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**APPLICATION ANALYSIS
OF SOLAR TOTAL ENERGY SYSTEMS
TO THE RESIDENTIAL SECTOR**

**Volume II.
ENERGY REQUIREMENTS**

Project 8987 Final Report

**Prepared by
Institute of Gas Technology
IIT Center, 3424 S. State Street
Chicago, Illinois 60616**

Date Published — July 1979

**Prepared for the
UNITED STATES DEPARTMENT OF ENERGY**

Under Contract No. EG-77-C-04-3787

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Microfiche	\$ 3.00 (domestic)

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T. P. Whaley

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Program Manager

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PREFACE

This is the final report of the Institute of Gas Technology (IGT) on "Application Analysis of Solar Total Energy Systems to the Residential Sector," sponsored by the Department of Energy under Contract No. EG-77-C-04-3787. The period of performance was from 1 February 1977 through 30 April 1978.

The work is reported in four volumes, as follows:

- Volume I. Executive Summary
- Volume II. Energy Requirements
- Volume III. Conceptual Design
- Volume IV. Market Penetration.

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HIGHLIGHTS

- RESIDENTIAL MARKET SEGMENTS ARE: SINGLE-FAMILY HOMES, TOWNHOUSES, LOW-RISE APARTMENTS, HIGH-RISE APARTMENTS
- ELECTRICAL ENERGY REQUIREMENTS ARE INDEPENDENT OF REGION
- REGION-DEPENDENT HEAT/COOLING DEMANDS CAN BE SIMULATED WITH COMPUTER PROGRAM
- SIMULATED HEATING LOADS CORRELATE WELL WITH REAL DATA. SIMULATED COOLING LOADS CORRELATE WELL WITH REAL DATA IN SUMMER MONTHS.

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SUMMARY

A solar total energy system (STES) is defined as an energy system designed to maximize the efficient use of collected solar energy by supplying both the low-grade (low-temperature thermal) and high-grade (electrical and/or mechanical) energy needs of selected applications. DOE's Solar Total Energy Program is concerned primarily with those solar total energy systems that use heat engine or photovoltaic devices to produce electricity (and/or mechanical work) and apply the residual thermal energy from the conversion process to some useful purpose. The solar total energy is backed up and supplemented to the extent required by conventional fossil fuel-derived energy for periods when solar-derived energy is inadequate.

This project analyzed the application of solar total energy systems to appropriate segments of the residential sector and determined their market penetration potential.

This volume (Volume II) covers the work done on energy requirements definition and includes the following:

- Identification of the single-family and multi-family market segments
- Regionalization of the United States
- Electrical and thermal load requirements, including time-dependent profiles
- Effect of conservation measures on energy requirements
- Verification of simulated load data with real data.

Market segments have been defined as:

- Single-family detached dwellings. Two-story buildings with a total area of 1700 square feet.
- Single-family attached (townhouse) dwellings. Two-story buildings with an area of 1452 square feet for each unit; 9 units per building.
- Low-rise, multi-family dwellings (apartments). Two-story buildings with 24 dwelling units and a total area of 26,880 square feet.
- High-rise, multi-family dwellings (apartments). Fifteen-story buildings with 180 dwelling units and a total area of 153,500 square feet.

Regionalization, based on insolation (climate), heating-degree-days, cooling-degree-days, cost of electricity, fuel types, and population, defines the following regions and representative cities:

- Region 1: Southern Florida (Miami)
- Region 2: California (Los Angeles)
- Region 3: Arizona, Nevada (Phoenix)
- Region 4: New Mexico, Colorado, Utah (Albuquerque)
- Region 5: Texas, Oklahoma (Fort Worth)
- Region 6: Louisiana, Mississippi, Alabama, Georgia, North Carolina, Northern Florida (Charleston)
- Region 7: Arkansas, Tennessee, Kentucky, Virginia, West Virginia, Maryland, Washington, D.C. (Nashville)
- Region 8: Delaware, New Jersey, New York, Pennsylvania, Michigan, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine (Boston)
- Region 9: Wisconsin, Illinois, Ohio, Indiana, Missouri, Kansas, Nebraska, Iowa, Southern Minnesota (Chicago)
- Region 10: Northern Minnesota, North Dakota, South Dakota, Montana, Wyoming, Idaho (Bismark, but using Boston data for evaluation)
- Region 11: Washington, Oregon (Seattle, but using Boston data for evaluation).

Computer simulation of thermal load requirements for the four market segments in the different regions was carried out with the Meriwether energy requirements program for space heating, space cooling, and domestic hot water. Base electrical loads and base electrical plus cooking loads were determined from data provided by Public Service Electric and Gas Co. for both weekday and weekend usage. The effect of ASHRAE 90-75 conservation measures on thermal load requirements was also simulated with the Merriwether computer program. These data were used to provide 24-hour profiles, seasonal profiles, 12-month yearly profiles, and thermal/electric ratios for the four market segments in the nine representative cities. The results of the computer simulation runs were transferred to tapes for use as inputs to the design evaluation program. (See Volume III.) These tapes are available from SERI.

Comparison of simulated load requirements with real data on both single-family and multi-family dwelling units shows good correlation for space heating. Correlation for space cooling was good during most of the cooling system, but not during transitional months.

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Section 1
INTRODUCTION

This is Volume II of the Institute of Gas Technology's (IGT) Final Report on "Application Analysis of Solar Total Energy Systems to the Residential Sector," sponsored by the Energy Research and Development Administration (now the Department of Energy) under Contract No. EG-77-C-04-3787. The contract objectives were:

- To produce and evaluate conceptual designs for solar total energy systems in residential applications having minimum electric load of 50 kW.
- To assess the extent and rate to which solar total energy systems can penetrate energy markets in residential sector in the 1980's (i.e., to identify the innovators) and to project market penetration to the year 2020. (The term "innovator" is a marketing term used to describe the more venturesome segment of the public or industry that is the first to try new products or accept new concepts.)

Roughly 20% of the primary energy consumed in the United States is represented by the residential sector, compared with 41.3% industrial, 14.5% commercial, and 24.6% transportation. This residential energy use can be further broken down into 55.0% space heating, 14.5% water heating, 4.6% air conditioning, and 5.1% cooling, the remaining 21% being primarily electrical uses, such as lighting, refrigeration/freezing, television, etc. Consequently, the residential sector represents a significant potential for energy savings by the implementation of solar total energy, if economically viable systems can be developed.

In order to assess the market penetration potential of STE systems in the residential sector, appropriate conceptual designs were constructed and evaluated by computer simulation (Volume III). This evaluation involved an hourly determination of the performance of the design in supplying energy to the electrical and thermal load requirements of the building under study. This determined the amount of back-up energy required and, consequently, the amount of energy that is supplied by the solar collector. From these results, the annual fuel savings resulting from the use of STE were determined and compared with the cost of the system. This comparison provided the basis for determining the cost-effectiveness of the system and its potential for competing in the market place with conventional energy systems (Volume IV).

The design performance could only be carried out if the electrical and thermal load requirements were known and used as the basis for evaluating the extent to which solar total energy can supply these requirements. The overall program approach is shown in the following diagram:

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The objective of the energy requirements effort was to identify and characterize the energy consumption patterns of energy users within the residential sectors that represent potential markets for solar total energy systems or have the potential for significantly affecting their market penetration. The work breakdown for achieving this objective was as follows:

- Regionalization: divide the United States into regions based on climate, insolation, building load characteristics, fuel cost, and any other parameters that are considered significant.
- Identification of Residential Market Segments: identify the types of single-family and multi-family dwelling units to be characterized in this study, with primary emphasis placed on groupings having peak electrical loads in excess of 50 kWe.
- Simulation of Load Requirements: characterize electrical and thermal requirements for each of the market segments in different regions of the country, providing time-dependent profiles as well as seasonal and energy usage summaries by means of an appropriate computer simulation program where necessary.
- Verification of Simulated Load Programs: where possible, compare results of load simulation program with actual load data.

Section 2

IDENTIFICATION OF RESIDENTIAL MARKET SEGMENTS

The objective of this section was to identify and characterize the residential sectors that would be potentially suitable for the application of solar total energy systems.

2.1 Generic Classification of Residential Sectors

Based on statistics obtained from the National Association of Home Builders and from the U.S. Census Bureau,^{1,2} six forms of housing that are potentially suitable for the application of solar total energy systems have been identified. These include single- and multi-family structures and are defined as follows:

- Single-family houses
 1. Detached
 2. Attached (townhouses)
- Multi-family structures
 3. Structures with two dwelling units
 4. Structures with three or four dwelling units
 5. Low-rise structures (1 to 3 stories)
 6. Mid- and high-rise structures (4 or more stories).

Identification of the structural characteristics and the energy-related parameters for the appropriate dwelling types determines the input data for computer synthesis of the thermal load requirements.

2.2 Construction Starts Trends

Construction starts trends over the past few years, relative to each of the residential market segments cited above, were investigated to determine the total potential market for solar total energy systems in each type of dwelling unit and any indicated trend.

The single-family detached house is the most common form of housing in the United States, which can be seen from Tables 1 and 2. From 1969 through 1973, the portion of the private-dwelling units constructed nationwide which were for single-family residences has remained essentially constant at approximately 56%. From 1973 through 1976, this portion has increased to approximately 76%, shown in Figure 1. This has been due to the sharp drop in the number of multi-family dwelling units constructed during that period.

Table 1. STATISTICS ON PRIVATE CONSTRUCTION STARTS NATIONWIDE

Year	Number of Dwelling Units and Percentage of Total				Total No. of D.U.*
	Single-Family**		Multi-Family		Nationally Privately Owned
	No. of D.U.*	%	No. of D.U.*	%	
1964	970,500	63.5	558,300	36.5	1,528,800
1965	963,700	65.4	509,100	34.6	1,472,800
1966	778,600	66.8	386,200	33.2	1,164,800
1967	843,900	65.4	447,700	34.6	1,291,600
1968	899,400	59.5	608,200	43.4	1,507,600
1969	810,600	55.4	656,200	44.6	1,466,800
1970	812,900	56.6	620,700	43.4	1,433,600
1971	1,151,000	56.3	901,200	43.7	2,052,200
1972	1,309,200	55.6	1,047,500	44.4	2,356,700
1973	1,132,000	55.5	913,300	44.5	2,045,300
1974	888,100	65.6	458,100	34.4	1,346,200
1975	892,200	76.9	272,100	23.1	1,164,300
1976	1,162,900	75.6	378,200	24.4	1,541,100

* D.U. = Dwelling units.

** Includes both detached and attached (townhouse) units.

Table 2. BREAKDOWN OF HOUSING STARTS NATIONWIDE

Year	Single-Family Detached	Single-Family Attached	Two D.U. Structures (No. of D.U.)	Three or Four D.U. Structures (No. of D.U.)	Low-Rise Structures (No. of D.U.)	High-Rise Structures (No. of D.U.)
1973	1,040,000	92,000	57,700	66,300	625,000	164,300
1974	822,000	66,100	38,800	37,700	298,200	83,400
1975	854,000	38,000	36,000	31,800	179,400	24,900
1976	1,162,900*		44,900	44,100	263,100	26,100

* A breakdown among attached and detached units is not available.

Figure 1. NUMBER OF DWELLING UNITS CONSTRUCTED
(Percent of Total — Privately Owned)

The breakdown among the various types of dwelling units constructed over the past four years is shown in Table 2. These data indicate that the detached house dominates the single-family sector and the low-rise structure dominates the multi-family sector.

2.3 Construction Parameters

The generic characteristics of the single-family structures (detached and attached), and the multi-family structures (low-rise and high-rise) are shown in Table 3-6. (Structures with two, three, and four dwelling units have not been described.) The presented construction parameters were based on data published by the U.S. Bureau of Census,^{1,2} by Hittman Associates, Inc.,³ by the Center for Environmental Studies at Princeton University,⁴ and by Decision Sciences Corporation.⁵

The more common types of single-family detached houses can be classified under two categories: 1) the four-bedroom, two-story, and 2) the three-bedroom, ranch style. The generic structural characteristics of both types are described in Table 3, and the floor plans are shown in Figures 2 and 3.

Typical structural characteristics of a two-story, three-bedroom townhouse are shown in Table 4. Floor plans and elevations are shown in Figures 4 and 5.

We have distinguished among three typical low-rise structures: 1) two-story buildings with concrete block construction, 2) two-story buildings with wood frame construction, and 3) three-story buildings with wood frame construction. The structural characteristics of these buildings are shown in Table 5. The floor plans are shown in Figure 6.

Table 6 shows the characteristics of a 15-story building. This number of stories per building represents the norm value for high-rise, residential structures. The floor plan is shown in Figure 6.

Directional orientation of structures on building sites has not been specified in the construction parameters, but is indicated in the section on energy-related parameters (Tables 14-17). As is shown there, the structures were not oriented on the lot to maximize passive solar effects.

Table 3. GENERIC STRUCTURAL CHARACTERISTICS OF SINGLE-FAMILY DETACHED HOUSE

Basic Design	4-bedroom, 2-story 9-ft ceiling height*	3-bedroom rancher 9-ft ceiling height
Foundation	Full basement	Full basement
Garage	2-car, attached	2-car, attached
Floor area, sq ft	1700	1150
Construction	Wood frame 2 x 4 studs 16 in. on center	Wood frame 2 x 4 studs 16 in. on center
Exterior Wall		
Outside surface	Brick veneer	Brick veneer
Sheathing	1/2-in. insulation board	1/2-in. insulation board
Insulation	3-1/2-in. fiberglass batting	3-1/2-in. fiberglass batting
Inside surface	1/2-in. gypsum	1/2-in. gypsum
Ceiling	Asphalt shingles, 1/2 in. Plywood sheathing, air Space, 6-in. fiberglass Loose-fill, 1/2-in. gypsum	Asphalt shingles, 1/2 in. Plywood sheathing, air Space 6-in. fiberglass Loose-fill, 1/2-in. gypsum
Roof	Gable	Gable
Windows		
Type	Aluminum, double hung	Aluminum, single hung
Glazing	Single (with draperies)	Single (with draperies)
Area, sq ft	180	105
Exterior Doors		
Type	Wood	Wood
Number	2	2
Total area, sq ft	40	40
Patio Doors		
Type	Aluminum, sliding	Aluminum, sliding
Glazing	Double (with draperies)	Double (with draperies)
Area, sq ft	40	40

* Floor-to-floor, i.e., includes floor joists, flooring materials, etc.

Figure 2. FLOOR PLAN FOR THE CHARACTERISTIC SINGLE-FAMILY, 4-BEDROOM, 2-STORY HOUSE

Figure 3. FLOOR PLAN FOR THE CHARACTERISTIC SINGLE-FAMILY, RANCH-STYLE HOUSE

Table 4. GENERIC STRUCTURAL CHARACTERISTICS OF TOWNHOUSE RESIDENCES

Basic Design	2-story, 3-bedroom	
Foundation	Full basement	
Areas, sq ft	<u>Interior Unit</u>	<u>End Unit</u>
Total floor	1452	1452
Basement floor	726	726
Ceiling	763	763
Exterior wall	737	1348
Window glass	139	155
Patio door	60	60
Front door	20	20
Basement wall (ext.)	275	481
Exterior Wall Material		
Siding	Wood (1/2-in. x 8-in., lapped) 15-lb felt (building paper)	
Sheathing	1/2-in. plywood	
Insulation	Batt insulation, R-7, 1-in. air space	
Inside surface	1/2-in. gypsum	
Ceiling Material	1/2-in. gypsumboard, batt insulation, R-11	
Roof Material	1/2-in. plywood sheathing, 15 lb felt (building paper), asphalt shingle	
Windows (with draperies)	Single glaze, aluminum sash	
Patio door (with draperies)	Single glaze, aluminum slider	
Roof	Gable

Figure 4. FLOOR PLAN FOR A 3-BEDROOM, 2-STORY TOWNHOUSE

Figure 5. PROFILE OF A 3-BEDROOM TOWNHOUSE

Table 5. GENERIC STRUCTURAL CHARACTERISTICS OF LOW-RISE APARTMENTS¹⁻⁵

Arrangement	Eight units around an enclosed stairwell. Three stairwells per building.		Eight units around an enclosed stairwell. Three stairwells per building.		Twelve units around an enclosed stairwell. Two stairwells per building	
No. of Stories	2		2		3	
Apartments	24 two-bedroom		24 two-bedroom		24 two-bedroom	
Areas, sq ft	<u>Int. unit</u>	<u>End unit</u>	<u>Int. unit</u>	<u>End unit</u>	<u>Int. unit</u>	<u>End Unit</u>
Floor	980	980	1120	1120	1120	1120
Exterior wall	460	712	482	734	312	565
Total glass	89	89	110	110	98	98
Doors, steel	20	20	20	20	20	20
Ceiling	980	980	1120	1120	1120	1120
Story height	9	9	9	9	9	9
Construction	Concrete block		Wood frame, 2 x 4 studs, on 16-in. center		Wood frame, 2 x 4 studs on 16-in. center	
Foundation	Slab-on-grade		Slab-on-grade		Slab-on-grade	
Exterior Wall	Stucco, 8-in. concrete block, air gap, gypsumboard		Brick veneer, 1/2-in. insulation board, 3-1/2 in. fiberglass batts		Brick veneer, 1/2-in. insulation board, 3-1/2-in. fiberglass batts, 1/2-in. gypsumboard	
Interior Wall	1/2-in. gypsumboard 2 x 3 studs on 16-in. center, 1/2-in. gypsumboard		1/2-in. gypsumboard 2 x 3 studs on 16-in. center, 1/2-in. gypsumboard		1/2-in. gypsumboard 2 x 3 studs on 16-in. center, 1/2-in. gypsumboard	
Roof	Gable		Gable		Gable	
Windows, patio	Single glazing, Aluminum frames		Single glazing Aluminum frames		Single glazing Aluminum frames	
Ceiling	Asphalt shingles, 3/8-in. plywood, air space, 6-in. fiberglass loose-fill insulation, 1/2-in. gypsumboard		Asphalt shingles, 3/8-in. plywood, air space, 6-in. fiberglass loose-fill insulation 1/2-in. gypsumboard		Asphalt shingles, 3/8-in. plywood air space, 6-in. fiberglass batt insulation, 1/2-in. gypsumboard

