

SHACOB: Requirements Definition and Impact Analysis

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Final Report
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El Segundo, California

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Solar Heating and Cooling of Buildings
(SHACOB)
Requirements Definition and Impact Analysis

Reference Systems and Simulation Models

ER-808, Volume 3
Research Project 553

Final Report, June 1978

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FOREWORD

This report is the third volume of the Final Report for the Electric Power Research Institute Research Project 553, "Solar Heating and Cooling of Building (SHACOB) Requirements Definition and Impact Analysis" conducted by The Aerospace Corporation between January 1976 and March 1978.

Volume 3, "Reference Systems and Simulation Models," reviews the definition of reference buildings, reference SHACOB systems, simulation models for performance evaluation and the process for aggregating individual building demands over the appropriate markets in each utility service area addressed. The general context for use of this information is given in Volume 1, "Methodology and Results."

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INTRODUCTION

This volume describes the definition of buildings and HVAC systems developed for the analysis of the impact of solar heating and cooling of buildings (SHACOB) on electric utilities. In addition, the computer simulation models and procedures for determining system performance and service area demand impact are reviewed.

The computation of the change in utility demand patterns, as a function of geographic region and season, requires the analytic definition of a variety of building types and solar systems consistent with the physical information required to process the simulation code. The computations must be done for a reference set of buildings equipped with solar heating and cooling systems, and then the same set equipped with conventional HVAC systems in order to determine the differential impact.

The definition of building types which would be representative of future building construction requires taking into account regional climatic differences, regional building construction characteristics, and consideration of energy conserving building design requirements. Within the residential sector, a reference set of buildings was identified which would be representative of single family (detached and attached), multi-family (low-rise and high-rise), and motel occupancies. Within the nonresidential sector, a reference set of buildings was selected which would be representative of office, mercantile (retail store and shopping center), educational (elementary and high school), hospital, and light industrial occupancies. The identification of reference building types is reviewed in Section 2.0.

The determination and calculation of specific numerical values required for the parameters input to the simulation code to compute building heating and cooling loads are discussed in Section 3.0. For residential buildings, the TRNSYS code (Ref. 1) was used directly with modifications for solar heat gain through windows, infiltration of outside air, and latent heat gains. However, the simulation of the thermal response of the heavier construction of nonresidential structures and the behavior of secondary HVAC distribution systems required the more extensive thermal loads models provided by the AXCESS computer program.

Section 4.0 is concerned with the classification and system configuration selection for solar heating and cooling systems. The determination of specific numerical values required as input parameters for simulation of solar systems is also discussed. The TRNSYS code was used for all primary HVAC (solar and conventional) system performance simulations. Simplified collector area sizing and component parameter selection procedures are reviewed and the general procedure used for determining the required TRNSYS parameters for any specific location is given. In addition the SHACOB system models for the systems simulated in this study are reviewed.

Section 5.0 briefly addresses the simulation process itself, including automated sizing procedures, the primary simulation constraints, and the post-simulation processing required to develop the service area impact. Additional details on these topics are given in Volume 2.

2.0

IDENTIFICATION OF REFERENCE BUILDING TYPES

A set of buildings, representative of the nine basic building occupancy categories shown in Table 2-1, was identified and provided with outline specifications. The resulting group of building definitions was selected to serve as a reference set of buildings to be utilized in assessing the impact of solar heating and cooling installations on electric utility planning and operation in the 1990 to 2000 time period.

An implicit assumption, utilized in the selection of the reference set of buildings, was that the retrofit of the building inventory with solar (space) heating and cooling systems would remain negligible throughout the period to be studied. This assumption was based upon the judgment that more cost-effective energy conservation gains can be obtained from conventional HVAC system retrofit and modification of existing building HVAC controls. Thus, the reference set of buildings was selected to be representative of the expected new construction of the post-1980 period (i.e., after completion of the DOE solar demonstration program). However, solar heating of domestic hot water was considered to be an exception, being a viable option for both retrofit and new construction applications.

Several studies (Ref. 2-5) have been concerned with estimates of the future energy usage within the residential and nonresidential building sectors. These studies utilized growth scenarios that included varying rates of additions and removals from the building inventory. Since estimates of new construction are functions of population growth and economic projections (Ref. 6), the census regions shown in Figure 2-2 were utilized in the reference studies to present the geographic distribution of the projected building inventory. Estimates of the residential inventory by number of household units and nonresidential inventory by floor area are available from various sources (Ref. 2-4). Data from Reference 2 are shown in Tables 2-3 and 2-4. Extensive statistical data for the physical characteristics of new residential construction within each census region are also available (Ref. 8, 9).

No comparable data base for the nonresidential sector has been published. Domestic hot water demand is not a function of the building's physical characteristics, but rather a function of building occupancy; thus the impact of solar domestic water heating may be assessed by assuming a given penetration of the total future inventory (both new construction and retrofit) of building types.

Energy conservation has become a dominant concern (Ref. 12, 13) in the design of new buildings. Over 30 states (Figure 2-1) have enacted or are considering legislation to regulate energy usage by application of building code restrictions in the design of new construction. Most of the regulations developed to date (e.g., Ref. 16, 17) are based upon ASHRAE Standard 90-75, "Energy Conservation in New Building Design." This document (Ref. 14, 15) is currently undergoing the approval process for adoption as an ANSI National Standard. The basic requirements of 90-75 are prescriptive in nature, with allowance for demonstration of equal performance for noncompliance. The effect of climatic variation on building design (residential and nonresidential) was considered in the ASHRAE 90-75 exterior envelope requirements by specifying maximum overall thermal transmittance values (U_o - Factors) for exterior walls, roofs, slabs, and floors as a function of annual heating degree-days. In addition, for nonresidential buildings, an overall thermal transfer value was specified for cooling as a function of latitude. An example of the ASHRAE 90-75 requirements showing the constraints on the thermal conductance in walls as a function of degree-days is given in Figure 2-3. For the definition of the reference set of buildings considered herein, it was assumed that new construction would be governed by regulations at least as restrictive as ASHRAE 90-75, whether based upon prescriptive requirements or resulting from performance requirements (i.e., Btu/sq ft limitations).

2.1 NEW CONSTRUCTION DATA

A climatic regionalization consistent with the geographic census divisions was necessary to allow definition of a set of reference buildings representative of future U.S. new building construction. Discrete values of annual heating degree-days within each geographic region were selected for joint application of ASHRAE 90-75

exterior envelope requirements with available construction statistics and building inventory projections. Four annual heating degree-day regions were selected as indicated in Figure 2-4. Using Reference 18, the range of annual heating degree-days within each state was determined and Figure 2-5 prepared showing the general distribution of heating degree-days within each census region. Using this presentation as a guide, the following discrete values of annual heating degree-days ($^{\circ}\text{F}$) were selected as representative of the geographic census regions:

- Northeast: 5400, 7200
- North Central: 5400, 7200
- South: 1800, 3600
- West: 1800, 3600, 5400, 7200

Approximate contours of the representative values of heating degree-days are indicated in Figure 2-4 and a summary of the regionalization procedure is shown in Figure 2-6.

Residential new construction statistics are available from several sources (Ref. 2-11, 19-21). Extensive descriptive data for current single family (detached) residential new construction are tabulated annually (Ref. 8) by census region. Of interest for the definition of the reference set of buildings, are the regional distribution of floor area, type of foundation, number of stories, and type of exterior wall material. As can be noted from Figure 2-6, 50% of the homes are within ± 400 sq ft of the average house size. Approximately 90% of the homes are within the floor area range, $\bar{A} - 400 \leq \bar{A} \leq \bar{A} + 800$ where $\bar{A}$ is the average house floor area. The distribution of floor area for 1966, 1971, and 1974 is compared in Figure 2-8. The general character of the distributions within each census region are approximately the same for 1974. Comparison of the annual distributions within each region also are similar except for the South, which has experienced greater growth during the 1971 to 1974 period (and through the present).

For the definition of single family (detached) construction, the 1974 distribution of descriptive characteristics given in Table 2-4 was assumed to be applicable for future new construction. By selecting four reference floor areas of 1200, 1600,

2000, and 2400 sq ft, the foundation characteristics were quantified (assuming foundation distribution to be independent of floor area, i.e., uniformly distributed) as shown in Table 2-5.

Descriptive data (1973) for multi-family, low-rise apartments (Ref. 9, 10) are tabulated in Table 2-6. The regional differences of basic geometric layout for multi-family, low-rise construction are shown in Table 2-7. For the definition of multi-family (low-rise) construction, the 1973 distribution of descriptive characteristics was assumed to be applicable for future new construction.

Data is also available (Ref. 11) giving the distribution of general descriptive characteristics of residences by heating degree-day region.

For the numerical definition of the reference set of buildings, discrete values of thermal transmittance for the exterior building envelopes were chosen using the ASHRAE 90-75 design requirements for each value of representative annual heating degree-day defined previously. The wall-design parameters are tabulated in Table 2-8; the roof- and ceiling-design parameters are tabulated in Table 2-9; and the floor-design parameters are tabulated in Table 2-10. The perimeter heat loss coefficient, F , for slabs was computed, assuming the 90-75 requirement of 24 inches of perimeter insulation with resistance, R , and the ASHRAE data presented in Reference 22. ASHRAE 90-75 does not address basement-design parameters; thus the recommendations of Reference 22 were utilized for selecting the heat loss coefficients of heated basement floors and below-grade heated basement walls. The winter ground temperatures, representative of each heating degree-day region given in Table 2-10 were used in computing the heat loss coefficients. For unheated basements, an average temperature between the outside temperature and heated space temperature was assumed for the unheated basement space. Thus, the design parameter for unheated basements was taken as 50% of the parameter for floors over unheated spaces.

For application of the 90-75 cooling design requirements (Type B buildings only), discrete values of solar factor (SF) for each latitude and outdoor summer-design

temperature (2-1/2% dry bulb) are required to determine the overall thermal transfer value (OTTV) for a given building design. The discrete values of latitude and outdoor summer design temperature were chosen as shown in Table 2-11. ASHRAE summer-design temperatures were used as a guide to determine upper-bound summer temperatures representative of the geographical area within the boundaries of each winter heating-degree region. The limiting OTTV value, along with the SF value, are tabulated in Table 2-11 for each latitude.

2.2 RESIDENTIAL BUILDING TYPES

The general characteristics of the reference residential building set is outlined in Figure 2-9. For the definition of the single family detached and multi-family low-rise occupancy, the available construction statistics were utilized to select buildings representative of the distribution of descriptive characteristics within each region. For the definition of single family attached, multi-family high-rise, and motel occupancies, a single representative configuration was selected for each category due to the lack of available descriptive construction characteristics.

The primary descriptive characteristics for a single family detached, which affect the magnitude of the heating or cooling load of a single enclosed space, are floor (plan) area, type of foundation, and number of stories. The effect of building shape, or building aspect ratio, on building wall area, is examined in Figure 2-10. A rectangular building with an aspect ratio of 2.0 has 6% greater wall surface area than a square building with the same floor area. The aspect ratios of the reference set of single family buildings were determined by the average of the minimum aspect ratio ($r_a = 1.0$) and the maximum allowable aspect ratio for a given floor area found by assuming a minimum dimension of 30 ft.

Using the single family (detached) new construction statistics as a guide, the set of buildings listed in Table 2-12 were selected for each geographic census region. Due to reductions in family size and increased housing construction costs, the average future U.S. single family home was assumed to maintain the same average size or floor area of 1550 sq ft as in 1970 to 1971 (Ref. 2). The average regional

representative floor areas (NE: $\bar{A} = 1640$, NC: $\bar{A} = 1520$, S: $\bar{A} = 1440$, W: $\bar{A} = 1615$) were selected to be within the range of historical (1966 to 1974) data and yield an average for the U.S. equal to 1550 sq ft. The distribution of floor area ($\bar{A}$, $\bar{A} \pm 400$, $\bar{A} + 800$) was selected as shown in Figure 2-7. The entire reference set selected is not necessarily to be used for discrete samples in the study simulation, but rather to establish the range of variation of the thermal parameters for this type of construction. Once the effect of floor area, foundation type, and number of stories is established, a reduced reference set of discrete single family homes may be utilized for simulation.

Story heights of 8.0 and 17.0 ft were assumed for one- and two-story construction, respectively. The minimum floor area for two-story construction was assumed to be approximately 10% greater than the average representative floor area. Basements were assumed to be 7.5 ft in height with 4.0 ft of basement wall below grade. In the absence of available statistics, 50% of basements (when defined) were assumed to be heated, with the balance of 50% unheated.

Single family (attached) dwellings were defined as shown in Table 2-21. The town-house configuration (Ref. 21) shown in Figure 2-11 was assumed to be representative of future construction for this occupancy category. Four- and eight-unit attached configurations, each with unit floor areas of 1300 and 1500 sq ft, were selected as the reference buildings for each degree-day region.

Using the regional characteristics of recently built apartment buildings (Ref. 10) given in Tables 2-6 and 2-7, the set of reference multi-family (low-rise) buildings shown in Table 2-13 were selected. Again, the intent of the selection was to establish suitable variation of thermal parameters. Story heights of 17 and 26 ft were assumed for two- and three-story construction, respectively. Unit floor areas were selected to represent the regional average ($\bar{A}$), as given in Table 2-6, and the average plus 200 sq ft ($\bar{A} + 200$).

A four-story multi-family apartment building (Ref. 16) was selected to be representative of multi-family high-rise (greater than three stories) residential construction. The descriptive characteristics are given in Table 2-21.

A two-story, 32-unit building was selected to be representative of a motel occupancy. Details are not given here since this building was not included in the subsequent analysis.

2.3 NONRESIDENTIAL BUILDING TYPES

The nonresidential sector is characterized by highly diverse types of structures. Descriptive characteristics of the various occupancies have not been assembled into a statistical base, thus the following selection of reference building types was based upon judgment as to the direction of future construction for the occupancies considered. The general characteristics of the reference set of nonresidential buildings are shown in Figure 2-12. The building size and shape were selected to yield an annual energy requirement (Btu/sq ft) for heating and cooling which would be representative of the occupancy category.

Two reference office buildings were selected for this occupancy. A building representative of low-rise construction was selected, as well as a high-rise building. The high-rise building was defined with the understanding that the solar applications are limited if the available collector areas are limited to the roof area. However, several buildings have been proposed with spandrel collectors and detached, ground-mounted, collector arrays. The low-rise building defined is shown in Figure 2-13.

The reference building description and outline plan shown in Figure 2-14 are typical of narrow, glass-front retail stores.

Both an elementary (primary) and high school (secondary) building were defined. The high school building was selected to represent the classroom elements of a large campus and does not include gymnasium, auditorium, or shops. The reference buildings are shown in Figure 2-15.

Details of the shopping center, high-rise office, hospital, and light industrial reference buildings were generated but are not shown here since they were not included in the subsequent analysis.

2.4 SUMMARY OF REFERENCE BUILDING SELECTION

The selection of the reference set of buildings is summarized in Table 2-22. The residential single family (detached) and multi-family (low-rise) buildings dominate the reference set. The reduction of the reference set of buildings to a smaller number for simulation purposes is discussed in Section 3.0.

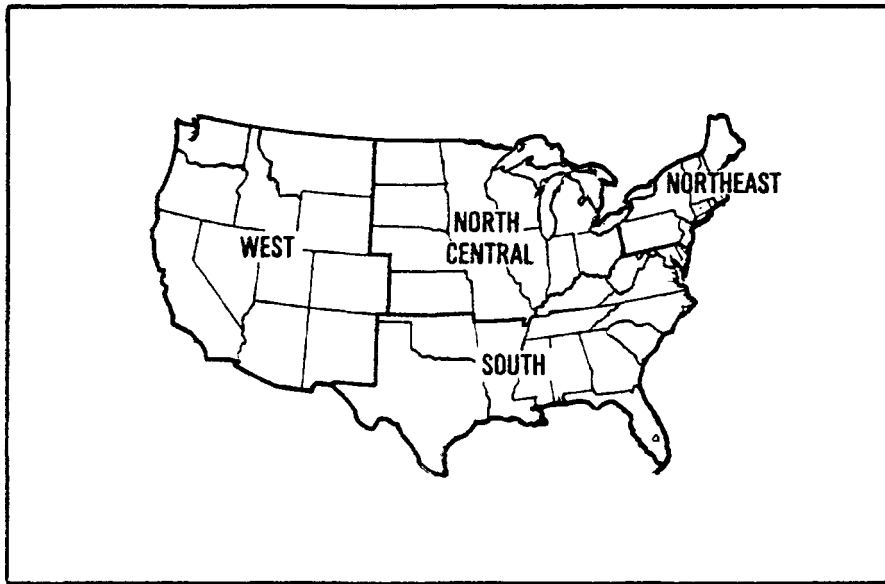


Figure 2-2
Composition of Geographic Census Regions

TYPE A BUILDINGS SHALL INCLUDE:

A 1 DETACHED ONE AND TWO FAMILY DWELLINGS

A 2 ALL OTHER RESIDENTIAL BUILDINGS, THREE
STORIES OR LESS, INCLUDING BUT NOT LIMITED
TO:

MULTI-FAMILY DWELLINGS
HOTELS AND MOTELS

ANNUAL CELSIUS HEATING DEGREE DAYS (18 C BASE)
(IN THOUSANDS)

