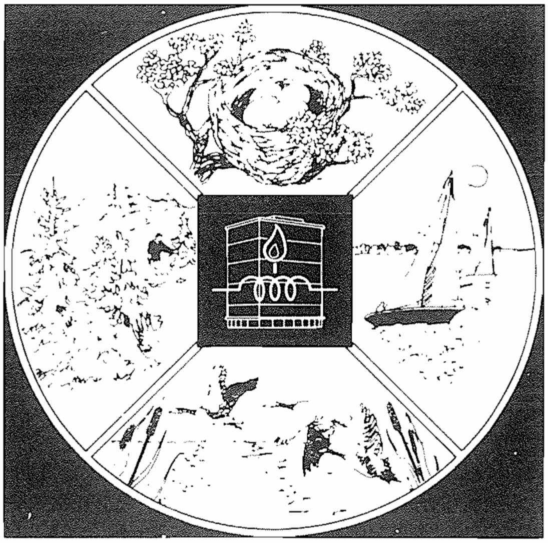
LOS ANGELES RESIDENTIAL ENERGY CONSUMPTION

Final Report
September 1976

Department of Housing and Urban Development

Office of the Assistant Secretary for Policy Development and Research



ENERGY CONSERVATION

LOS ANGELES RESIDENTIAL ENERGY CONSUMPTION

HIT-650-6

FINAL REPORT

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for
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Department of
Housing and Urban Development

HITTMAN ASSOCIATES, INC.
COLUMBIA, MARYLAND 21045

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Harvey M. Bernstein
Taghi Alereza

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (CONTINUED)

I. INTRODUCTION

This report on residential energy consumption in Los Angeles, California, 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 Los Angeles is the sixth 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 Los Angeles residences, on the computation of heating and cooling energy requirements in the typical residences, and on the energy consumption of thermally "improved" Los Angeles residences.

The most basic location-specific factor in determining heating and cooling energy consumption is climate, which for Los Angeles, is normally pleasant and mild through the year. The Pacific Ocean is the primary moderating influence, but coastal mountain ranges lying along the north and east sides of the Los Angeles coastal basin act as a buffer against extremes of summer heat and winter cold occurring in desert and plateau regions in the interior. A variable balance between mild sea breezes, and either hot or cold winds from the interior, results in some variety in weather conditions, but temperature and humidity are usually well within the limits of human comfort.

The Los Angeles weather year is characterized by 1245 heating degree days (base 65°F) and 1185 cooling degree days (base 65°F). The yearly mean wind velocity is 6.2 mph, with a fastest recorded wind velocity of 49 mph, in January 1946. There are normally 187 clear days, 104 partly cloudy days, and 74 cloudy days per year in Los Angeles (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 Los Angeles'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 Los Angeles. Based on national weather records kept since 1935, 1951 was picked as being a typical weather year for the Los Angeles area. Heating and cooling energy requirements were determined similarly for modified versions of these Los Angeles characteristic residences, incorporating various structural and systems improvements.

To identify the current trends in housing in the Los Angeles 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 building containing 12 one bedroom and 12 two bedroom units.
High-Rise:	A 15 story building with 89 one bedroom and 90 two bedroom units.

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

The energy requirements for the Los Angeles residences were calculated for 1951 weather year using a two-step process. In the first step, the hourly heating and cooling loads were calculated for each dwelling unit. Calculations were made using a computer program whose inputs included design and materials of the structure, building surroundings, internal thermal loads (lights, appliances, and occupants), hourly weather data, and pertinent astronomy of the sun. Included in this program was the calculation of heating and cooling loads (both sensible and latent) due to the infiltration of outside air. In the second step, the monthly and annual energy required to meet the heating and cooling loads 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 1951 Los Angeles weather year. This approach to the development of annual loads and primary energy consumption produced data for Los Angeles 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. The cooling load for the single family unit was moderately larger than the heating load, and due to increased internal heat generation, the cooling load for the remaining residences was much larger than the heating load.

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

The improved single-family residence required 55 percent of the primary energy consumed by the characteristic structure. This savings was due in part to a heating and cooling load reduction caused by structural modifications including added insulation and weatherstripping, and also due to a more efficient heating and cooling system. The structure consumed more energy per unit than any other residence, and had the next to highest floor area-normalized primary energy requirement (0.31 therm/sq ft).

The improved townhouse required 57 percent of the primary energy consumed by the characteristic townhouse, a result obtained by modifications similar to those made to the single-family building. However, the load reduction played a rather minor role in the overall improvement, owing to the fact that the characteristic residence's loads were very small. The improved townhouse required only 0.24 therm/sq ft of floor area.

The improved low-rise consumed 55 percent of the primary energy required by the characteristic building. This was one of the largest percent reductions of any residence, a surprising result, considering the fact that the characteristic low-rise was the most efficient building studied. The improved low-rise had a floor area-normalized primary energy requirement of 0.2 therm/sq ft, slightly higher than that of the townhouse and lower than the other two residences.

