	Aluminum Sliding
Roof composition	Asphalt shingles, 1/2" plywood, air space, 6" fiberglass loose fill insulation, 1/2" gypsumboard

ENERGY CONSUMPTION PARAMETERS:*

Heating system	Forced air, electric
Cooling system	Forced air, electric
Hot water heater	Electric (9317 Kw-hr/year)
Cooking range	Electric (2340 Kw-hr/year)
Clothes dryer	Electric (2637 Kw-hr/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	1960

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

Second Floor

First Floor

Figure 2. Floor Plan for Characteristic Townhouse

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 Miami metropolitan area, approximately 9100 low-rise units were built in 1974. Builders responding to this survey were responsible for 4332 of those units, giving a 48 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.

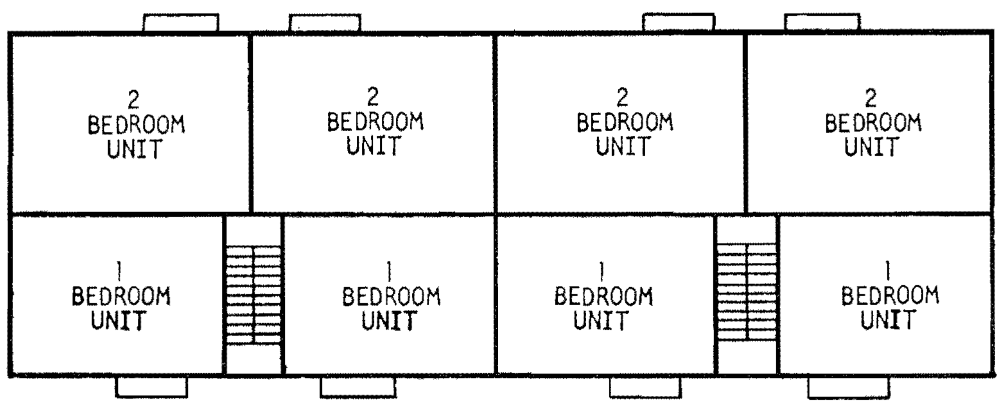

Figure 3. Floor Plan for Characteristic Low-Rise Structure

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

GENERAL PARAMETERS:

Arrangement	Four units around each enclosed stairwell. Two enclosed stairwells per building.
Number of stories	Three
Apartments	Sixteen one-bedroom, Sixteen two-bedroom.

DIMENSIONAL PARAMETERS:

	Interior Units	End Units
Floor area, ft^2	800[1], 980[2]	800[1], 980[2]
Exterior wall area, ft^2	196[1], 212[2]	421[1], 456[2]
Window glass, ft^2	52[1], 68[2]	52[1], 68[2]
Door(s), steel, ft^2	20	20
Patio/balcony door(s), aluminum, ft^2	40	40
Roof area, ft^2	800	980
Story height, ft	9	9

CONSTRUCTION PARAMETERS:

Construction type	Concrete Block
Foundation	Slab-on-grade
Exterior walls:	
Siding	Stucco finish
Sheathing	8" concrete block
Insulation	1" air space
Inside surface	1/2" gypsumboard
Interior Walls:	1/2" gypsumboard, 2x3 studs on 16" ctrs, 1/2" gypsumboard
Roof	Flat
Entrance doors, per unit	One, Wood frame
Windows and patio doors per unit:	
Glazing	Single
Frames	Aluminum
Ceiling composition	Built Up Roof Polyurethane Insulation Concrete Deck 1/2" Gypsumboard

ENERGY CONSUMPTION PARAMETERS:*

Electric metering	Individual (per apartment)
Gas metering	Individual (per structure)
Equipment in each structure:	
Clothes washers	Electric
Clothes dryers	Gas
Equipment in each apartment:	
Hot water heater	Individual unit, gas
Heating system	Individual forced air furnaces, gas
Cooling system	Individual units, electric
Cooking range/oven	Electric (2000 kw-hr/yr)
Refrigerator	Electric (1400 Kw-hr/year)
Dishwasher	Electric (280 Kw-hr/year)
Lights	Electric (1070[1], 1290[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	1960

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

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

1 One-Bedroom apartment
2 Two-Bedroom apartment

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 Miami area, approximately 13,000 multifamily dwelling units were constructed in 1974. Of these, approximately 3900 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 Miami area, the typical high-rise structure was a 10 story building, comprised of 150 two bedroom and 58 one bedroom condo units. Table VI provides structural and energy consumption parameters for the typical high-rise building in Miami. Figure 4 shows the typical high-rise floor plan.