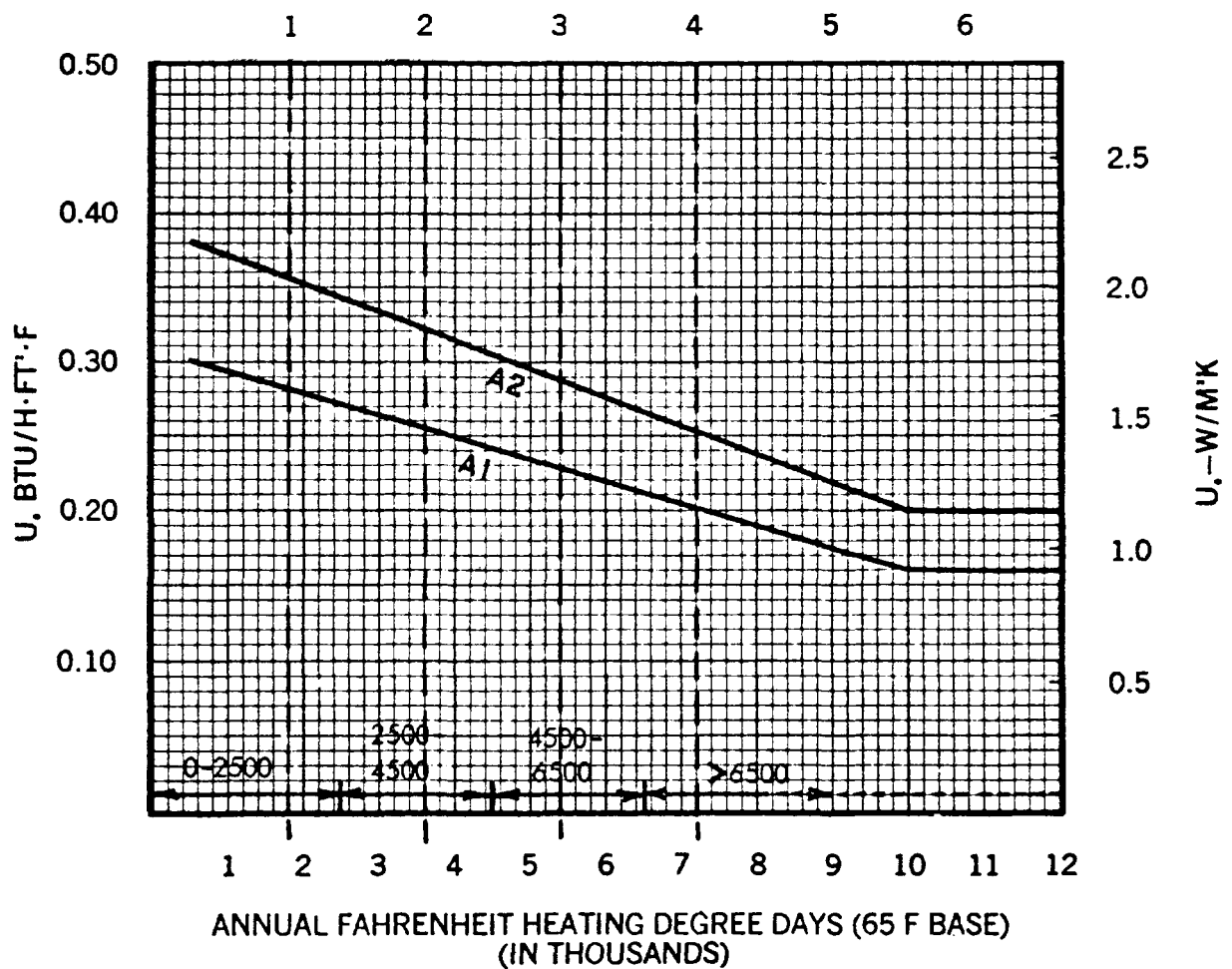
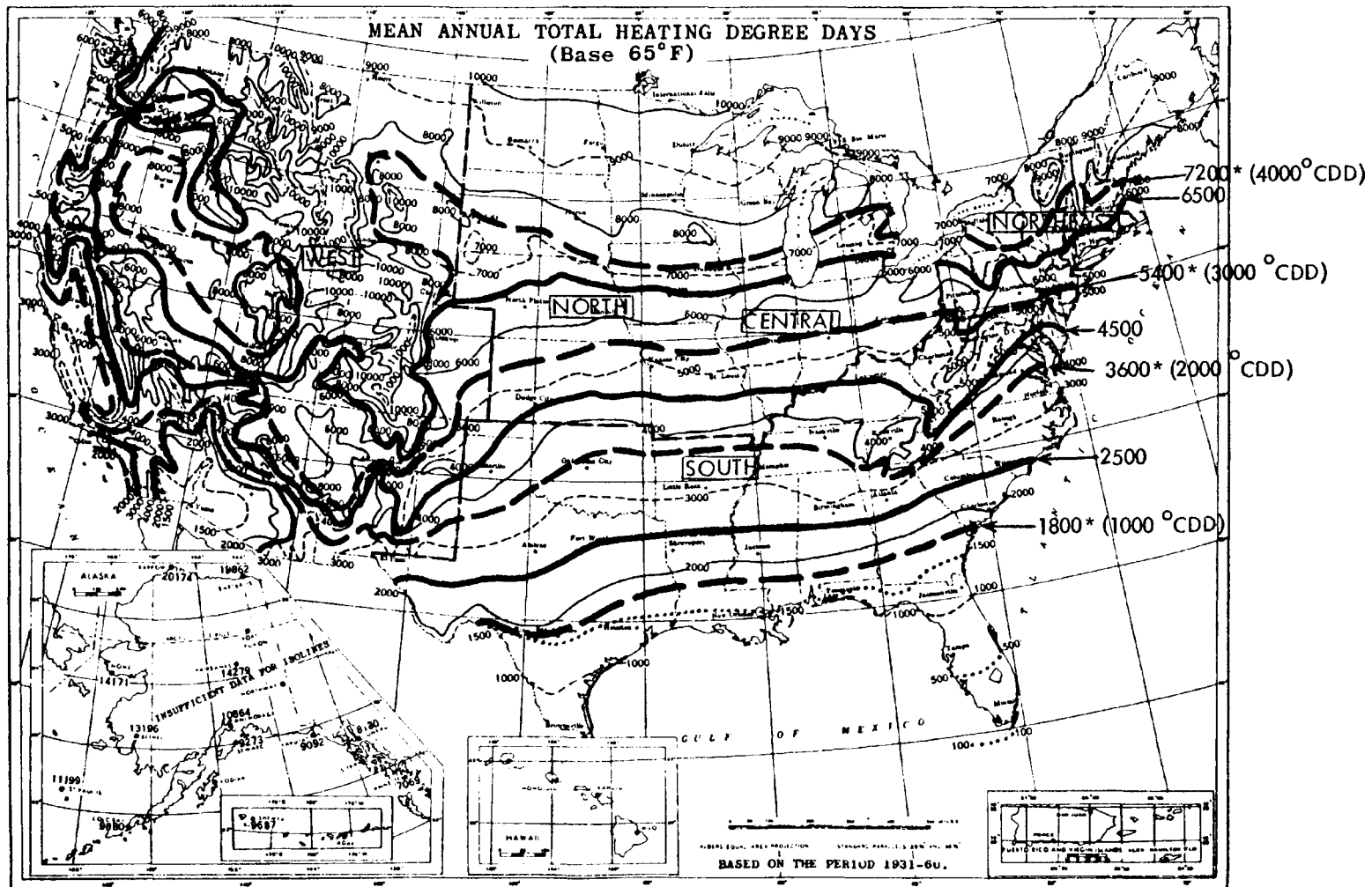


Figure 2-3

ASHRAE Standard 90-75

U_o Walls - Type "A" Buildings



Source: U.S. Department of Commerce, Environmental Data Service, *Selected Climatic Maps of the United States, 1966*

* Representative Degree-Day Values

Figure 2-4
Heating Degree-Day Regionalization

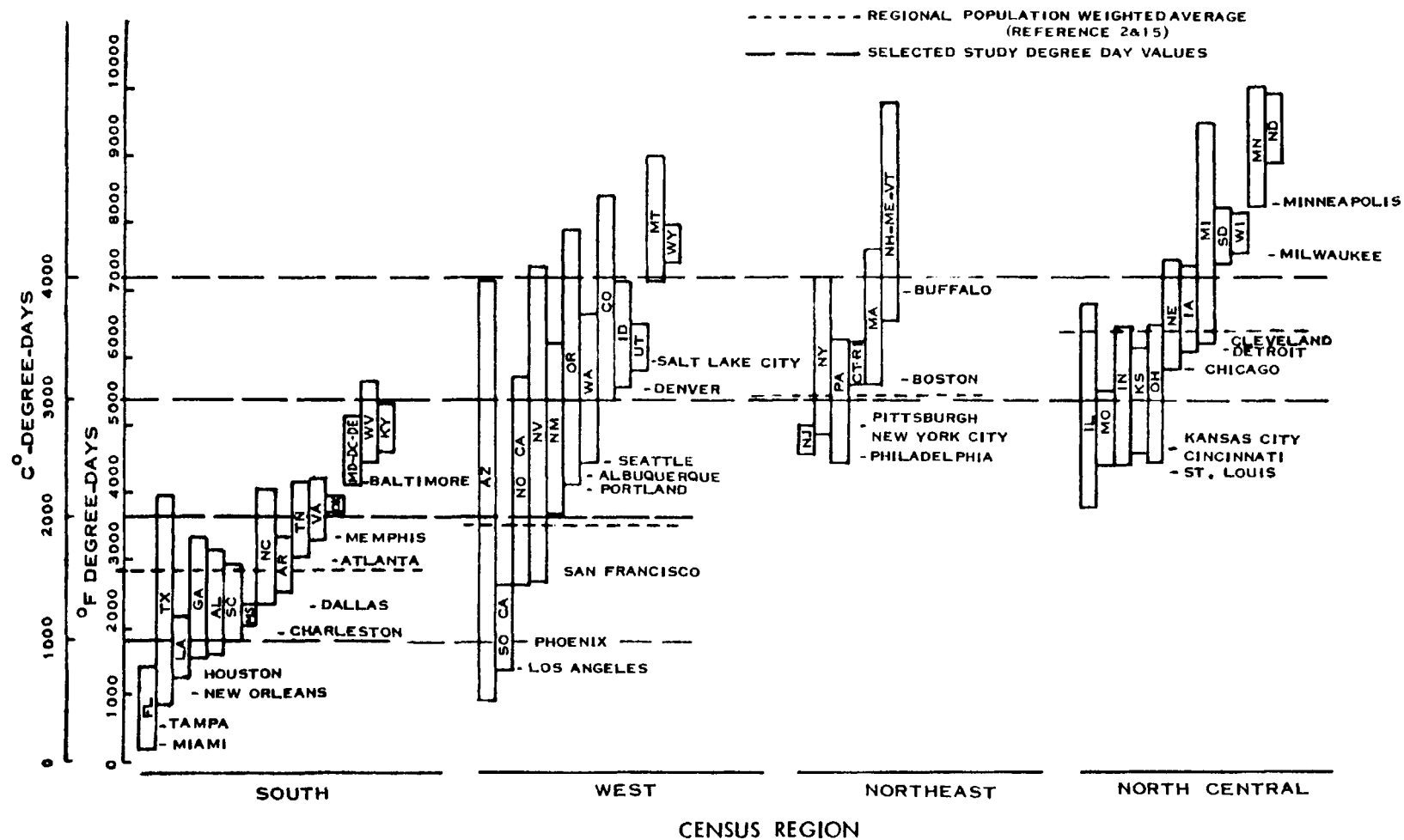


Figure 2-5
Degree-Day Range Regional Variation

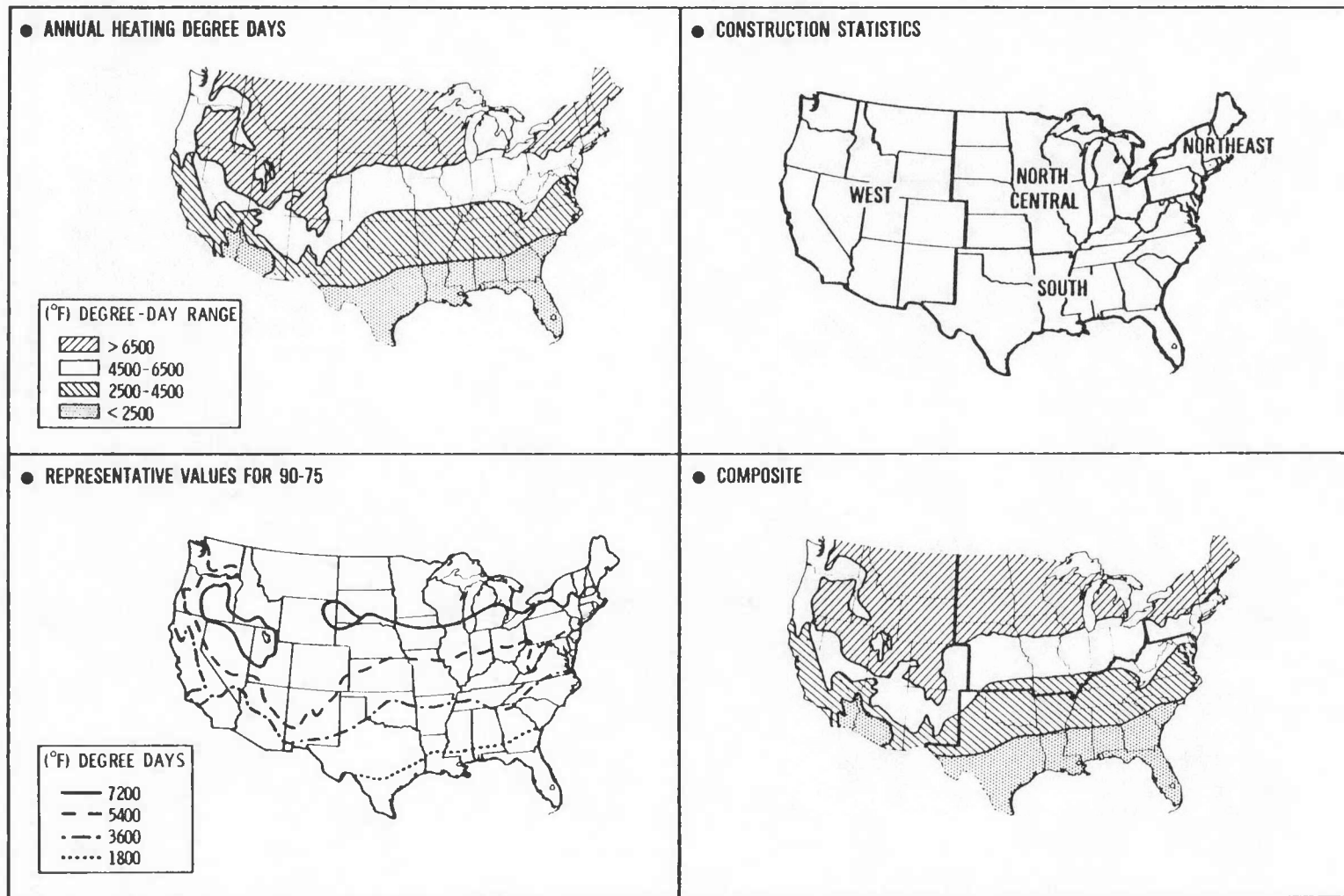


Figure 2-6
Regionalization

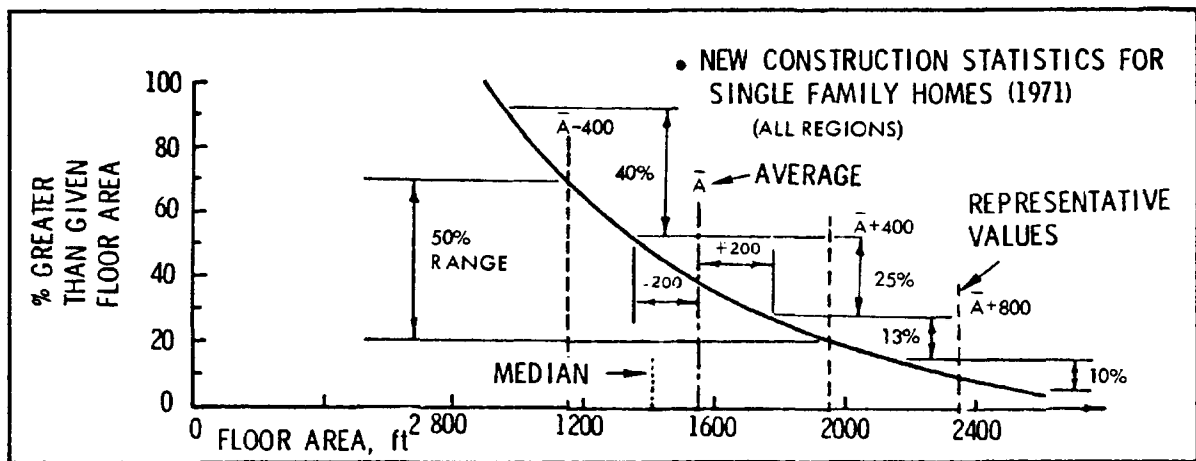


Figure 2-7
Residential Building Distribution

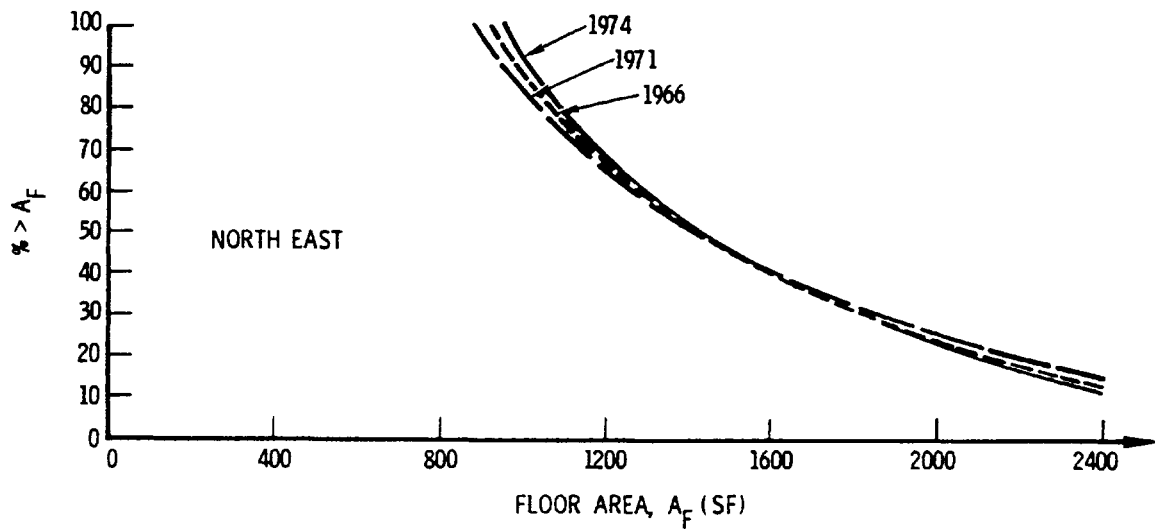


Figure 2-8(a)
New Construction Statistics: Single Family Homes

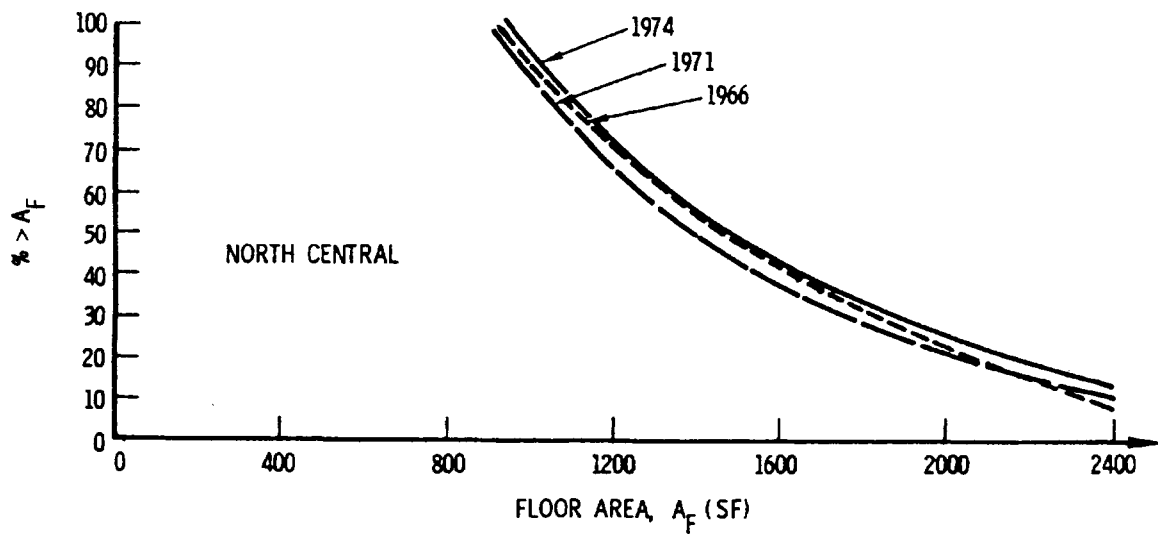


Figure 2-8(b)
New Construction Statistics: Single Family Homes

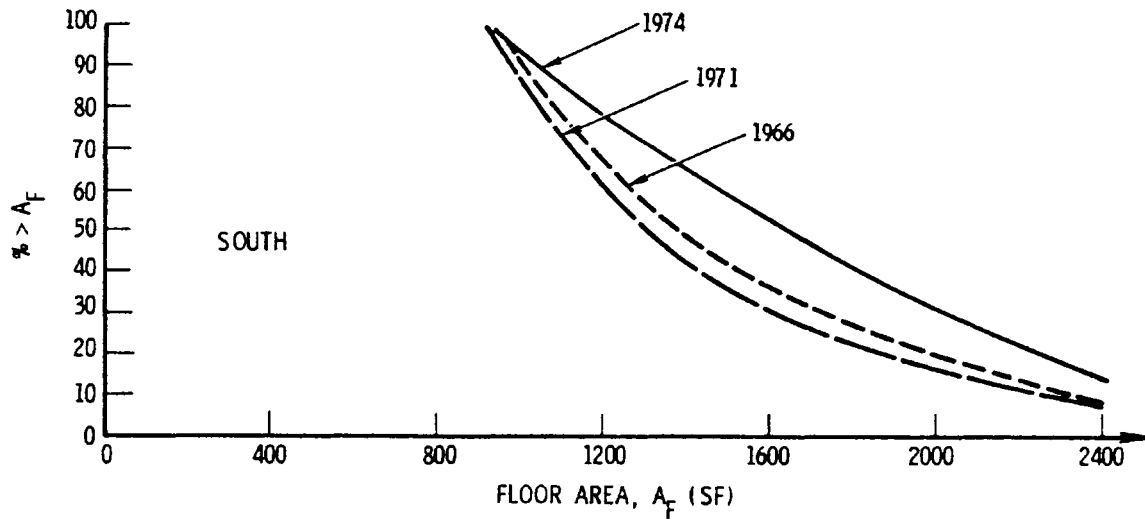


Figure 2-8(c)
New Construction Statistics: Single Family Homes

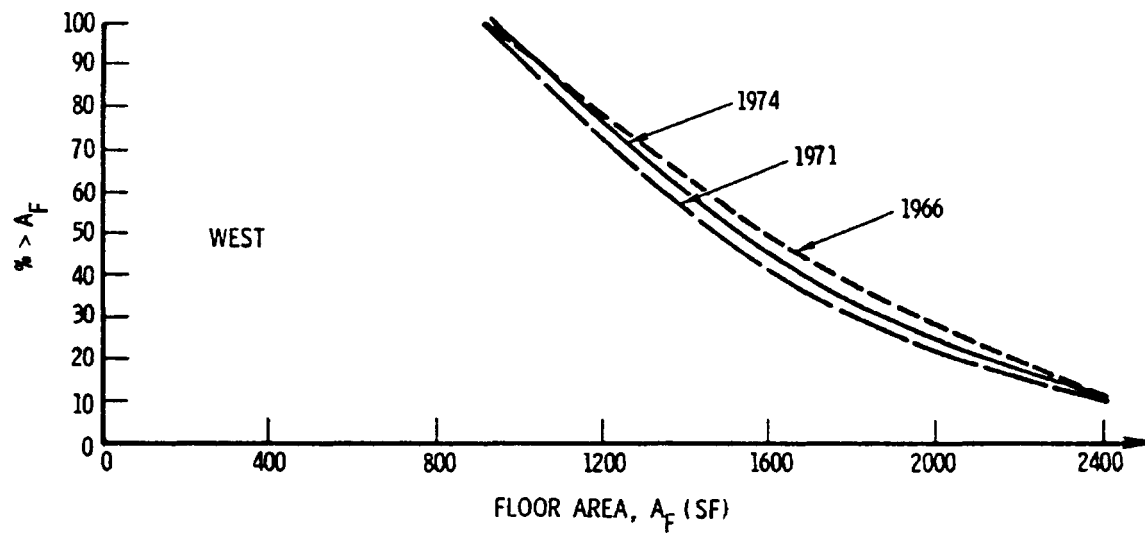


Figure 2-8(d)
New Construction Statistics: Single Family Homes

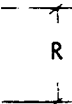
• SINGLE FAMILY DETACHED	• SINGLE FAMILY ATTACHED
• ONE STORY, TWO STORY AND SPLIT LEVEL • FOUNDATIONS: HEATED BASEMENT, UNHEATED BASEMENT, SLAB, CRAWL SPACE • FLOOR AREA: 1200, 1600, 2000, 2400 ft²	• TWO STORY TOWN HOUSE • 4 AND 8 UNIT CONFIGURATIONS • UNIT FLOOR AREAS: 1300, 1500 ft²
• MULTI-FAMILY LOW RISE	• MULTI-FAMILY HIGH RISE
• TWO AND THREE STORY APARTMENTS • BASIC APARTMENT LAYOUT • FOUNDATIONS: HEATED BASEMENT, UNHEATED BASEMENT, SLAB • UNIT FLOOR AREA: 900, 1100 ft²	• FOUR STORY APARTMENT BUILDING • 17,000 GROSS ft² • 13 UNITS • UNIT FLOOR AREA: 1100 ft²
	• MOTEL
	• 2 STORY: 13,500 ft ² (32 units)