The improved high-rise consumed 82 percent of the primary energy required by the characteristic building. This very small savings was due to three facts, the first being the characteristic building required very little energy and the second two being typical of all high-rises: large amounts of required ventilation, (which introduces significant amounts of unconditioned outside air to the building) and much non-apartment floor space such as halls and lobbies, which require heating and cooling.

TABLE I. SUMMARY OF ANNUAL HEATING AND COOLING LOADS AND PRIMARY ENERGY REQUIREMENTS FOR THE LOS ANGELES 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	254.8	143.3	72.0	31.6	27.1	10.7	40.2	30.8
Cooling load per average unit, therms	359.9	314.6	291.4	284.7	222.0	198.2	211.9	166.0
Primary energy consumption per average unit, therms*	961.0	530.8 (45)	575.0	329.1 (43)	411.0	223.6 (45)	427.7	348.4 (18)
Primary energy consumption per sq ft of floor area, therms	0.56	0.31	0.44	0.25	0.53	0.27	0.43	0.35

**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 LOS ANGELES RESIDENCES

	Glass[1] Reduction in North Face (%)	Glass[1] Reduction in South Face (%)	Addition of Weather Stripping	Use of Reflective Glass	Revised Wall Insulation R Value	Revised Ceiling Insulation R Value	Revised Floor U Value	Improved Gas/Oil Furnace Efficiency	Improved Cooling System C.O.P.
Single-Family	25	25	*		17	27	0.1 Exists	*	*
Town-house	25	25	*		17	27	0.1	*	*
Low-Rise	See Note 1		*	*	17	27	0.1 Exists	*	*
High-Rise	See Note 1		*	*	11 Exists	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 LOS ANGELES

Typical, or characteristic, new residential buildings for the Los Angeles 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 Los Angeles 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 Los Angeles 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 Los Angeles metropolitan area, this trend is even more pronounced. In 1970, the total stock of residential units in the SMSA included 60.1 percent single-family buildings; and in 1973, only 22.0 percent of the building starts in the residential market were in single-family buildings.

In this context, the term "single-family residence" refers to the completely detached single-family house. Approximately 9450 such houses were built in the Los Angeles 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 Los Angeles area builders were responsible for the construction of 1470 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 Los Angeles 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 Los Angeles 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 Los Angeles SMSA, the portion of all housing units started which were in structures with five units or more has been over 69

TABLE III. STRUCTURAL CHARACTERISTICS FOR TYPICAL SINGLE-FAMILY RESIDENCES - LOS ANGELES AREA

STRUCTURAL PARAMETERS:	
Basic House Design	3-Bedroom Rancher, 9 ft. Ceiling Height
Foundation	Slab-on-Grade with Perimeter Insulation
Garage/carport	2-Car Garage
Floor area, ft^2	1705
Construction	Wood Frame, 2x4 Studs 16" on ctr
Exterior walls:	
Outside surface	1" Stucco and Felt
Sheathing	None
Insulation	3 1/2" Fiberglass Batts
Inside surface	1/2" Gypsumboard
Ceiling insulation	Asphalt Shingles, 1/2" Plywood Sheathing, Air Space, 3 1/2" Fiberglass Batts, 1/2" Gypsumboard
Roof	Gable
Windows:	
Type	Aluminum Sliders
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	80
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	Electric (2340 Kw-hr/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	1951