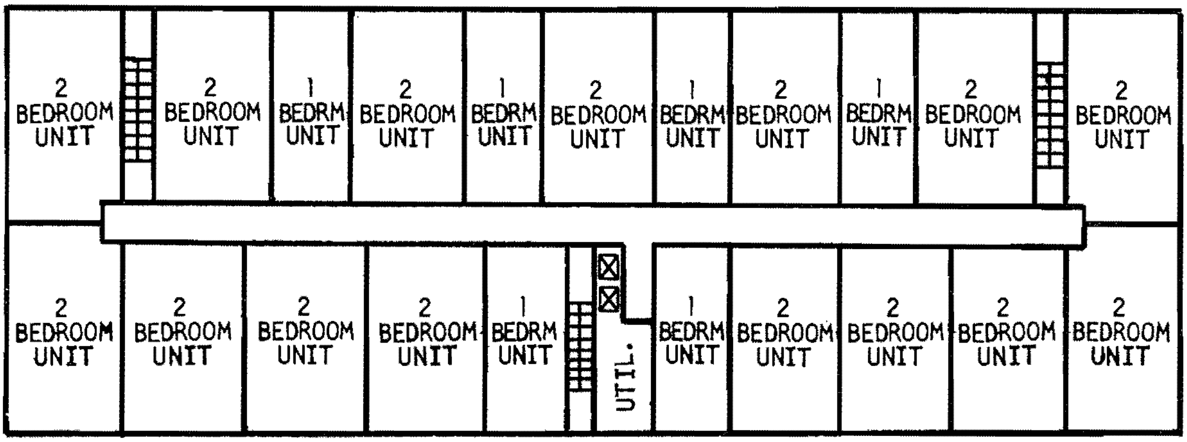

Figure 4. Floor Plan for Characteristic High-Rise Structure

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

GENERAL PARAMETERS:

Arrangement	Rectangular structure, central hall on each floor, three stairwells, two elevators		
Number of stories	Ten		
Basement	None		
Apartments	First floor:	four one-bedroom fifteen two-bedroom	Total 208
	Other floors:	six one-bedroom fifteen two-bedroom	

DIMENSIONAL PARAMETERS:

	Interior Apartments	End Apartments	Halls & Lobbies	Stairwells & Elevators	Utility Rooms
Floor area, ft^2	700 (1-br) 1155 (2-br)	1178 (2-br)	2336 (ff)* 1713 (of)**	1008	987 (ff)* 210 (of)**
Exterior wall area, ft^2	98.6 (1-br) 176.6 (2-br)	393 (2-br)		180 (ff)* 240 (of)**	330 (ff)* 150 (of)**
Roof area, ft^2	700 (1-br) 1155 (2-br)	1178 (2-br)	1713	1008	210
Window glass, ft^2	48 (1-br) 100 (2-br)	244 (2-br)	240 (ff)*		
Entrance doors, ft^2	20	20	20	20	
Story height, ft	10	10	10	10	10

CONSTRUCTION PARAMETERS:

Frame	Block
Floors and roof deck	6" concrete deck
Exterior walls:	
Siding	5/8" stucco
Sheathing	8" block
Insulation	Air gap
Inside surface	1/2" gypsumboard
Roof	Flat, built-up roofing, 1" rigid insulation, air gap, 1/2" gypsumboard
Entrance doors:	
Apartments	One, metal
Lobby	Three, metal
Staircases	Three, metal
Windows:	
Glazing	Single
Frames	Sliding, aluminum