FLOOR PLAN FOR 2-STORY LOW-RISE

FLOOR PLAN FOR 3-STORY LOW-RISE

FLOOR PLAN FOR 15-STORY HIGH-RISE

Figure 6. FLOOR PLANS FOR LOW- AND HIGH-RISE STRUCTURES

Table 6. STRUCTURAL CHARACTERISTICS OF GENERIC
HIGH-RISE RESIDENTIAL STRUCTURES¹⁻⁵

Arrangement	Rectangular structure, central hall on each floor, two stairwells, two elevators.				
Number of stories	15				
Basement	None				
Apartments	First floor: five one-bedroom, six two-bedroom. Other floors: six one-bedroom, six two-bedroom.				
Areas, sq ft	<u>Middle Apartments</u>	<u>Corner Apartments</u>	<u>Halls & Lobbies</u>	<u>Stairs & Elevator</u>	<u>Utility Rooms</u>
Floor	753/899 [†]	884	1551/1017 [*]	632	580/360 [*]
Exterior wall	52/62 [†]	316	0	106/160 [*]	200/240 [*]
Roof [†]	754/899	884	1017	632	360
Window glass	168/208 [†]	244	192	0	192
Entrance doors	20	20	53	53	0
Story height	10	10	10	10	10
Construction frame	Reinforced concrete				
Floors and roof deck	6" reinforced concrete				
Exterior walls	4" concrete, 1" rigid insulation, air space, 1/2" gypsumboard.				
Roof	Built-up; felt bitumen composition, 1-1/2" rigid insulation, 2" concrete deck, air gap, 1/2" gypsumboard.				
Entrance doors	<u>Apartments</u>	<u>Lobby</u>	<u>Staircases</u>		
	Metal, 1/unit	Steel, 4	Metal, 3		
Windows	Single glazing, aluminum sliders.				

* First floor/other floors.

† 20% of roof is occupied by penthouse and mechanical room.

† One-bedroom/two-bedroom.

Section 3

REGIONALIZATION

In order to determine which regions of the United States are most suitable for residential applications of solar total energy systems, the country has been divided into regions based on the following factors:

- Availability of solar radiation (insolation)
- Heating requirements
- Cooling requirements
- Population
- Cost of electricity
- Type of conventional fuel used for thermal needs.

The economic feasibility of solar total energy systems is a direct function of their ability to supply energy to the user at a cost that is at least competitive with conventional energy systems. This can best be accomplished in those regions of the country where adequate solar energy is most readily available, where the amount of insolation most closely matches the energy needs, and where the cost of conventional energy is highest. Since market penetration is often a function of innovator-imitator interaction and visibility of demonstration units, economic feasibility of STE systems can be more effectively demonstrated in regions of higher population densities.

3.1 Insolation and Thermal Requirements

The amount of solar energy available to a solar collector in any given location is determined largely by the time of day, the season of the year, and the cloudiness. Cloudiness, in turn, is a function of topography and weather patterns, the major factors in determining the climate for a geographic region.

The weather patterns of the United States (exclusive of Alaska and Hawaii) are determined primarily by four different masses:

- Continental polar (cP) air, whose source region is the interior regions of Canada and is characterized by low humidity and low temperatures
- Maritime tropical (mT) air from the Atlantic, whose source region is the Atlantic Ocean, east of Bermuda, and is characterized by high humidity and high temperatures

- Maritime tropical (mT) and maritime polar (mP) air from the Pacific Ocean west of the West Coast of the United States. (The only distinction between the two is the higher latitude trajectory of the mP air and the more southerly trajectory of the mT air, both originating in the North Pacific Ocean source region.) This is moist air, with temperatures ranging from moderate in the north to high in the south.
- Continental tropical (cT) air, whose source region is northern Mexico and southern Arizona/New Mexico, and is characterized by low humidity and high temperatures.

The topography over which these air masses flow across the country plays an important role in determining cloud formation and, conversely, insolation for many regions. Air that crosses a mountain range produces clouds as it rises and results in warm, cloudless conditions as it descends the leeward side; this explains the cloudiness on the western slopes of the coastal range and cloudless, arid conditions in eastern Washington and eastern California. In a similar manner, local climatic anomalies can result from the influence of adjacent mountains or large bodies of water, where insolation data are not characteristic of an entire region; wherever possible, insolation data from stations located a few miles inland are preferred over those data from stations located near a coastline.

The first step in the regionalization was to divide the country into climatic regions to provide a good regional basis for insolation data. Based on the air mass patterns and topographic modifications discussed above, these climatic regions are as follows:

1. Southern Florida-type: Weather dominated almost exclusively by the maritime tropical (mT) air from the Bermuda source region, with cloudiness the result of daily convection rather than frontal movements or topography. This is sometimes included in the Gulf-type climate classification, but is probably better defined as a separate category.
2. California-type: Weather dominated by maritime air from the Pacific, with almost no intrusions from continental air masses.
3. Arizona-type: Weather dominated by the dry continental tropical (cT) air during much of the year, but with intrusions of maritime Pacific air during winter months.
4. Mild, high-elevation Southwest-type: Weather due to both maritime Pacific and continental air masses, but modified by mountainous topography.
5. Southern Plains-type: Weather dominated primarily by modified maritime air from the Atlantic during the summer, but with frequent intrusions by cold continental (cP) air or maritime Pacific air during the winter. It is sometimes included in a broader Plains-type climate extending from Canada to southern Texas.

6. Southern-southeastern-type: Weather dominated primarily by maritime air from the Atlantic, but with occasional intrusions by continental air during the winter. Sometimes referred to as Gulf-type climate.
7. East Central-type: Weather represented by frequent intrusions of both maritime air from the Atlantic and continental air from the north. A true mixing zone of the two air masses. Sometimes described as Southern Appalachian-type climate.
8. Northeast-type: Weather dominated primarily by modified continental air as storm centers pass in a northeasterly direction from the midwest toward the St. Lawrence valley. Sometimes called St. Lawrence-type climate.
9. Midwest-type: Weather dominated primarily by continental air from Canada during the winter, but with frequent intrusions by modified maritime air from the South during the summer. Often included as part of a broader Plains-type climatic classification.
10. Northern-northwestern-type: Weather dominated by cold continental air from Canada and modified maritime polar air from the North Pacific. This region is so dominated by topographic influences, however, that truly consistent climatic patterns exist only in the mountainous areas or in the plains areas. The climate of the mountainous areas is sometimes referred to as the "Snake River-type."
11. Pacific-type: Weather dominated by moist maritime polar air from the North Pacific moving eastward toward the Cascade mountain range. Generally cool, wet, cloudy in winter.

These climatic regions are shown on the map in Figure 7, as are the corresponding air mass flows. Modifications to this climate-based regionalization pattern are produced as other factors are considered, e.g., heating and cooling requirements, cost of electricity, regional fuel types, and population.

Insolation data for selected metropolitan areas within these climatic regions are shown in Table 7, together with data on heating-degree-days (HDD) and the length of the heating season. Concentrating collectors are expected to play a major role in the conceptual designs produced in this program; therefore, all insolation data are based on direct normal radiation. The first column of data includes the total number of HDD (i.e., number of degrees Fahrenheit that the daily mean temperature is below 65°F), and the second column indicates the length of the normal heating season. The third column indicates the portion of the HDD that occurs during the normal heating season; in effect, this indicates the occasional cool days during the remainder of the year when the average temperature is below 65°F but which are not considered part of the normal heating season. The fifth column indicates the total direct normal insolation, in Btu/sq ft, received at the location during the months of the heating season, and this value divided by the number of days in the normal heating season gives the daily average, shown in the next column.

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Table 7. SEASONAL INSOLATION VERSUS DEGREE-DAYS DURING HEATING SEASON

City	Total HDD	Heating Season, Months	HDD During Heating Season, %	Direct Normal Insolation During Heating Season ^a		(FR) Insolation/HDD ^b Btu/sq ft-HDD
				Total	Daily Avg	
Bismark	8851 ^c	7mo (Oct-Apr)	92	344803 ^e	1619	42
Chicago (Midway)	6127 ^d	6mo (Nov-Apr)	90	254290	1397	46
Omaha	6612 ^c	6mo (Nov-Apr)	89	311240	1710	53
Boston	6368	6mo (Nov-Apr)	87	193075	1061	35
Seattle	5145 ^c	7mo (Oct-Apr)	86	225072	1057	51
New York	4871 ^c	6mo (Nov-Apr)	92	198982 ^e	1093	44
Washington	4211	5mo (Nov-Mar)	87	193791	1275	53
Nashville	3944	5mo (Nov-Mar)	87	170955	1125	50
Los Angeles	1653 ^d	7mo (Nov-May)	88	418688	1966	254 (avg)
Albuquerque	4348 ^c	5mo (Nov-Mar)	86	349028	2296	94
Fort Worth-Dallas	2621	5mo (Nov-Mar)	93	256310	1686	105
Phoenix	1765 ^c	5mo (Nov-Mar)	95	332637	2188	198
Charleston-Raleigh	2033	5mo (Nov-Mar)	94	205161	1350	107
Lake Charles	1459	5mo (Nov-Mar)	96	210999 ^e	1388	151
Miami	214	3mo (Dec-Feb)	85	168858	1856	928

a. In Btu/sq ft.

b. Feasibility ratio (FR) = total direct normal insolation during heating season divided by the number of heating-degree-days occurring in the heating season (total HDD X %HDD during the season).

c. Data from "Climatic Atlas of U.S." U.S. Dept. of Commerce, 1968. Other HDD data (except Chicago and Los Angeles) from "Intertechnology Corporation Proposed Systems Level Plan for Solar Heating and Cooling Commercial Buildings, National Solar Demonstration Program," V.3, COO-2688-6, ITC, Warrenton, Va., 1976.

d. HDD data for Chicago (Midway) and Los Angeles (average of airport [2061] and city [1245] values) taken from the ASHRAE Handbook and Product Directory, 1976 System.

e. Boes, E.C., et al., "Distribution of Direct and Total Solar Radiation Availabilities for the U.S.A.," SAND76-0411, Sandia Laboratories, Albuquerque, N.M., 1976. Other insolation data from "Commercial Applications of Solar Total Energy Systems," unpublished Third Quarterly Report (1977), Atomics International Division, Rockwell International Corporation.

The last column of Table 7 indicates the feasibility ratio (FR) for the selected location; this is the total direct normal insolation received during the heating season divided by the number of HDD occurring in the heating season (in Btu/sq ft-HDD).

$$\text{Feasibility ratio (FR)} = \frac{\text{Total direct normal radiation}}{\text{Number of degree days}}$$

The significance of this ratio lies in its ability to indicate, in a rough quantitative fashion, the extent to which direct normal solar radiation can satisfy the heating requirements during the heating season. A low value (arbitrarily set at 75 Btu/sq ft-HDD or less) suggests that the available insolation may not be sufficient to meet the heating needs for a specific location. A high value (arbitrarily set at 400 Btu/sq ft-HDD) indicates that the available insolation may be more than required to meet the heating requirements; in effect, a high FR indicates that heating requirements may not be great enough to utilize the available solar radiation. These generalizations are only for regionalization purposes, and no relationship between heating and cooling FR's should be construed.

Table 8 presents a similar analysis of direct normal insolation with respect to cooling-degree-days (CDD), the number of degrees Fahrenheit that the mean temperature is above 65°F. (Data on the cooling season for Bismark and the Charleston-Raleigh area are not complete and the percent CDD during the cooling season have been estimated from comparable locations.) No particularly low values for feasibility ratio are indicated, and the level for high values has been arbitrarily set as 500 Btu/sq ft-CDD or greater. A high FR value indicates that cooling requirements may not be great enough to adequately utilize the available solar energy during the cooling season.

The importance of the primary heating months and the respective fraction of total HDD occurring in these months lies in the fact that erroneous results would be obtained if the insolation available over the entire season were used as the basis for the calculations. Generally, more sunlight is available at the beginning and end of the heating season than during the height of the season, yet the heating requirements at the onset and end of the season are minimal. If the insolation and heating data for the beginning and end of the heating season were used, results of the insolation/load calculations would give an overly optimistic indication of the sun's ability to satisfy the heating requirements over the season.

Table 8. SEASONAL INSOLATION VERSUS DEGREE-DAYS DURING COOLING SEASON

City	Total CDD*	Cooling Season, Months	CDD During Cooling Season, %	Direct Normal Insolation During Cooling Season†		(Direct Normal) Insolation/CDD Btu/sq ft-CDD
				Total	Daily Avg	
Bismark	487	3mo (Jun-Aug)	92 (est)	248703	2703	555
Madison	460	3mo (Jun-Aug)	92	232222	2524	549
Omaha	1173	4mo (Jun-Sep)	90	282024	2312	267
Boston	457	3mo (Jun-Aug)	91	193792	2106	466
Seattle	199	3mo (Jun-Aug)	80	136710	2205	859
Chicago	925	3mo (Jun-Sep)	83	232222	2524	301
Washington	1345	4mo (Jun-Sep)	88	218438	1791	185
Nashville	1694	4mo (Jun-Sep)	85	226119	1853	157
Los Angeles	1185	5mo (Jun-Oct)	87	375226	2453	364
Albuquerque	1316	3mo (Jun-Aug)	82	269935	2934	250
Fort Worth-Dallas	2587	5mo (May-Sep)	90	378921	2477	163
Phoenix	3508	5mo (May-Sep)	87	429196	2805	141
Charleston-Raleigh	2078	6mo (May-Oct)	90 (est)	324664	1765	174
Lake Charles	2739	6mo (May-Oct)	90	382247	2077	155
Miami	4038	9mo (Mar-Nov)	90	574050	2088	158

* Except for Chicago data, taken from TRW SH/CB Phase O Final Report, CDD data were taken from "Intertechnology Corporation Proposed Systems Level Plan for Solar Heating and Cooling Commercial Buildings, National Solar Demonstration Program," V3, COO-2688-6, Intertechnology Corporation, Warrenton, Va., 1976.

† Insolation data taken from "Commercial Applications of Solar Total Energy Systems," unpublished Third Quarterly Report (1977), Atomics International Division, Rockwell International Corporation. Madison data used for Chicago.

3.2 Representative Cities

Tables 7 and 8 listed the data on available seasonal insolation and corresponding energy requirements for candidate cities for heating and cooling seasons, respectively. (The feasibility ratios for the candidate cities were also shown.) This listed information is aggregated in Figures 8 and 9 to show schematically that many cities may be considered comparable, and this information was used to eliminate duplication. (The final selection is shown later, together with a summary of pertinent information).

The HDD values were divided arbitrarily into three categories: low (0 to 2250), medium (2250 to 4500), and high (4500 to 9000). CDD values were divided similarly into three categories: low (0 to 1000), medium (1000 to 2000), and high (greater than 2000). Average direct normal insolation values during the heating and cooling seasons were divided into four categories: low (0 to 1150 Btu/sq ft-day for the heating season and 0 to 2000 Btu/sq ft-day for the cooling season), low-medium (1150 to 1400 Btu/sq ft-day for the heating season and 2000 to 3000 Btu/sq ft-day for the cooling season), high-medium (1400 to 1700 Btu/sq ft-day for the heating season and 2300 to 2500 Btu/sq ft-day for the cooling season), and high (1700 to 2300 Btu/sq ft-day for the heating season and greater than 2500 Btu/sq ft-day for the cooling season).

Aggregating the values for 16 cities throughout the country shows that many cities have similar values of direct normal insolation and thermal requirements; as would be expected, these similarities are also reflected in the feasibility ratios for the respective locations. Some cities show similarities during the heating season but not in the cooling season; for example, Los Angeles and Phoenix show similarities during the heating season but not during the cooling season. The following comparisons can be made:

- Boston and Seattle are comparable on all counts, so Boston will be used as the representative city because of a more favorable feasibility ratio.
- Madison and Chicago are comparable on most counts, so Chicago will be used as the representative city because more marketing data will be available.
- Nashville and Washington are comparable on all counts, so Nashville will be used because it is more typical of the climatic region (Appalachian).
- Lake Charles and Charleston are nearly comparable for both heating and cooling seasons; they are not as close as other combinations, but they are both in the Gulf Coast-type climatic region and have quite similar feasibility ratios for both heating and cooling. Charleston was selected as the preferred location because it more nearly represents an average for the region.