Figure 2-9
Residential Buildings Definition

A = BUILDING FLOOR AREA
 S, R, R' = BUILDING PLAN LENGTH AND WIDTH
 P = BUILDING PERIMETER
 H = BUILDING HEIGHT
 W = BUILDING WALL AREA
 r_a = BUILDING ASPECT RATIO

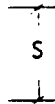
RECTANGLE

$$R' = r_a R$$

$$A = R'R = r_a R^2$$


SQUARE

$$S = S$$

$$A = S^2$$


$$R = \sqrt{\frac{A}{r_a}}$$

$$S = \sqrt{A}$$

$$\begin{aligned}
 P_R &= 2(R' + R) \\
 &= 2(1 + r_a)R \\
 &= \frac{2(1 + r_a)\sqrt{A}}{\sqrt{r_a}}
 \end{aligned}$$

$$\begin{aligned}
 P_S &= 4S \\
 &= 4\sqrt{A}
 \end{aligned}$$

$$W_R = P_R H$$

$$W_S = P_S H$$

$$\frac{W_R}{W_S} = \frac{P_R H}{P_S H} = \frac{1}{2} \frac{(1 + r_a)}{\sqrt{r_a}}$$

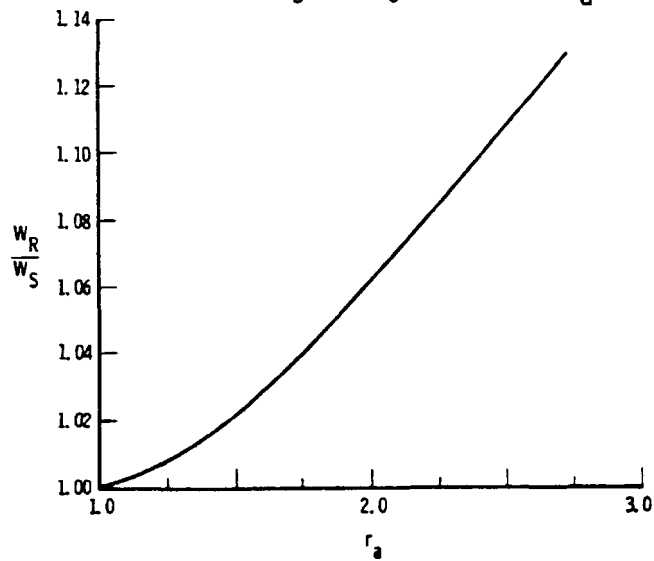


Figure 2-10
Effect of Building Shape

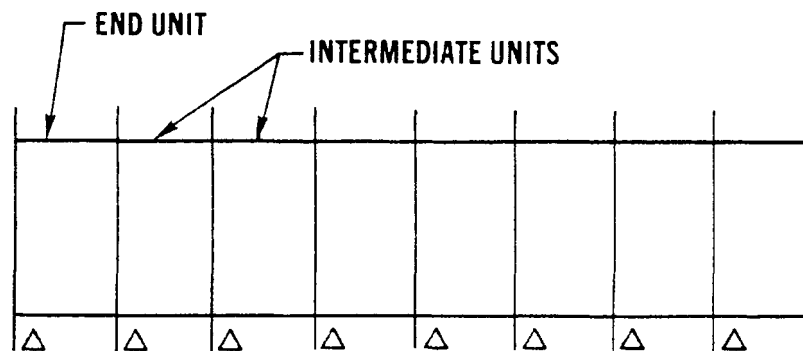
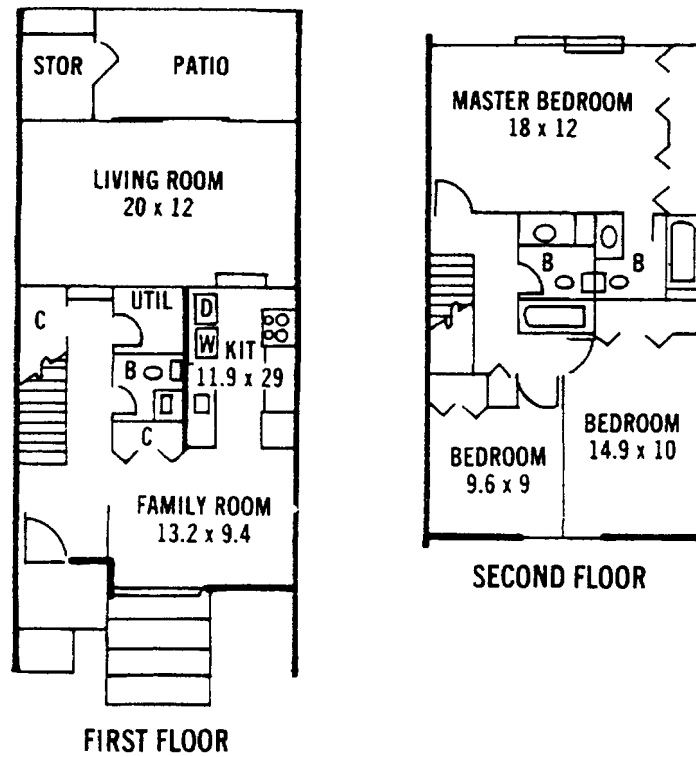
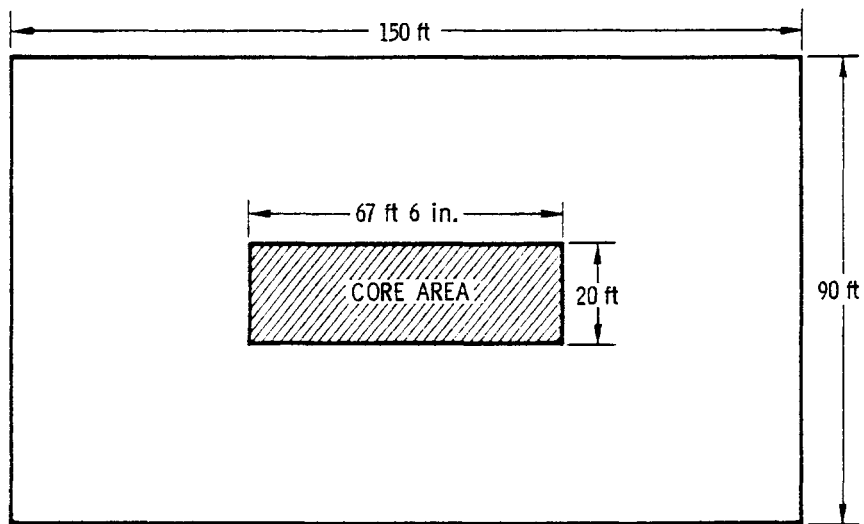


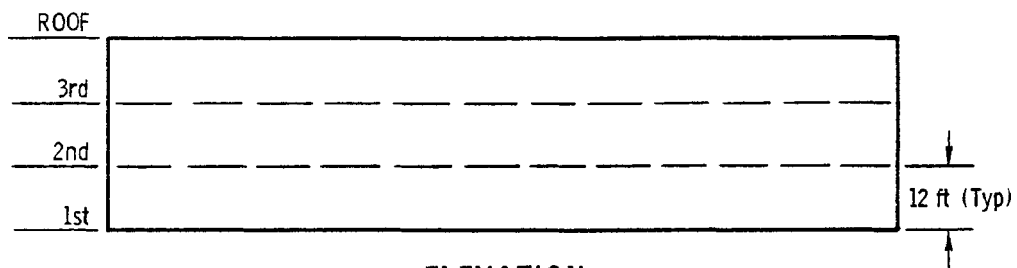
Figure 2-11
 Single Family, Attached
 Town House Configuration
 4 & 8 Units, Unit Area = 1300 & 1500 SF

• OFFICE BUILDINGS	• RETAIL STORE
• 3 STORY: 40,500 ft ² (90 ft x 150 ft)	• 1 STORY: 40,000 ft ² (100 ft x 400 ft)
• 10 STORY: 14,400 ft ² PER FLOOR	• SCHOOLS
• SHOPPING CENTER	• 1 STORY: 20,000 ft ² (elementary, 360 students)
• 390,000 ft ² , 60% LARGE STORES, 30% SMALL STORES, 10% MALL	• 2 STORY: 40,000 ft ² (high school, 950 students)
• HOSPITAL	• LIGHT INDUSTRIAL
• 4 STORY, 60,000 ft ² (120 beds)	• 142,200 ft ²

Figure 2-12
Non-Residential Buildings Definition



FLOOR PLAN

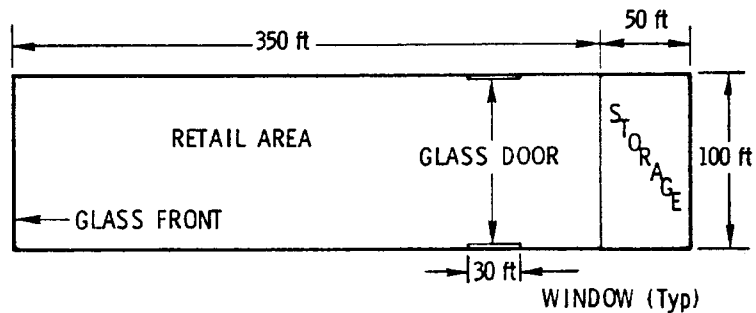


ELEVATION

NO. OF STORIES: 3
 STORY HEIGHT: 12 FT
 FOUNDATION: UNHEATED GARAGE
 GROSS FLOOR AREA: 40,500 SF
 CORE AREA: 4,050 SF (10% FLOOR AREA)
 ROOF AREA: 12,150 SF
 GROSS WALL AREA: 17,280 SF
 GLASS AREA: 5,184 (30% WALL AREA)
 WALL TYPE: 6 IN CONCRETE
 ROOF TYPE: CONCRETE/DECK
 FLOOR TYPE: CONCRETE/METAL DECK
 GLASS TYPE: DOUBLE PANE, SOLAR GREY

Figure 2-13
 Office Building: Low-Rise

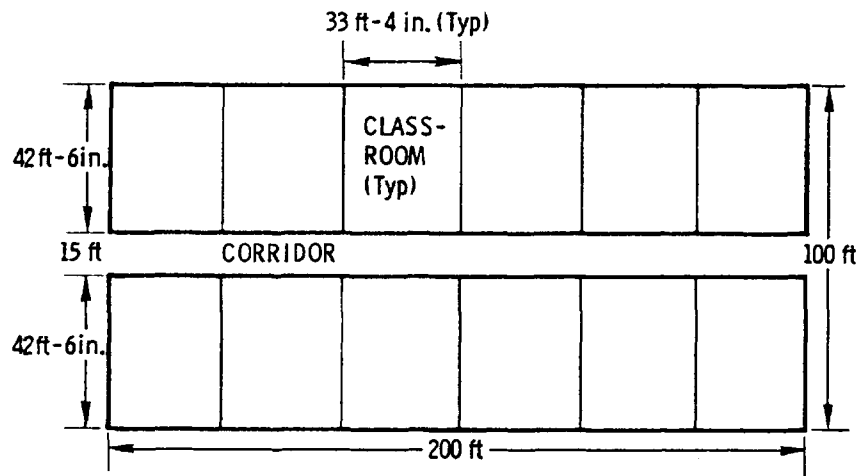
NO. OF STORIES: 1
STORY HEIGHT: 12 FT
FOUNDATION/FLOOR: SLAB ON GRADE
GROSS FLOOR AREA: 40,000
STORAGE AREA: 5,000 (12.5% FLOOR AREA)
ROOF AREA: 40,000
GROSS WALL AREA: 12,000 SF
GLASS AREA: 1,920 SF (16% x WALL AREA)
WALL TYPE: FACE BRICK/CONCRETE BLOCK
ROOF TYPE: FLAT NONVENTED ATTIC
GLASS: 1/4 IN. SINGLE OR DOUBLE PANE, CLEAR



FLOOR PLAN

Figure 2-14
Retail Store

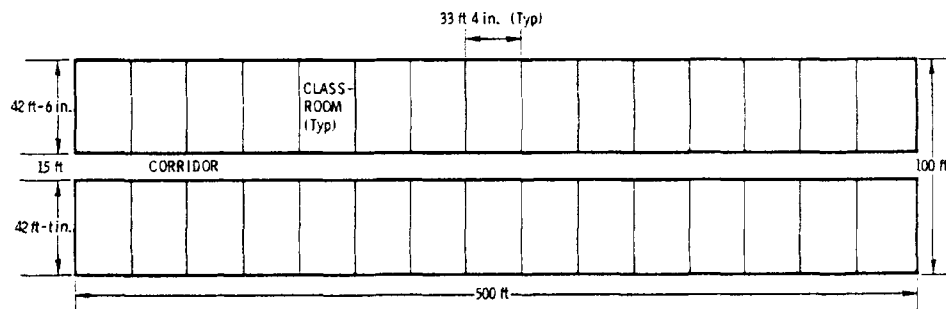
NO. OF STORIES: 1
 STORY HEIGHT: 10 FT
 FOUNDATION/FLOOR: SLAB ON GRADE
 GROSS FLOOR AREA: 20,000 SF
 NO. OF CLASS ROOMS: 12 @ 1,415 SF ea.
 NO. OF STUDENTS: 360 @ 30 per CLASS RM.
 ROOF AREA: 20,000 SF
 GROSS WALL AREA: 6,000 SF
 GLASS AREA: 1,200 SF (20% WALL AREA)
 WALL TYPE: FACE BRICK/CONCRETE BLOCK
 ROOF TYPE: INSULATED STEEL DECK
 GLASS TYPE: 1/4 in. SINGLE OR DOUBLE PANE, CLEAR



FLOOR PLAN

Figure 2-15(a)
 Elementary School

NO. OF STORIES: 2
 STORY HEIGHT: 10 FT
 FOUNDATION/FLOOR: SLAB ON GRADE
 GROSS FLOOR AREA: 100,000 SF
 NO. OF CLASS ROOMS: 48 @ 1,728 SF ea.
 NO. OF STUDENTS: 960 @ 20 per CLASS RM.
 ROOF AREA: 50,000 SF
 GROSS WALL AREA: 24,000 SF
 GLASS AREA: 4,800 SF (20% WALL AREA)
 WALL TYPE: FACE BRICK/CONCRETE BLOCK
 ROOF TYPE: INSULATED STEEL DECK
 GLASS TYPE: 1/4 in. SINGLE OR DOUBLE PANE, CLEAR



FLOOR PLAN

Figure 2-15(b)
 High School

Table 2-1
Basic Building Occupancy Categories

- o RESIDENTIAL BUILDING TYPES
 - o Single Family: Detached; Attached
 - o Multi-Family: Low-Rise; High-Rise
 - o Motel
- o NON-RESIDENTIAL BUILDING TYPES
 - o Office: Low-Rise; High-Rise
 - o Retail Store
 - o Shopping Center
 - o School: Primary; Secondary
 - o Hospital
 - o Light Industrial

Table 2-2
Residential Inventory
(thousand year-round units)

	1970 Inventory	New Construction 1970-80	Removals 1970-80	1980 Inventory	New Construction 1980-85	Removals 1980-85	1985 Inventory	New Construction 1985-90	Removals 1985-90	1990 Inventory
Northeast	16,198	5,354	2,357	19,195	2,770	1,288	20,677	2,540	1,371	21,846
Mobile Home	241	710	201	750	320	150	920	267	165	1,022
Single-Family	7,778	2,186	391	9,573	1,137	227	10,483	1,176	249	11,410
Low-Density	4,552	1,163	1,164	4,551	636	594	4,593	529	605	4,517
Low-Rise	1,392	760	133	2,019	396	110	2,305	327	138	2,494
High-Rise	2,235	535	468	2,302	281	207	2,376	241	214	2,403
North Central	18,675	6,889	3,436	22,128	2,978	1,691	23,415	2,944	1,754	24,605
Mobile Home	499	1,439	322	1,616	559	291	1,884	521	350	2,055
Single-Family	13,261	3,440	1,696	15,005	1,500	750	15,755	1,570	788	16,537
Low-Density	2,773	1,176	739	3,210	534	368	3,376	502	360	3,518
Low-Rise	1,686	507	550	1,643	238	197	1,684	243	163	1,764
High-Rise	456	327	129	654	147	85	716	108	93	731
South	20,884	9,979	4,259	26,604	4,817	2,070	29,351	4,800	2,040	32,111
Mobile Home	869	2,146	460	2,555	893	460	2,988	841	538	3,291
Single-Family	15,683	5,312	2,530	18,465	2,586	1,107	19,944	2,734	997	21,681
Low-Density	2,293	1,514	641	3,166	756	340	3,582	745	337	3,990
Low-Rise	1,698	698	511	1,885	413	110	2,188	332	109	2,411
High-Rise	341	309	117	533	169	53	649	148	59	738
West	11,942	5,352	3,132	14,162	2,656	1,459	15,359	2,269	1,284	16,344
Mobile Home	464	730	312	882	329	176	1,035	236	186	1,085
Single-Family	8,079	2,366	1,725	8,720	1,165	697	9,188	1,096	551	9,733
Low-Density	1,379	1,136	371	2,144	592	228	2,508	469	237	2,740
Low-Rise	1,757	807	624	1,940	411	291	2,060	336	241	2,155
High-Rise	263	313	100	476	159	67	568	132	69	631
U.S. Total	67,699	27,574	13,184	82,089	13,221	6,508	88,802	12,553	6,449	94,906
Mobile Home	2,073	5,025	1,295	5,803	2,101	1,077	6,827	1,865	1,239	7,453
Single-Family	44,801	13,304	6,342	51,763	6,388	2,781	55,370	6,576	2,585	59,361
Low-Density	10,997	4,989	2,915	13,071	2,518	1,530	14,059	2,245	1,539	14,765
Low-Rise	6,533	2,772	1,818	7,487	1,458	708	8,237	1,238	651	8,824
High-Rise	3,295	1,484	814	3,965	756	412	4,309	629	435	4,503

Sources: United States Department of Commerce, *1970 Census of Housing* and Arthur D. Little, Inc.