ENERGY CONSUMPTION PARAMETERS:***

Gas and Electric metering	Individual (per unit)
Equipment in each structure:	
Hot water heater	Electric
Clothes washers	Electric
Clothes dryers	Electric
Elevators	Electric
Lights, signal system, miscellaneous appliances	Electric
Equipment in each apartment:	
Heating system, cooling system	Heat pump, electric
Cooking range	Electric (2000 Kw-hr/year)
Refrigerator	Electric (1400 Kw-hr/year)
Dishwasher	Electric (280 Kw-hr/year)
Lights:	
1-bedroom unit	Electric (1000 Kw-hr/year)
2-bedroom unit	Electric (1650 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	1960

* 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 Miami 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 Miami area were calculated for the 1960 Miami weather year. The method used for making the calculation 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 Miami 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.*

**For example, a small heating load, caused by an early morning temperature drop in November, would not be met in anticipation of a day-time cooling load.*

TABLE VII. MIAMI 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)
<u>Wall</u>	0.361					
Stucco		0.083	0.417	116.	0.19	---
Concrete Block		0.666	0.60	82.	0.20	---
Air Space		---	---	---	---	1.01
Gypsumboard		0.042	0.093	50.	0.26	---
<u>Roof</u>	0.0677					
Built-up Roof		0.031	0.094	70.	0.35	---
Plywood Sheathing		0.042	0.064	34.	0.29	---
Air Space		---	---	---	---	0.96
Loose Fill Insulation		0.333	0.0274	10.	0.18	---
Plaster		0.042	0.130	45.	0.26	---
<u>Door</u>						
Wood Frame	0.67	---	---	---	---	---
<u>Floor</u>						
Concrete Slab	0.10	---	---	---	---	---

TABLE VIII. MIAMI 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						
Stucco		0.083	0.417	116.	0.19	---
Concrete Block		0.666	0.6	82.	0.20	---
Air Space	0.361	---	---	---	---	1.01
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	0.049	---	---	---	---	0.96
Loose Fill Insulation		0.50	0.0274	10.	0.18	---
Plaster		0.042	0.130	45.	0.26	---
Door						
Steel	0.56	---	---	---	---	---
Floor						
Concrete Slab	0.10	---	---	---	---	---

TABLE IX. MIAMI 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						
Stucco		0.083	0.417	116.	0.19	---
Concrete Block	0.361	0.666	0.60	82.	0.20	---
Air Gap		---	---	---	---	1.01
Gypsumboard		0.042	0.093	50.	0.26	---
Roof						
Built-up Roof		0.031	0.094	70.	0.35	---
1½" Rigid Insulation		---	---	---	---	4.17
2" Concrete Deck	0.160	0.167	0.54	144.	0.16	---
Air Gap		---	---	---	---	0.96
Gypsumboard		0.042	0.093	50.	0.26	---
Door						
Steel Door	0.35	---	---	---	---	---
Floor						
Concrete Slab	0.10	---	---	---	---	---

TABLE X. MIAMI CHARACTERISTIC HIGH-RISE RESIDENCE STRUCTURAL PARAMETERS

Components	"U" Value ($Btu/hr\text{-}ft^2\text{-}°F$)	Thickness (ft)	Conductivity (Btu/hr-ft-°F)	Density (lb/ft^3)	Specific Heat (Btu/lb-°F)	"R" Value ($hr\text{-}ft^2\text{-}°F/Btu$)
Wall	0.361					
Stucco		0.083	0.417	116.	0.19	---
Concrete Block		0.666	0.60	82.	0.20	---
Air Gap		---	---	---	---	1.01
Gypsumboard		0.042	0.093	50.	0.26	---
Roof	0.184					
Built-up Roof		0.031	0.094	70.	0.35	---
1" Rigid Insulation		---	---	---	---	2.78
6" Concrete Deck		0.50	0.54	144.	0.16	---
Air Gap		---	---	---	---	0.96
Gypsumboard		0.042	0.093	50.	0.26	---
Floor						
Concrete Slab	0.10	---	---	---	---	---

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 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	30	26
Townhouse	50	21
Low-Rise	35	12
High-Rise	77	29

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	0.02	0.02
Townhouse	0.01	0.01
Low-Rise	0.01	0.01
High-Rise	0.01	0.02

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.