Average Direct Normal Insolation During Heating Season - Btu/sq ft-day

		1000 - 1150	1150 - 1400	1400 - 1700	1700 - 2300
Heating Degree-Days (HDD)	0 - 2250		Lake Charles 1459 <u>(151)</u> Charleston 2033 <u>(107)</u>		Los Angeles 1653 <u>(254)</u> Phoenix 1765 <u>(198)</u> Miami 214 <u>(928)</u>
	2250 - 4500	Nashville 3944 <u>(50)</u> Washington 4211 <u>(53)</u>		Fort Worth 2621 <u>(105)</u>	Albuquerque 4348 <u>(94)</u>
	4500 - 9000	Boston (Blue Hill) 6368 <u>(35)</u> Seattle 5145 <u>(51)</u> New York 4871 <u>(44)</u>	Madison 7863 <u>(38)</u> Chicago 6127 <u>(46)</u>	Bismark 8851 <u>(42)</u>	Omaha 6612 <u>(53)</u>

Figure 8. INSOLATION VERSUS DEGREE-DAYS IN HEATING SEASON

Note: Feasibility ratios are shown in parentheses.

Average Direct Normal Insolation During Cooling Season - Btu/sq ft-day

		0 - 2000	2000 - 2300	2300 - 2500	>2500
Cooling Degree-Days	0 - 1000		Boston 457 (466) Seattle 199 (859)	Madison 460 (549) Chicago 925 (301)	Bismark 487 (537)
	1000 - 2000	Washington 1345 (185) Nashville 1694 (157)		Omaha 1173 (267) Los Angeles 1185 (364)	Albuquerque 1316 (250)
	2000	Charleston 2078 (165)	Lake Charles 2739 (155) Miami 4038 (158)	Fort Worth 2587 (163)	Phoenix 3508 (141)

Figure 9. INSOLATION VERSUS DEGREE-DAYS IN COOLING SEASON

Note: Feasibility ratios are shown in parentheses.

- Albuquerque and Fort Worth are sufficiently unique that they were both selected to represent their respective climatic regions.
- Although Miami and Lake Charles are quite similar for the cooling season, Miami is sufficiently unique for the heating season that it was selected as a unique representative area.
- Phoenix and Los Angeles are similar for heating but differ enough for cooling that they were each selected. This is further confirmed by the fact that each is in a different climatic region.

3.3 Regional Fuels for Residential Heating, Cooling, and Hot Water

Table 9 shows the annual usage of gas and oil for residential heating, cooling, and hot water in different regions of the country, including their use to generate electricity for electric heating, cooling, and hot water. The regions used are census regions rather than the STE regions defined in this study because the data were available on this basis; nevertheless, this regional breakdown of fuel data is adequate to generalize on fuel usage for purposes of confirming our STE regionalization pattern. The data are reaggregated by the STE regions in the market penetration study (Volume IV).

These data indicate that 80% to 90% of the residential thermal requirements of the country is being provided by gas and oil, with the exception of the southeastern portions of the country, where a considerable amount of coal-generated electricity is used to provide electric heating, cooling, and hot water. The reasons for the lower usage of gas and oil to provide thermal energy (50% to 60%) in the southeast are related to the milder winters and warmer summers, where electric heat pumps and electric resistance heating are most feasible, plus the availability of coal-generated electricity in that region and the generally lower thermal requirements. By contrast, a similar climate in the west south central census region (e.g., Texas) has a much higher gas/oil usage because most of the electricity is natural-gas-generated.

The significance of these data lies in the fact that the potential for displacing oil and gas with the thermal output from solar total energy systems is high, and roughly the same throughout most of the regions of the country, except portions of the southeast. By contrast, the potential for replacing gas and oil with the electrical output of STE systems is obviously greater in those regions of the country that use considerable amounts of gas and oil to generate electricity, e.g., New England, Florida, Texas, and California. (See Table 10.)

Table 9. REGIONAL FUEL FOR RESIDENTIAL HEATING, COOLING, AND HOT WATER, 10^{12} Btu

Region	Gas	Oil	Total	Gas + Oil as % of Total
Northeast	141.24	427.14	656.86	86.53%
Middle Atlantic	730.24	893.47	1885.00	86.14%
East North Central	1553.56	437.00	2403.73	82.81%
West North Central	632.73	147.27	919.84	84.80%
South Atlantic	437.94	382.74	1393.06	58.91%*
East South Central	265.81	20.92	566.18	50.64%*
West South Central	627.41	2.04	758.43	88.93%
Mountain	270.49	23.27	367.26	79.99%
Pacific	560.39	63.82	776.51	80.39%

* Considerable coal-generated electric heating.

Table 10. ELECTRIC COSTS AND FUEL SOURCES BY REGION

Region	City	ELECTRIC COST	ELECTRICAL ENERGY FUEL SOURCE, kWh X 10 ⁶			
		¢/kWh*	Coal	Fuel Oil	Gas	Nuclear
1	Miami	4.60	12573(16.2%)	43967(56.66%)	12693(16.36%)	8370(10.79%)
2	Los Angeles	4.12	— —	48311(58.90%)	27639(33.70%)	6070(7.4%)
3	Phoenix	4.89	17653(66.79%)	4745(17.95%)	4032(15.26%)	— —
4	Albuquerque	3.61	27477(70.00%)	1496(3.8%)	10254(26.14%)	— —
5	Fort Worth	2.99	16539(8.47%)	4055(2.08%)	174582(89.45%)	— —
6	Charleston	3.73	97562(56.21%)	11996(6.91%)	40439(23.30%)	23567(13.58%)
7	Nashville	2.52	20483(77.93%)	36720(14.27%)	3622(1.41%)	16449(6.39%)
8	Boston	5.32	107330(39.04%)	113108(41.14%)	2098(0.76%)	52389(19.06%)
9	Chicago	4.78	347678(78.15%)	18405(4.14%)	19888(4.47%)	58892(13.23%)
10	Bismark	4.55	19120(96.98%)	187(0.95%)	408(2.07%)	— —
11	Seattle	1.47	6093(64.46%)	51(0.54%)	— —	3309(35.00%)

Note: Hydroelectric energy is not included since this does not involve a fuel.

* Based on low-use commercial rates, 10,000 kWh consumption.

3.4 Electrical Costs

The cost of electricity in different portions of the country has a direct bearing on the extent to which solar total energy systems can be cost competitive. The higher the cost of electricity from conventional sources, the more readily solar total energy costs can compete in energy markets. Generally speaking, the cost of electricity in a given region reflects the type and cost of fuel used, although this is only part of the overall costs. Because electric rates are established within state boundaries and thus reflect the influence of the state regulatory commissions, the STE regionalization boundaries should coincide with state boundaries wherever possible. To reflect this effect and recognize the available form of the data, the STE regional boundaries have been changed to coincide with state boundaries wherever it does not drastically alter the climatic boundaries; for example, the boundary lines have been drawn through the states of Minnesota and Florida to reflect somewhat different climatic conditions.

The costs of electricity in different regions are shown in Table 10. The rates selected are low-usage commercial rates because the 50-kWe load guideline for this study places the demand in a different category than either the single-unit residential or the high-usage commercial rate category. For regionalization purposes, only the relative rates in one area vs. another should be important, but the low-usage commercial rates probably reflect a more realistic value to use.

3.5 Population

The population factor was addressed by using the U.S. Department of Commerce's Bureau of Economic Analysis (BEA) 1990 population projections for each of the 171 BEA economic areas within the contiguous 48 states. Population projections were then used to finalize selection of typical cities for analysis. A major objective of the STES program is to identify factors for selecting demonstration sites; regions of very low population would have less appeal for siting demonstration units.

A breakdown, by STE region, of projected (1990) population is shown in Table 11.

In order of population density, i.e., population per square mile, the STE regions can be ranked as shown in Table 12.

Table 11. REGIONAL POPULATION VERSUS AREA

<u>Region</u>	<u>States</u>	<u>Population (1990) X 1000</u>	<u>Area, square miles</u>
1	Florida (1/2)	8816 (3.5%)	30,000 (1.0%)
2	California	24845 (10.0%)	156,803 (5.3%)
3	Arizona, Nevada	2865 (1.1%)	223,382 (7.5%)
4	New Mexico, Colorado, Utah	5654 (2.3%)	307,824 (10.3%)
5	Texas, Oklahoma	22018 (8.8%)	332,927 (11.2%)
6	Louisiana, Mississippi, Alabama, Georgia, North Carolina, South Carolina, Florida (1/2)	28434 (11.4%)	306,191 (10.3%)
7	Arkansas, Tennessee, Kentucky, W. Virginia, Virginia, Maryland, Washington, D.C.	23575 (9.4%)	208,671 (7.0%)
8	Michigan, Pennsylvania, New York, Delaware, New Jersey, Rhode Island, Connecticut, Massachusetts, Vermont, New Hampshire, Maine	68151 (27.3%)	222,702 (7.5%)
9	Ohio, Illinois, Wisconsin, Minnesota, Iowa, Missouri, Nebraska, Kansas	55856 (22.3%)	522,020 (17.5%)
10	N. Dakota, S. Dakota, Montana, Wyoming, Idaho, Minnesota (1/2)	3009 (1.2%)	503,220 (16.9%)
11	Washington, Oregon	6468 (2.6%)	163,327 (5.5%)

Table 12. POPULATION DENSITY BY REGION

<u>STE Region</u>	<u>Population Density, Pop/sq mile</u>	<u>Rank</u>
1 (Miami)	293.9 (high)	2
2 (Los Angeles)	158.4 (high)	3
3 (Phoenix)	12.8 (low)	10
4 (Albuquerque)	18.4 (low)	9
5 (Fort Worth)	66.1 (moderate)	7
6 (Charleston-Raleigh)	92.9 (moderate)	6
7 (Nashville)	113.0 (moderate)	4
8 (Boston)	306.0 (high)	1
9 (Chicago)	107.0 (moderate)	5
10 (Bismark)	6.0 (low)	11
11 (Seattle)	39.6 (low)	8

These data, in conjunction with data on insolation, thermal requirements, electricity costs, and fuel usage, provide the basis for the final regionalization map, Figure 10. Data are summarized in Table 13.

As a result of the low population densities, unfavorable feasibility ratios, and unfavorable potential for savings from fuel displacement, separate load analyses were not carried out for Regions 10 and 11; rather, load analysis data for Region 8 were used for these regions because insolation data, thermal requirements, and feasibility ratios are at least comparable for the three regions, even though some differences exist.

Figure 10. STE REGIONS

Table 13. SUMMARY OF FINAL REGIONALIZATION FACTORS

Region	Climatic/Geographic Description	Characteristics (FR in parentheses)			Electricity Costs, ¢/kWhr
		Insolation [*] /HDD	Insolation [*] /CDD	Population	
1	Hot, humid, southeast (Miami)	high/very low (928)	moderate/high (158)	high	4.60
2	California coastal (Los Angeles)	high/low (231)	moderate/moderate (364)	high	4.12
3	Hot, arid, southwest (Phoenix)	high/low (198)	high/high (141)	low	4.89
4	Mild, high elevation, southwest (Albuquerque)	high/moderate (94)	high/moderate (250)	low	3.61
5	Southern plains (Fort Worth)	moderate/moderate (105)	moderate/high (163)	moderate	2.99
6	Southern-southeastern coastal (Charleston- Raleigh)	moderate/low (129)	low/high (165)	moderate	3.73
7	East central (Nashville)	low/moderate (51)	low/moderate (157)	moderate	2.52
8	Northeast (Boston)	low/high (35)	moderate/low (466)	high	5.32
9	Midwest (Chicago)	high/high (46)	moderate/moderate (301)	moderate	4.78
10	Northern-northwestern (Bismark - use Boston data)	moderate/very high (42)	high/low (537)	low	4.55
11	Pacific northwest (Seattle- use Boston data)	low/high (51)	moderate/very low (859)	low	1.47

* Direct normal insolation.

Section 4

SYNTHESIS OF LOAD REQUIREMENTS

The objective of this subtask is to synthesize the base electrical loads, the electrical loads with electric cooking, the thermal loads due to space heating and cooling, the thermal loads due to domestic water heating, and the ratio of the thermal loads to the electrical load. In addition, the effects of ASHRAE 90-75 conservation measures on the thermal loads due to space heating and cooling were assessed; this is part of the standard Meriwether computer program.

4.1 Energy Related Parameters

The energy related parameters are listed in Tables 14 through 17. They pertain to the four-bedroom, two-story detached house, the townhouse interior unit, the two-story wood-frame low-rise structure, and the 15-story high-rise structure, which were selected as the most typical of the 7 units described earlier. Analyses of the load requirements pertinent to these structures provide a guideline for estimating the loads relative to modified designs of these structures. Structures were not oriented to maximize solar effects.

The "U" values of the walls and roofs were based on the properties of the materials listed in Tables 3 through 6. The "U" values of the windows and patio doors were based on single-glazing (except for the patio door of the detached house, which was double-glazed), with aluminum frames and internal shading (draperies). The summer "U" values were slightly lower than the winter "U" values due to reduced wind speed in the summer.

The indoor temperature in winter was maintained at 70°F. The transmission losses were proportional to the difference between 70°F and the outdoor temperature. The proportionality constant was set according to the particular building, and the outdoor temperature was obtained from the weather tape of the particular city. Similarly, the summer transmission gains were based on an indoor temperature of 75°F, so that these gains were proportional to the outdoor temperature less 75°F. The summer proportionality constant was slightly lower than the winter value due to lower "U" values of the roof and of the fenestration (window areas).

Table 14. ENERGY-RELATED PARAMETERS FOR A 4-BEDROOM,
2-STORY, SINGLE-FAMILY DETACHED HOUSE

		<u>Wall</u>	<u>Roof</u>	<u>Door</u>	<u>Floor</u>	<u>Windows</u>	<u>Patio Door</u>	
1.	"U" Values, <u>Btu/hr-sq ft-°F</u>	Winter Summer	0.072 0.072	0.048 0.046	0.67 0.67	0.10 0.10	0.87 0.81	0.55 0.52
		<u>North</u>	<u>East</u>	<u>South</u>	<u>West</u>	<u>Total</u>		
2.	<u>Areas, sq ft</u>	Walls Glass Doors Floor Ceiling	458 42 0 -- --	566 40 ^b /54 20 -- --	180 ^a /300 0 20 ^a -- --	576 84 20 -- --	1900 180 60 1700 850	
3.	Transmission Losses, <u>Btu/hr</u> ($\Delta T_L = 70^\circ\text{F} - T_{\text{outdoor}}$)	Walls Glass Doors Basement ^c Ceiling	33 ΔT_L 37 ΔT_L 0 -- --	41 ΔT_L 68 ΔT_L 14 ΔT_L -- --	28 ΔT_L 0 7 ΔT_L -- --	42 ΔT_L 73 ΔT_L 14 ΔT_L -- --	144 ΔT_L 178 ΔT_L 35 ΔT_L 55000 41 ΔT_L	
4.	Transmission Gains, <u>Btu/hr</u> ($\Delta T_G = 75^\circ\text{F} - T_{\text{outdoor}}$)	Walls Glass Doors Ceiling	33 ΔT_G 34 ΔT_G 0 --	41 ΔT_G 64 ΔT_G 14 ΔT_G --	28 ΔT_G 0 7 ΔT_G --	42 ΔT_G 68 ΔT_G 14 ΔT_G --	144 ΔT_G 166 ΔT_G 35 ΔT_G 39 ΔT_G	
5.	Reference Solar Gains, ^d Btu/hr	Walls Doors Glass ^e Roof ^e	0 0 3-1000 --	900 300 18-1900 --	200 60 0 --	0 0 5400 --	1100 360 80-300 17-1900	
6.	Solar Area Percentages		15%	43%	2%	32%	(Roof, 8%)	
7.	Air Infiltration, CF/min.	Winter	$= 96 + 5.1\Delta T_L$		Summer	$= 130$		
8.	Total Heat Gain From Cooking = 2700 Btu/hr; From People ^f = 2000 Btu/hr							
a.	Faces garage							
b.	Double glass sliding patio door.							
c.	Assumed water temp = 50°F							
d.	On June 21 at 2:00 p.m.							
e.	Latitude		<u>North</u>	<u>East</u>	<u>Roof</u>			
		24° 32° 40° 48°	1000 900 800 800	1900 1900 1900 1800	1900 1900 1800 1700			
f.	Four people per dwelling unit.							