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

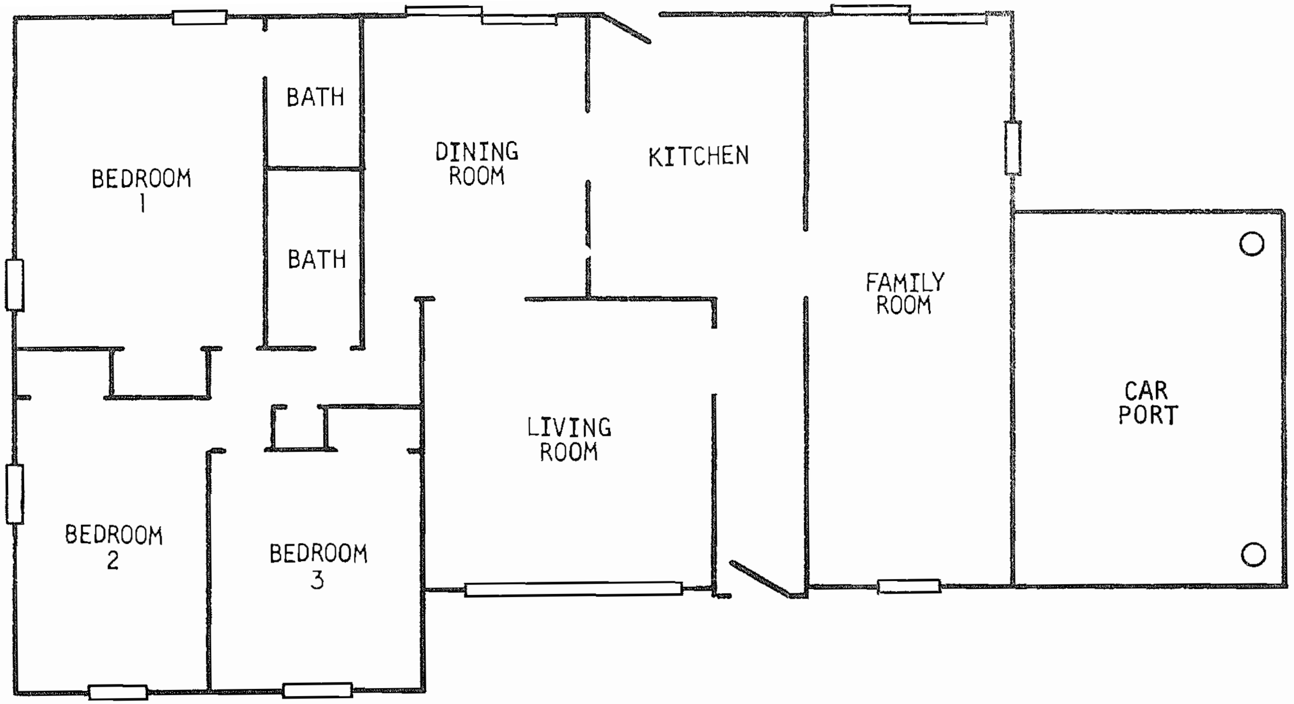

Figure 1. Floor Plan for the Characteristic Single-Family House in Los Angeles

percent since 1970, and in 1969, it was 66 percent. In the nation, the portion of private housing starts which were for single-family detached residences has decreased steadily. from 79.5 percent in 1960, to 65.4 percent in 1965, to 56.8 percent in 1970, to 55.4 percent in 1973. These trends indicate that, in the future, construction of townhouse and 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 Los Angeles area sub-sample included 6 contractors who together were responsible for the construction of 926 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 Los Angeles area townhouse residence are presented in Table IV. The floor plan for the typical Los Angeles 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 Los Angeles area, approximately 14,400 multifamily dwelling units were constructed in 1974, and of these, approximately 12,960 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 Los Angeles area are applicable.

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

GENERAL PARAMETERS:		
Arrangement	Rectangular structure, eight townhouse units in a row	
Basic design	Two-story, three-bedroom	
Foundation	Slab-on-grade (no insulation)	
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	Wood frame, 2x4 studs 16" on ctr	
Exterior walls:		
Siding	1" stucco and felt	
Sheathing	None	
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)	One, wood frame	
Windows Glazing	Single	
Windows Frames	Sliding, Aluminum	
Patio door:		
Glazing	Single	
Frames	Aluminum Sliding	
Roof composition	Asphalt shingles, 1/2" plywood, air space, 3 1/2" fiberglass batt 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	Electric (2340 Kw-hr/year)	
Clothes dryer	Gas (90 Therms/year)	
Refrigerator/freezer	Electric (1830 Kw-hr/year)	
Lights	Electric-incandescent (1570 Kw-hr/year)	
Color TV	Electric (500 Kw-hr/year)	
Furnace fan	Electric (394 Kw-hr/year)	
Dishwasher	Electric (363 Kw-hr/year)	
Clothes washer	Electric (103 Kw-hr/year)	
Iron	Electric (144 Kw-hr/year)	
Coffee maker	Electric (106 Kw-hr/year)	
Miscellaneous	Electric (1200 Kw-hr/year)	
HEATING/COOLING LOAD PARAMETERS:		
Dwelling facing	North	
People per unit	Two adults, two children	
Typical weather year	1951	

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

Figure 2. Floor Plan for Characteristic Townhouse

The 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 per-cent 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 Los Angeles metropolitan area, approximately 12,960 low-rise units were built in 1974. Builders responding to this survey were responsible for 624 of those units, giving a five 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.