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 - electric, forced air system;
loads not met between March 15 and December 15;
efficiency = 0.9

Cooling - central, electric, forced air system;
loads met all year;
C.O.P. = 1.7

b. Townhouse

Heating - electric, forced air system
loads not met between March 15 and December 15;
efficiency = 0.9

Cooling - central, electric, forced air system;
loads met all year
C.O.P. = 1.7

c. Low-Rise

Heating - individual central electric forced air system;
loads not met between March 5 and December 20;
efficiency = 0.9

Cooling - individual electric units, forced air system;
loads met all year;
C.O.P. = 1.7

d. High-Rise

Heating - heat pump; loads not met between March 5 and December 20;
efficiency = 2.6

Cooling - heat pump;
loads met all year;
C.O.P. = 1.5

Detailed analyses of the energy consumed for heating and cooling of the Miami 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; 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 XI. HEATING AND COOLING LOADS FOR CHARACTERISTIC MIAMI 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	23.5	43.4	47.7	292.4	102.8	610.3	770.8	7712.3
February	20.4	35.4	36.0	297.5	56.9	600.1	392.1	7611.4
March	20.4	46.6	45.0	329.8	65.0	673.2	452.7	7969.9
April	1.3	83.6	3.6	430.1	0.9	926.5	10.4	11302.2
May	0.2	117.3	0.2	535.5	0.0	1169.6	0.5	13777.7
June	0.0	154.0	0.0	666.4	0.0	1394.0	0.0	30574.6
July	0.0	186.6	0.0	787.1	0.0	1640.5	0.0	19082.6
August	0.0	196.2	0.0	778.6	0.0	1596.3	0.0	19477.7
September	0.0	174.2	0.0	785.4	0.0	1521.5	0.0	17961.2
October	0.0	152.6	0.0	676.6	0.0	1346.4	0.0	16353.0
November	0.3	104.5	0.5	520.2	0.6	1020.0	4.3	12299.1
December	20.1	31.1	52.2	255.0	86.1	501.5	624.3	5982.8
Annual Load	86.2	1325.5	185.2	6354.6	312.3	12999.9	2255.1	156326.8
Annual Load Per Unit	86.2	1325.5	23.1	794.3	13.0	541.6	10.8	751.6

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

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS
Month	Heating	Cooling	Total*	Total*
January	25	25	50	161
February	22	20	42	135
March	22	27	49	158
April	0	49	49	158
May	0	69	69	222
June	0	90	90	292
July	0	109	109	354
August	0	115	115	372
September	0	102	102	330
October	0	89	89	289
November	0	61	61	198
December	21	18	39	125
Annual Consumption	90	774	864	2787
Average Annual Consumption Per Square Foot	0.05	0.45	0.51	1.63

**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 MIAMI CHARACTERISTIC TOWNHOUSE

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS
Month	Heating	Cooling	Total*	Total*
January	53	172	225	725
February	40	175	215	693
March	50	194	244	787
April	0	253	253	816
May	0	315	315	1017
June	0	392	392	1267
July	0	463	463	1493
August	0	458	458	1479
September	0	462	462	1493
October	0	398	398	1286
November	0	306	306	988
December	58	150	208	670
Annual Consumption	201	3738	3939	12714
Average Annual Consumption Per Unit	25	467	492	1589
Average Annual Consumption Per Sq Ft	0.02	0.35	0.37	1.20

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 MIAMI CHARACTERISTIC LOW-RISE

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS
Month	Heating	Cooling	Total*	Total*
January	114	359	473	1525
February	63	353	416	1341
March	0	396	396	1280
April	0	545	545	1759
May	0	688	688	2222
June	0	820	820	2645
July	0	965	965	3113
August	0	939	939	3031
September	0	895	895	2887
October	0	792	792	2556
November	0	600	600	1938
December	95	295	390	1258
Annual Consumption	272	7647	7919	25555
Average Annual Consumption Per Unit	11	318	329	1064
Average Annual Consumption Per Sq Ft	0.01	0.36	0.37	1.19

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 MIAMI CHARACTERISTIC HIGH-RISE