Table 15. ENERGY-RELATED PARAMETERS
FOR TOWNHOUSE INTERIOR UNIT

		Wall	Roof	Door	Floor	Windows	Patio Door
1. "U" Values, Btu/hr-sq ft-°F	Winter	0.092	0.070	0.54	0.10	0.87	0.87
	Summer	0.092	0.066	0.54	0.10	0.81	0.81
		North	East	South	West	Total	
2. Areas, sq ft	Walls	0	352	0	385	737	
	Glass	0	108	0	91	199	
	Doors	0	0	0	20	20	
	Floor	--	--	--	--	1452	
	Ceiling	--	--	--	--	763	
3. Transmission Losses, Btu/hr ($\Delta T_L = 70^\circ\text{F} - T_{\text{outdoor}}$)	Walls	0	32 ΔT_L	0	35 ΔT_L	67 ΔT_L	
	Glass	0	94 ΔT_L	0	79 ΔT_L	1730 ΔT_L	
	Doors	0	0	0	11 ΔT_L	11 ΔT_L	
	Basement	--	--	--	--	2600	
	Ceiling	--	--	--	--	54 ΔT_L	
4. Transmission Gains, Btu/hr ($\Delta T_G = 75^\circ\text{F} - T_{\text{outdoor}}$)	Walls	0	32 ΔT_G	0	35 ΔT_G	67 ΔT_G	
	Glass	0	87 ΔT_G	0	74 ΔT_G	161 ΔT_G	
	Doors	0	0	0	11 ΔT_G	11 ΔT_G	
	Ceiling	--	--	--	--	50 ΔT_G	
5. Reference Solar Gains, Btu/hr 2:00 p.m., June 21	Walls	0	800	0	0	800	
	Doors	0	0	0	0	0	
	Glass ^a	0	22-2300	0	5800	80-8100	
	Roof ^a	--	--	--	--	22-2400	
6. Solar Area Percentages		0%	50%	0%	40%	(Roof, 10%)	
7. Air Infiltration, CF/min	Winter = 72 + 3.8 ΔT_L			Summer = 97			
8. Total Heat Gain From Cooking = 2700 Btu/hr; From People ^b = 2000 Btu/hr							
a. Latitude Dependent: Latitude		East	Roof	Total			
	24°	2300	2400	11,300			
	32°	2300	2400	11,300			
	40°	2300	2300	11,200			
	48°	2200	2200	11,000			
b. Four people per dwelling unit.							

Table 16. ENERGY-RELATED PARAMETERS FOR A 2-STORY WOOD-FRAME, LOW-RISE STRUCTURE

		Wall	Roof	Door	Floor	Windows	Patio Door
1. "U" Values	Winter	0.072	0.048	0.67	0.10	0.87	0.87
<u>Btu/hr-sq ft-°F</u>	Summer	0.072	0.046	0.67	0.10	0.81	0.81
		North	East	South	West	Total	
2. <u>Areas, sq ft</u>	Walls	2784/1008 ^a	3000	2784/1008 ^a	3000	11,568	
	Glass	0	1320	0	1320	2,640	
	Doors	240	0	240	0	480	
	Floor	--	--	--	--	26,880	
	Ceiling	--	--	--	--	13,440	
3. Transmission Losses,	Walls	110ΔT _L	216ΔT _L	110ΔT _L	216ΔT _L	652ΔT _L	
<u>Btu/hr</u>	Glass	0	1150ΔT _L	0	1150ΔT _L	2300ΔT _L	
(ΔT _L =70°F-T outdoor)	Doors	35ΔT _L	0	35ΔT _L	0	70ΔT _L	
	Ceiling	--	--	--	--	650ΔT _L	
	Slab	--	--	--	--	27,000	
4. Transmission Gains,	Walls	110ΔT _G	216ΔT _G	110ΔT _G	216ΔT _G	652ΔT _G	
<u>Btu/hr</u>	Glass	0	1070ΔT _G	0	1070	2140ΔT _G	
(ΔT _G =75°F-T outdoor)	Doors	35ΔT _G	0	35ΔT _G	0	70ΔT _G	
	Ceiling	--	--	--	--	620ΔT _G	
5. Reference Solar Gains,	Walls	0	4800	300	0	5,100	
<u>Btu/hr</u>	Doors	0	0	0	0	0	
2:00p.m., June 21	Glass ^b	0	26,400-27,700	0	83,400	111,100	
	Roof ^b	--	--	--	--	26,900-29,600	
6. Solar Area Percentages		0%	42%	1%	46%	(Roof, 11%)	
7. Air Infiltration, CF/min	Winter = 2020 (avg)	Summer = 1620 (avg)					
8. Total Heat Gain From Cooking = 56,000 Btu/hr; From People ^c = 36,000 Btu/hr							
a. Facing stairwell/exposed to outside.							
b. Latitude dependent: Total at 48°=142,600 Btu/hr, at 24°=146,600 Btu/hr.							
c. Three people per dwelling unit.							

Table 17. ENERGY-RELATED PARAMETERS FOR HIGH-RISE STRUCTURES

		Wall	Roof	Door	Floor	Windows	Patio Door
1. "U" Values, Btu/hr-sq ft-°F	Winter	0.200	0.146	0.67	0.10	0.87	0.87
	Summer	0.200	0.146	0.67	0.10	0.81	0.81
		North	East	South	West	Total	
2. Areas, sq ft	Walls	1,380	11,520	1,380	15,270	29,550	
	Glass	7,320	11,280	7,320	10,080	36,000	
	Floor	--	--	--	--	153,500	
	Roof	--	--	--	--	10,218	
3. Transmission Losses, Btu/hr ($\Delta T_L = 70^\circ\text{F} - T_{\text{outdoor}}$)	Walls	276 ΔT_L	2304 ΔT_L	276 ΔT_L	3054 ΔT_L	5,910 ΔT_L	
	Glass	6380 ΔT_L	9850 ΔT_L	6380 ΔT_L	8710 ΔT_L	31,320 ΔT_L	
	Roof	--	--	--	--	1,500 ΔT_L	
	Slat	--	--	--	--	24,000	
4. Transmission Gains, Btu/hr ($\Delta T_G = 75^\circ\text{F} - T_{\text{outdoor}}$)	Walls	276 ΔT_G	2304 ΔT_G	276 ΔT_G	3054 ΔT_G	5,910 ΔT_G	
	Glass	5940 ΔT_G	9160 ΔT_G	5940 ΔT_G	8100 ΔT_G	29,140 ΔT_G	
	Roof	--	--	--	--	1,500 ΔT_G	
5. Reference Solar Gains, Btu/hr 2:00 p.m., June 21	Walls	0	51,400	1,100	0		
	Glass ^a	146,300- 168,400	225,700- 237,000	484,000- 168,200	630,000		
	Roof ^a	--	--	--	--	65,000-71,500	
6. Solar Area Percentages		19%	33%	19%	28%	(Roof, 1%)	
7. Air Infiltration, CF/min	Winter = 5600 (avg)	Summer = 4400 (avg)					
8. Ventilation = 18,500 CF/min							
9. Total Heat Gain From Cooking = 420,000 Btu/hr; From People ^b = 225,000 Btu/hr							
a. Latitude dependent: total at 48° = 1,603,500 Btu/hr, at 24° = 1,327,600 Btu/hr.							
b. Five people per 2 dwelling units.							

The solar heat gains would depend upon the intensity of solar radiation received at the building surfaces and upon several factors relating to the building. The method used in calculating the solar heat gains followed closely the one described in the ASHRAE Handbook of Fundamentals.⁶ An appropriate shading coefficient was applied to the solar heat gains at the window surfaces to account for the internal shading due to draperies made of semi-open weave fabric with medium-colored yarn. External shadings due to adjacent buildings or trees were not taken into account in this study, although their effects on the thermal loads will be discussed in a later section.

In order to calculate the "unlagged" solar heat gain at any fenestration, we used the following equation:⁶

$$\begin{array}{lcl} \text{Solar} & & \text{Shading} & & \text{Solar Heat Gain Factor (SHGF)} \\ \text{Heat (Btu/hr-sq ft)} & = & \text{Coefficient (SC)} & \times & \text{for Given Orientation} & (1) \\ \text{Gain} & & \text{for Fenestration} & & \text{and Existing Conditions} \end{array}$$

We have calculated the solar heat gains at 2 p.m. on June 21 and used these gains as a reference for calculating the solar heat gains at other hours. For example, the solar heat gain (unlagged) at the west window will be equal to:

$$\begin{array}{lcl} \text{Solar gain (Btu/hr-sq ft)} & = & 0.6 \times 145 = 87 & (2) \\ & & \text{SC} & \text{SHGF} \end{array}$$

While the convective portion of the instantaneous heat gain at the fenestration could be considered as instantaneous cooling load, the radiant portion due to building thermal storage had to be spread uniformly over 4 hours, including the given hour. The lagging time was appropriate to lightweight construction. Table 18a includes the lagging data for the vertical as well as for the horizontal surfaces. Consequently, the table of Solar Heat Gain Factors had to be modified to take this storage effect into account.

The solar heat gains at the roof surface were lagged (i.e., adjusted to reflect a time lag) in order to correlate well* with the difference between the Total Equivalent Temperature Difference (TETD) and the actual indoor-outdoor temperature difference. This correlation works best if we spread the gains uniformly over 10 hours, including the given hour (9-hour spread) as shown in Table 18b. Thus, data in columns 3 and 5 in Table 18b should show a good correlation, because subtracting (75-temp) from TETD produces a value that reflects the solar contribution to the total. This correlation, given graphically in

* i.e., proportional to the difference.

Table 18a REFERENCE SOLAR HEAT GAINS
Btu/hr-sq ft

Glass (Single glaze, 11m shades,* 95% clearance, 3-hour lag.)

<u>Latitude</u>	<u>N</u>	<u>E</u>	<u>S</u>	<u>W</u>
24°	23	21	23	63
32°	22	21	30	63
40°	20	21	45	63
48°	20	20	66	63

Walls/Doors

0/0 1.6/15 0.3/3 0/0

Roof

<u>Latitude</u>	<u>Roof</u>
24°	2.2
32°	2.2
40°	2.1
48°	2.0

Lagging Data

<u>Vertical</u>	<u>Horizontal</u>
55% First hour	10% First hour
3-hour spread	9-hour spread
Uniform type spread	Uniform type spread

* Medium color, semi-open weave.

Table 18b. ROOF SOLAR HEAT GAINS*

Time	$\alpha I_t/h_o$ ** °F	10%, 9-hour spread†, °F	TETD‡ °F	TETD - (T _{outside} - 75)
1	0	10.0	11	10
2	0	4.8	4	3
3	0	1.4	-1	-1
4	0	0.0	-6	-5
5	0	0.0	-7	-6
6	14	1.4	-4	-3
7	34	4.8	0	0
8	52	10.0	1	-1
9	67	16.7	10	5
10	79	24.6	19	11
11	86	33.2	31	19
12	89	42.1	43	27
13	86	50.7	54	36
14	79	58.6	65	46
15	67	65.3	71	51
16	52	69.1	76	57
17	34	69.1	74	56
18	14	65.3	72	56
19	0	58.6	62	50
20	0	50.7	53	43
21	0	42.1	43	35
22	0	33.2	33	27
23	0	24.6	25	21
24	0	16.7	18	16

* Excluding effect of solar collectors, not appreciable for a well-insulated roof.

** This is a term that is proportional to the absorbed solar energy at the outer surface of the roof (from ASHRAE).

† Ten percent of the absorbed energy is sensed by the cooling system; the remaining 90% is spread over the next 9 hours, reflecting a 9-hour time lag. For example, the value for hour 10 (24.6) is equal to 10% of $\alpha I_t/h_o$ for hour 10 (7.9) plus 10% of the sum of $\alpha I_t/h_o$ for the preceding 9 hours (6.7 + 5.2 + 3.4 + 1.4 + 0).

‡ Total Equivalent Temperature Difference — a term that accounts for storage of thermal energy in the building, considering both convection and radiation. These values, obtained from the literature, are derived by a "thermal response method" of calculation. Subtracting the transmission contribution (T_{outside} - 75) from TETD gives the solar contribution, indicated by the expression, TETD - (T_{outside} - 75), in the fifth column.

Figure 11, shows that the heat gains from the roof surface reach a maximum between the hours of 4 p.m. to 6 p.m., although the Solar Heat Gain Factor is at a maximum at 12 noon.

Figure 11. ROOF SOLAR GAINS PROFILE

The rates of air infiltration in winter are generally higher than those in summer, because air infiltration increases with an increasing indoor-outdoor air density difference, which is generally higher in winter than in the summer for most of the selected cities. Summer air infiltration is generally in the neighborhood of 0.4 air changes per hour, while winter air infiltration can exceed 1 air change per hour in cold climates. Air infiltration is also increased with increased wind speed, which is generally higher in winter than in the summer. As a result, the rates of air infiltration in air changes per hour have been expressed as functions of the indoor-outdoor temperature difference, with the wind speed kept constant at 15 mph in winter and at 7.5 mph in summer. These rates were multiplied by the volume of the air-conditioned space to get the total rate of air infiltration. The results in units of cubic feet per minute (CF/min) were included in Tables 14 through 17.

Air infiltration has been determined experimentally⁷ to be temperature-dependent in winter for single-family structures; this is reflected in the winter air-infiltration terms used in Tables 14 and 15. Although summer air infiltration rates show a slight dependence upon temperature difference, the dependence is so slight that the infiltration rate can be considered constant. This explains the lack of a ΔT term for summer air infiltration rates in Tables 14 and 15. Information on temperature-dependence is not available for low-rise and high-rise apartment buildings, so average ASHRAE values for both summer and winter air-infiltration rates were used in Tables 16 and 17 for low-rise and high-rise apartment buildings.

The remainder of the energy-related parameters included the internal heat gains from the kitchen appliances, which were assumed to follow the diversified cooking profile, and the internal heat gains from people, which followed the occupancy profile.

Tables 14 through 17 include the major assumptions used in calculating the thermal loads due to space heating and cooling, which will be described in a later section.

4.2 Conservation Measures

The conservation measures applied to the structures, based on ASHRAE Standard 90-75, are listed in Table 19. Applied to single-family houses and to low-rise apartment structures, these measures were governed by only the heating-

Table 19. CONSERVATION MEASURES

Conservation Regions:

- I. Boston, Chicago
- II. Albuquerque, Nashville, Raleigh
- III. Dallas, Los Angeles, Phoenix
- IV. Miami

<u>Region</u>	<u>Single-Family Detached</u>	<u>Townhouse</u>	<u>Low-Rise</u>	<u>High-Rise</u>
I	Reduce Infiltration	Reduce Infiltration Add Storm Windows	Reduce Infiltration Add Storm Windows	Var. Vol. Ventilation Reduce Infiltration Decrease Window Surface Double Glass Windows Increase Wall Insulation Increase Roof Insulation
II	Reduce Infiltration	Reduce Infiltration Add Storm Windows	Reduce Infiltration Add Storm Windows	Var. Vol. Ventilation Reduce Infiltration Decrease Window Surface Double Glass Windows Increase Roof Insulation
III	Reduce Infiltration	Reduce Infiltration	Reduce Infiltration	Var. Vol. Ventilation Reduce Infiltration Decrease Window Surface Double Glass Windows Increase Roof Insulation
IV	Reduce Infiltration	Reduce Infiltration	Reduce Infiltration	Var. Vol. Ventilation Reduce Infiltration Decrease Window Surface

degree-days. Applied to high-rise structures, the conservation measures depended upon both the latitude and the heating-degree-days. Pertinent to all the structures, the Standard specified limit values for the combined thermal transmittance (U_0 value) of wall and roof/ceiling and for the rates of air infiltration. Moreover, for the high-rise structure, the Standard sets a limit value for the overall thermal transfer rate, in order to decrease the cooling load.

The extent to which conservation measures are applied depends upon the heating requirements, so four conservation regions were defined (Table 19): Conservation Region I, Chicago and Boston; II, Albuquerque, Nashville, and Charleston-Raleigh; III, Fort Worth-Dallas, Phoenix, Los Angeles; and IV, Miami.

In the single-family detached house, the air-infiltration rate had to be reduced substantially. Some cases relevant to the low-rise structure and to the townhouse required the addition of storm windows, in order to reduce the U_0 value. The high-rise structure received a large number of conservation measures due to the excessive heating as well as cooling loads. The fenestration areas had to be cut in half in order to reduce the overall thermal transfer value.

Tables 20 through 27 describe the energy-related parameters as affected by the conservation measures. They show the extent of reduction in the heat losses and gains and in the rates of air infiltration, relevant to each of the selected cities.

4.3 Base-Electric Loads^{8,9,10}

The base-electric loads are those due to lighting and electrical appliances, including refrigerators, television sets, dishwashers, clothes washers, and miscellaneous electrical gadgets, but excluding electrical clothes dryers, electrical ranges, electric water heaters, and HVAC processing equipment.

The study of base-electrical loads for aggregates of single-family dwelling units and for low- and high-rise apartment complexes involves the considerations of hourly diversified demand profiles for weekdays and weekends, the average weekday and the average weekend maximum diversified demand for each month, the monthly ratios of average demand to peak demand for average weekdays and weekends, and the monthly ratios of maximum diversified demand to average weekday maximum diversified demand.