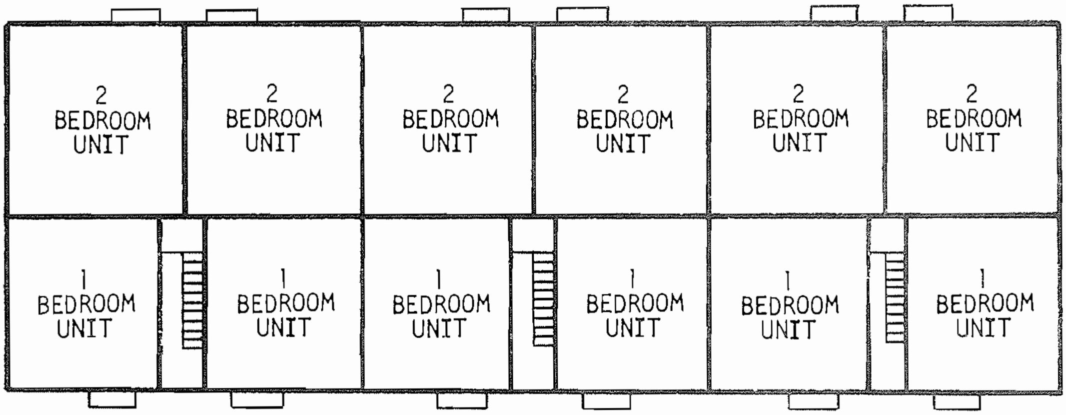

Figure 3. Floor Plan for Characteristic Low-Rise Structure

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

GENERAL PARAMETERS:		
Arrangement	Eight units around each enclosed stairwell. Three enclosed stairwells per building.	
Number of stories	Two	
Apartments	Twelve one-bedroom, Twelve two-bedroom.	
DIMENSIONAL PARAMETERS:		
	Interior Units	End Units
Floor area, ft^2	750[1], 900[2]	750[1], 900[2]
Exterior wall area, ft^2	391[1], 208[2]	616[1], 451[2]
Window glass, ft^2	45[1], 54[2]	45[1], 54[2]
Door(s), steel, ft^2	20	20
Patio/balcony door(s), aluminum, ft^2	40	40
Roof area, ft^2	750[1], 900[2]	750[1], 900[2]
Story height, ft	9	9
CONSTRUCTION PARAMETERS:		
Construction type	Wood frame, 2x4 studs 16" on ctr	
Foundation	Slab-on-grade	
Exterior walls:		
Siding	1/2" stucco and felt over metal lath	
Sheathing	None	
Insulation	2 1/4" fiberglass batt insulation	
Inside surface	1/2" gypsumboard	
Interior Walls:	1/2" gypsumboard, 2x3 studs on 16" ctrs, 1/2" gypsumboard	
Roof	Shed	
Entrance doors, per unit	One, Wood frame	
Windows and patio doors per unit:		
Glazing	Single	
Frames	Aluminum	
Ceiling composition	Asphalt shingles, 1/2" plywood, air space, 3 1/2" fiberglass batt insulation, 1/2" gypsumboard	

ENERGY CONSUMPTION PARAMETERS:*	
Electric metering	Individual (per apartment)
Gas metering	Master (per structure)
Equipment in each structure:	
Hot water heater	Gas
Clothes washers	Electric
Clothes dryers	Gas
Equipment in each apartment:	
Heating system	Individual forced air furnaces, gas
Cooling system	Individual units, electric
Cooking range/oven	Gas (68 Therms/year)
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	1951

* 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 Los Angeles area, approximately 14,400 multifamily dwelling units were constructed in 1974. Of these, approximately 1440 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 Los Angeles area, the typical high-rise structure was a 15 story building, comprised of 90 two bedroom and 89 one bedroom rental units. Table VI provides structural and energy consumption parameters for the typical high-rise building in Los Angeles. Figure 4 shows the typical high-rise floor plan.

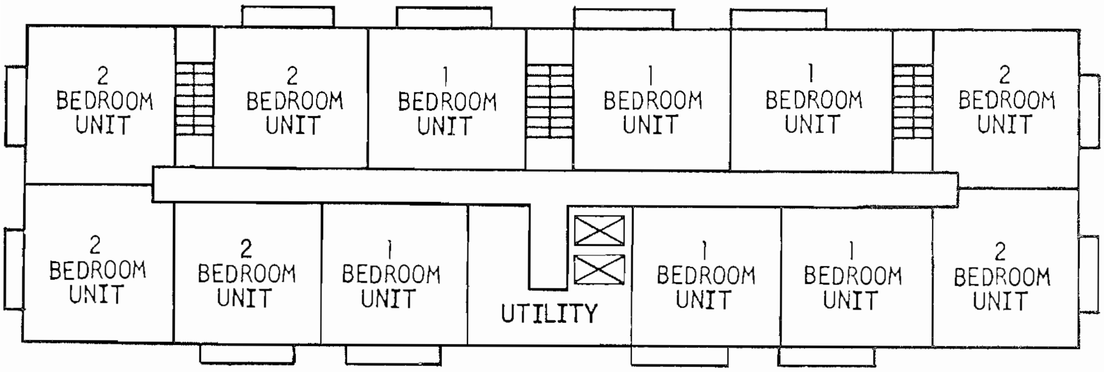

Figure 4. Floor Plan for Characteristic High-Rise Structure

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

GENERAL PARAMETERS:

Arrangement	Rectangular structure, central hall on each floor, three stairwells, two elevators
Number of stories	Fifteen
Basement	None
Apartments	First floor: five one-bedroom, six two-bedroom; Other floors: six one-bedroom, six two-bedroom; Total 179