Table 2-3
Commercial Inventory
(million square feet)

	1970 Inventory	New Construction 1970-80	Removals 1970-80	1980 Inventory	New Construction 1980-85	Removals 1980-85	1985 Inventory	New Construction 1985-90	Removals 1985-90	1990 Inventory
Northeast	5,401	3,472	456	8,417	2,309	359	10,367	2,724	442	12,649
Offices	913	728	77	1,564	520	67	2,017	636	86	2,567
Retail	1,094	997	92	1,999	734	86	2,647	907	114	3,440
Schools	1,159	570	98	1,631	308	69	1,870	319	79	2,110
Hospitals	435	233	37	631	136	27	740	150	31	859
Other	1,800	944	152	2,592	611	110	3,093	712	132	3,673
North Central	5,990	3,707	667	9,030	2,484	506	11,008	2,951	619	13,340
Offices	845	677	94	1,428	468	80	1,834	597	103	2,328
Retail	1,221	1,094	136	2,179	814	123	2,870	1,015	163	3,722
Schools	1,411	641	157	1,895	353	106	2,142	374	120	2,396
Hospitals	420	225	47	598	132	33	697	146	39	804
Other	2,093	1,070	233	2,930	699	164	3,465	819	194	4,090
South	6,303	3,994	927	9,370	2,710	694	11,386	3,269	840	13,815
Offices	946	788	139	1,595	573	118	2,050	715	152	2,613
Retail	1,137	1,078	167	2,048	822	151	2,719	1,051	200	3,570
Schools	1,613	760	237	2,136	426	158	2,404	457	178	2,683
Hospitals	435	234	64	605	136	45	696	151	51	796
Other	2,172	1,134	320	2,986	753	222	3,517	895	259	4,153
West	3,916	2,457	545	5,828	1,652	406	7,074	1,966	494	8,546
Offices	676	512	94	1,094	366	76	1,384	447	97	1,734
Retail	758	696	106	1,348	520	94	1,774	652	124	2,302
Schools	857	404	119	1,142	223	80	1,285	235	90	1,430
Hospitals	210	113	29	294	66	21	339	73	24	388
Other	1,415	732	197	1,950	477	135	2,292	559	159	2,692
U.S. Total	21,610	13,630	2,595	32,645	9,155	1,965	39,835	10,910	2,395	48,350
Offices	3,380	2,705	404	5,681	1,945	341	7,285	2,395	438	9,242
Retail	4,210	3,865	501	7,575	2,890	454	10,010	3,625	601	13,034
Schools	5,040	2,375	611	6,804	1,310	413	7,701	1,385	467	8,619
Hospitals	1,500	805	177	2,128	470	126	2,472	520	145	2,847
Other	7,480	3,880	902	10,458	2,540	631	12,367	2,985	744	12,406

Table 2-4
Residential New Construction Statistics
Single Family Detached (1974)

<u>CHARACTERISTIC</u>	<u>US</u>	<u>SMSA</u>	<u>NON SMSA</u>	<u>NORTH- EAST</u>	<u>NORTH CENTRAL</u>	<u>SOUTH</u>	<u>WEST</u>
FLOOR AREA, (SF)							
(AVE)	1695	1785	1545	1600	1660	1760	1660
(MEDIAN)	1560	1665	1405	1465	1490	1640	1540
FLOOR AREA, (%)							
(< 1000 SF)	7	4	11	13	7	6	5
(1000 - 1200 SF)	17	14	21	20	21	14	16
(1200 - 1600 SF)	29	28	32	26	29	28	34
(1600 - 2400 SF)	34	39	27	31	30	38	33
(> 2400 SF)	13	15	9	11	13	14	11
TYPE OF FOUND., (%)							
(BSMT)	45	43	49	76	80	23	28
(SLAB)	36	45	22	16	8	52	48
(CR.SP.)	19	13	29	8	12	25	23
NO. OF STORIES, (%)							
(1)	65	56	77	45	60	75	64
(2)	25	33	14	45	24	19	26
(SL)	10	11	8	10	17	6	11
EXT. WALL MAT'L., (%)							
(BRICK)	35	33	37	8	20	65	7
(WD. PROD.)	32	28	38	46	46	15	40
(STUCCO)	10	16	1	1	1	5	40
(AL. SIDE.)	12	13	11	21	27	6	2
(OTHER)	11	10	13	25	7	9	12

Table 2-5
Residential New Construction Statistics
Single Family Detached (1974)

REGION	ΔA_F FLOOR AREA RANGE (SF)	A_F REFERENCE FLOOR AREA (SF)	% HOMES WITHIN ΔA_F RANGE	% HOMES WITH FOUNDATION TYPE WITHIN ΔA_F RANGE		
				BSMT*	SLAB	CR.SP.
US	1000-1400	1200	33	15	12	6
	1400-1800	1600	24	11	9	4
	1800-2200	2000	16	7	6	3
	2200-2600	2400	13	6	5	2
NORTH EAST	1000-1400	1200	40	30	7	3
	1400-1800	1600	20	15	3	2
	1800-2200	2000	15	11	3	1
	2200-2600	2400	12	9	2	1
NORTH CENTRAL	1000-1400	1200	36	29	3	4
	1400-1800	1600	22	18	2	2
	1800-2200	2000	15	12	1	2
	2200-2600	2400	12	10	1	1
SOUTH	1000-1400	1200	29	7	15	7
	1400-1800	1600	23	5	12	6
	1800-2200	2000	19	4	10	5
	2200-2600	2400	15	3	8	4
WEST	1000-1400	1200	35	10	17	8
	1400-1800	1600	26	7	13	6
	1800-2200	2000	16	4	8	4
	2200-2600	2400	10	3	5	2

* 50% BASEMENTS ASSUMED HEATED ,

50% BASEMENTS ASSUMED UNHEATED .

Table 2-6
Typical Regional Characteristics of Recently Built
Apartment Buildings

TYPICAL CHARACTERISTIC	REGION			
	NE	NC	S	W
UNITS PER BUILDING	14	20	15	16
No. STORIES	2.2	2.4	2.3	2.2
FLOOR AREA/UNIT	800	860	900	910
FOUNDATION TYPE	BSMT (44)*	SLAB (49)	SLAB (74)	SLAB (64)
EXT WALL SLDING	BR VEN (78)	BR VEN (95)	BR VEN (85)	WD PROD (63)

* Percent of homes having most prominent characteristics is indicated in brackets.

Source: Nat'l Asso. of Home Builders Low-Rise Apartment Survey, 155.29, 1973

Table 2-7
Basic Apartment Layouts

TYPICAL REGIONAL CHARACTERISTICS OF RECENTLY BUILT APARTMENT BUILDINGS
(Source: National Association of Home Builders Low-Rise Apartment Survey, 155.29, 1973)

DESIGN TYPE	PERCENT OF RESPONDENTS* REGIONS				
	NORTH- EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
D	28	32	19	18	25
C	15	22	26	12	23
B	17	12	26	64	22
Other (H)	24	22	15	0	17
G	6	15	4	0	8
A	4	2	11	0	6
F	7	4	7	0	5
E	0	1	5	0	3

* PERCENTAGES do not necessarily equal 100 due to multiple answers.

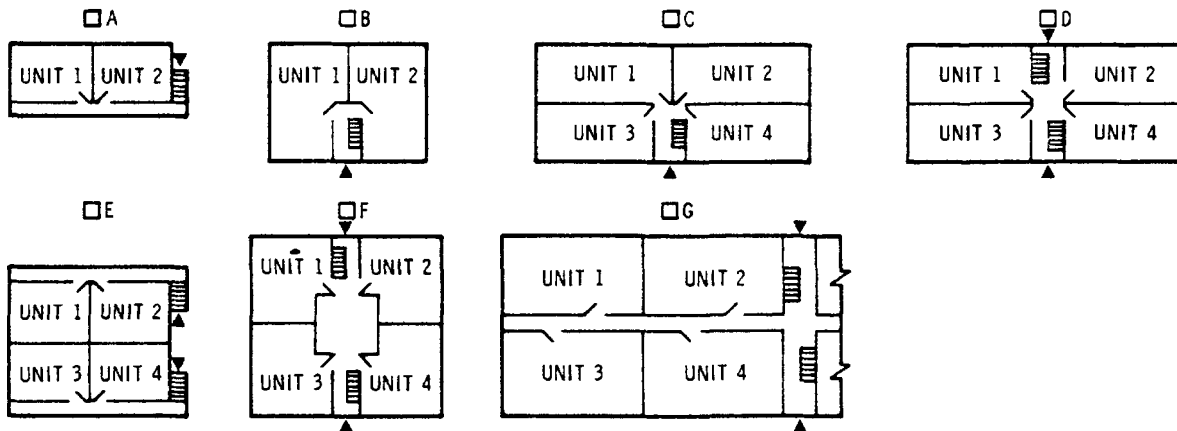


Table 2-8
ASHRAE 90-75
Wall Design Parameters

Wall U_o : Type "A" Buildings (residential buildings less than three stories)

		<u>Annual heating degree day</u>		<u>Maximum U_o - factor</u>	
		$^{\circ}\text{C-day}$	$^{\circ}\text{F-day}$	$\text{KJ/HRm}^2\ ^{\circ}\text{C}$	$\text{BTU/HR FT}^2\ ^{\circ}\text{F}$
<u>Type "A1" Buildings:</u>					
1,000			1,800	5.723	0.280
(Detached one and two family dwellings)	2,000		3,600	5.212	0.255
	3,000		5,400	4.701	0.230
	4,000		7,200	4.088	0.200
<u>Type "A2" Buildings:</u>					
1,000			1,800	7.256	0.355
(All other residential buildings, three stories or less, including multi-family dwellings, hotels, and motels)	2,000		3,600	6.541	0.320
	3,000		5,400	5.927	0.290
	4,000		7,200	5.212	0.255

Wall U_o : Type "B" Buildings (residential buildings greater than three stories and all other nonresidential buildings)

		<u>Annual heating degree day</u>		<u>Maximum U_o - factor</u>	
		$^{\circ}\text{C-day}$	$^{\circ}\text{F-day}$	$\text{KJ/HRm}^2\ ^{\circ}\text{C}$	$\text{BTU/HR FT}^2\ ^{\circ}\text{F}$
<u>≤ 3 stories:</u>					
1,000			1,800	7.256	0.355
2,000			3,600	6.541	0.320
3,000			5,400	5.927	0.290
4,000			7,200	5.212	0.255
<u>> 3 stories:</u>					
1,000			1,800	8.892	0.435
2,000			3,600	7.972	0.390
3,000			5,400	7.154	0.350
4,000			7,200	6.132	0.300

Table 2-9
ASHRAE 90-75
Roof and Ceiling Design Parameters

U_o Roofs and ceilings: Type "A" Buildings (Residential buildings less than three stories)

<u>Annual heating degree day</u>	<u>Maximum U_o factor*</u>
≤ 4444 °C-day (8000 °F-day)	1.022 KJ/HRm ² °C (0.05 BTU/HR SF °F)
4444 °C-day (8000 °F-day)	0.818 KJ/HRm ² °C (0.04 BTU/HR SF °F)

*Exception: exposed roof deck ceiling, Maximum U_o = 1.636 KJ/HRm² °C
(0.08 BTU/HR SF °F)

U_o Roofs and ceilings: Type "B" Buildings (Residential buildings greater than three stories and all other non-residential buildings)

<u>Annual heating degree day</u>		<u>Maximum U_o - factor</u>	
°C-day	°F-day	KJ/HRm ² °C	BTU/HR FT ² °F
1,000	1,800	2.044	0.100
2,000	3,600	1.942	0.095
3,000	5,400	1.635	0.080
4,000	7,200	1.349	0.066

Table 2-10
ASHRAE 90-75
Floor Design Parameters

F: Heat loss coefficient for
unheated slabs with 2 ft.
insulation (based on 1972
ASHRAE Handbook, p. 378)

		<u>U_o: Floors over unheated spaces</u>		<u>R: Slabs on grade</u>			
<u>Annual heating degree day</u>		<u>Maximum U_o - factor</u>		<u>Minimum R-factor</u>		<u>Maximum F - coefficient</u>	
^o C-day	^o F-day	KJ/HRm ² ^o C	BTU/HR FT ² ^o F	HRm ² ^o C/KJ	HR FT ² ^o F/BTU	KJ/HRm ² ^o C	BTU/HR FT ² ^o F
1,000	1,800	5.519	0.270	0.122	2.50	4.156	0.667
2,000	3,600	2.964	0.145	0.157	3.20	3.246	0.521
3,000	5,400	1.636	0.08	0.215	4.40	2.362	0.379
4,000	7,200	1.635	0.08	0.274	5.60	1.857	0.298

U_o: Heated basement (based on 1972 ASHRAE Handbook, p. 378)

		<u>Winter</u>					
<u>Annual heating degree day</u>		<u>Ground temp.</u>		<u>Basement Floor heat loss</u>		<u>Below grade heat loss</u>	
^o C-day	^o F-day	^o C	^o F	KJ/HRm ²	BTU/HR FT ²	KJ/HRm ²	BTU/HR FT ²
1,000	1,800	15.56	60	11.357	1.0	22.713	2.0
2,000	3,600	15.56	60	11.357	1.0	22.713	2.0
3,000	5,400	10.00	50	22.713	2.0	45.426	4.0
4,000	7,200	4.44	40	34.070	3.0	68.139	6.0

Table 2-11(a)
Cooling Design Conditions

<u>ANNUAL HEATING DEGREE-DAY REGION (°F)</u>	<u>SUMMER OUTDOOR DESIGN CONDITION</u>	<u>ΔT (INDOOR TEMP = 78°)</u>
7200	93	15
5400	98	20
3600	98	20
1800	103	25

Table 2-11(b)
ASHRAE 90-75
Cooling Design Parameters

Type 'B' Buildings (Residential buildings
greater than three stories and all other non-
residential buildings)

<u>Latitude</u> °N	<u>SF: Solar factor</u>		<u>Maximum Wall Overall Thermal Transfer Value (OTTV):</u>	
	<u>SF</u>		<u>OTTV</u>	
	<u>KJ/HRm²</u>	<u>BTU/HR FT²</u>	<u>KJ/HRm²</u>	<u>BTU/HR FT²</u>
27.5	1351.43	119.0	340.70	30.0
32.5	1385.50	122.0	356.60	31.4
37.5	1419.57	125.0	372.49	32.8
42.5	1476.35	130.0	388.39	34.2
47.5	1538.81	135.5	404.29	35.6

Table 2-12
Reference Residential Building Selection
Single Family: Detached

GEOGRAPHIC REGION: NORTHEAST

<u>BLDG TYPE</u>	<u>FLOOR AREA (FT²)</u>	<u>ASPECT RATIO</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>VOLUME (FT³)</u>
1	1240	1.2	1	8	B	9920
2	1640	1.4	1	8	B	13120
3	1640	1.4	1	8	S	13120
4	2040	1.3	1	8	B	16320
5	1800	1.0	2	17	B	15300
6	2200	1.1	2	17	B	18700
7	2600	1.4	2	17	B	22100
8	2440	1.3	1	8	B	19520

B = BASEMENT (50% ARE HEATED; 50% ARE UNHEATED); S = SLAB

ROOF TYPE: VENTED ATTIC

GEOGRAPHIC REGION: NORTH CENTRAL

<u>BLDG TYPE</u>	<u>FLOOR AREA (FT²)</u>	<u>ASPECT RATIO</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>VOLUME (FT³)</u>
1	1120	1.2	1	8	B	8960
2	1520	1.4	1	8	B	12160
3	1520	1.4	1	8	CS	12160
4	1920	1.3	1	8	B	15360
5	1700	1.0	2	17	B	14450
6	2100	1.1	2	17	B	17850
7	2500	1.4	2	17	B	21250
8	2320	1.3	1	8	B	18560
9	1520	1.4	1	8	S	12160

B = BASEMENT (50% ARE HEATED; 50% ARE UNHEATED); S = SLAB

ROOF TYPE: VENTED ATTIC

Table 2-12
Reference Residential Building Selection
Single Family: Detached
(Continued)

GEOGRAPHIC REGION: SOUTH

<u>BLDG TYPE</u>	<u>FLOOR AREA (FT²)</u>	<u>ASPECT RATIO</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>VOLUME (FT³)</u>
1	1040	1.1	1	8	S	8320
2	1440	1.3	1	8	S	11520
3	1440	1.3	1	8	CS	11520
4	1440	1.3	1	8	B	11520
5	1840	1.3	1	8	S	14720
6	1440 (UFC)	1.3	1	8	S	11520
7	1040	1.1	1	8	CS	8320
8	1840	1.3	1	8	CS	14720
9	2240	1.3	1	8	S	17920
10	2240	1.3	1	8	CS	17920
11	1600	1.1	2	17	S	13600

B = BASEMENT (50% ARE HEATED; 50% ARE UNHEATED); S = SLAB; CS = CRAWL SPACE

ROOF TYPE: VENTED ATTIC EXCEPT UFC = UNFINISHED CEILING

GEOGRAPHIC REGION: WEST

<u>BLDG TYPE</u>	<u>FLOOR AREA (FT²)</u>	<u>ASPECT RATIO</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>VOLUME (FT³)</u>
1	1215	1.2	1	8	S	9720
2	1615	1.4	1	8	S	12920
3	1615	1.4	1	8	CS	12920
4	2015	1.3	1	8	S	16120
5	1615	1.4	1	8	B	12920
6	1615 (UFC)	1.4	1	8	S	12920
7	2415	1.3	1	8	S	19320
8	1800	1.1	2	17	S	15300

B = BASEMENT (50% ARE HEATED; 50% ARE UNHEATED); S = SLAB; CS = CRAWL SPACE

ROOF TYPE: VENTED ATTIC EXCEPT UFC = UNFINISHED CEILING

Table 2-13
Reference Residential Building Selection
Multi-Family: Low-Rise

GEOGRAPHIC REGION: NORTHEAST

<u>BLDG TYPE</u>	<u>FLOOR AREA PER UNIT (FT²)</u>	<u>BASIC* LAYOUT TYPE</u>	<u>LAYOUT ASPECT RATIO</u>	<u>NO. OF UNITS</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>TOTAL VOLUME (FT³)</u>
1	880	D	1.7	16	2	17	SB	119680
2	880	B	1.9	12	2	17	SB	89760
3	880	D	1.7	16	2	17	BMT	119680
4	880	B	1.9	12	2	17	BMT	89760
5	1080	D	1.7	16	2	17	BMT	146880
6	1080	B	1.9	12	2	17	BMT	110160

BMT = BASEMENT (50% ARE HEATED; 50% ARE UNHEATED); SB = SLAB

ROOF TYPE: NONVENTED ATTIC

* REFER TO TABLE

GEOGRAPHIC REGION: NORTH CENTRAL

<u>BLDG TYPE</u>	<u>FLOOR AREA PER UNIT (FT²)</u>	<u>BASIC* LAYOUT TYPE</u>	<u>LAYOUT ASPECT RATIO</u>	<u>NO. OF UNITS</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>TOTAL VOLUME (FT³)</u>
1	860	D	1.7	24	2	17	SB	175440
2	860	C	3.5	16	2	17	SB	116960
3	860	D	1.7	24	3	26	SB	178880
4	860	D	1.7	24	2	17	BMT	175440
5	860	C	3.5	16	2	17	BMT	116960
6	860	D	1.7	24	3	26	BMT	178880
7	1060	D	1.7	24	2	17	SB	216240
8	1060	C	3.5	16	2	17	SB	144160
9	1060	D	1.7	24	3	26	SB	220480

BMT = BASEMENT (50% ARE HEATED; 50% ARE UNHEATED); SB = SLAB

ROOF TYPE: NONVENTED ATTIC

* REFER TO TABLE

Table 2-13
Reference Residential Building Selection
Multi-Family: Low-Rise
(Continued)