Table 20. ENERGY-RELATED PARAMETERS FOR SINGLE-FAMILY DETACHED HOUSE,
ENERGY CONSERVATIVE, ALL REGIONS

1. "U" Values
2. Areas
3. Transmission Losses SAME VALUES AS
4. Transmission Gains GENERIC DATA
5. Solar Gains
6. Solar Area Percentages
7. Winter Air Infiltration = $51 + 1.2 \Delta T$ CF/min
8. Summer Air Infiltration = 64 CF/min

Table 21. ENERGY-RELATED PARAMETERS, TOWNHOUSE,
CONSERVATIVE, CONSERVATION REGIONS I AND II
(Boston, Chicago, Nashville, Raleigh, Albuquerque)

1. U glass = 0.52/0.50, Others Unchanged
2. Areas Unchanged
3. Transmission Losses, Btu/hr

Glass = 130 ΔT	Ceiling = 54 ΔT
Walls = 67 ΔT	Basement = 2600
Doors = 11 ΔT	
4. Transmission Gains, Btu/hr

Glass = 123 ΔT	Doors = 11 ΔT
Walls = 67 ΔT	Ceiling = 50 ΔT
5. Reference, Solar Gains Btu/hr

<u>Total</u>	<u>Latitude</u>	<u>Walls</u>	<u>E</u> 800	<u>W</u> 0	<u>Roof</u>
10,200	24		2000	5000	2400
10,200	32		2000	5000	2400
		<u>Glass</u>			
10,100	40		2000	5000	2300
10,000	48		2000	5000	2200
6. Solar Area, %

	49%	39%	12%
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7. Winter Infiltration = 39 = $0.9 \Delta T$ CF/min
8. Summer Infiltration = 49 CF/min

Table 22. ENERGY-RELATED PARAMETERS, TOWNHOUSE,
CONSERVATIVE, CONSERVATION REGIONS III AND IV
(Dallas, Los Angeles, Miami, Phoenix)

1. "U" Values
2. Areas
3. Transmission Losses
4. Transmission Gains
5. Solar Gains
6. Solar Area Percentages
7. Winter Air Infiltration = $39 + 0.9 \Delta T$ CF/min
8. Summer Air Infiltration = 49 CF/min

Table 23. ENERGY-RELATED PARAMETERS, LOW-RISE STRUCTURE,
CONSERVATIVE, CONSERVATION REGIONS I AND II
(Boston, Chicago, Nashville, Raleigh, Albuquerque)

1. U glass = 0.52/0.50, Others Unchanged
2. Areas Unchanged
3. Transmission Losses, Btu/hr

Glass = 1699 ΔT	Ceiling = 650 ΔT
Walls = 652 ΔT	Slab = 27,000
Doors = 70 ΔT	

4. Transmission Gains, Btu/hr

Glass = 1618 ΔT	Doors = 11 ΔT
Walls = 652 ΔT	Ceiling = 620 ΔT

5. Reference Solar Gains, Btu/hr

<u>Total</u>	<u>Latitude</u>	<u>Walls</u>	<u>E</u>	<u>S</u>	<u>W</u>	<u>Roof</u>
131,800	24		4,800	300	0	29,600
131,800	32		24,000		72,300	29,600
			24,000		72,300	29,600
		<u>Glass</u>				
130,500	40		24,000		72,300	28,300
128,000	48		22,900		72,300	26,900
		<u>Doors</u>				
			0	800	0	

6. Solar Area, %
7. Winter Air Infiltration = 1,440 CF/min (Average)
8. Summer Air Infiltration = 896 CF/min (Average)

Table 24. ENERGY-RELATED PARAMETERS, LOW-RISE STRUCTURES,
CONSERVATIVE, CONSERVATION REGIONS III AND IV
(Dallas, Los Angeles, Miami, Phoenix)

1. "U" Values
2. Areas
3. Transmission Losses
4. Transmission Gains
5. Solar Gains
6. Solar Area Percentages
7. Winter Air Infiltration = 1440 CF/min (Average)
8. Summer Air Infiltration = 896 CF/min (Average)

SAME VALUES AS
GENERIC DATA

Table 25. ENERGY-RELATED PARAMETERS, HIGH-RISE STRUCTURES,
CONSERVATIVE, MIAMI

1. "U" Values Unchanged
2. Areas, sq ft

	<u>N</u>	<u>E</u>	<u>S</u>	<u>W</u>
Walls	5,040	17,160	5,040	20,310
Windows	3,660	5,640	3,660	5,040
3. Transmission Losses Btu/hr

Walls	10,242 ΔT	Roof = 1,500 ΔT
Windows	15,660 ΔT	Slab = 24,000
4. Transmission Gains Btu/hr

Walls	10,242 ΔT	Roof = 1,500 ΔT
Windows	14,580 ΔT	
5. Reference Solar Gains, Btu/hr

	<u>N</u>	<u>E</u>	<u>S</u>	<u>W</u>	
<u>Total</u>		76,600	4,000		<u>Roof</u>
753,900	84,200	118,500	84,100	315,000	71,500
<u>Latitude</u>					
25°					
6. Solar Area,%

	17	39	17	25	2
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7. Winter Air Infiltration = 3800 CF/min
8. Summer Air Infiltration = 3000 CF/min
9. Ventilation = 4600 CF/min

Table 26. ENERGY-RELATED PARAMETERS FOR HIGH-RISE STRUCTURES,
CONSERVATIVE, CONSERVATION REGIONS II AND III
(Nashville, Dallas, Los Angeles, Phoenix, Raleigh, Albuquerque)

1. "U" glass = 0.60, $U_{\text{roof}} = 0.09$, Others Unchanged
2. "Areas" as in Table 25
- 3,4. Transmission Losses
and Gains, Btu/hr

Walls	10,242	ΔT		Roof = 900	ΔT
Windows	10,800	ΔT		Slab = 24,000	(Losses)
5. Reference Solar
Gains, Btu/hr

Total	670,000
-------	---------
6. Solar Area, %

<u>N</u>	<u>E</u>	<u>S</u>	<u>W</u>	<u>Roof</u>
17	39	17	25	2
7. Average Winter Infiltration = 5000 CF/min
8. Average Summer Infiltration = 3000 CF/min
9. Ventilation = 4600 CF/min

Table 27. ENERGY-RELATED PARAMETERS FOR HIGH-RISE STRUCTURES,
CONSERVATIVE, CONSERVATION REGION I
(Boston, Chicago)

1. $U_{\text{wall}} = 0.18$, $U_{\text{glass}} = 0.60$, $U_{\text{roof}} = 0.07$
2. "Areas" as in Table 25
- 3,4. Transmission Losses
and Gains, Btu/hr

Walls	9,000	ΔT		Roof	700	ΔT
Windows	10,800	ΔT		Slab	24,000	(Losses)
5. Total Reference Solar Gains 670,000 Btu/hr
6. Solar Area, %

<u>N</u>	<u>E</u>	<u>S</u>	<u>W</u>	<u>Roof</u>
17	39	17	25	2
7. Average Winter Infiltration = 6500 CF/min
8. Average Summer Infiltration = 3000 CF/min
9. Ventilation = 4600 CF/min

Given the total yearly base-electric consumption for an aggregate of dwelling units, we can determine the average weekday maximum diversified demand for December. This will be enough to determine the hourly diversified demand over the whole year. The method can be readily applied to the generic low-rise structure, to the generic high-rise structure, to a complex of these, or to an aggregate of single-family dwelling units. Given the yearly base-electric consumption for each sector, we can deduce the diversified demand for that sector.

4.3.1 Hourly Profiles of Diversified Demand

The analysis presented in this section is based on four aggregates with the following numbers of dwelling units (includes both single- and multi-family units):

<u>Aggregate</u>	<u>Units</u>
1	135
2	60
3	43
4	48

The diversified demand profiles and data have been obtained from the Rates and Market Research Department of the Public Service Electric and Gas Company.* Figures 12 through 17** show the hourly base-electric demand profiles for the four aggregates of dwelling units. These profiles are for average weekdays in those months of the year with essentially no cooling requirements for residences located in the northeastern section of the country.

The average weekday hourly profiles for a given month essentially follow the same pattern for all aggregates. The minimum diversified demand is reached at 3:00 a.m. to 5:00 a.m. with a value of 25% to 35% of peak demand. For Aggregates 1, 3, and 4, the profiles level off at approximately 50% to 55% of peak demand for the hours between 9:00 a.m. and 3:00 p.m. It is slightly lower for Aggregate 2, which is at about 40% to 45% of peak demand. There is a usual small peak at 8:00 a.m. for all aggregates. Between the hours of 3:00 p.m. and 10:00 p.m., the profiles behave differently for different months; during these hours, the profiles for May show a marked distinction from the profiles of December or January, mainly due to the effects of an increased demand for lighting.

* New Jersey.

** Figures 12 through 17, and all remaining figures, are shown in Appendix A.

Figure 18* compares a profile for a typical weekend with that for a typical weekday. The marked difference appears between the hours of 8:00 a.m. and 5:00 p.m. The diversified demand as percent of peak is markedly higher for the weekend than for the weekday.

4.3.2 Daily Summary

The base-electric load study involves the average weekday and the average weekend for each month. The days of each month are characterized by a single weekday profile and a single weekend profile, i.e., the average weekday profile and the average weekend profile, respectively. The actual hourly demand for a given month fluctuates around the average weekday or the average weekend profile. Monthly variations of average weekday and average weekend demand parameters will be discussed in the next section.

4.3.3 Monthly Summary

The monthly variations of the average weekday maximum diversified base-electric demand is shown in Figure 19* for the four aggregates. Generally, this peak is at a maximum for the month of December, drops slightly for the month of January, and eventually reaches a minimum for the months of May and June. It is important to note that it may be misleading to use summer base-electric load data for non-air-conditioned spaces, due to the excessive consumption of energy by the refrigerator compressors with higher indoor temperatures, especially during the months of July and August, when the refrigerator door is opened more frequently. For this reason, we have shown the upper bounds of the summer peaks.

Figure 20* shows the monthly variation of the ratio of average weekend maximum diversified demand to average weekday maximum diversified demand. It varies between 0.91 and 0.98 for all the months except for December, when it assumes the value of 1.03.

The analysis of the ratio of average demand to peak demand is important in the study of base-electric loads. Figure 21* shows the variation of this ratio over the year for average weekday. Figure 22* compares the ratio for weekends with that for weekdays.

Figure 23* shows the ratio of the maximum diversified demand for a given month to the average weekday maximum diversified demand for that month. This ratio is at a maximum in December, due to the effect of the Christmas holidays.

* See Appendix A.

Table 28 shows the relative (or normalized) values of four important parameters related to base electric loads, based on a reference value of 1.00 for the average weekday maximum diversified demand for December. Table 29 shows the values in kW of the four parameters in terms of W, which is the reference value in kW of the average weekday maximum diversified demand for December and will be different for different structures; not to be confused with the symbol for "watt."

4.3.4 Yearly Summary

Table 30 shows the number of weekdays and the number of weekends per month for the year 1976. Table 31 shows the monthly and the yearly base electric consumption in terms of W. The total yearly consumption in kWhr is equal to 4704 W. This method of aggregation is used instead of the 365-day, 8760-hour yearly aggregation because weekend consumption is different from weekday consumption.

4.3.5 Low-Rise Structures

Table 32 illustrates the application of the above method to low-rise structures. Given the total yearly consumption of 111,000 kWhr per structure, we find that W is equal to 23.6 kW. The maximum diversified demand for the whole year is equal to 1.35 W (or 31.9 kW), as indicated in Figure 23.

4.3.6 All Structures

We can calculate the value of W for all structures considered in this study by estimating the total yearly consumption. The analyses are described in Tables 32 through 35 and the results are summarized as follows:

W, Single-family = 1.26 kW (for a single unit)
W, Low-rise = 23.6 kW (for a 24-unit structure)
W, High-rise = 163 kW (for a 180-unit structure).

4.4 Electrical Loads With Electric Ranges

Figure 24 through 28* show hourly profiles of electrical demands including electric ranges. The peak demand occurs at about 6:00 p.m. for all the months shown. For the month of May, two peaks are observed, one occurring at 6:00 p.m. and the other at 10:00 p.m. Moreover, we observe that the minimum diversified demand as percent of peak is lower than that observed in the profiles of base electric loads.

* See Appendix A.

Table 28. MONTHLY PARAMETRIC VALUES — BASE ELECTRIC LOADS

Month	Avg Weekday Max Diversified Demand (Normalized Values)	Ratio of Avg Weekend Max Div Demand to Avg Weekday Max Div Demand	Ratio of Avg Demand to Peak Demand for Weekdays	Ratio of Avg Demand to Peak Demand for Weekends
January	0.97	0.96	0.58	0.62
February	0.96	0.93	0.59	0.64
March	0.92	0.97	0.57	0.60
April	0.88	0.97	0.55	0.58
May	0.84	0.97	0.56	0.62
June	0.84	0.94	0.57	0.65
July	0.93	0.91	0.63	0.68
August	0.93	0.96	0.63	0.67
September	0.86	0.96	0.58	0.64
October	0.89	0.96	0.55	0.61
November	0.92	0.98	0.59	0.60
December	1.00	1.03	0.58	0.59

Table 29. MONTHLY PARAMETRIC VALUES FOR BASE ELECTRIC LOADS IN TERMS OF W*

Month	Avg Weekday Max Div Demand, kW	Avg Weekend Max Div Demand, kW	Avg Div Demand for Weekdays, kW	Avg Div Demand for Weekends, kW
January	0.97 W	0.93 W	0.56 W	0.58 W
February	0.96 W	0.89 W	0.57 W	0.57 W
March	0.92 W	0.88 W	0.52 W	0.53 W
April	0.88 W	0.85 W	0.48 W	0.49 W
May	0.84 W	0.81 W	0.47 W	0.50 W
June	0.84 W	0.79 W	0.48 W	0.51 W
July	0.93 W	0.84 W	0.58 W	0.57 W
August	0.93 W	0.89 W	0.59 W	0.59 W
September	0.86 W	0.83 W	0.50 W	0.53 W
October	0.89 W	0.86 W	0.49 W	0.53 W
November	0.92 W	0.90 W	0.54 W	0.54 W
December	W	1.03 W	0.58 W	0.61 W

* W = Average weekday maximum diversified demand for December in kW.

Table 30. NUMBER OF WEEKDAYS AND OF WEEKENDS PER MONTH FOR 1976

<u>Month</u>	<u>Number of Weekdays</u>	<u>Number of Weekends</u>
January	22	9
February	20	9
March	23	8
April	22	8
May	21	10
June	22	8
July	22	9
August	22	9
September	22	8
October	21	10
November	22	8
December	23	8

Table 31. MONTHLY CONSUMPTION VALUES FOR 1976 IN TERMS OF W* —
BASE ELECTRIC LOADS

<u>Month</u>	<u>Total Weekday Consumption, kWhr</u>	<u>Total Weekend Consumption, kWhr</u>	<u>Total Monthly Consumption, kWhr</u>
January	296W	125W	421W
February	273W	123W	396W
March	288W	102W	390W
April	253W	94W	347W
May	237W	120W	357W
June	254W	98W	352W
July	307W	123W	430W
August	312W	127W	439W
September	264W	102W	366W
October	247W	127W	374W
November	285W	108W	393W
December	321W	118W	439W
Total	3337 W	1367 W	4704 W

* W = Average weekday maximum diversified demand for December in kW.

E = Total Yearly Consumption, kWhr = 4704 W.

Table 32. APPLICATION OF METHOD TO MULTI-FAMILY DWELLING UNITS

Low-Rise StructuresBase Electric Yearly Consumption Per Dwelling Unit, kWhr

	<u>Chicago</u>	<u>Atlanta</u>	<u>St. Louis</u>	<u>Boston</u>
Refrigerator	1400	1400	1400	1400
Dishwasher	280	280	280	280
Lights	1205	1600	1400	1600
Television	400	400	400	400
Misc. Appliances	1100	1100	1100	1100
Total	4385	4780	4580	4780

Number of dwelling units per structure = 24.

Average yearly consumption per dwelling unit = 4631 kWhr.

E = Total consumption per structure = 111,000 kWhr (for 24 dwelling units).

$\%W = 23.6 \text{ kW}$, or $\frac{E}{4704} \text{ kW}$.

W = Average weekday maximum diversified demand for December in kW.

Maximum diversified demand = $1.35 \times 23.6 = 31.9 \text{ kW}$ (for a 24-unit structure).

Table 33. HIGH-RISE STRUCTURES

Base Electric Yearly Consumption Per Dwelling Unit, kWhr

	<u>Chicago</u>	<u>Atlanta</u>	<u>St. Louis</u>	<u>Boston</u>
Refrigerator	1400	1400	1400	1400
Dishwasher	280	280	280	280
Lights	1265	1175	970	860
Television	400	400	400	400
Misc. Appliances	1100	1100	1100	1100
Total	4445	4355	4150	4040

Number of dwelling units per structure = 180.

Average yearly consumption per dwelling unit = 4248 kWhr.

E = Total consumption per structure = 764,640 kWhr (for 180 dwelling units).

$\%W = 163 \text{ kW}$, or $\frac{E}{4704} \text{ kW}$ (for a 180-unit structure).