DIMENSIONAL PARAMETERS:

	Interior Apartments	End Apartments	Halls & Lobbies	Stairwells & Elevators	Utility Rooms
Floor area, ft^2	696 (1-br) 899 (2-br)	896 (2-br)	1464 (ff)* 930 (of)**	864	522 (ff)* 360 (of)**
Exterior wall area, ft^2	120 (1-br) 160 (2-br)	405 (2-br)		200 (ff)* 240 (of)**	522 (ff)* 360 (of)**
Roof area, ft^2	696 (1-br) 899 (2-br)	896 (2-br)	930	864	360
Window glass, ft^2	45 (1-br) 75 (2-br)	120 (2-br)	160 (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	
Exterior walls:	
Siding	4" precast concrete
Sheathing	None
Insulation	3 1/2" batt insulation
inside surface	1/2" gypsumboard
Roof	Flat, built-up roofing, 2" rigid insulation, 2" concrete deck, air gap, 1/2" gypsumboard
Entrance doors:	
Apartments	One, metal
Lobby	Four, wood
Staircases	Three, steel
Windows:	
Glazing	Single
Frames	Sliding, aluminum

ENERGY CONSUMPTION PARAMETERS:***

Gas and Electric metering	Master (per structure)
Equipment in each structure:	
Central heating system	Gas
Central cooling system	Electric
Hot water heater	Gas
Clothes washers	Electric
Clothes dryers	Gas
Elevators	Electric
Lights, signal system, miscellaneous appliances	Electric
Equipment in each apartment:	
Cooking range	Gas (68 therms/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 (1290 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	1951

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

A. Description of the Computer Program Used for Load Calculations

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

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

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

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

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

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

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

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

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

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

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

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

The amount of heat gained by the building through an exterior surface (roof, exterior walls, or windows) depends upon the radiant environment to which the surface is exposed. This radiant environment may be simulated more accurately by a computer than by hand calculations because the computer can evaluate the components of 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 Los Angeles area were calculated for the 1951 Los Angeles 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 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 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. LOS ANGELES 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						
Stucco		0.083	0.417	116.	0.19	---
3-½" Batt Insulation	0.086	0.292	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Roof						
Asphalt Shingles		0.042	0.096	99.	0.26	---
Wood Sheathing		0.042	0.065	34.	0.29	---
Air Space	0.074	---	---	---	---	0.96
3-½" Batts		0.292	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Door						
Wood Frame	0.67	---	---	---	---	---
Floor						
Concrete Slab	0.10	---	---	--	---	---

TABLE VIII. LOS ANGELES 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	0.086	0.083	0.417	116.	0.19	---
3½" Batt Insulation		0.292	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Roof						
Asphalt Shingles	0.074	0.042	0.096	99.	0.66	---
Wood Sheathing		0.042	0.065	34.	0.29	---
Air Space		---	---	---	---	0.96
3½" Batts		0.292	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Door						
Wood Frame	0.67	---	---	---	---	---
Floor						
Concrete Slab	0.10	---	---	---	---	---

TABLE IX. LOS ANGELES 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	---
Air Gap	0.113	---	---	---	---	1.01
2¼" Batt Insulation		0.187	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Roof						
Asphalt Shingles		0.042	0.096	99.	0.26	---
Wood Sheathing		0.042	0.065	34.	0.29	---
Air Space	0.074	---	---	---	---	0.96
3½" Batt Insulation		0.292	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Door						
Wood Frame	0.67	---	---	---	---	---
Floor						
Concrete Slab	0.10	---	---	---	---	---

TABLE X. LOS ANGELES 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						
Precast Concrete		0.333	0.54	144.	0.16	---
3½" Batt Insulation	0.085	0.292	0.0265	3.	0.18	---
Gypsumboard		0.042	0.093	50.	0.26	---
Roof						
Built-up Roof		0.031	0.094	70.	0.35	---
2" Rigid Insulation		---	---	---	---	5.56
2" Concrete Deck	0.131	0.167	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 LOS ANGELES 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	49.1	5.8	121.1	71.5	158.2	214.9	1635.9	1183.4
February	51.2	3.5	126.7	51.8	176.4	179.6	1501.2	980.0
March	38.5	15.3	92.4	126.1	116.9	294.1	1022.2	1949.9
April	25.6	9.7	50.4	91.8	18.2	244.8	518.4	1521.3
May	15.8	21.2	26.9	147.9	3.5	389.3	270.2	2432.1
June	4.6	35.3	2.5	222.7	0.1	518.5	27.3	3913.8
July	0.7	66.0	0.0	345.1	0.0	722.5	4.3	6352.3
August	0.5	62.4	0.0	340.0	0.0	708.9	6.0	5806.6
September	0.8	59.6	0.0	340.0	0.0	705.5	9.1	4734.1
October	5.1	52.3	5.6	328.1	5.2	688.5	86.2	5057.8
November	18.7	23.8	35.0	188.7	30.1	433.5	454.0	2895.5
December	44.2	5.0	115.5	77.3	142.8	230.1	1671.3	1104.0
Annual Load	254.8	359.9	576.1	2331.0	651.4	5330.2	7206.1	37931.8
Annual Load Per Unit	254.8	359.9	72.0	291.4	27.1	222.0	40.2	211.9

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	32	0
Townhouse	31	0
Low-Rise	28	0
High-Rise	99	0

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	0.06	0.00
Townhouse	0.03	0.00
Low-Rise	0.02	0.00
High-Rise	0.04	0.00

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.