GEOGRAPHIC REGION: SOUTH

<u>BLDG TYPE</u>	<u>FLOOR AREA PER UNIT (FT²)</u>	<u>BASIC* LAYOUT TYPE</u>	<u>LAYOUT ASPECT RATIO</u>	<u>NO. OF UNITS</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>TOTAL VOLUME (FT³)</u>
1	900	C	3.5	16	2	17	SB	122400
2	900	B	1.9	12	2	17	SB	91800
3	1100	C	3.5	16	2	17	SB	149600
4	1100	B	1.9	12	2	17	SB	112200
5	900	D	1.7	24	3	26	SB	187200
6	900	B	1.9	12	3	26	SB	93600
7	1100	D	1.7	24	3	26	SB	228800
8	1100	B	1.9	12	3	26	SB	114400

SB = SLAB

ROOF TYPE: NONVENTED ATTIC

* REFER TO TABLE

GEOGRAPHIC REGION: WEST

<u>BLDG TYPE</u>	<u>FLOOR AREA PER UNIT (FT²)</u>	<u>BASIC* LAYOUT TYPE</u>	<u>LAYOUT ASPECT RATIO</u>	<u>NO. OF UNITS</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>TOTAL VOLUME (FT³)</u>
1	910	B	1.9	16	2	17	SB	123760
2	910	D	1.7	16	2	17	SB	123760
3	1110	B	1.9	16	2	17	SB	150960
4	1110	D	1.7	16	2	17	SB	150960

SB = SLAB

ROOF TYPE: NONVENTED ATTIC

* REFER TO TABLE

Table 2-14
Reference Residential Building Selection

GEOGRAPHIC REGION: ALL

SINGLE FAMILY: ATTACHED

<u>BLDG TYPE</u>	<u>FLOOR AREA PER UNIT (FT²)</u>	<u>UNIT ASPECT RATIO</u>	<u>NO. OF UNITS</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>TOTAL VOLUME (FT³)</u>
1	1300	1.8	4	2	17	S	44200
2	1300	1.8	8	2	17	S	88400
3	1500	1.8	4	2	17	S	51000
4	1500	1.8	8	2	17	S	102000

MULTI FAMILY: HIGH-RISE

<u>BLDG TYPE</u>	<u>AVERAGE FLOOR AREA PER UNIT (FT²)</u>	<u>BUILDING ASPECT RATIO</u>	<u>NO. OF UNITS</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>TOTAL VOLUME (FT³)</u>
1	1076	2.29	13	4	40	CS	173160

MOTEL

<u>BLDG TYPE</u>	<u>AVERAGE FLOOR AREA PER UNIT (FT²)</u>	<u>BUILDING ASPECT RATIO</u>	<u>NO. OF UNITS</u>	<u>NO. OF STORIES</u>	<u>BUILDING HEIGHT (FT)</u>	<u>FOUNDATION</u>	<u>TOTAL VOLUME (FT³)</u>
1	422	3.33	32	2	10	S	135000

CS = CRAWL SPACE, S = SLAB

ROOF TYPE: NONVENTED ATTIC

Table 2-15
Building Definition Summary: Reference Buildings

BUILDING CATEGORY	DEGREE-DAY (°F) REGION				TOTAL
	1800 (W,S)	3600 (W,S)	5400 (W,NC,NE)	7200 (W,NC,NE)	
<u>RESIDENTIAL</u>					
SINGLE FAMILY DETACHED	21	21	40	40	122
SINGLE FAMILY ATTACHED	4	4	4	4	16
MULTI-FAMILY (3 STORIES)	12	12	26	26	76
MULTI-FAMILY (3 STORIES)	1	1	1	1	4
MOTEL	1	1	1	1	<u>4</u>
					222
<u>NON-RESIDENTIAL</u>					
OFFICE					
3 STORY	1	1	1	1	4
10 STORY	1	1	1	1	4
RETAIL STORE	1	1	1	1	4
SHOPPING CENTER	1	1	1	1	4
SCHOOL					
ELEMENTARY	1	1	1	1	4
HIGH SCHOOL	1	1	1	1	4
HOSPITAL	1	1	1	1	4
LIGHT INDUSTRIAL					<u>4</u>
			TOTAL	254	32

DEFINITION OF REFERENCE BUILDING THERMAL PARAMETERS

The primary goal of the simulation study is to determine the differential electric demand between conventional and solar augmented building HVAC systems. Therefore, the building heating and cooling loads were computed independently for each weather environment and set of building occupant activity schedules using the building thermal model appropriate for the thermal response rate of the type of construction. The computed building thermal loads were then used as time-varying input functions to both conventional system and solar augmented system simulations for demand determination. The building thermal loads are the rates of energy addition (heating) or removal (cooling) required to maintain the desired building thermal environment. To meet these loads the building HVAC system requires an amount of input energy. The rate of input energy, or building energy demands, depends upon the efficiency and power requirements of the primary HVAC equipment. A solar augmented HVAC system allows a fraction of the building heating load to be supplied directly from a solar heat storage unit or a portion of the input energy demand for an absorption refrigeration machine to be met by stored solar heat. Thus, the building thermal loads are independent of the primary HVAC system which meets them. A single building thermal load time history can then be used to drive the simulations for any of the HVAC systems. An additional motivation for separate calculation of the building loads is that hour-by-hour computation is considered adequate for engineering accuracy, while shorter time steps are usually required for SHAC simulations.

The outline of the basic information flows in the determination of the building thermal loads are shown in Figure 3-1 and 3-2. For residential buildings, which have light-weight construction, the thermal response may be approximated by a steady-state heat balance. The residential thermal model may be simply represented as the sum of the load components determined by the instantaneous outside temperature conditions and the scheduled heat gains (or losses). However, nonresidential buildings, with heavier construction, must allow for thermal storage effects, thus

necessitating a dynamic heat balance for thermal load determination. The size and shape of nonresidential buildings also require the partition of the building into thermal zones: (1) perimeter zones, which respond to the changes of outside weather conditions and insolation; and (2) interior zones, which require a year-round consideration for cooling. The load components of each zone are met by an HVAC secondary distribution system which requires additional load components that must be considered in the determination of the building thermal loads, since this is the point of interface of the primary system or the solar augmented system.

3.1 OVERALL BUILDING INSULATION REQUIREMENTS (ASHRAE 90-75)

To determine the range of glazing area allowable using the overall thermal wall transmittance values stated in ASHRAE 90-75, several types of wall construction were analyzed. An example of the insulation requirements is shown in Table 3-1. The use of these data is shown in Figure 3-3, which shows the range of maximum allowable glass-to-wall area ratio for residential buildings using single- and double-pane glazing. As can be noted from Figure 3-3, single-pane glass is allowable for an average house with 14-15% glass for locations with an annual heating degree-day value of less than 5500-5700 ($^{\circ}\text{F HDD}$). In the building load simulations it was assumed that there was 10% unshaded glass in winter and 5% unshaded in summer.

Examples of additional data concerning the application of ASHRAE 90-75 requirements to roof/ceiling and floor construction are represented in Table 3-2. These data were prepared to demonstrate the general applicability of ASHRAE 90-75 requirements. It should be noted that the insulation thickness required to meet the Standard is not inordinate.

3.2 TIME-DEPENDENT USAGE PROFILES

Daily normalized schedules of occupancy, electric baseload (heat gain from lights, appliances and equipment), and domestic water consumption were prepared for each building occupancy type using the format shown in Figure 3-4 for residential

buildings. The schedules were prepared using the normalized format of Reference 37. The maximum values of the various profile ordinate parameters, as shown in Table 3-3, were selected after review of the pertinent literature (Ref. 7, 10, 17-19, 32-38). Considerable variation of the values exist within the literature, reflecting a lack of accurate data. The most important profile, from an HVAC standpoint, is the electric baseload, which is often the dominant heat gain in a nonresidential building. The values chosen are applications of Reference 17 which are representative of energy regulations at the state level. A value of 0.5 watt/sq ft was added to the general lighting intensity levels to allow for equipment heat gain (except for light industrial which was estimated at 4 watt/sq ft).

3.3 RESIDENTIAL BUILDING PARAMETERS

The TRNSYS computer program discussed in Section 3.4 was used as the simulation tool for determining residential building loads. The building parameters defined were those required as inputs to this simulation.

Single Family: Detached. Values for each of the following input parameters are tabulated in Table 3-4 for each of the single family (detached) buildings defined in Section 2.0.

UA:	Thermal Conductance
Q_{BASE} :	Basement Heat Loss
$Q_{Occup,s}$:	Maximum Occupant Sensible Load
$Q_{Occup,l}$:	Maximum Occupant Latent Load
Q_{Elect} :	Maximum Electric Baseload

The volume, V_B , needed as an input parameter for the infiltration modules, is also tabulated. The variance of the parameter, UA, is shown in Figure 3-5 as a function of floor area for a 5400 degree-day region and the variance of the parameter, Q_{BASE} , is plotted in Figure 3-6 for several degree-day regions. As can be noted from Figure 3-5, the effect of foundation type and number of stories on building

envelope thermal conductance within each geographic region is a second order variance about a mean trend of linear dependence on floor area except for crawl space foundations, (which deviate within the 1800 degree-day region due to the ASHRAE 90-75 minimum insulation requirements). Thus, the functional representation shown in Figure 3-5 may be used to select four reference single family (detached) residences, of 1200, 1600, 2000, and 2400 sq ft, which are representative of any desired annual heating value by simple linear interpolation. The deviation of crawl space foundations in the 1800 degree-day region and the constant basement heat loss term may be incorporated into the four selected reference homes by use of the appropriate weighting factors given in Table 2-5.

Multi-Family: Low-Rise. Values of the input parameters are tabulated in Table 3-5 for each multi-family (low-rise) building defined in Section 2.0. The variance of UA is shown in Figure 3-7 for a 5400 degree-day area and again a mean linear dependence on floor area is evident. Thus, three reference buildings of 12,000; 18,000; and 24,000 sq ft may be selected as representative of each annual heating degree-day region.

Multi-Family: High-Rise; Single Family: Attached; and Motel. The tabulated parameter values for multi-family (high-rise), single family (attached), and motel occupancies are given in Table 3-6. The values of UA for each of the defined buildings within these occupancies are included in Figure 3-4 and 3-6 for comparison to multi-family (low-rise) and single family (detached) occupancy definition.

3.4 TRNSYS LOAD SIMULATIONS

The TRNSYS computer program developed by the University of Wisconsin was designed to simulate the dynamic performance of solar heating and cooling systems. It is in extensive use as a research tool across the country. TRNSYS is modularized by subsystem components which can be wired together to produce any likely solar space heating, hot water heating or absorption cooling system configuration. New component models can be readily accommodated by the code design.

While widely accepted as a standard for simulating SHAC systems, TRNSYS's capabilities for generating thermal loads on a structure is somewhat limited. Since

systems analyses of the type conducted for this study cannot cost effectively use a complex loads program, it was expedient to develop loads models for TRNSYS consistent with the solar component simulation models. The models required for residential building load simulations (existing and added) are described below.

As shown in Figure 3-1 the basic components of the loads calculations are:

- a. Heat transferred through the shell of the building
- b. Infiltration through windows and doors
- c. The heat gain due to solar radiation through the windows
- d. Heat losses or gains through basement walls and floors
- e. Latent heat gains due to moisture in the infiltrating air and from occupants
- f. Internal loads consisting of sensible heat given off by occupants, electric lights, and electric appliances

In addition, the domestic hot water loads are required.

Appropriate modules are available in TRNSYS for modeling shell losses (or gains), basement losses, and internal loads, using the input parameters defined in Section 3.3, as follows:

Wall and Roof Loads. The heat transfer through the wall was computed as the product of a thermal loss coefficient, U , the wall area of the structure and the temperature difference across the wall. The outside wall temperature was increased slightly from the ambient to account for heat buildup on the wall due to insolation on the wall. The temperature of the heated space was taken as 72°F. Roof loads were computed similarly.

Occupant Loads. The heat generated by the occupants of the residence was computed to be a maximum of 250 Btu's per person with the number of people based on a diurnal profile. The maximum number of people was taken as four in a single family residence and two per unit for multi-family buildings.

Base Load. Using a diurnal profile, which utilized a peak thermal load of two watts/sq ft, the base heating load due to electric appliances and lighting was computed as the product of the area, diurnal profile (see Figure 3-4), and peak load.

Basement Loads. For structures with heated basements a constant heat loss to the environment was calculated for each building, whenever the ambient temperature exceeds the room set-point temperature. As discussed in Section 2.1, the losses for unheated basements were one-half the loss for floors over unheated spaces.

Hot Water Loads. Assuming a set-point temperature of 140°F and the diurnal use profile shown in Figure 3-4, the hot water load was computed as the product of the maximum mass demand, the specific heat of water, and the temperature differential between set-point and tank temperature.

The modifications of the TRNSYS code discussed below were necessary in order to determine a realistic differential demand between the conventional and solar-equipped buildings to be used in the study simulations.

The basic modifications considered are as follows:

- Window Solar Heat Gain
- Residential Infiltration
- Latent Heat Gain

Window Solar Heat Gain. The contribution of solar radiation heat transfer through windows is, at some time during the daylight hours, the dominant component of a building's heating or cooling load. The current degree-hour heating or cooling modules of TRNSYS do not consider solar heat gain. Although there is a capability for allowing input of window area and shading fraction for admittance of solar gains in other modules, the overall complexity of these modules and the resulting increases in computer time were unwarranted in this study. Thus, the basic residential load model required additional coding to allow the incorporation of this load component into the residential simulations.

Several studies (e.g., Ref. 30) have allowed for solar heat gain by inclusion of a single, equivalent, southfacing window in models based upon the same level of approximation (i.e., $UA = \text{constant}$) as the degree-hour heating or cooling module. The assumption of an equivalent south-facing window is reasonable if only the

average daily energy requirement of the building model is being sought. However, as shown in Table 3-7, a comparison of the hourly ratio of solar heat gain through a south window and the average solar heat gain of all orientations indicates that the use of an equivalent south-facing window yields a different time sequence of the solar contribution to the total heating (negative contribution) or cooling (positive contribution) load. The model adopted determined the instantaneous average of solar insolation on four vertical surfaces with south, east, west, and north orientations computed with the TRNSYS solar radiation processors. This average was then input to a modified degree-hour module for residential loads modeling. The model required in the degree-hour modules is

$$\text{Total Solar Heat Gain} = A_w \times \text{SHGF}$$

where

A_w = Window Area

SHGF = Solar Heat Gain Factor
= $SC \times FR \times I$

SC = Shading Coefficient = F/FR

F = Ratio of Solar Heat Gain to Incident Solar Radiation

FR = 0.87 = F for Reference Glazing

The additional parameters required are window area, the ASHRAE reference solar heat gain coefficient and the ASHRAE shading coefficient. The last two quantities are given in Reference 22. For this study it was assumed that 10% of the wall area was unshaded glass in the winter and 5% was unshaded glass in the summer.

Residential Infiltration Model. Uncontrolled entry of outside air into the conditioned space can contribute significantly to the space conditioning load. It is known that wind velocity, inside-outside temperature differential, and door openings all affect the magnitude of this infiltration (Ref. 23). Due to common weather and similar daily home-usage patterns within a particular service area, this component of the load may significantly affect a utility's demand curve, as well as total energy consumption.

Infiltration can be attributed to the following component sources:

- Window Leakage
- Door Leakage
- Wall Leakage
- Door Opening Effects
- Other Factors (exhaust fans, unidentified leaks)

The most satisfactory model of leakage around the window sashes and around the doors suggests that it varies with "crack length," defined as the total length of unsealed joints of window sash and door jamb. Also, it is known to vary with wind speed and inside-outside temperature difference.

A limited amount of test data is available, such as that given by Coblentz and Achenback (Ref. 23). These data can be generalized for varying weather parameters, as proposed by those authors, using the equation

$$I = (I_1/I_R) (0.15 + 0.013 v_w + 0.005 \Delta T) \quad (a)$$

where

v_w = Wind Velocity

T = Absolute value of inside-outside temperature difference

I_1 = Air changes per hour for building in question at reference weather conditions ($v_w = 10$ mph, $\Delta T = 40^\circ\text{F}$)

I_R = Air changes per hour for reference building at reference conditions, i.e., the value of $(0.15 + 0.013 v_w + 0.005 \Delta T)$ at reference conditions

I = Air changes per hour for building in question at designed conditions of v_w and ΔT

The reference buildings upon which the coefficients in equation (a) are based were tested at the University of Illinois (Ref. 24).

In an effort to correlate their results, Coblentz and Achenbach "adjusted" infiltration for each building to a wind speed of 10 mph and a temperature

difference of 40°F by solving equation (a) for I_1 . These adjusted infiltration rates correlate well with the parameter L_c/V_B as shown in Figure 3-20, where L_c is the total building crack length including doors and V_B is the building volume. The dashed line in Figure 3-8 represents application of ASHRAE Standard 90-75 building air leakage requirements adjusted to standard conditions by use of equation (a). It is evident that the standard does not represent a large reduction.

In reviewing more recent literature (Ref. 22, 25-29) it was found that wide variations between laboratory and field data exist, most likely due to variations in construction. The spread of the data due to differences in fit and type of window, as reflected in Figure 3-8, exceeds the effects of wind. The work of Hunt (Ref. 26) suggests that the temperature coefficient in equation (a) should be 0.0066 and the constant term 0.072. However, since the scatter in Hunt's data is about 0.07 air changes/hr, the coefficients in equation (a) are adequate.

Reference 22 presents a table of infiltration through walls of various construction as a function of overall pressure difference. For a building with $L_c/V_B = 0.024 \text{ ft/ft}^3$ and plastered frame walls, the ratio of wall infiltration to that due to doors and windows is about 0.02 and is therefore negligible.

The leakage through an open door can be estimated by the relationship (Ref. 22)

$$\dot{V} = 0.3 A_D v_w$$

where

$$A_D = \text{Door Area}$$

$$\dot{V} = \text{Air Volume Rate of Change}$$

If Δt represents the average open time in seconds for an entrance or exit and N the number of persons passing through in an hour, the infiltration can be expressed in terms of air changes per hours as

$$(\dot{V}/V_B)_{\text{door}} = (88/60) (0.3) \Delta t N A_D v_w / V_B \quad (b)$$

Here A_D represents the area of a single door and V_B is the building volume.

The parameters Δt and N can have a very strong effect and are difficult to assess. The time to open, pass through and close the door will likely vary from 2 to 15 seconds. N may be as large as 20 for households with children during the afternoon. However, considering a large number of houses with random door orientation and some diversity in the times of peak activity, a more typical number would be perhaps five openings per hour in the late afternoon. Also, there is probably a correlation between N and wind speed; high wind conditions tend to discourage outdoor activity and hence in/out traffic.

Most tests on buildings have found a certain minimum leakage seemingly unaccounted for by crack length. Kitchen and bathroom exhausts, unidentified leaks and porous areas probably explain this observation. It is best represented for purposes of this study by the constant term in equation (a).

Combining equation (a) and equation (b) gives the following expression for total infiltration model in terms of air changes per hour

$$I = (a_1 \Delta t A_D / V_B) N v_w + I_1 (a_2 + a_3 v_w + a_4 \Delta T) \quad (c)$$

where

I = Building Air Changes per hour

Δt = Average Door-Open Time, secs

A_D = Area of a Single Door, ft^2 or m^2

V_B = Building Volume, ft^3 or m^3

N = Door Openings per hour

v_w = Wind Velocity, mph or mps

I_1 = Air changes for the building when
 $v_w = 10 \text{ mph}$ and $\Delta T = 40^\circ\text{F}$

ΔT = Absolute value of inside-outside temperature difference,
 $^\circ\text{F}$ or $^\circ\text{C}$

The coefficients for this equation are $a_1 = 0.30$; $a_2 = 0.31$; $a_3 = 0.06$; and $a_4 = 0.018$ when metric units are used; and 0.44; 0.31; 0.27; and 0.01, respectively, when English units are used.

Note that I_1 can be estimated from Figure 3-8 for a given value of L_C/V_B . A recommended value is $I_1 = 0.5$, corresponding to $L_C/V_B = 0.024/\text{ft}^2$. Equation (c) is plotted for typical residential parameters in Figure 3-9.

From Figure 3-9 it is evident that the first term of equation (c) dominates. During a typical day N might vary from zero to five, doubling the infiltration at typical wind and temperature conditions. The door opening schedule used is shown in Figure 3-10.