Table 34. SINGLE-FAMILY DETACHED HOUSE⁹Base Electric Yearly Consumption Per Dwelling Unit, kWhr

	<u>Chicago</u>	<u>Atlanta</u>	<u>St. Louis</u>	<u>Boston</u>
Refrigerator/Freezer	1830	1830	1830	1830
Lights	2020	2020	1350	1320
Television	500	500	500	500
Dishwasher	363	363	363	363
Clothes Washer	103	103	103	103
Iron	144	144	144	144
Coffee Maker	106	106	106	106
Miscellaneous	1200	1200	1200	1200
Total	6266	6266	5596	5566

E = Average yearly consumption = 5924 kWhr.

W = 5924/4704, or 1.26 kW.

Table 35. TOWNHOUSE RESIDENCE^{3,9}Base Electric Yearly Consumption Per Dwelling Unit, kWhr

	<u>Chicago</u>	<u>Atlanta</u>	<u>St. Louis</u>	<u>Boston</u>
Refrigerator	1830	1830	1830	1830
Lights	1570	1990	1570	1570
Television	500	500	500	500
Dishwasher	363	363	363	363
Clothes Washer	103	103	103	103
Iron	144	144	144	144
Coffee Maker	106	106	106	106
Miscellaneous	1200	1200	1200	1200
Total	5816	6236	5816	5816

E = Average yearly consumption = 5921 kWhr.

W = 5921/4704, or 1.26 kW.

Tables 36 through 38 show the monthly parametric values and how they relate to W_t , which is the average weekday maximum diversified demand for December (contrasted with W , which does not include the cooking load). The total yearly consumption, E_t (base-electric plus cooking load), is related to W_t by a proportionality constant that is lower than that found for the base-electrical loads. The difference between E_t and E is the total yearly electrical consumption for cooking. In the multi-family structures, the yearly electrical consumption for cooking is taken at 2000 kWhr per dwelling unit, and in the single-family houses, it is taken at 2340 kWhr per dwelling unit.³ Table 39 shows the values of E_t and W_t for each of the four sectors.

4.5 Thermal Loads for Space Heating

Analyses of the thermal loads for space heating involved the hourly profiles, the monthly consumption, and the monthly peaks. These loads pertained to the generic as well as to the energy-conservative structures, including the single-family attached and detached dwellings and the multi-family low-rise and high-rise dwellings. The thermal loads were calculated using the Merriwether energy requirements computer program employing typical weather data relevant to each of the nine selected cities. (See Appendix B.)

The values of the energy-related parameters which are described in Sections 2.3.1 and 2.3.2 constituted the main input data to the Meriwether program. Although the cooking and base-electric loads had been synthesized separately, they were input to the program for obtaining a complete set of thermal and electrical load output. A total of 72 sets of output (8 buildings, 9 cities) were copied on magnetic tape to be used subsequently in system performance tests.

To produce the hourly heating profiles shown in Figures 29 through 46, we plotted the hourly heating loads for January 15 as percentages of the peak value (which is indicated in each case), using the following methodology:

The peak heating load occurs at about 6:00 a.m. If we indicate this peak load by H_0 , then we can write:

$$H_0 \text{ (Btu/hr)} = (B + I) \Delta T_0 \text{ [At 6:00 a.m., Jan. 15]} \quad (3)$$

The term B represents the transmission losses, the term I represents the infiltration losses, and ΔT_0 is the indoor-outdoor temperature difference corresponding to H_0 . The total heat load, therefore, is proportional to ΔT . At 6:00 p.m.,

* See Appendix A.

Table 36. MONTHLY PARAMETRIC VALUES — BASE AND COOKING LOADS

Month	Avg Weekday Max Diversified Demand (Normalized Values) with range / without range	Ratio of Avg Weekend Max Div Dem to Avg Weekday Max Div Dem with range / without range	Ratio of Avg Demand to Peak Dem for Weekdays with range / without range	Ratio of Avg Demand to Peak Demand for Weekends with range / without range
Jan.	0.93/0.97	0.99/0.96	0.59/0.58	0.61/0.62
Feb.	0.86/0.96	0.99/0.93	0.59/0.59	0.61/0.64
Mar.	0.82/0.92	0.95/0.97	0.60/0.57	0.63/0.60
Apr.	0.75/0.88	0.96/0.97	0.56/0.55	0.63/0.58
May	0.60/0.84	0.97/0.97	0.63/0.56	0.67/0.62
June	0.66/0.84	0.94/0.94	0.70/0.57	0.73/0.65
July	0.70/0.93	0.95/0.91	0.72/0.63	0.70/0.68
Aug.	0.70/0.93	0.95/0.96	0.68/0.63	0.70/0.67
Sept.	0.65/0.86	0.92/0.96	0.68/0.58	0.70/0.64
Oct.	0.84/0.89	0.83/0.96	0.54/0.55	0.65/0.61
Nov.	0.92/0.92	0.87/0.98	0.53/0.59	0.60/0.60
Dec.	1.00/1.00	0.96/1.03	0.55/0.58	0.61/0.59

Table 37. MONTHLY PARAMETRIC VALUES FOR BASE PLUS COOKING ELECTRIC LOADS[†]

Month	Avg Weekday Max Div Dem, kW	Avg Weekend Max Div Dem, kW	Avg Div Dem for Weekdays, kW	Avg Div Dem for Weekends, kW
January	$0.93W_t^*$	$0.92W_t$	$0.55W_t$	$0.56W_t$
February	$0.86W_t$	$0.85W_t$	$0.51W_t$	$0.52W_t$
March	$0.82W_t$	$0.78W_t$	$0.49W_t$	$0.49W_t$
April	$0.75W_t$	$0.72W_t$	$0.42W_t$	$0.45W_t$
May	$0.60W_t$	$0.58W_t$	$0.38W_t$	$0.39W_t$
June	$0.66W_t$	$0.62W_t$	$0.46W_t$	$0.45W_t$
July	$0.70W_t$	$0.67W_t$	$0.50W_t$	$0.47W_t$
August	$0.70W_t$	$0.67W_t$	$0.48W_t$	$0.47W_t$
September	$0.65W_t$	$0.60W_t$	$0.45W_t$	$0.42W_t$
October	$0.84W_t$	$0.70W_t$	$0.46W_t$	$0.45W_t$
November	$0.92W_t$	$0.80W_t$	$0.49W_t$	$0.48W_t$
December	W_t	$0.96W_t$	$0.55W_t$	$0.59W_t$

* W_t = Average weekday maximum diversified demand for December in kW.

[†] All building types.

Table 38. MONTHLY CONSUMPTION VALUES FOR 1976 IN TERMS OF W

Month	<u>Base and Cooking Electric Loads</u>		
	Total Weekday Consumption, kWhr	Total Weekend Consumption, kWhr	Total Monthly Consumption, kWhr
January	291W _t *	121W _t	412W _t
February	245W _t	112W _t	357W _t
March	272W _t	94W _t	366W _t
April	222W _t	87W _t	309W _t
May	192W _t	94W _t	286W _t
June	244W _t	86W _t	330W _t
July	265W _t	102W _t	367W _t
August	253W _t	102W _t	355W _t
September	238W _t	81W _t	319W _t
October	232W _t	108W _t	340W _t
November	260W _t	92W _t	352W _t
December	304W _t	113W _t	417W _t
Total			4210W _t

* W_t = Average weekday maximum diversified demand for December in kW,

E = Total yearly consumption, kWhr = 4210W_t.

Table 39. ELECTRICAL LOADS WITH ELECTRIC RANGES

	<u>E</u> <u>(kWhr)</u>	<u>E+</u> <u>(kWhr)</u>	<u>W</u> <u>(kW)</u>	<u>W+</u> <u>(kW)</u>
Single-Family Unit	5,924	8,264	1.26	1.96
Townhouse Unit	5,921	8,261	1.26	1.96
Low-Rise (24 Units)	111,000	159,000	23.60	37.80
High-Rise (180 Units)	764,640	1,124,640	16.30	26.70

the internal heat gains are in most cases small enough, compared with the heat losses, to be omitted from the equation. Under steady state conditions, the heating load at any other hour will be:

$$H = (B + I) \Delta T - (S + J) \quad (4)$$

where S and J are the solar and the internal heat, respectively, in Btu/hr. The hourly profiles represent the ratio of H to H_0 for each hour of the day. This may be written as:

$$\frac{H}{H_0} = \frac{\Delta T}{\Delta T_0} - \frac{(S + J)}{(B + I) \Delta T_0} \quad (5)$$

When the solar heat gains are absent and the internal gains negligible, this ratio is independent of the type of structure: All structures follow essentially the same profile. In the presence of the solar heat gain, the value of H/H_0 depends upon both $\Delta T/\Delta T_0$ and the ratio of the solar and internal heat gains to the transmission and infiltration losses at 6:00 p.m. The latter depends upon the type of structure. We observed that the value of H/H_0 for the high-rise is generally lower than that for the single-family detached house. In some cities, the ratio of the solar gains to the peak transmission and infiltration losses is large enough to drive H/H_0 to zero. The house will then be under a non-steady-state condition, with the indoor temperature allowed to rise above 70°F. In this case, the energy balance equation becomes a differential equation of the form —

$$\frac{dc}{dt} = - (B + I) \Delta T + (S + J) > 0 \quad (6)$$

where $\frac{dc}{dt}$ indicates the change in the heat content of the house. We observed that the larger the solar and the internal heat gains compared with the transmission and infiltration losses, the longer will be the time period with no heating.

Generally, the conservation measures have not only lowered the values of the peaks but also lowered the values of H/H_0 and increased the periods with no heating. This would result in percentage reductions in consumption that are greater than the percentage reductions in the peaks.

Figures 47 through 64* show the profiles of the monthly consumptions. We have indicated the maximum monthly consumption which generally occurs in January, and plotted the consumptions in the other months as percentages of the maximum value.

Figures 65 through 82* show the profiles of the monthly peaks as percentages of the maximum monthly peak which generally occurs in January. The hourly profiles have indicated the peak values for a particular day, which are not necessarily the peak values for the whole month. For this reason, the monthly peaks are treated separately.

4.6 Thermal Loads for Space Cooling

The study of the thermal loads for space cooling has involved the hourly profiles, the monthly peak, and the monthly consumption.

Figures 83 through 98* show the hourly cooling load profiles for the nine selected cities and for the generic as well as for the energy conservative structures. The peak cooling load generally occurs at about 4:00 p.m. to 5:00 p.m. The demand at any other hour is expressed as a percent of peak, as indicated in each case. In some cases, cooling peaks occur in the morning, which are due to the solar heat gains at the east-facing fenestration.

Figures 99 through 114* show the monthly cooling consumption as percentages of the maximum monthly consumption which generally occurs in July.

* See Appendix A.

Figures 115 through 136* show the monthly cooling peaks as percentages of the maximum cooling peak. We observed that the profiles of monthly peaks have wider peaks than those of the monthly consumptions. This indicates that the percentage reduction in consumption is larger than the percentage reduction in peaks.

4.7 Thermal Loads for Domestic Water Heating^{14,15,16}

The energy consumption for domestic water heating not only depends upon the consumption of hot water, but also upon the type of water heating. The losses encountered in electric or district heating include standby losses and the losses from pipes and fittings. Energy losses other than standby and piping losses occur in gas water heating due to stack gases leaving at a high temperature. The current study considers the energy consumption for domestic water heating using electric water heaters** (or using district heating systems). However, this load will be classified as a thermal load and not as an electric load.

Figure 137 shows the generic hourly profile for an average day. The peak demand is indicated by h and is in units of 1000 Btu/hr. The peak demand is equal to the reduction factor multiplied by the maximum demand. The reduction factor depends upon the season and upon the particular city.[†] The values of the reduction factors and of the maximum demands are as indicated in Table 40.

4.8 Electric Add-On Loads for HVAC Processing

The electric loads that have been synthesized did not include any loads due to HVAC processing. These loads are attributed to a combination of energy conversion for space heating or cooling, and the energy expended by auxiliary equipment, such as fan motors and pump motors. These loads have been excluded thus far from this study because they depend upon the system used. To add these

* See Appendix A.

** That is, taking only heat transfer losses into account, no combustion losses considered.

† The reduction factor depends on the ground water temperature, which varies with season and location.

Table 40. PARAMETRIC VALUES — DOMESTIC WATER HEATING¹³Maximum Demands

Single-Family:	$H_s = 7 \cdot 10^3$	Btu/hr
Townhouse:	$H_t = 7 \cdot 10^3$	Btu/hr
Low-Rise:	$H_e = 145 \cdot 10^3$	Btu/hr (for 24 units)
High-Rise:	$H_h = 1090 \cdot 10^3$	Btu/hr (for 180 units)

Actual Demands

$$h = f \times H$$

↑
Reduction Factor

Reduction Factors

<u>City</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>
Albuquerque	0.87	0.87	0.81	0.69	0.72	0.66	0.64	0.60	0.60	0.64	0.76	0.81
Boston	1.00	0.96	0.93	0.82	0.76	0.64	0.61	0.68	0.75	0.78	0.85	0.88
Chicago	1.00	1.00	0.98	0.91	0.82	0.77	0.70	0.68	0.72	0.77	0.88	0.97
Dallas	0.78	0.84	0.77	0.65	0.60	0.55	0.57	0.53	0.55	0.63	0.78	0.87
Los Angeles	0.83	0.83	0.80	0.72	0.67	0.62	0.61	0.59	0.60	0.66	0.74	0.79
Miami	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Nashville	0.87	0.87	0.81	0.69	0.72	0.66	0.64	0.60	0.60	0.64	0.76	0.81
Phoenix	0.85	0.85	0.83	0.82	0.77	0.75	0.72	0.60	0.57	0.66	0.75	0.80
Raleigh	0.90	0.90	0.81	0.78	0.72	0.68	0.68	0.57	0.57	0.66	0.78	0.87

loads, the HVAC system has to be determined and the electric energy demand calculated as a function of thermal energy demand. The auxiliary energy maximum demands vary with the type of system; they are of the order of 25% of the base-electric demand, including electric ranges.

When testing the solar total energy system performance, the HVAC system was determined as part of the conceptual design in order to provide accurate electric loads. Once the HVAC system was determined, the HVAC electric loads formed a separate input to be blended with the base-electric loads.

4.9 Thermal-to-Electric Ratio

The Meriwether energy requirement estimating computer program provides the thermal and electric loads. The thermal loads constitute the space heating and cooling loads,* and the domestic water heating loads. The electric loads constitute either the base-electric, or the base-electric plus cooking loads. Therefore, two sets of ratios are possible depending upon whether cooking is done electrically or by gas. These loads form the input to the routine that calculates the ratios whenever they are needed in performance tests. This is important in the conceptual design phase because the STES design and sizing have to address the subject of satisfying the thermal/electric load ratio.

* Space cooling is often part of the electric load when electric air conditioning is used. In this study, space cooling is considered only as part of the thermal load.

Section 5

VERIFICATION OF SIMULATED LOAD DATA

We have compared some of the simulated heating and cooling loads with measured data pertaining to the heating and cooling loads in single- and multi-family dwelling units, using data from roughly comparable structures in the same geographic regions.

5.1 Heating Loads: Single-Family Dwelling Units

The Twin-Rivers Project affiliated with the Center for Environmental Studies at Princeton University has dealt extensively with energy consumption and conservation in various types of single-family dwelling units. In particular, the three-bedroom townhouse selected for the present study is similar in design to some of the houses tested at Twin Rivers, New Jersey. The measured data employed in this comparison were obtained from the Four-Year Summary Report of the Twin Rivers Program On Energy Conservation in Housing.¹¹

Using data pertaining to 12 townhouses, the winter gas consumption for space heating was found to be strongly predicted by the following equation:

$$G = 21 (62^\circ - T) \quad (9)$$

where G is the gas consumption in cubic feet per day and T is the daily average value of the outside temperature in degrees Fahrenheit. Since Twin Rivers falls in the region where Boston is the key city, we have calculated the daily energy requirements for space heating in a townhouse in Boston on January 15. With an average outside temperature of 26°F , the total requirement is 582,570 Btu/hr. With the combustion of one cubic foot per hour of gas, 1030 Btu/hr of heat is released. The above equation becomes therefore:

$$G = 21,630 (62^\circ - T) \text{ Btu/day} \quad (= 778,680 \text{ Btu/day at } T = 26^\circ\text{F}) \quad (10)$$

The energy requirements for space heating should be less than the energy consumption, due to the inefficiency of the furnace. The energy requirement is expressed by:

$$H = \zeta G \quad (11)$$

where ζ is the furnace efficiency. Independently from the Twin Rivers data, another equation was developed from measured data, which predicted the gas consumption for space heating in the absence of solar heat gains. The gas consumption could be expressed by:

$$G = -450 + 18(\Delta T) + 11 (\overline{AI})(\Delta T) \text{ cu ft/day} \quad (12)$$

where ΔT is the indoor-outdoor temperature difference and $\overline{AI}$ is the air infiltration in air changes per hour. On January 15, the average temperature during the night in Boston was 22°F and the average requirement for space heating in a townhouse was 721,258 Btu/day. At $\Delta T = 48^\circ\text{F}$ and at $AI = 72 + 3.8\Delta T$ cubic feet per minute = 254 CFM = 1.068 changes/hr, the value of G is 1,007,241 Btu/day. The efficiency is then:

$$\frac{H}{G} = \frac{721,258}{1,007,241} = 0.72 \quad (13)$$

Using this value of furnace efficiency to calculate the value of H for the other houses, we obtain:

$$H = 0.72 \times 778,680 = 560,650 \text{ Btu/day} \quad (14)$$

The deduced energy requirement from measured data is 560,650 Btu/day, while the simulated value is equal to 582,570 Btu/day. This indicates that the space heating load computations for a townhouse have been based on sound assumptions.