**The total annual infiltration cooling load is small because the warm air that infiltrates during the day - contributing to the cooling load - is balanced by the cool air infiltrating at night - decreasing the cooling load.*

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

The energy consumption required to heat, cool, and ventilate the characteristic residences were determined using the previously calculated heating and cooling loads. The heating, cooling, and ventilation equipment used in the residences are described below. For the computation of energy required for cooling, cooling loads were discarded if they occurred in the cold weather period since the simple expediency of opening windows (for entry of cooler outside air) would be a more practical method of meeting these cooling requirements. For both heating and cooling, the thermostat was 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 May 20 and November 10;
efficiency = 0.7

Cooling - central, electric, forced air system;
loads not met between November 10 and May 20;
C.O.P. = 1.7

b. Townhouse

Heating - gas fired furnace, forced air system;
loads not met between April 15 and November 10;
efficiency = 0.7

Cooling - central, electric, forced air system;
loads not met between November 10 and April 15;
C.O.P. = 1.7

c. Low-Rise

Heating - gas fired furnace, forced air system;
loads not met between March 20 and November 30;
efficiency = 0.7

Cooling - individual electric units;
loads not met between November 25 and March 15;
C.O.P. = 1.7

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

Heating - gas fired furnace, 2-pipe fan coil system;
loads not met between March 20 and November 30;
efficiency = 0.7

Cooling - central, electric, 2-pipe fan coil distribution system; loads not met between November and March 20;
C.O.P. = 3.2

Detailed analyses of the energy consumed for heating and cooling of the Los Angeles 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 XII. HEATING AND COOLING ENERGY CONSUMPTION IN THE LOS ANGELES CHARACTERISTIC SINGLE-FAMILY RESIDENCE

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS		
Month	Heating	Cooling	Total*	Gas	Electric	Total*
January	70	0	70	72	0	72
February	73	0	73	75	0	75
March	55	0	55	56	0	56
April	36	0	36	37	0	37
May	22	12	34	23	40	63
June	0	20	20	0	66	66
July	0	38	38	0	125	125
August	0	36	36	0	118	118
September	0	35	35	0	113	113
October	0	30	30	0	99	99
November	26	14	40	27	45	72
December	63	0	63	65	0	65
Annual Consumption	345	185	530	355	606	961
Average Annual Consumption Per Square Foot	0.20	0.10	0.31	0.20	0.35	0.56

**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 LOS ANGELES CHARACTERISTIC TOWNHOUSE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total*	Gas	Electric	Total*
January	173	0	173	178	0	178
February	181	0	181	187	0	187
March	132	0	132	136	0	136
April	72	54	126	74	176	250
May	0	87	87	0	282	282
June	0	131	131	0	422	422
July	0	203	203	0	656	656
August	0	200	200	0	645	645
September	0	200	200	0	648	648
October	0	193	193	0	623	623
November	50	111	161	52	358	410
December	165	0	165	170	0	170
Annual Consumption	773	1179	1952	797	3810	4607
Average Annual Consumption Per Unit	96	147	244	99	476	575
Average Annual Consumption Per Square Foot	0.07	0.11	0.18	0.07	0.36	0.44

**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 LOS ANGELES CHARACTERISTIC LOW-RISE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total*	Gas	Electric	Total*
January	226	0	226	233	0	233
February	252	0	252	260	0	260
March	167	173	340	172	560	733
April	0	144	144	0	465	465
May	0	229	234	0	741	741
June	0	306	306	0	989	989
July	0	425	425	0	1370	1370
August	0	417	417	0	1345	1345
September	0	415	415	0	1340	1340
October	0	405	405	0	1308	1308
November	43	255	298	44	825	869
December	204	0	204	211	0	211
Annual Consumption	892	2769	3661	920	8943	9863
Average Annual Consumption Per Unit	37	115	153	38	373	411
Average Annual Consumption Per Square Foot	0.05	0.14	0.2	0.05	0.48	0.53