Latent Cooling Load Algorithm. Dehumidification of the outside air component, introduced by infiltration or minimum ventilation, is an important HVAC design consideration for both residential and nonresidential air conditioning systems. The latent heat gain caused by the addition of outside air can be a significant portion of the time-varying cooling load. Figure 3-11 shows that in some regions of the U.S. the latent heat gain component of the infiltration can be equal to the sensible heat gain component for summer wet- and dry-bulb temperature conditions. The current TRNSYS modules do not consider latent heat gain. The module implemented is described below.

The psychrometric calculations required for determination of the enthalpy of moist air are complex. The ASHRAE recommended algorithms (Ref. 31) were implemented into TRNSYS for these calculations. When the ambient temperature is greater than 78°F , there is a check made to compare the ambient humidity to that in the structure. If there is more water vapor in the outside air, a cooling load is calculated based on the air changes through the building. The latent load is energy required to "dry" the air to a more comfortable level and increases the work of any cooling device.

In determining the net cooling and/or heating loads, two situations may be encountered. In the first case the ambient temperature is greater than the set-point room temperature, thus indicating a cooling situation. The only heating then required is the hot water load, and the cooling load is set equal to the sum of the wall, infiltration, fenestration, occupant, base and latent loads. In the second case, the ambient temperature is less than the room set point. In this case the wall, infiltration, window, occupant and baseloads are summed. If the result is positive, then the cooling load is set equal to this value and the heating load is set equal to the hot water load. If the algebraic sum of these loads is negative, then the hot water load is combined with the sum to give the total heating load, and the cooling load set to zero.

3.5 NONRESIDENTIAL BUILDING MODELS

The simulation of the thermal response of buildings with heavier construction requires consideration of thermal storage or capacitance effects. Furthermore, nonresidential space conditioning energy requirements are larger than predicted by simply meeting the space net sensible load. The reasons for this are as follows:

- a. A phenomena known as load cancellation occurs if an insufficient number of zones are modeled. Typically, the building has nonuniform heating and cooling loads due to either solar load shifting and/or occupancy patterns. If the zone models are too simplified, the fact that some portions of the zone may be requiring cooling at that instant and others requiring heating may be overlooked. A well-designed air distribution system will meet these local heating and cooling loads, thus demanding both heating and cooling at that point of time which is not reflected in the net sensible figure for the entire zone.
- b. Additional energy is also required for control purposes. For example, some systems achieve the thermostat setting in a zone by either reheating over-cooled supply air or mixing hot and cold air streams. Either of these control methods adds energy requirements at the coils, over and above that which would be predicted by the net space sensible load calculation.
- c. Another component of load reflected at the coils, but not present in the net space sensible load, is the energy required to heat or cool the outside air provided for ventilation. Under some conditions the net energy requirement may be reduced by the outside air (economizer cycle) directly.

- d. The air distribution system itself, (i.e., the supply and return fans) adds energy to the air stream which must be removed by the cooling coils if cooling is required.
- e. Latent loads such as those introduced by occupancy, infiltration and the introduction of ventilation air, represent loads on the coils.

To effectively incorporate all of these considerations into the nonresidential thermal loads simulations, the AXCESS code was utilized.

The AXCESS Energy Analysis Computer Program developed by the Edison Electric Institute, New York, provides estimates of the comparative energy uses of alternate methods of meeting the energy requirements of buildings or processes. It is particularly applicable to multi-zone, thick wall nonresidential structures.

On a block building basis, building data are input such as areas for total roof, net wall, total glass and gross floor. Outdoor design conditions are input for the building while indoor design conditions may be input zone by zone. Baseloads are input in terms of maximum electrical connected load or peak Btu, together with a profile which describes the percentage use. Typical wall and roof construction weights are selected by the user so that the proper ASHRAE response factor for the input design loads may be utilized in the calculation procedure.

Most of the HVAC systems in popular use today are simulated by AXCESS. These HVAC simulations are broken down by terminal and primary system types.

The output capabilities of AXCESS were modified by S&H Information Systems, New York, to provide hourly demands on the heating and cooling costs that the SHACOB systems will attempt to meet.

3.6 HVAC SYSTEM CONSIDERATIONS

A schematic of a state-of-the-art HVAC system design is shown in Figure 3-12. The block loads of the perimeter and interior zones are met by a secondary HVAC system. Due to zone diversity, introduction of outside air, and temperature control

(i.e., chilled air requiring reheat) requirements, the secondary system determines the equivalent coil load that the primary (or solar augmented) HVAC system must meet. The HVAC systems selected as being representative of future construction are shown in Table 3-8 along with the minimum outside air required. The general characteristics of the self-contained air conditioning units (single-zone or multi-zone nonmixing) and variable air column distribution systems are given in Figures 3-13 and 3-14.

As an energy conservation measure, most new systems employ the economizer cycle in which the quantity of outside air introduced into the space is varied according to some strategy seeking to minimize energy consumption. Several different strategies are employed by various equipment manufacturers, but the method commonly used is the enthalpy control strategy. The enthalpy of the outside air is compared to the enthalpy of the room air and whenever it is lower, energy can be saved by using outdoor air for cooling purposes. If on the other hand the outside air enthalpy is greater than the room air enthalpy, the outside air is set to the minimum amount required for ventilation purposes. Further, if the outside air temperature is below some selected minimum value, the outside air amount is scheduled downward even though the outside air enthalpy may be less than the room enthalpy. This strategy is intended to minimize heating requirements for outside air under conditions of simultaneous heating and cooling requirements in the zone. It is based on the idea that the cooling load drops with outside air dry-bulb temperature, thus reducing the amount of outside air required for 100% free cooling. This is an approximate operational procedure intended to simulate enthalpy controllers without introducing the need for iterative calculation in the system model.

The calculation of heating and cooling loads, in general, involves the following considerations:

Cooling. The fundamental idea in calculating the load at the cooling coil in an air handling system is to determine the entering air temperature, the discharge air temperature, and the air flow rate at the cooling coil. From these quantities the heat required to be removed by the chilled water or refrigerant fluid in the coil is

easily calculated. The entering air temperature is determined by an energy balance for the mixing process between outside and return air. The return air temperature is assumed to be given since it can be calculated from the room conditions, the head added by the return air fan, and the heat gain through the return air duct. The fraction of outside air to be mixed with this return air is determined by the economizer described above. The calculation of coil discharge air temperature depends upon the type of system being simulated. If the system is Variable Air Volume or a reheat type, the coil discharge air temperature is assumed to be a constant value. On the other hand if the system is the constant volume such as a self-contained air conditioning unit, coil discharge air temperature is calculated as to exactly meeting the room cooling load with the prescribed volumetric flow. The determination of volumetric flow is also depending upon the kind of system being simulated. In the case of reheat systems or self-contained air conditioning unit, the volume is set at some designed value. In the case of variable volume systems, a volumetric rate is calculated to exactly meet the space load with the prescribed coil discharge air temperature.

The above logic may be used to calculate the sensible load on the cooling coil. To this must be added the latent load introduced via the outside air and the occupancy in the space. These latent components are simply calculated and added to the coil sensible load to give the coil total load.

Reheat Coils. In reheat-type systems with either constant or variable air volume, the cooling effect provided by the selected volume and the selected coil discharge air temperature may exceed the sensible cooling requirements of the space. Under this condition the difference between the calculated cooling coil load and the space sensible load may be calculated and assigned to the load at the reheat coils. In pure reheat systems there will be some amount of reheat load for all cooling loads less than the maximum designed load. Variable volume systems with reheat coils will experience the need for reheat energy whenever the cooling load falls below the point that is matched by the prescribed minimum allowable volume for the space. Under such conditions, the system volume is set at the minimum, the cooling coil load calculated, and the difference between the cooling coil load and the zone cooling demand is computed and assigned to reheat load.

Heating Coils. Whereas reheating compensates for overcooling in an attempt to meet the cooling load, the load at the heating coils represents energy added to meet an actual space heating demand at some point in the zone. The energy which must be added at the heating coils is simply the space heating demand minus the heat equivalent of the fan work and plus or minus the effect of the outside air. This heating coil energy is calculated as the sum of the space heating demand plus a term which is proportional to the volumetric flow and the difference between room temperature and mixed air temperature.

3.7 NONRESIDENTIAL BUILDING PARAMETERS

The peak loads for each of the nonresidential buildings defined were computed using the design conditions listed in Table 3-9. Summary results, listing all necessary data required to accomplish a nonresidential simulation, are listed in Tables 3-10 and 3-11. The particular parameters defined were those required as inputs to the AXCESS simulation code. The peak heating and cooling loads and maximum supply air rate as presented in Table 3-12 are normalized values (on a sq ft basis) to allow comparison with normal HVAC design practices. As can be noted from the Tables, the cooling loads range from 220 to 472 sq ft/ton of refrigeration, while the peak heating loads range from 6.1 to 23.4 Btuh/sq ft. The minimum outside air ratio ranges from 3.4 to 7.7% for all buildings except hospitals, which were assumed to have 25% outside ventilation air. All of the computed loads are generally within the range of values commonly used as design rules of thumb for HVAC systems in the various occupancies.

Unlike residential heating and cooling equipment which operates off or on at full load (or at most two levels of operation), the primary HVAC equipment, such as boilers and chillers, have built-in controls that allow part-load performance.

The self-contained (roof top) air conditioning units were assumed to be direct expansion, air cooled, refrigeration units operating at full load with the temperature dependence shown in Figure 3-15.

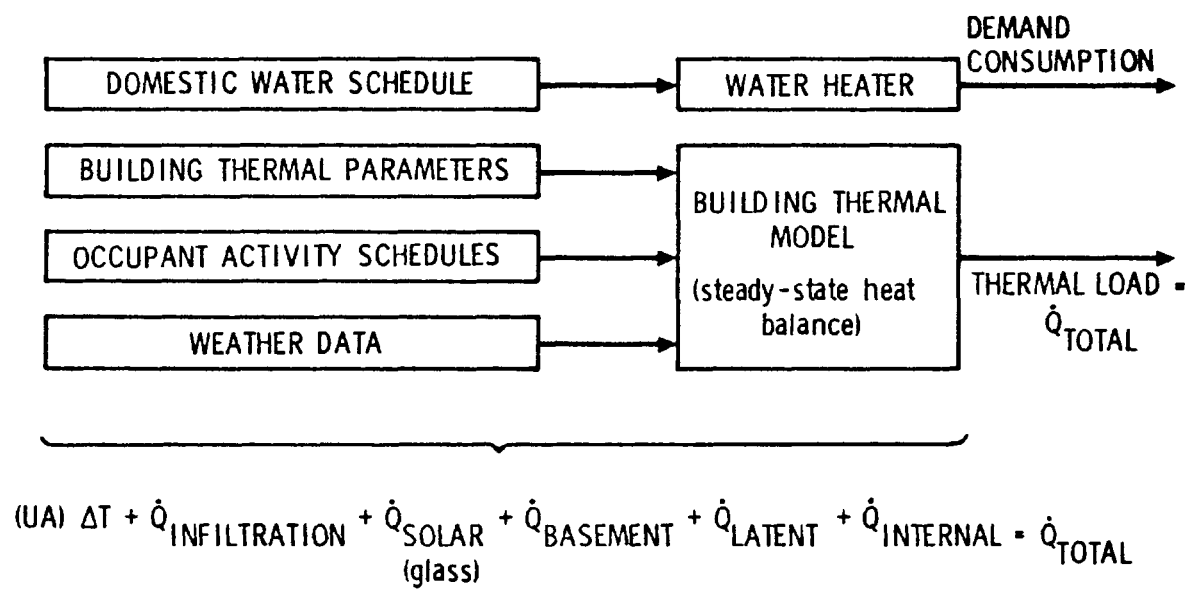


Figure 3-1
Residential Thermal Loads

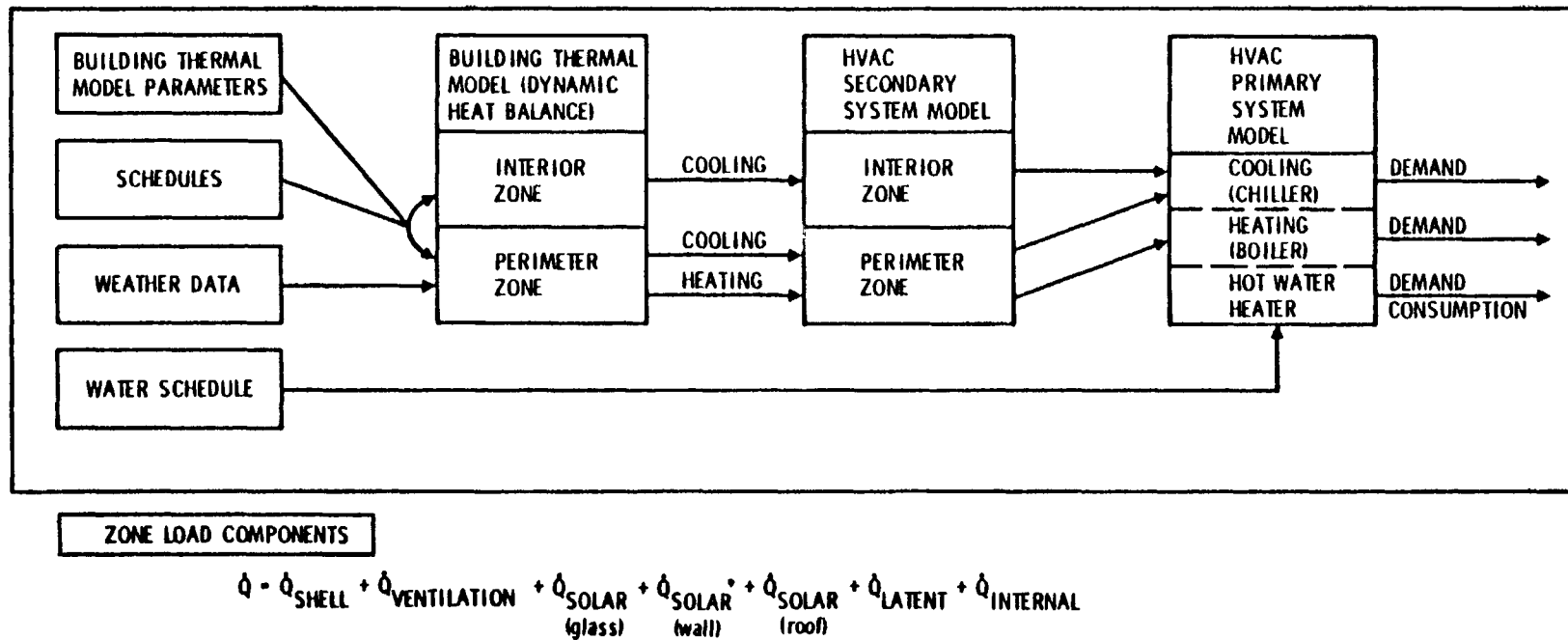


Figure 3-2
Non-Residential Thermal Loads

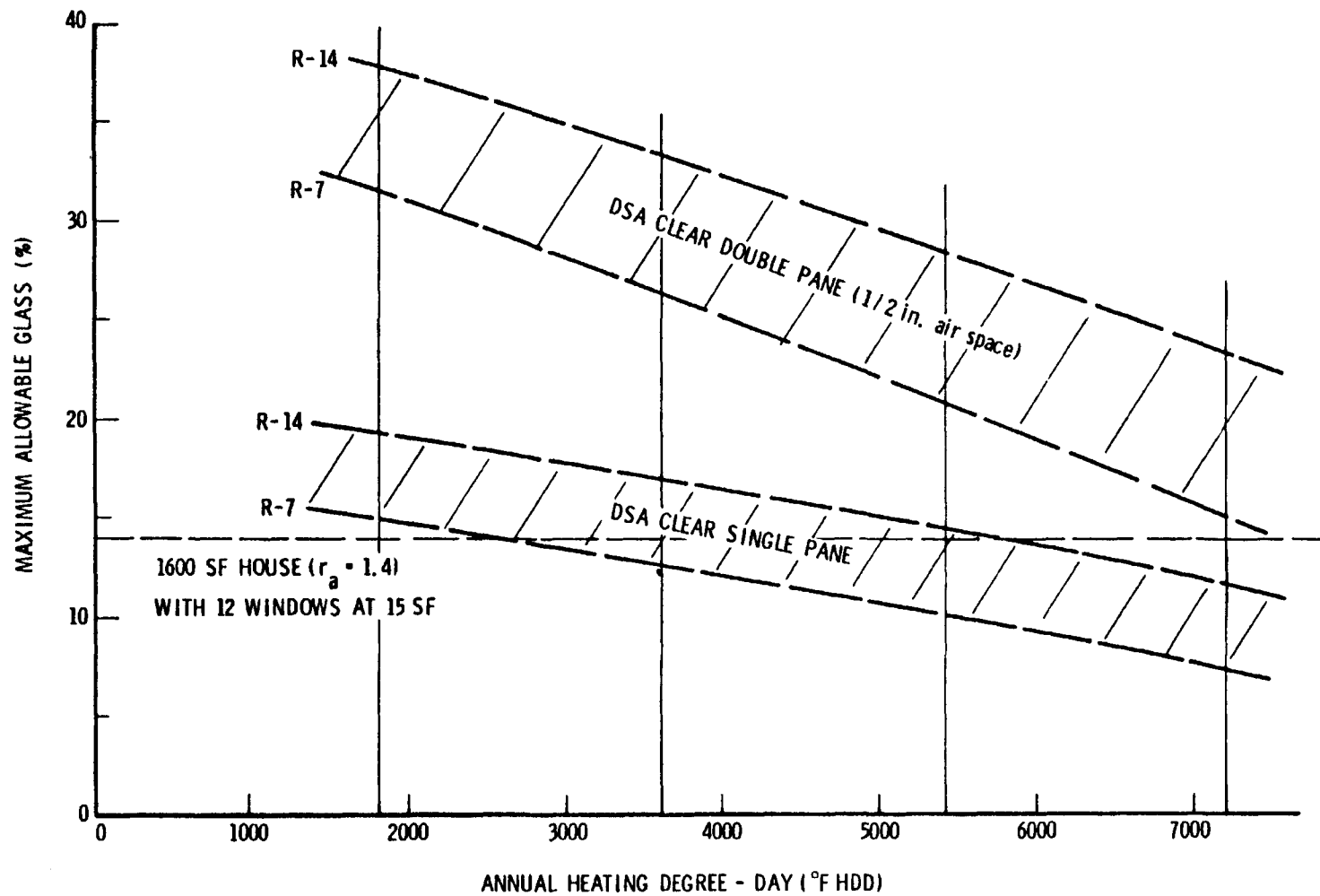


Figure 3-3
ASHRAE 90-75 Residential Buildings (Type A-1)
Maximum Allowable Glass for Opaque Wall Insulation, R