5.2 Cooling Loads: Single-Family Dwelling Units

Using data pertaining to 20 townhouses (also part of the Twin Rivers study), the electric consumption for space cooling was found to be strongly predicted by the expression:

$$E = 2.73T \text{ kWhr/day} \quad (15)$$

where E is the electric consumption for air-conditioning in kilowatt-hours per day and T is defined by ($T_{\max}$ and $T_{\min}$ are the daily high and low temperatures):

$$T = \text{the larger of } \left[\left(\frac{T_{\max} + T_{\min}}{2} \right) - 65^\circ\text{F} \right] \text{ or } 0 \quad (16)$$

A typical conversion of 1.65 kW per ton* can be used to estimate the ton-hours per day consumption of the central air-conditioning system.

The cooling load will then be predicted by the expression:

$$C = 19,855T \text{ Btu/day} \quad (17)$$

* Bryant Air-Conditioning, 1976 Architect and Engineer's File.

The cooling loads for a townhouse in Boston were determined by this equation for two successive days, July 15 and 16, of the "typical year", to be:

$$\text{July 15: } T = \left(\frac{82 + 66}{2} - 65 \right) = 9^{\circ}\text{F}; C = 19,855 \times 9 = 178,695 \text{ Btu/day} \quad (18)$$

$$\text{July 16: } T = \left(\frac{80 + 61}{2} - 65 \right) = 5.5^{\circ}\text{F}; C = 19,855 \times 5.5 = 109,202 \text{ Btu/day} \quad (19)$$

From the computer runs, the simulated cooling loads are:

$$\text{July 15: } C = 211,263 \text{ Btu/day}$$

$$\text{July 16: } C = 155,734 \text{ Btu/day}$$

For July 15, the simulated load exceeds the predicted load by 15% and for July 16, the simulated load exceeds the predicted load by 30%, an average of 22.5% for the two selected days. These results indicate that the simulated cooling loads are in general agreement with those calculated from real data, but the agreement is not as close as that achieved with the heating loads. These results are not surprising when we take into account the effects of external shading and the possible interference of the household usage patterns. As mentioned earlier, the computer calculations of cooling loads have not accounted for any external shading due to shade trees or adjacent buildings. (Some townhouses in Twin Rivers are partially protected from the sun by adjacent buildings.) Moreover, natural ventilation provided by window-opening during mild weather would reduce the cooling load by offsetting the solar gains. This would explain the larger discrepancy observed on July 16, when the outdoor temperature during much of the day did not exceed 75°F, which was the selected thermostat setting. Nevertheless, these results would indicate the extent to which the shading and usage patterns could result in a deviation from our energy requirement estimate.

We would expect a better cooling load correlation for those days when both T_{max} and T_{min} are higher (as is indicated by the better correlation for July 15) and usage patterns are less likely to modify some of the energy-related parameters.

Figure 138* shows the measured air-conditioning hourly load profile for a townhouse at Twin Rivers, which shows good correlation with the hourly cooling profile for Boston in Figure 85.*

* See Appendix A.

5.3 Heating Loads: Multi-Family Units^{8,12,13}

To obtain a verification of simulated load data for multi-family structures, comparisons were made between simulated heating requirements for a 24-unit low-rise apartment building in Boston and measured data from two different apartment complexes in New Jersey: 1) the total energy plant supplying the Summit Plaza Apartments in Jersey City [Table 41], and 2) an apartment complex monitored by Public Service Electric and Gas [PSEG] Co. of New Jersey. Although the buildings were not the same size as those used for the computer simulation study, correction factors were applied to the measured data, based on the difference in design loads, and the adjusted data compared with simulated Boston data.

Table 41. SUMMIT PLAZA APARTMENT DATA SUMMARY

Month	Total Consumption, 10 ⁶ Btu	Domestic Hot Water Use + Losses, 10 ⁶ Btu	Space Heating, 10 ⁶ Btu
November '75	3,360	1,500	1,860
December '75	5,546	1,700	3,846
January '76	6,903	1,700	5,203
February '76	5,158	1,600	3,558
March '76	4,376	1,500	2,876
April '76	2,871	1,400	1,471
May '76	1,748	1,300	448
June '76	1,144	1,144	0
July '76	1,081	1,081	0
August '76	1,090	1,090	0
September '76	1,124	1,124	0
October '76	2,952	1,200	1,752

5.3.1 Summit Plaza Apartments, Jersey City, New Jersey

The measured data from the Summit Plaza Apartment Complex (Table 41) include the total thermal energy extracted from the primary hot water loop and distributed to the site for space and domestic water heating. The thermal energy used for space heating was obtained by subtracting the piping losses and energy used for domestic hot water from the measured data.

Monthly space heating requirements (in 10⁶ Btu) for the Summit Plaza Apartments are taken from the summary of design loads shown in Table 42. By dividing the total design space heating load by the number of dwelling units,

Table 42. DESIGN LOADS (Thermal and Electrical)

Building or Facility	Area Sq. Ft.	No. of Floors	Dwelling Units	Glazing	Per Cent Glass Area	Ventilation	Space Heating, MBH	Domestic Hot Water, MBH	Space Cooling Tons	Electric Demand, KW
Shelley A	185,000	18	152	Double	45.9	Standard	2,729	380	318.7	277
Shelley B	52,104	7	40	Double	26.8	Standard	974	183	81.1	92
Camci	116,925	10	150	Double	27.6	Standard	2,890	550	255.6	241
Descon	127,627	17	142	Single	39.1	Variable	2,487	550	207.1	241
Commercial	50,000	3		Single	23.9	Variable	1,343	97	173.6	191
School	15,700	2		Single	27.5	Standard	946	117	71.8	60
CEB*	9,950	1-1/2					700		100	28(1)
Totals	557,306		484				12,069	1,877	1,207.9	1,130
Total Simultaneous Load							10,660		1,092	1,031
Total Plus HVAC Pumps and Auxiliaries										1,365(2)

(1) The given demand includes lights only.

(2) The total demand includes heating pumps, chilled water pumps, total energy system auxiliaries and the pneumatic trash collection system.

* Central Equipment Building

and dividing by 59 (the difference between 70°F and the design temperature of 11°F), a value of 373 Btu/hr-DU-°F is obtained for the Jersey City Summit Plaza Apartments. A comparable calculation for the hypothetical Boston low-rise building provides a value of 312 Btu/hr-DU-°F, based on 24 units and a 4°F design temperature. The ratio of these two values gives a correction factor of 0.84 to be applied to the Jersey City data in order to compensate for the difference in construction characteristics. The monthly heating values for the Jersey City apartments were multiplied by 0.84 to obtain the values designated in the fourth column of Table 43 as "Corrected Jersey City Space Heating." These corrected values were then compared with the simulated Boston data shown in the fifth column.

The monthly data shown in Table 43 represent the curves designated JC (for Jersey City) and Boston shown in Figure 139.*

5.3.2 PSEG-Monitored Apartment Complex

The consumption data for the apartment complex in New Jersey monitored by PSEG are given in therms/month of gas consumption and converted to space heating values by multiplying by assumed monthly burner efficiencies. Burner efficiencies have been assumed to range from 50% to 70%, and the efficiency at the design load is assumed to be 80%. The space heating values shown in the fourth column of Table 44 were converted to the values in the fifth column by multiplying by the 0.454 correction factor in order to compensate for differences in construction characteristics, as described in the previous section. The corrected values are shown in Figure 139,* together with the data from Boston and Summit Plaza Apartments. Correlation appears to be quite good.

* See Appendix A.

Table 43. COMPARISON OF JERSEY CITY DATA WITH BOSTON DATA

<u>Project</u>	<u>Number of Dwelling Units</u>	<u>Design Temperature, °F</u>	<u>Design 10⁶ Btu/hr</u>	<u>Btu/hr-DU-°F</u>
Boston	24	4	494	312
New Jersey	549	11	12,069	373

$$\text{Correction Factor, } f = \frac{312}{373} = 0.84.$$

<u>Month</u>	<u>Jersey City Space Heating, therms/DU</u>	<u>Corrected Jersey City Space Heating, therms/DU</u>	<u>Boston Space Heating, therms/DU</u>
January	95	80	70
February	65	55	58
March	52	44	43
April	27	23	17
May	8	7	7
June	0	0	0
July	0	0	0
August	0	0	0
September	0	0	4
October	32	27	8
November	34	29	30
December	70	59	61

Table 44. COMPARISON OF PSEG DATA WITH BOSTON DATA

<u>Project</u>	<u>Design Load</u>			
PSEG	687 Btu/hr-DU-°F			
Boston	312 Btu/hr-DU-°F			
<u>Month</u>	<u>Therms/DU</u>	<u>Burner Efficiency, %</u>	<u>PSEG Space Heating, therms/DU</u>	<u>Corrected PSEG* Space Heating, therms/DU</u>
January	190.9	70	133.6	61
February	183.3	70	128.3	58
March	137.8	65	89.6	41
April	88.5	60	53.1	24
May	26.2	55	14.4	7
June	14.9	50	7.5	3
July	0	--	0	0
August	0	--	0	0
September	8.2	50	4.1	2
October	44.3	60	26.6	12
November	90.6	65	58.9	27
December	206.4	70	144.5	66

* Correction Factor, $f = \frac{312}{687} = 0.454.$

5.4 Cooling Loads: Multi-Family Units

The simulated data on space cooling loads have been compared with metered data obtained from the apartments monitored by PSEG. The kWhr consumption data for cooling are given monthly and have been corrected to ton-hours, using a conversion factor of 1.7 kW/ton. That is, for every one ton-hour output, there will be one kWhr input. Table 45 Summarizes the computations.

Table 45. MONTHLY COOLING REQUIREMENTS

	<u>May</u>	<u>June</u>	<u>July</u>	<u>August</u>	<u>September</u>
PSEG Cooling Requirement, kWhr/DU	17.1	91.1	561.4	368	95.4
PSEG Cooling Requirement, ton-hr/DU	10	54	330	216	56
Boston Cooling Requirement, ton-hr/DU	61	165	268	178	72

The results are plotted in Figure 140.* We observe that while agreement exists in the summer months, in milder months the measured consumption is only a fraction of the simulated consumption. This is due to the fact that in mild weather, no cooling will be required if natural ventilation (open windows) is allowed. Simulation does not allow for this effect and, therefore, cooling will be required by the computer in this case.

* See Appendix A.

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Appendix A. LOAD PROFILES

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Hourly and Monthly Heating and Cooling Profiles

Generic (Conventional)

Conservative (to ASHRAE 90-75 Standards)

NOTE: MBH = 10^3 Btu/hr

MBTU = 10^3 Btu

Ton Hours = 12,000 Btu

Hourly heating and cooling profiles are given in terms of percent of the peak load for the day, the value of which is indicated in MBH (10^3 Btu/hr) in the inserts above the individual graphs. The time of the day when this peak load occurs is the time shown for the 100% value. Thus, Figure 29 shows that the peak heating load for a generic single-family dwelling in Albuquerque on January 15 is 37,000 Btu/hr and occurs at 6:00 a.m.

Monthly profiles are given on the same basis as the hourly profiles (in MBH, or 10^3 Btu/hr) as well as percentages of the peak monthly consumption (in 10^3 Btu for heating and ton-hours for cooling). Thus, Figure 65 shows that the maximum monthly peak for a generic single-family dwelling in Albuquerque occurs in January and is equal to 50×10^3 Btu/hr, and Figure 47 shows that the peak monthly consumption is $16,940 \times 10^3$ Btu in January.

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Figure 12. HOURLY BASE ELECTRIC DEMAND - WEEKDAY, DECEMBER-MAY

Figure 13. HOURLY BASE ELECTRIC PROFILES - WEEKDAY, JANUARY-MAY

Figure 14. HOURLY BASE ELECTRIC PROFILES - WEEKDAY, OCTOBER-DECEMBER

Figure 15. HOURLY BASE ELECTRIC PROFILES - WEEKDAY, JANUARY-MAY

Figure 16. HOURLY BASE ELECTRIC PROFILES - WEEKDAY, OCTOBER-DECEMBER

Figure 17. HOURLY BASE ELECTRIC PROFILES - WEEKDAY, JANUARY-MAY

Figure 18. HOURLY BASE ELECTRIC PROFILE - WEEKEND, OCTOBER

Figure 19. MONTHLY, AVERAGE WEEKDAY MAXIMUM DIVERSIFIED DEMAND - BASE ELECTRIC LOADS

Figure 20. RATIO OF AVERAGE WEEKEND MAXIMUM DIVERSIFIED DEMAND TO AVERAGE WEEKDAY MAXIMUM DIVERSIFIED DEMAND — BASE ELECTRIC LOADS

Figure 21. RATIO OF AVERAGE DEMAND TO PEAK DEMAND FOR AVERAGE WEEKDAYS — BASE ELECTRIC LOADS

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Figure 24. ELECTRIC LOAD PROFILE WITH ELECTRIC RANGE —
AVERAGE WEEKDAY, OCTOBER

Figure 25. ELECTRIC LOAD PROFILE WITH ELECTRIC RANGE —
AVERAGE WEEKDAY, NOVEMBER

Figure 26. ELECTRIC LOAD PROFILE WITH ELECTRIC RANGE —
AVERAGE WEEKDAY, DECEMBER

Figure 27. ELECTRIC LOAD PROFILE WITH ELECTRIC RANGE —
AVERAGE WEEKDAY, MARCH

Figure 28. ELECTRIC LOAD PROFILE WITH ELECTRIC RANGE —
AVERAGE WEEKDAY, MAY

Figure 29. GENERIC STRUCTURES HEATING - ALBUQUERQUE

Figure 30. CONSERVATIVE STRUCTURES HEATING - ALBUQUERQUE

Figure 31. GENERIC STRUCTURES HEATING — BOSTON

Figure 32. CONSERVATIVE STRUCTURES HEATING — BOSTON

Figure 33. GENERIC STRUCTURES HEATING — CHICAGO

Figure 34. CONSERVATIVE STRUCTURES HEATING - CHICAGO

Figure 35. GENERIC STRUCTURES HEATING — DALLAS

Figure 36. CONSERVATIVE STRUCTURES HEATING — DALLAS

Figure 37. GENERIC STRUCTURES HEATING — LOS ANGELES

Figure 38. CONSERVATIVE STRUCTURES HEATING — LOS ANGELES

Figure 39. GENERIC STRUCTURES HEATING — MIAMI

Figure 40. CONSERVATIVE STRUCTURES HEATING — MIAMI

Figure 41. GENERIC STRUCTURES HEATING — NASHVILLE

Figure 42. CONSERVATIVE STRUCTURES HEATING - NASHVILLE

Figure 43. GENERIC STRUCTURES HEATING — PHOENIX

Figure 44. CONSERVATIVE STRUCTURES HEATING - PHOENIX

Figure 45. GENERIC STRUCTURES HEATING — RALEIGH

Figure 46. CONSERVATIVE STRUCTURES HEATING — RALEIGH

MAX. MONTHLY CONSUMPTION MBTU								
1	SINGLE FAMILY	1	6	9	4	0		
2	TOWNHOUSE	1	1	3	7	6		
3	LOW-RISE	1	2	5	0	9	2	
4	HIGH-RISE	1	0	2	7	5	4	2

Figure 47. GENERIC STRUCTURES HEATING — ALBUQUERQUE

MAX. MONTHLY CONSUMPTION MBTU	
5 SINGLE FAMILY	1 1 6 3 7
6 TOWNHOUSE	6 5 6 8
7 LOW-RISE	8 7 6 6 8
8 HIGH-RISE	4 2 2 2 5 5

Figure 48. CONSERVATIVE STRUCTURES HEATING — ALBUQUERQUE

Figure 49. GENERIC STRUCTURES HEATING — BOSTON

Figure 50. CONSERVATIVE STRUCTURES HEATING — BOSTON

Figure 51. GENERIC STRUCTURES HEATING — CHICAGO

Figure 52. CONSERVATIVE STRUCTURES HEATING — CHICAGO

Figure 53. GENERIC STRUCTURES HEATING — DALLAS

Figure 54. CONSERVATIVE STRUCTURES HEATING — DALLAS

MAX. MONTHLY CONSUMPTION MBTU	
1 SINGLE FAMILY	3 9 5 2
2 TOWNHOUSE	2 1 2 0
3 LOW-RISE	1 8 4 7 2
4 HIGH-RISE	1 9 5 4 7 2

Figure 55. GENERIC STRUCTURES HEATING — LOS ANGELES
(See note following Figure 56.)