Month	Energy Consumption in Therms				Primary Energy in Therms
	Heating	Cooling	Fans	Total	Total (Electric)
January	296	5141	515	5953	19205
February	150	5074	465	5690	18357
March	174	5313	575	6003	19364
April	0	7534	499	8034	25916
May	0	9185	515	9700	31293
June	0	20383	499	20882	67361
July	0	12721	515	13237	42701
August	0	12985	515	13500	43551
September	0	11974	499	12473	40236
October	0	10902	515	11417	36831
November	0	8199	499	8698	28060
December	241	3988	515	4744	15304
Annual Consumption	861	113402	6073	120337	388184
Average Annual Consumption Per Unit	4.1	545.2	29.2	579.5	1866.3
Average Annual Consumption Per Square Foot *	0.0	0.46	0.02	0.49	1.58

**Halls, lobbies and stairwells included.*

TABLE XVI. COMPARISON OF THE ENERGY REQUIREMENTS FOR HEATING AND COOLING THE CHARACTERISTIC MIAMI 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	864	0.51	216	2787	1.63	697
Townhouse	492	0.37	123	1589	1.20	397
Low-Rise	329	0.37	132	1064	1.19	426
High-Rise	549	0.46	196	1772	1.50	666

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" comparisons. 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, 0.77, 0.52, and 0.69, whereas the corresponding ratios for "per unit" primary energy consumption were 1.00, 0.57, 0.38, and 0.67. 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 Miami residences on the basis of floor area, the townhouse and low-rise units consumed the least in-structure and primary energy, while the single-family residence consumed the most.

When comparing the primary energy consumption of the residences on the basis of number of occupants, the high-rise 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, 2.5 per low-rise apartment, and 2.8 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.*

V. ENERGY CONSUMPTION OF IMPROVED MIAMI 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	11	27
Townhouse	11	11	27
Low-Rise	11	17	27
High-Rise	11	12	17

In addition, the south faces of the single-family and townhouse buildings were shaded all year. 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 - substitution of heat pump for existing electric system, C.O.P. = 2.6

Cooling - heat pump with improved C.O.P. of 2.5

(b) Improved Townhouse

Heating - substitution of heat pump for existing electric system, C.O.P. = 2.6

Cooling - heat pump with improved C.O.P. of 2.5

(c) Improved Low-Rise

Heating - substitution of heat pump for existing electric system, C.O.P. = 2.6

Cooling - heat pump with improved C.O.P. of 2.5

(d) Improved High-Rise

Heating - no improvement

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. Detailed energy consumption data for heating and cooling the modified Miami 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 Miami characteristic residences, shown previously in Table XVI.

Comparison of the primary energy consumption of the improved Miami 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 townhouse, high-rise, and single-family, in that order.

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

(3) In terms of primary energy per occupant, the townhouse (four occupants) again used the least energy, followed by the low-rise (2.5 occupants), the single-family (four occupants) and the high-rise (2.8 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.

TABLE XVII. HEATING AND COOLING LOADS FOR IMPROVED MIAMI 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	11.1	27.5	31.4	195.7	25.0	504.6	438.6	6174.6
February	10.6	21.4	20.5	197.6	11.0	506.8	217.9	6024.0
March	9.8	29.1	23.3	228.6	12.0	554.7	251.9	6295.6
April	0.5	55.3	0.9	328.5	0.0	711.7	6.3	9029.1
May	0.0	76.1	0.0	416.0	0.0	851.9	0.4	10847.5
June	0.0	99.5	0.0	512.2	0.0	989.6	0.0	13240.1
July	0.0	118.2	0.0	596.6	0.0	1133.2	0.0	14812.3
August	0.0	127.2	0.0	592.4	0.0	1118.4	0.0	15344.9
September	0.0	113.8	0.0	590.9	0.0	1099.1	0.0	14268.6
October	0.0	98.0	0.0	486.8	0.0	976.2	0.0	12852.6
November	0.0	69.0	0.0	366.4	0.0	786.9	0.9	9676.3
December	7.8	23.9	25.6	179.7	15.3	483.5	315.4	4953.4
Annual Load	39.8	859.0	101.7	4691.4	63.3	9716.6	1231.4	123519.0
Annual Load per Dwelling Unit	39.8	859.0	12.7	586.4	2.6	404.8	5.9	593.8