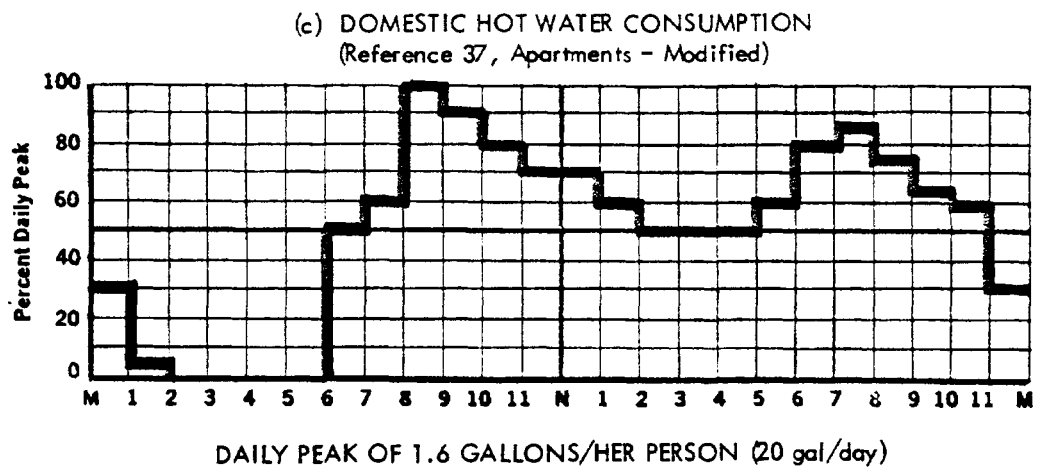
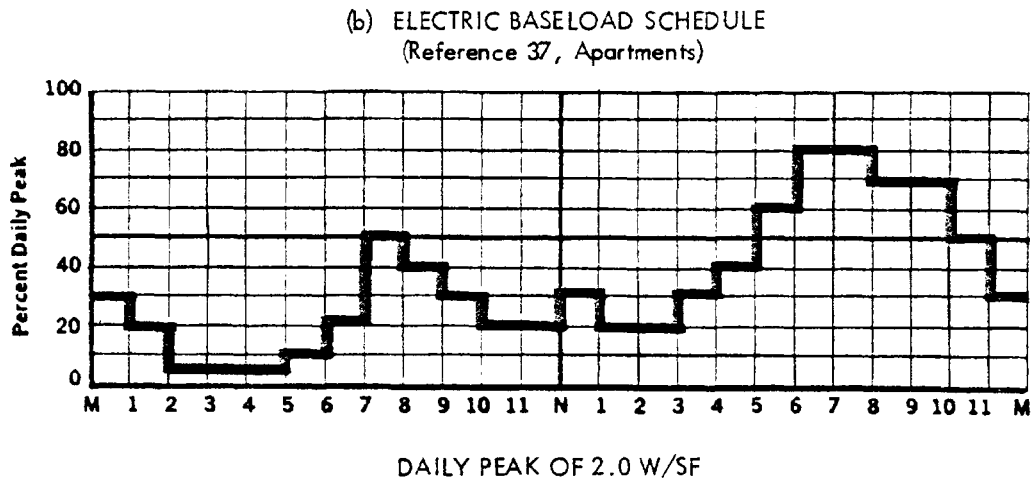
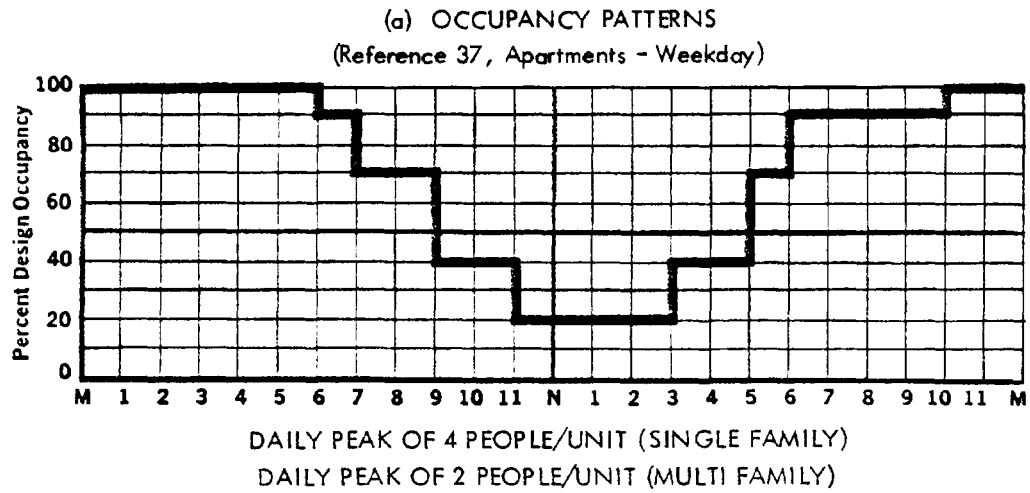


Figure 3-4
Time-Dependent Usage Profiles

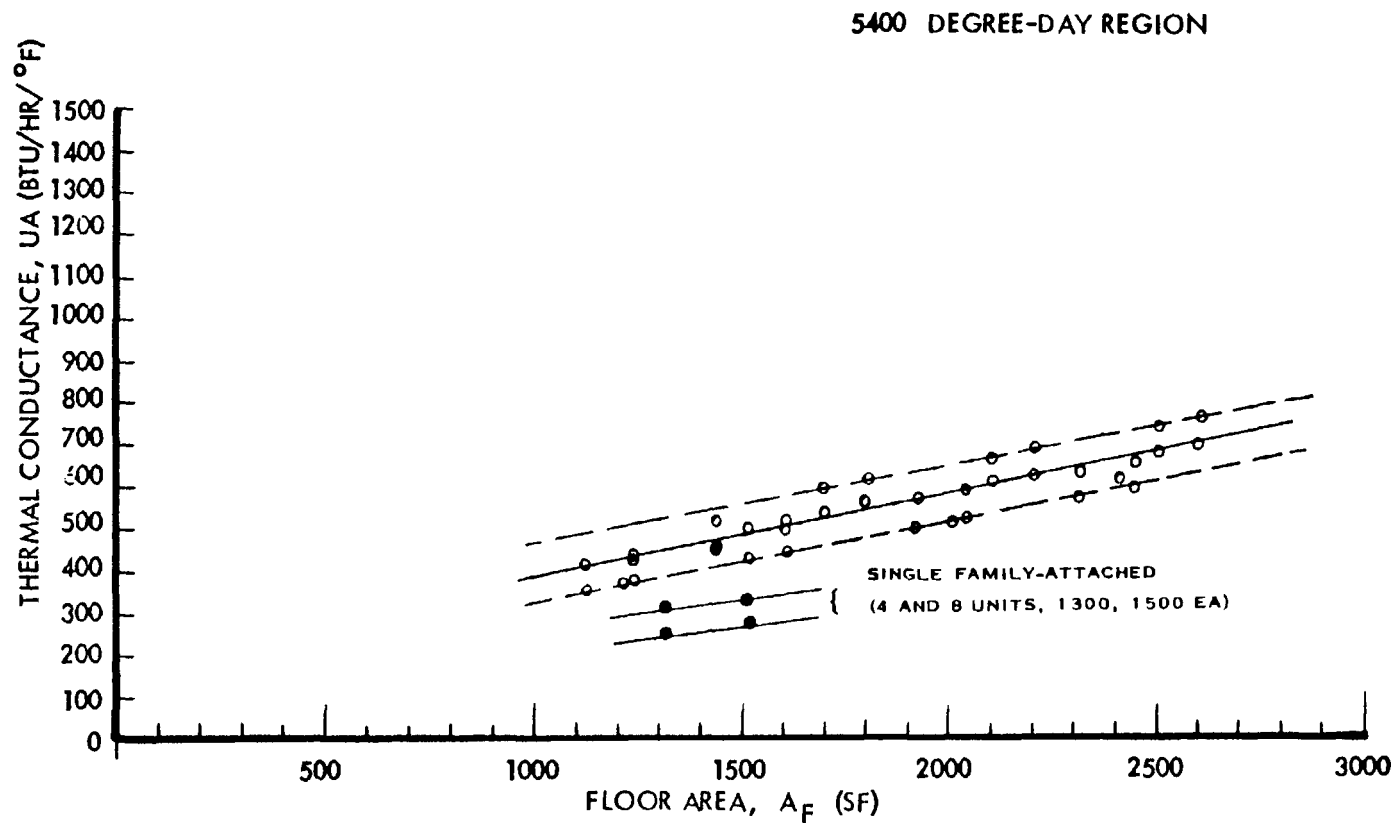


Figure 3-5
Single Family Residence
Variance of Thermal Conductance

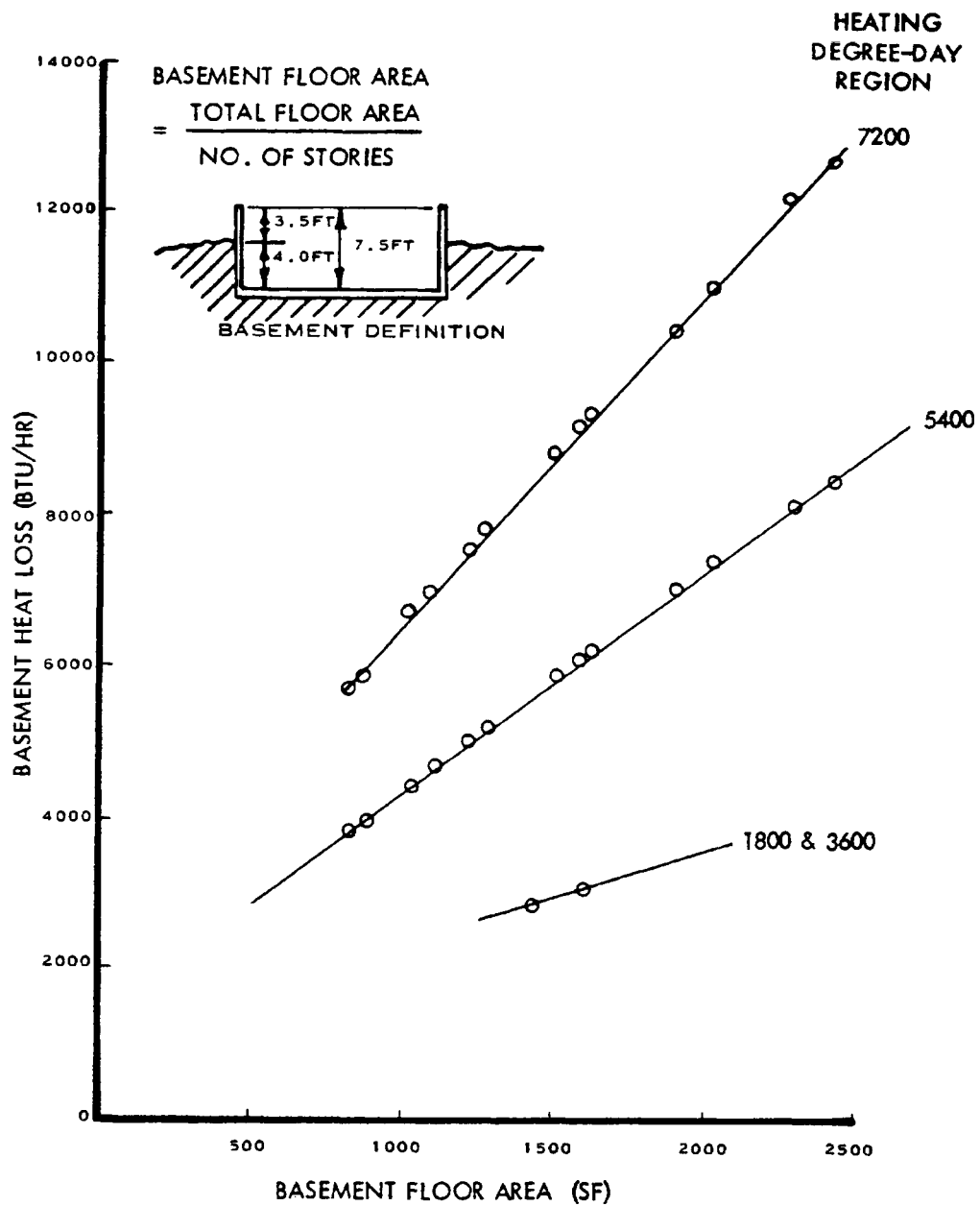


Figure 3-6
Single Family Residence
Variance of Heated Basement Loss

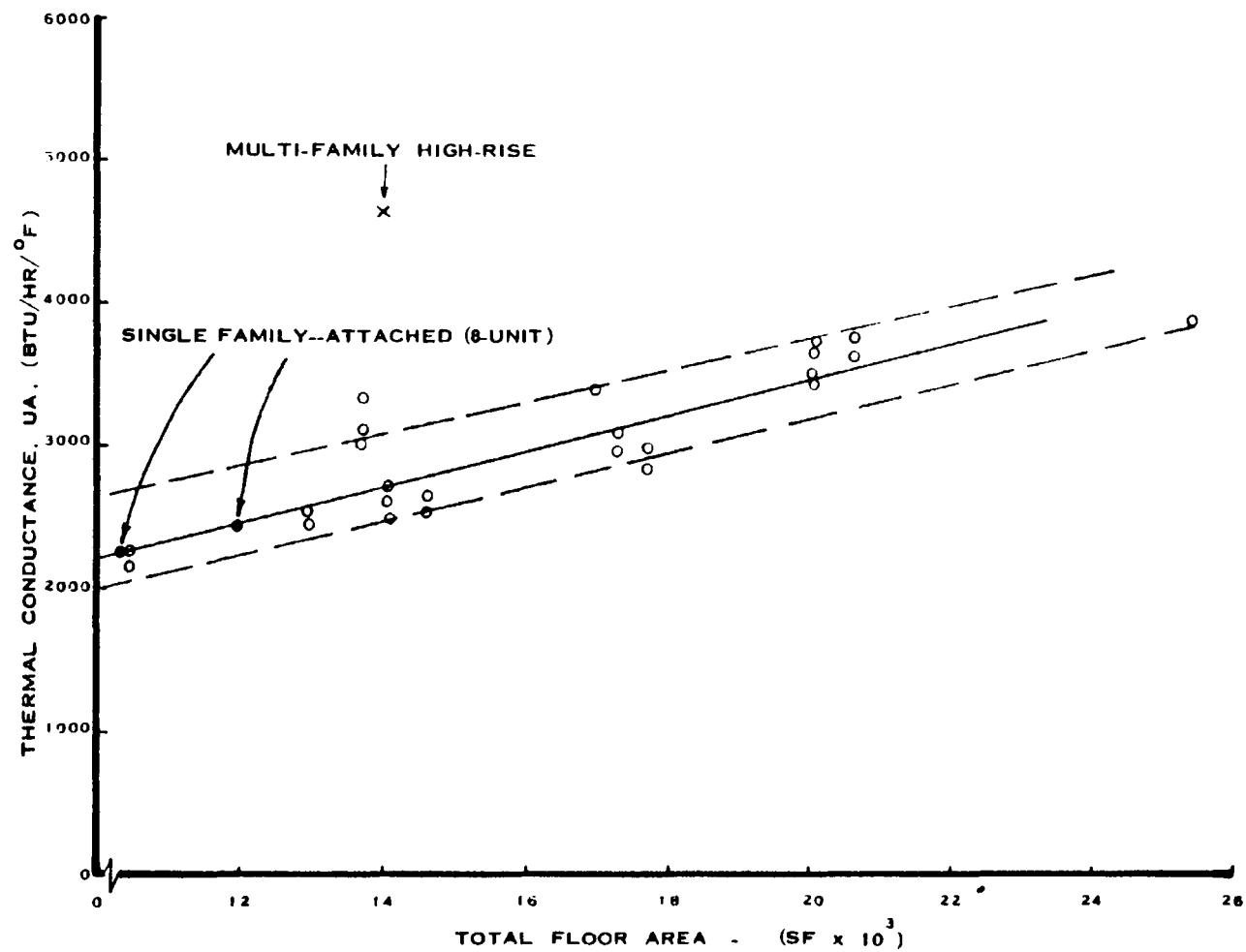
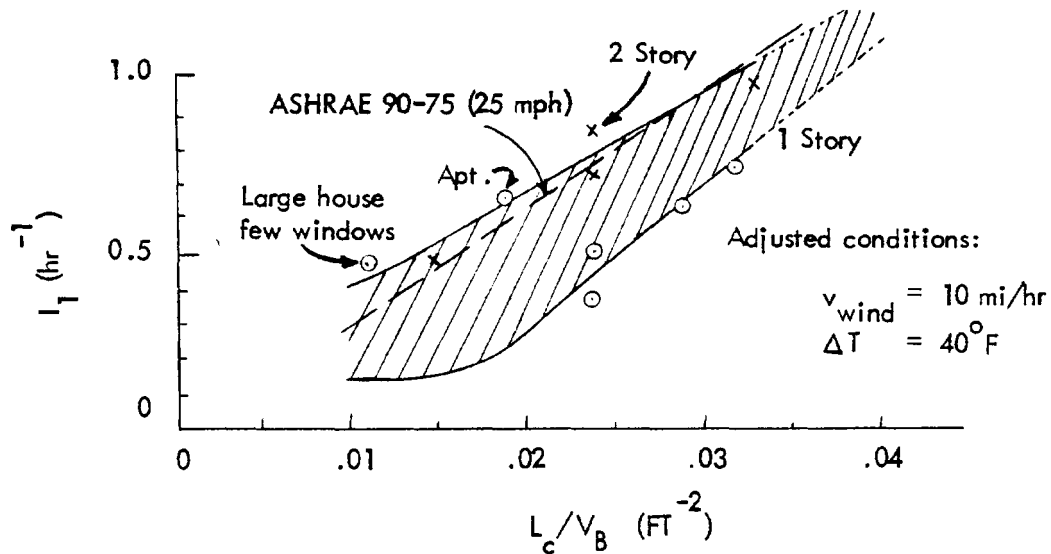


Figure 3-7
Multi-Family Residential Variance of Thermal Conductance
5400 Degree-Day Region



ASHRAE 90-75 RESIDENTIAL AIR LEAKAGE REQUIREMENTS (@ 25 mi/hr wind)

WINDOWS: 0.5 CFM/FT(sash crack)

$$\text{OR } I = \frac{\dot{V}}{V_B} = \frac{L_c \times 0.5 \times 60}{V_B} = 30 \frac{L_c}{V_B}$$

SLIDING GLASS PATIO DOORS: 0.5 CFM/FT² (door area)

ENTRANCE SWINGING DOORS: 1.25 CFM/FT² (door area)

Figure 3-8
Normalized Infiltration
(After Coblenz and Achenbach, Reference 23)

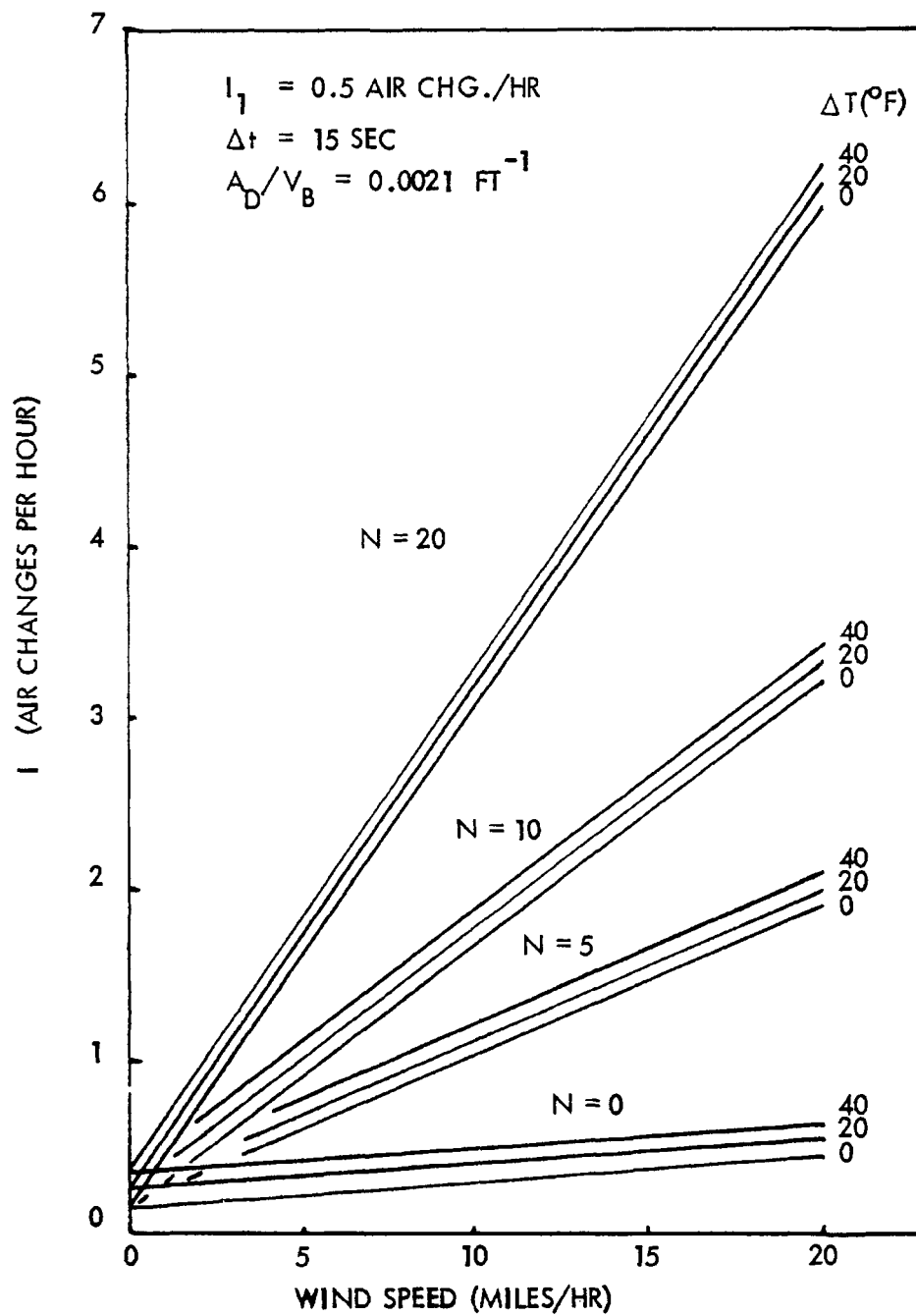


Figure 3-9
Air Changes per Hour as a Function of Wind Speed
Temperature Difference and Door Openings