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

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

Month	Energy Consumption in Therms				Primary Energy in Therms		
	Heating	Cooling	Fans	Total	Gas	Electric	Total
January	2337.0	0.0	730.7	3067.7	2409.2	2357.0	4766.2
February	2144.5	0.0	725.3	2869.8	2210.8	2339.6	4550.4
March	1460.2	609.3	707.7	2777.2	1505.3	4248.4	5753.7
April	0.0	475.4	673.6	1149.0	0.0	3706.4	3706.4
May	0.0	760.0	744.6	1504.6	0.0	4853.5	4853.5
June	0.0	1223.0	939.9	2162.9	0.0	6977.0	6977.0
July	0.0	1985.4	1161.6	3147.0	0.0	10151.6	10151.6
August	0.0	1814.5	1118.9	2933.4	0.0	9462.5	9462.5
September	0.0	1479.4	1001.9	2481.3	0.0	8002.9	8002.9
October	0.0	1580.5	1060.5	2641.0	0.0	8519.3	8519.3
November	0.0	904.8	755.6	1660.4	0.0	5356.1	5356.1
December	2387.5	0.0	621.1	3008.6	2461.3	2003.5	4464.8
Annual Consumption	8329.2	10832.2	10241.1	29402.5	8586.6	67977.8	76564.4
Average Annual Consumption Per Unit	46.5	60.5	57.1	164.2	47.9	379.7	427.7
Average Annual Consumption * Per Square Foot	0.05	0.06	0.06	0.17	0.05	0.38	0.43

**Halls, lobbies and stairwells included.*

TABLE XVI. COMPARISON OF THE ENERGY REQUIREMENTS FOR HEATING AND COOLING THE CHARACTERISTIC LOS ANGELES 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	530	0.31	133	961	0.56	240
Townhouse	244	0.18	61	575	0.44	144
Low-Rise	153	0.20	62	411	0.53	168
High-Rise	164	0.17	66	427	0.43	171

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, 0.77, 0.48, and 0.57, whereas the corresponding ratios for "per unit" primary energy consumption were 1.00, 0.60, 0.43, and 0.44. 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 Los Angeles residences on the basis of floor area, the high-rise had the lowest consumption of in-structure and primary energy and the single-family residence had the highest.

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, 2.5 per low-rise apartment, and 2.5 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 LOS ANGELES 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	11	17

In addition, reflective glass was installed in the low-rise and high-rise buildings. 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 improved furnace efficiency and improved cooling C.O.P. in following table:

(a) Improved Single-Family Detached

Heating efficiency = 0.77

Cooling C.O.P. = 2.7

(b) Improved Townhouse

Heating efficiency = 0.77

Cooling C.O.P. = 2.7

(c) Improved Low-Rise

Heating efficiency = 0.77

Cooling C.O.P. = 2.7

(d) Improved High-Rise

Heating efficiency = 0.78

Cooling C.O.P. = 3.2

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 Los Angeles 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 Los Angeles characteristic residences, shown previously in Table XVI.

Comparison of the primary energy consumption of the improved Los Angeles 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 low-rise used the least energy, followed closely by the townhouse, then by the high-rise and finally by the single-family.

(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 (4

TABLE XVII. HEATING AND COOLING LOADS FOR IMPROVED LOS ANGELES 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	29.8	4.4	57.7	81.6	60.6	185.3	1243.6	660.6
February	33.6	1.9	64.0	58.5	86.6	141.7	1222.8	472.9
March	23.7	10.6	43.3	123.5	49.5	258.7	841.0	1222.8
April	13.8	7.5	16.5	107.2	9.1	280.2	385.2	1149.3
May	6.9	18.1	6.2	159.6	0.8	381.3	200.5	1844.0
June	1.0	31.7	0.0	221.6	0.0	480.2	20.9	3175.5
July	0.0	57.2	0.0	313.6	0.0	623.8	3.3	5100.1
August	0.0	56.5	0.0	312.1	0.0	622.1	0.0	4737.1
September	0.0	54.3	0.0	312.4	0.0	603.7	5.1	4600.0
October	1.3	47.6	0.5	306.5	0.0	581.2	49.6	3994.9
November	8.9	21.6	10.8	189.0	5.0	383.1	301.9	2128.7
December	24.3	5.1	53.9	91.7	45.7	215.5	1250.7	638.0
Annual Load	143.3	314.6	252.9	2277.6	257.3	4756.8	5524.6	29723.9
Annual Load per Dwelling Unit	143.3	314.6	31.6	284.7	10.7	198.2	30.8	166.0

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

	ENERGY CONSUMPTION IN THERMS			PRIMARY ENERGY IN THERMS		
Month	Heating	Cooling	Total*	Gas	Electric	Total*
January	38.7	0.0	38.7	39.9	0.0	39.9
February	43.6	0.0	43.6	44.9	0.0	44.9
March	30.8	0.0	30.8	31.7	0.0	31.7
April	17.9	0.0	17.9	18.4	0.0	18.4
May	8.9	6.7	15.6	9.1	21.6	30.7
June	0.0	11.8	11.7	0	37.7	37.7
July	0.0	21.2	21.2	0	68.4	68.4
August	0.0	20.9	20.9	0	67.4	67.4
September	0.0	20.1	20.1	0	64.8	64.8
October	0.0	17.6	17.6	0	56.8	56.8
November	11.5	8.0	19.5	11.8	25.8	37.6
December	31.5	0.0	31.5	32.5	0.0	32.5
Annual Consumption	182.9	106.2	289.1	188.3	342.5	530.8
Average Annual Consumption Per Square Foot	0.10	0.06	0.17	0.11	0.20	0.31