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

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS
Month	Heating	Cooling	Total*	Total*
January	4.2	11.0	15.2	49.0
February	4.0	8.5	12.5	40.3
March	3.7	11.6	15.3	49.3
April	0.0	22.1	22.1	71.3
May	0.0	30.4	30.4	98.0
June	0.0	39.8	39.8	128.4
July	0.0	47.3	47.3	152.6
August	0.0	50.9	50.9	164.2
September	0.0	45.5	45.5	146.8
October	0.0	39.2	39.2	126.4
November	0.0	27.6	27.6	89.0
December	3.0	9.5	12.5	40.3
Annual Consumption	14.9	343.4	358.3	1155.8
Average Annual Consumption Per Square Foot	0.01	0.20	0.21	0.67

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 MIAMI IMPROVED TOWNHOUSE

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS
Month	Heating	Cooling	Total*	Total*
January	12.0	78.3	90.3	291.3
February	7.9	79.0	86.9	280.3
March	8.9	91.4	100.3	323.5
April	0.0	131.4	131.4	423.9
May	0.0	166.4	166.4	536.8
June	0.0	204.9	204.9	660.9
July	0.0	238.6	238.6	769.6
August	0.0	236.9	236.9	764.2
September	0.0	236.3	236.3	762.2
October	0.0	194.7	194.7	628.0
November	0.0	146.5	146.5	472.6
December	9.8	71.9	81.7	263.5
Annual Consumption	38.6	1876.3	1914.9	6177.0
Average Annual Consumption Per Unit	4.8	234.5	239.3	772.1
Average Annual Consumption Per Sq Ft	0.0	0.18	0.18	0.58

**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 MIAMI IMPROVED LOW-RISE

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS
Month	Heating	Cooling	Total*	Total*
January	9.6	201.8	211.4	681.9
February	4.2	702.7	206.9	667.4
March	0.0	221.9	221.9	715.8
April	0.0	284.7	284.7	918.4
May	0.0	340.7	340.7	1099.0
June	0.0	395.8	395.8	1276.8
July	0.0	453.3	453.3	1462.2
August	0.0	447.3	447.3	1442.9
September	0.0	439.6	439.6	1418.0
October	0.0	390.5	390.5	1259.6
November	0.0	314.7	314.7	1015.1
December	5.9	193.4	199.3	642.9
Annual Consumption	19.5	3892.3	3911.8	12618.7
Average Annual Consumption Per Unit	0.8	162.2	163.0	525.8
Average Annual Consumption Per Sq Ft	0.0	0.18	0.18	0.59

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 MIAMI IMPROVED HIGH-RISE

Month	Energy Consumption in Therms: Heating	Cooling	Fans	Total	Primary Energy in Therms: Total (Electric)
January	168.7	2469.8	515.8	3154.3	10175.1
February	83.8	2409.6	465.9	2959.3	9546.1
March	96.9	2518.2	515.8	3130.9	10099.6
April	0.0	3611.6	499.2	4110.8	13260.6
May	0.0	4339.0	515.8	4854.8	15660.5
June	0.0	5296.0	499.2	5795.2	18694.2
July	0.0	5294.9	515.8	6440.7	20776.4
August	0.0	6137.9	515.8	6653.7	21463.5
September	0.0	5707.4	499.2	6206.6	20021.3
October	0.0	5141.0	515.8	5656.8	18247.7
November	0.0	3870.5	499.2	4369.7	14095.8
December	121.3	1981.3	515.8	2618.4	8446.4
Annual Consumption	470.7	49407.2	6073.3	55951.2	180487.7
Average Annual Consumption Per Unit	2.2	237.5	29.2	268.9	867.7
Average Annual Consumption Per Square Foot *	0.0	0.20	0.02	0.22	0.73

Halls, lobbies and stairwells included.

TABLE XXII. COMPARISON OF THE ENERGY REQUIREMENTS FOR HEATING AND COOLING THE IMPROVED MIAMI 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	358	0.21	90	1156	0.67	289
Townhouse	239	0.18	60	772	0.58	193
Low-Rise	163	0.18	65	526	0.59	210
High-Rise	269	0.22*	96	868	0.73*	310

**Floor area includes halls, stairwells and lobbies.*

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