MAX. MONTHLY CONSUMPTION MBTU	
5 SINGLE FAMILY	2 6 2 4
6 TOWNHOUSE	1 1 8 3
7 LOW-RISE	1 3 8 6 3
8 HIGH-RISE	2 7 5 3 0

Figure 56. CONSERVATIVE STRUCTURES HEATING — LOS ANGELES
(See note following Figure 56.)

NOTE FOR FIGURES 55 AND 56

The months of February and March in the Los Angeles area often display substantial variations in monthly heating-degree-days (HDD) over the years, even though the average temperatures and time-averaged HDD values are approximately equal. For example, the following HDD values for February and March from 1957 through 1970 show considerable variation, even though the average values are roughly the same:

<u>Year</u>	<u>February HDD</u>	<u>March HDD</u>
1957	172	158
1958	131	211
1959	209	55
1960	272	227
1961	193	248
1962	308	344
1963	123	255
1964	254	285
1965	271	226
1966	328	225
1967	150	171
1968	118	135
1969	306	266
1970	<u>121</u>	<u>168</u>
Total	211	212

The Meriwether program uses average temperatures rather than heating-degree-days for Los Angeles, because more data are available for average temperatures which have been recorded since 1937. The average temperature for February (57.9°F) was taken from 1961 data, and the average temperature for March (57.19°F) was taken from 1958 data. These data indicate that the average temperatures for the two months are identical even though HDD data for these same two months have varied considerably throughout the years. This explains why March can show up as having a higher heating requirement than February for a given year, even though the average temperatures might be the same.

Figure 57. GENERIC STRUCTURES HEATING - MIAMI

MAX. MONTHLY CONSUMPTION MBTU			
5	SINGLE FAMILY	4	2 2
6	TOWNHOUSE	1	3 4
7	LOW-RISE	6	7 9
8	HIGH-RISE	3	1 8 8

Figure 58. CONSERVATIVE STRUCTURES HEATING - MIAMI

Figure 59. GENERIC STRUCTURES HEATING — NASHVILLE

Figure 60. CONSERVATIVE STRUCTURES HEATING — NASHVILLE

Figure 61. GENERIC STRUCTURES HEATING — PHOENIX

Figure 62. CONSERVATIVE STRUCTURES HEATING — PHOENIX

Figure 63. GENERIC STRUCTURES HEATING — RALEIGH

MAX. MONTHLY CONSUMPTION MBTU	
5 SINGLE FAMILY	9 1 6 7
6 TOWNHOUSE	4 9 3 0
7 LOW-RISE	6 2 0 7 9
8 HIGH-RISE	3 0 8 6 5 6

Figure 64. CONSERVATIVE STRUCTURES HEATING — RALEIGH

Figure 65. GENERIC STRUCTURES HEATING — ALBUQUERQUE

Figure 66. CONSERVATIVE STRUCTURES HEATING — ALBUQUERQUE

Figure 67. GENERIC STRUCTURES HEATING - BOSTON

Figure 68. CONSERVATIVE STRUCTURES HEATING — BOSTON

Figure 69. GENERIC STRUCTURES HEATING — CHICAGO

Figure 70. CONSERVATIVE STRUCTURES HEATING — CHICAGO

Figure 71. GENERIC STRUCTURES HEATING — DALLAS

Figure 72. CONSERVATIVE STRUCTURES HEATING — DALLAS

Figure 73. GENERIC STRUCTURES HEATING — LOS ANGELES

MAXIMUM MONTHLY PEAK MBH		
5	SINGLE FAMILY	1 7
6	TOWNHOUSE	1 2
7	LOW-RISE	1 6 3
8	HIGH-RISE	8 3 2

Figure 74. CONSERVATIVE STRUCTURES HEATING - LOS ANGELES

Figure 75. GENERIC STRUCTURES HEATING — MIAMI

MAXIMUM MONTHLY PEAK MBH			
5	SINGLE FAMILY	1	6
6	TOWNHOUSE	1	1
7	LOW-RISE	1	1
8	HIGH-RISE	5	3

Figure 76. CONSERVATIVE STRUCTURES HEATING — MIAMI

Figure 77. GENERIC STRUCTURES HEATING — NASHVILLE

Figure 78. CONSERVATIVE STRUCTURES HEATING — NASHVILLE

MAXIMUM MONTHLY PEAK MBH		
1	SINGLE FAMILY	3 8
2	TOWNHOUSE	2 7
3	LOW-RISE	3 2 3
4	HIGH-RISE	2 9 3 4

Figure 79. GENERIC STRUCTURES HEATING — PHOENIX

Figure 80. CONSERVATIVE STRUCTURES HEATING — PHOENIX

MAXIMUM MONTHLY PEAK MBH	
1 SINGLE FAMILY	4 8
2 TOWNHOUSE	3 5
3 LOW-RISE	4 0 8
4 HIGH-RISE	3 6 8 2

Figure 81. GENERIC STRUCTURES HEATING — RALEIGH

MAXIMUM MONTHLY PEAK MBH		
5	SINGLE FAMILY	3 4
6	TOWNHOUSE	2 2
7	LOW-RISE	3 0 4
8	HIGH-RISE	1 6 9 9

Figure 82. CONSERVATIVE STRUCTURES HEATING — RALEIGH

Figure 83. GENERIC STRUCTURES COOLING — ALBUQUERQUE

Figure 84. CONSERVATIVE STRUCTURES COOLING — ALBUQUERQUE

Figure 85. GENERIC STRUCTURES COOLING — BOSTON

Figure 86. CONSERVATIVE STRUCTURES COOLING — BOSTON

Figure 87. GENERIC STRUCTURES COOLING — CHICAGO

DAY PEAK LOADS MBH		
5	SINGLE-FAMILY	2 7
6	TOWNHOUSE	2 5
7	LOW-RISE	3 6 0
8	HIGH-RISE	1 5 0 7

Figure 88. CONSERVATIVE STRUCTURES COOLING — CHICAGO

Figure 89. GENERIC STRUCTURES COOLING — DALLAS

Figure 90. CONSERVATIVE STRUCTURES COOLING - DALLAS

Figure 91. GENERIC STRUCTURES COOLING — LOS ANGELES

Figure 92. CONSERVATIVE STRUCTURES COOLING — LOS ANGELES

Figure 93. GENERIC STRUCTURES COOLING - MIAMI

Figure 94. CONSERVATIVE STRUCTURES COOLING — MIAMI

Figure 95. GENERIC STRUCTURES COOLING — NASHVILLE

Figure 96. CONSERVATIVE STRUCTURES COOLING — NASHVILLE

Figure 97. GENERIC STRUCTURES COOLING - PHOENIX

Figure 98. CONSERVATIVE STRUCTURES COOLING — PHOENIX

DAY PEAK LOADS MBH		
1	SINGLE-FAMILY	33
2	TOWNHOUSE	30
3	LOW-RISE	428
4	HIGH-RISE	4137

Figure 99. GENERIC STRUCTURES COOLING — RALEIGH

Figure 100. CONSERVATIVE STRUCTURES COOLING - RALEIGH

Figure 101. GENERIC STRUCTURES COOLING - ALBUQUERQUE

MAX. MONTHLY CONSUMPTION TON-HOURS		
5	SINGLE FAMILY	565
6	TOWNHOUSE	502
7	LOW-RISE	6689
8	HIGH-RISE	44010

Figure 102. CONSERVATIVE STRUCTURES COOLING — ALBUQUERQUE

Figure 103. GENERIC STRUCTURES COOLING — BOSTON

MAX. MONTHLY CONSUMPTION TON-HOURS		
5	SINGLE FAMILY	4 5 4
6	TOWNHOUSE	4 3 3
7	LOW-RISE	5 9 9 3
8	HIGH-RISE	3 6 1 4 5

Figure 104. CONSERVATIVE STRUCTURES COOLING — BOSTON

MAX. MONTHLY CONSUMPTION TON-HOURS							
1	SINGLE FAMILY		3	4	6		
2	TOWNHOUSE		3	7	5		
3	LOW-RISE		5	4	5	8	
4	HIGH-RISE		5	1	6	4	4

Figure 105. GENERIC STRUCTURES COOLING — CHICAGO

MAX. MONTHLY CONSUMPTION TON-HOURS			
5	SINGLE FAMILY	3	6 1
6	TOWNHOUSE	3	6 6
7	LOW-RISE	5	1 5 5
8	HIGH-RISE	3	0 3 4 0

Figure 106. CONSERVATIVE STRUCTURES COOLING - CHICAGO

MAX. MONTHLY CONSUMPTION TON-HOURS	
1 SINGLE FAMILY	9 2 2
2 TOWNHOUSE	8 1 8
3 LOW-RISE	1 0 9 4 5
4 HIGH-RISE	1 2 4 8 2 9

Figure 107. GENERIC STRUCTURES COOLING - DALLAS

MAX. MONTHLY CONSUMPTION TON-HOURS				
5	SINGLE FAMILY			8 2 6
6	TOWNHOUSE			7 5 1
7	LOW-RISE	1	0	7 5 2
8	HIGH-RISE	6	7	8 0 2

Figure 108. CONSERVATIVE STRUCTURES COOLING — DALLAS

MAX. MONTHLY CONSUMPTION TON-HOURS	
1 SINGLE FAMILY	37.2
2 TOWNHOUSE	41.1
3 LOW-RISE	598.2
4 HIGH-RISE	5441.6

Figure 109. GENERIC STRUCTURES COOLING — LOS ANGELES

MAX. MONTHLY CONSUMPTION TON-HOURS	
5 SINGLE FAMILY	3 9 0
6 TOWNHOUSE	4 3 0
7 LOW-RISE	5 9 9 3
8 HIGH-RISE	3 3 7 1 6

Figure 110. CONSERVATIVE STRUCTURES COOLING — LOS ANGELES

Figure 111. GENERIC STRUCTURES COOLING - MIAMI

MAX. MONTHLY CONSUMPTION TON-HOURS	
5 SINGLE FAMILY	7 8 4
6 TOWNHOUSE	7 0 5
7 LOW-RISE	1 0 3 3 7
8 HIGH-RISE	6 8 3 7 6

Figure 112. CONSERVATIVE STRUCTURES COOLING - MIAMI

MAX. MONTHLY CONSUMPTION TON-HOURS	
1 SINGLE FAMILY	6 6 4
2 TOWNHOUSE	6 1 8
3 LOW-RISE	8 5 3 6
4 HIGH-RISE	9 2 9 6 6

Figure 113. GENERIC STRUCTURES COOLING - NASHVILLE

MAX. MONTHLY CONSUMPTION TON-HOURS	
5 SINGLE FAMILY	6 3 1
6 TOWNHOUSE	5 4 8
7 LOW-RISE	7 8 6 0
8 HIGH-RISE	5 1 2 9 3

Figure 114. CONSERVATIVE STRUCTURES COOLING - NASHVILLE

MAX. MONTHLY CONSUMPTION TON-HOURS							
1	SINGLE FAMILY	1	2	5	4		
2	TOWNHOUSE	1	0	7	0		
3	LOW-RISE	1	1	4	4	8	
4	HIGH-RISE	1	4	6	0	5	1

Figure 115. GENERIC STRUCTURES COOLING — PHOENIX

Figure 116. CONSERVATIVE STRUCTURES COOLING — PHOENIX

Figure 117. GENERIC STRUCTURES COOLING — RALEIGH

MAX. MONTHLY CONSUMPTION TON-HOURS	
5 SINGLE FAMILY	5 9 3
6 TOWNHOUSE	5 2 8
7 LOW-RISE	7 5 5 5
8 HIGH-RISE	4 8 8 2 4

Figure 118. CONSERVATIVE STRUCTURES COOLING — RALEIGH

MAXIMUM MONTHLY PEAK MBH		
1	SINGLE FAMILY	31
2	TOWNHOUSE	28
3	LOW-RISE	385
4	HIGH-RISE	4139

Figure 119. GENERIC STRUCTURES COOLING — ALBUQUERQUE

MAXIMUM MONTHLY PEAK MBH		
5	SINGLE FAMILY	3 0
6	TOWNHOUSE	2 5
7	LOW-RISE	3 5 1
8	HIGH-RISE	2 0 2 1

Figure 120. CONSERVATIVE STRUCTURES COOLING — ALBUQUERQUE

MAXIMUM MONTHLY PEAK MBH		
1	SINGLE FAMILY	3 6
2	TOWNHOUSE	3 6
3	LOW-RISE	4 5 1
4	HIGH-RISE	3 6 0 0

Figure 121. GENERIC STRUCTURES COOLING — BOSTON

MAXIMUM MONTHLY PEAK MBH	
5 SINGLE FAMILY	3 6
6 TOWNHOUSE	3 0
7 LOW-RISE	4 1 7
8 HIGH-RISE	2 7 4 3

Figure 122. CONSERVATIVE STRUCTURES COOLING — BOSTON

MAXIMUM MONTHLY PEAK MBH			
1	SINGLE FAMILY	3	6
2	TOWNHOUSE	3	2
3	LOW-RISE	4	6 0
4	HIGH-RISE	3	6 0 0

Figure 123. GENERIC STRUCTURES COOLING - CHICAGO

MAXIMUM MONTHLY PEAK MBH			
5	SINGLE FAMILY	3	6
6	TOWNHOUSE	2	8
7	LOW-RISE	4	2 0
8	HIGH-RISE	2	9 5 7

Figure 124. CONSERVATIVE STRUCTURES COOLING - CHICAGO

Figure 125. GENERIC STRUCTURES COOLING — DALLAS

MAXIMUM MONTHLY PEAK MBH			
5	SINGLE FAMILY	4	0
6	TOWNHOUSE	3	9
7	LOW-RISE	5	3 9
8	HIGH-RISE	2	9 8 2

Figure 126. CONSERVATIVE STRUCTURES COOLING - DALLAS

MAXIMUM MONTHLY PEAK MBH				
1	SINGLE FAMILY		3	6
2	TOWNHOUSE		3	6
3	LOW-RISE		4	4
4	HIGH-RISE		4	3

Figure 127. GENERIC STRUCTURES COOLING — LOS ANGELES

MAXIMUM MONTHLY PEAK MBH		
5	SINGLE FAMILY	3 6
6	TOWNHOUSE	3 3
7	LOW-RISE	3 9 2
8	HIGH-RISE	2 7 4 9

Figure 128. CONSERVATIVE STRUCTURES COOLING — LOS ANGELES

MAXIMUM MONTHLY PEAK MBH		
1	SINGLE FAMILY	3 6
2	TOWNHOUSE	3 6
3	LOW-RISE	4 8 4
4	HIGH-RISE	4 9 1 6

Figure 129. GENERIC STRUCTURES COOLING — MIAMI

MAXIMUM MONTHLY PEAK MBH		
1	SINGLE FAMILY	36
2	TOWNHOUSE	36
3	LOW-RISE	549
4	HIGH-RISE	5040

Figure 131. GENERIC STRUCTURES COOLING - NASHVILLE

Figure 132. CONSERVATIVE STRUCTURES COOLING — NASHVILLE

Figure 133. GENERIC STRUCTURES COOLING — PHOENIX

MAXIMUM MONTHLY PEAK MBH		
5	SINGLE FAMILY	4 0
6	TOWNHOUSE	3 6
7	LOW-RISE	5 2 2
8	HIGH-RISE	2 6 6 9

Figure 134. CONSERVATIVE STRUCTURES COOLING — PHOENIX

Figure 135. GENERIC STRUCTURES COOLING — RALEIGH

MAXIMUM MONTHLY PEAK MBH		
5	SINGLE FAMILY	3 6
6	TOWNHOUSE	3 3
7	LOW-RISE	4 6 5
8	HIGH-RISE	3 1 4 8

Figure 136. CONSERVATIVE STRUCTURES COOLING - RALEIGH

Figure 137. GENERIC HOURLY PROFILE — DOMESTIC WATER HEATING

Figure 138. LOAD PROFILE: AIR-CONDITIONER (HOUSE 2)
AND HOURLY AVERAGE TEMPERATURE

Figure 139. COMPARISON OF MONTHLY REQUIREMENTS

* Measured data.

† Simulated data.

Figure 140. COMPARISON OF THERMAL REQUIREMENTS FOR COOLING

Appendix B. MERIWETHER COMPUTER PROGRAM —
ENERGY REQUIREMENT ESTIMATE

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The computer program used for determining the heating and cooling profiles was the Meriwether Energy Requirements Estimate (ERE) program, a model of the thermal behavior of the building during each hour of the year. It requires the following inputs:

- Building external configuration
- Building skin definition (U-values)
- Fenestration
- Compass orientation
- Geographic location
- Weather extremes
- Indoor air temperature
- Indoor air humidity
- Occupancy profile
- Internal heat gains (lights, motors, appliances, etc.)
- Weather tape for the particular location giving hourly values of dry bulb temperature, dewpoint, cloud cover throughout one calendar year, and solar radiation
- Air infiltration profile
- Type of heating and cooling system.

The program utilizes these inputs to calculate the hourly energy demands for heating and cooling, and also gives a monthly summary, including hourly peaks for each month. The method of calculation follows essentially Part 1 of Chapter 22 of the ASHRAE Handbook of Fundamentals. The mass of the building (an input to the program) determines the effect of the hourly load profile of the storage of heat in the building.