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 LOS ANGELES IMPROVED TOWNHOUSE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total*	Gas	Electric	Total*
January	74.9	0.0	74.9	77.2	0.0	77.2
February	83.1	0.0	83.1	85.7	0.0	85.7
March	56.2	0.0	56.2	57.9	0.0	57.9
April	21.4	39.7	61.1	22.0	128.0	150.0
May	8.0	59.1	67.1	8.2	190.6	198.8
June	0.0	82.0	82.0	0.0	264.5	264.5
July	0.0	116.1	116.1	0.0	374.5	374.5
August	0.0	115.6	115.6	0.0	372.9	372.9
September	0.0	115.7	115.7	0.0	373.2	373.2
October	0.0	113.5	113.5	0.0	366.1	366.1
November	14.0	70.0	84.0	14.4	225.8	240.2
December	70.0	0.0	70.0	72.1	0.0	72.1
Annual Consumption	327.6	711.7	1039.3	337.5	2295.6	2633.1
Average Annual Consumption Per Unit	40.9	88.9	129.9	42.2	286.9	329.1
Average Annual Consumption Per Square Foot	0.03	0.07	0.10	0.03	0.22	0.25

**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 LOS ANGELES IMPROVED LOW-RISE

Month	Energy Consumption in Therms			Primary Energy in Therms		
	Heating	Cooling	Total*	Gas	Electric	Total*
January	78.7	0.0	78.7	81.1	0.0	81.1
February	112.4	0.0	112.4	115.9	0.0	115.9
March	64.0	95.8	160.1	66.3	309.0	375.3
April	0.0	103.8	103.8	0.0	334.8	334.8
May	0.0	141.2		0.0	455.5	455.5
June	0.0	177.8	177.8	0.0	573.5	573.5
July	0.0	231.0	231.0	0.0	745.1	745.1
August	0.0	230.4	230.4	0.0	743.2	743.2
September	0.0	223.6	223.6	0.0	721.3	721.3
October	0.0	215.2	215.2	0.0	694.2	694.2
November	6.4	141.9	148.3	6.6	457.7	464.3
December	59.3	0.0	59.3	61.1	0.0	61.1
Annual Consumption	311.1	1560.7	1871.8	331.0	5034.3	5365.3
Average Annual Consumption Per Unit	13.0	65.0	78.0	13.8	209.8	223.6
Average Annual Consumption Per Square Foot	0.01	0.08	0.09	0.02	0.25	0.27

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

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

Month	Energy Consumption in Therms				Primary Energy in Therms		
	Heating	Cooling	Fans	Total	Gas	Electric	Total
January	1594.3	0.0	710.1	2304.4	1643.6	2290.6	3934.2
February	1567.7	0.0	640.7	2208.4	1616.2	2066.7	3682.9
March	1078.2	382.1	673.0	2133.3	1111.5	3403.5	4515.0
April	0.0	359.0	623.7	982.7	0.0	3170.0	3170.0
May	0.0	576.3	698.8	1275.1	0.0	4113.2	4113.2
June	0.0	992.3	884.2	1876.5	0.0	6053.2	6053.2
July	0.0	1593.9	1063.9	2657.8	0.0	8573.5	8573.5
August	0.0	1480.3	1035.5	2515.8	0.0	8115.5	8115.5
September	0.0	1437.5	991.8	2429.3	0.0	7836.4	7836.4
October	0.0	1248.4	977.6	2226.0	0.0	4027.0	4027.0
November	0.0	665.3	697.7	1363.0	0.0	4396.8	4396.8
December	1603.4	0.0	710.3	2313.7	1652.9	2291.3	3944.2
Annual Consumption	5843.6	8735.1	9707.3	24286.0	6024.2	56337.7	62361.9
Average Annual Consumption Per Unit	32.6	48.8	54.2	135.6	33.6	314.7	348.4
Average Annual Consumption Per Square Foot*	0.03	0.05	0.05	0.14	0.03	0.32	0.35

Halls, lobbies and stairwells included.

TABLE XXII. COMPARISON OF THE ENERGY REQUIREMENTS FOR HEATING AND COOLING THE IMPROVED LOS ANGELES 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	289	0.17	72	531	0.31	133
Townhouse	130	0.10	31	329	0.25	78
Low-Rise	78	0.09	28	224	0.27	79
High-Rise	136	0.14	54	348	0.35	139

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

occupants) and the high-rise (2.5 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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