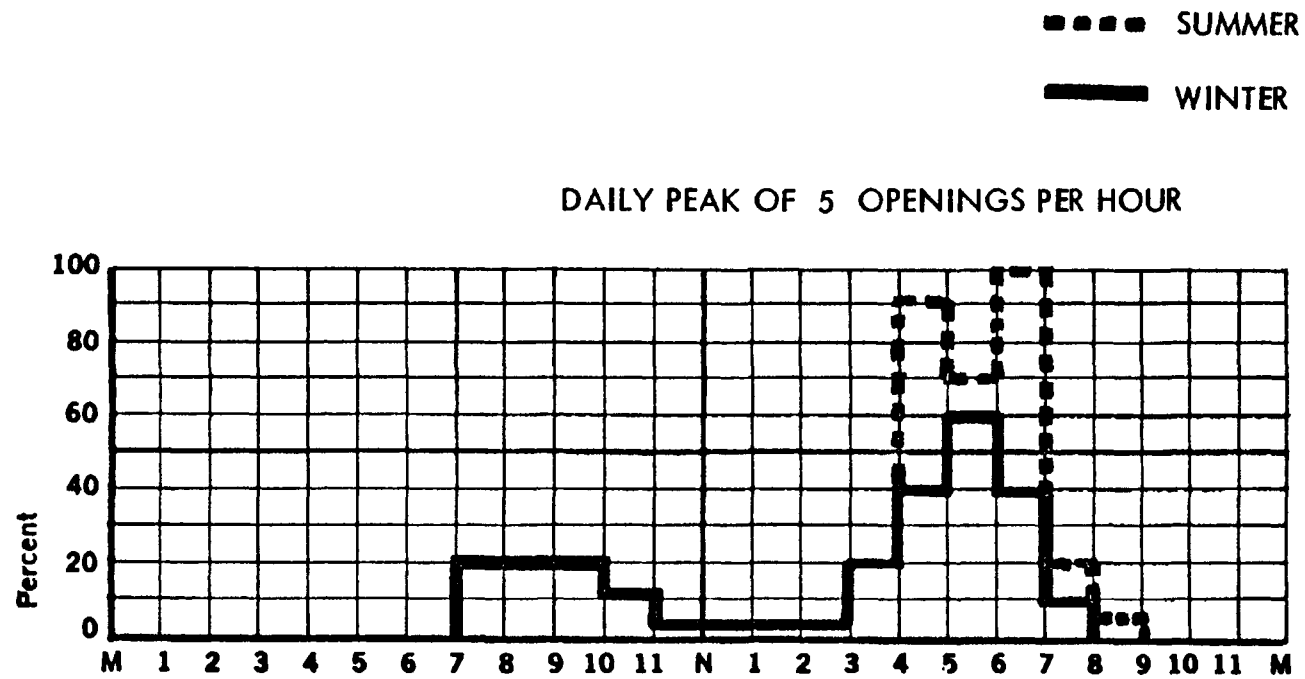


Figure 3-10
Door Opening Schedule
Residential Buildings

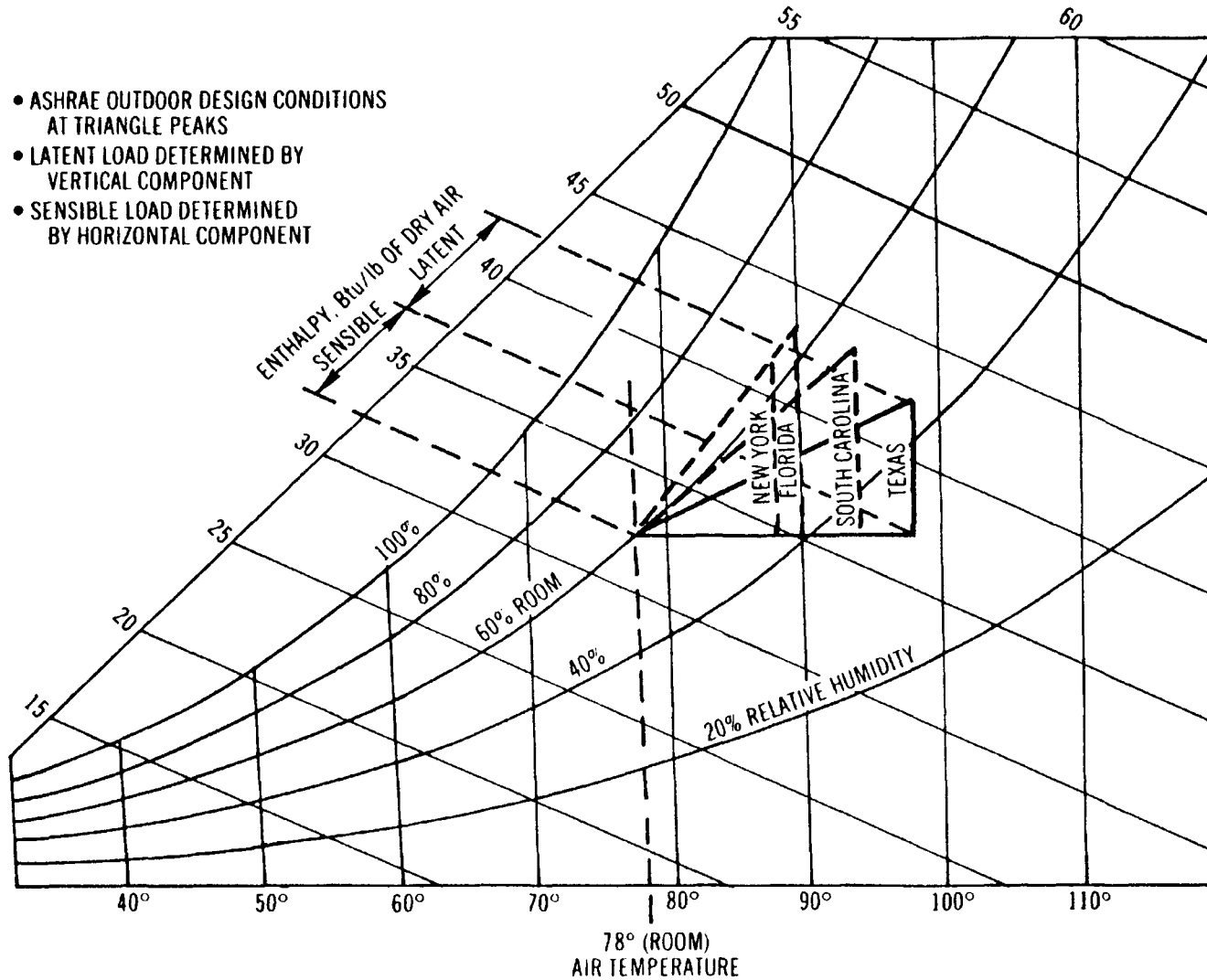


Figure 3-11
Representation of Latent and Sensible Portions
of Infiltration Heat Gain

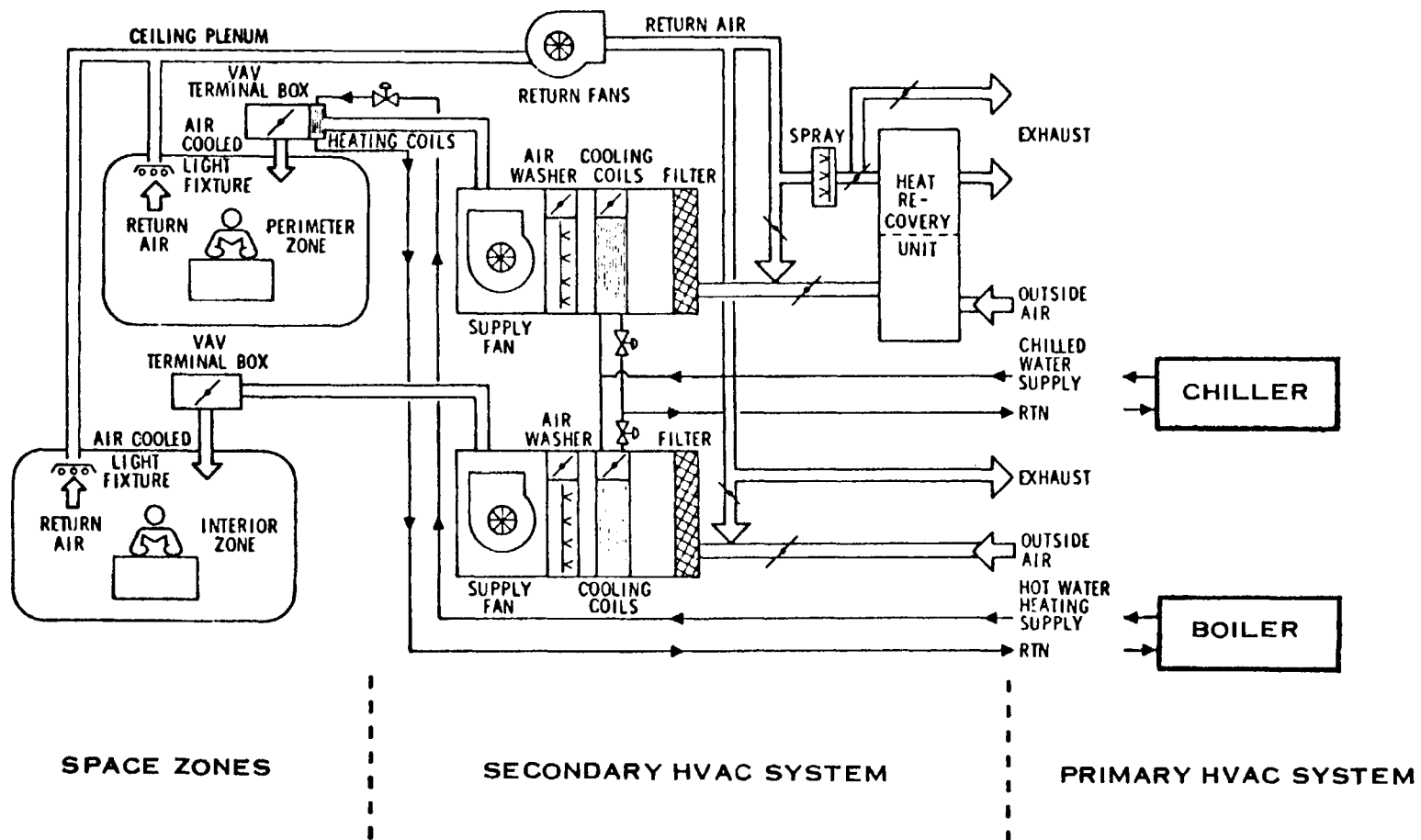
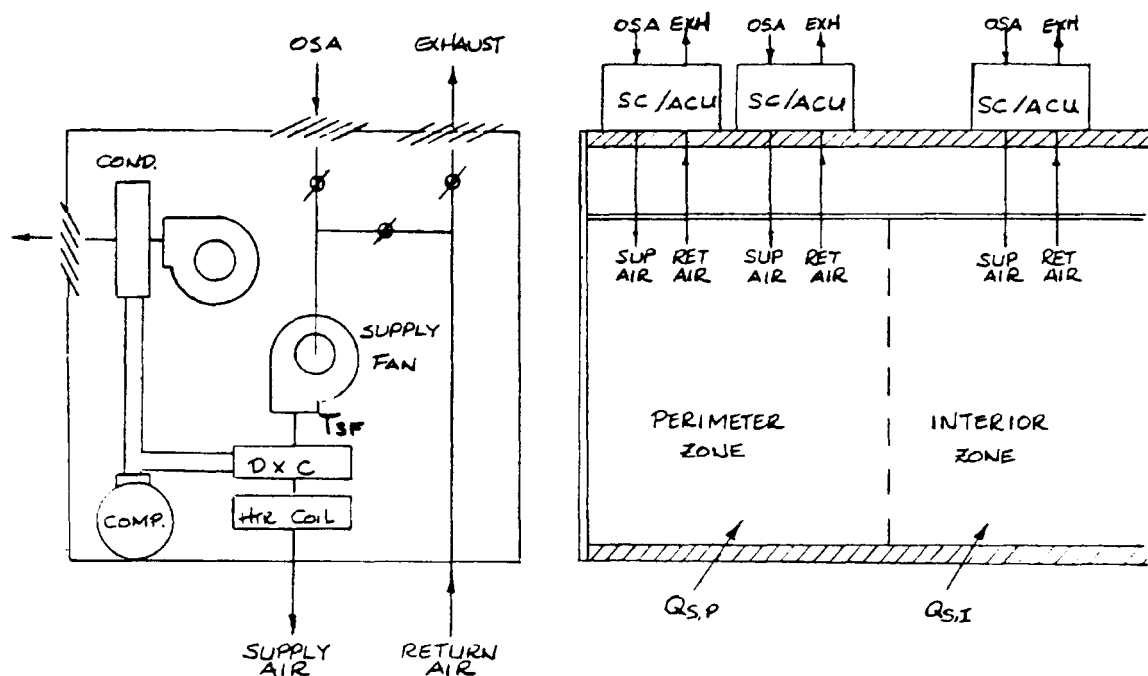


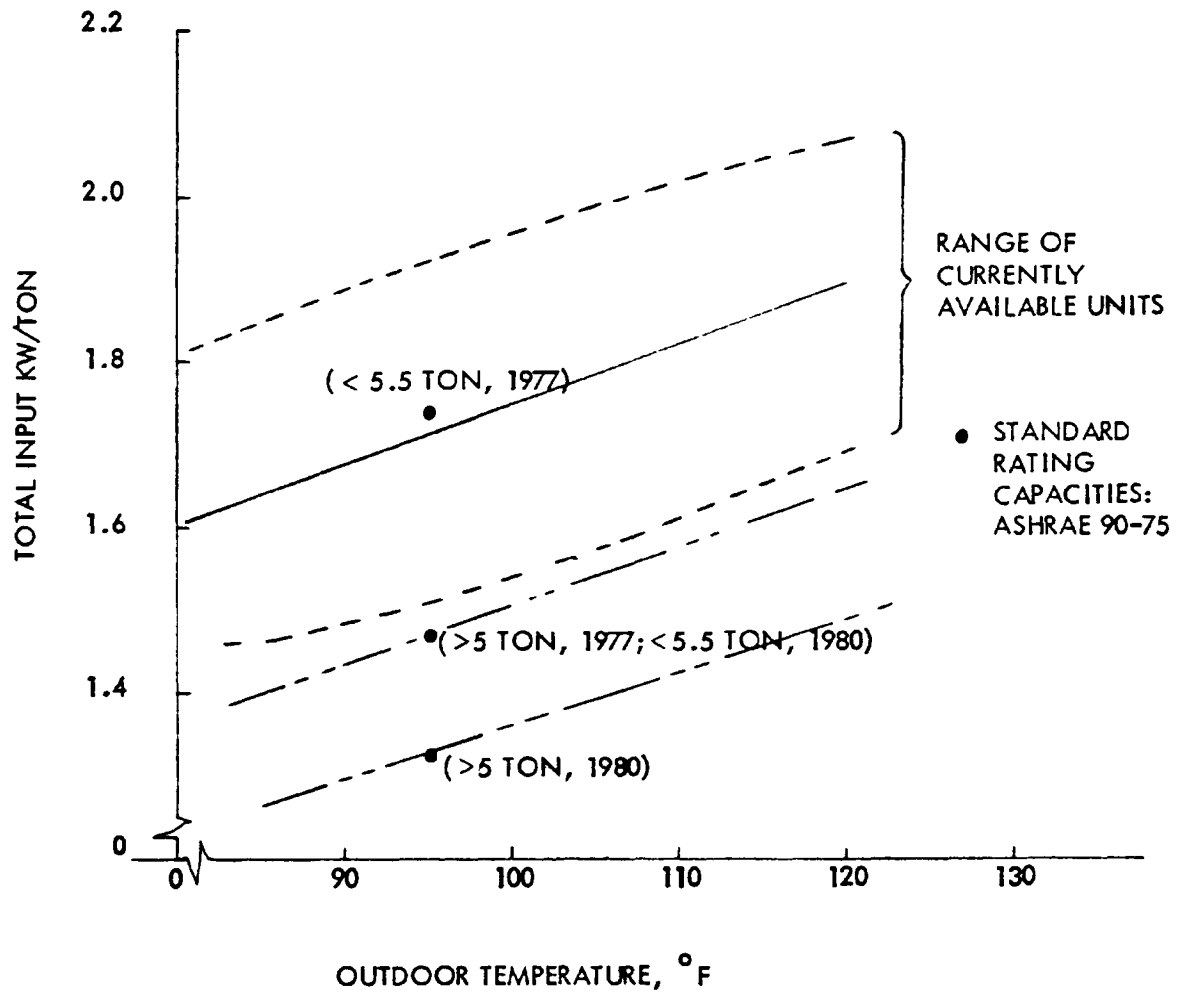
Figure 3-12
HVAC System Schematic



ASSUMPTIONS:

- (1) Delivery system:
 - (a) Each thermal zone is served by a single unit
 - (b) One thermostat per thermal zone
 - (c) No transfer of supply air between zones
- (2) Constant volume
- (3) No mixing of hot and cold air, no reheating
- (4) No induction, baseboard heaters, etc.
- (5) The model considers simultaneous heating and cooling in the single perimeter zone by assuming there to be two groups of SC/ACU's: Those which are heating and those which are cooling.
- (6) Whenever simultaneous heating and cooling called for, all outdoor air is thru units which are cooling.
- (7) Multi-zone units are thermodynamically the same as single zone units. These units have multiple DX coils and resistance heaters and air flow is divided downstream of the fan.
- (8) Economizer operates on enthalpy.

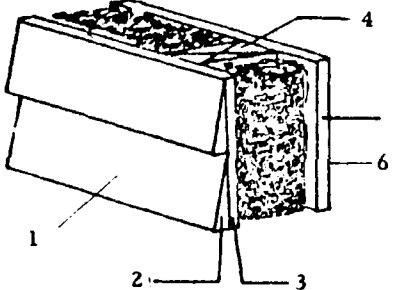
Figure 3-13
Self-Contained Air Conditioning Unit (Roof Mounted)
Single Zone or Multi-Zone Non-Mixing



SOURCE: TRANE Company Brochure DS-PKG3-176

Figure 3-15
Power Requirements
Self Contained Air Conditioning Unit
(2-15 Ton Roof Top Unit)

Table 3-1
Application of ASHRAE 90-75 Envelope Insulation Requirements
Type A-1 Buildings

WALL SECTION	COMPONENTS	Weight LB/SF	Thermal Resistance, R (Less Insulation)	Added Insulation R-Value	Maximum percent of glass °F Degree-day region			
					1800	3600	5400	7200
					1800	3600	5400	7200
Wood siding/wood frame 	1. Exterior air film		0.17	R - 7	16.2%	13.8%	11.4%	8.5%
	2. 1/2 in. wood siding	1.54	0.81		(33.3%)	(28.3%)	(23.4%)	(17.4%)
	3. 1/2 in. sheathing	0.75	1.32	R - 11	18.2%	15.9%	13.5%	10.7%
	4. 2 x 4 in. stud and insulation	1.54	----		(36.4%)	(31.7%)	(27.0%)	(21.4%)
	5. 1/2 in. gypsum wall board	4.17	0.45	R - 14	19.1%	16.8%	14.4%	11.6%
	6. Interior air film		0.68		(37.7%)	(33.1%)	(28.5%)	(23.0%)
	Total	8.00	3.43		(Percent Insulated Glass: Double, 1/2" air space)			

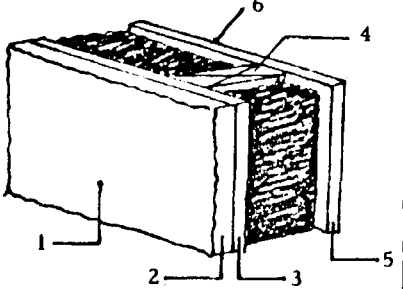
WALL SECTION	COMPONENTS	Weight LB/SF	Thermal Resistance, R (Less Insulation)	Added Insulation R-Value	Maximum percent of glass °F Degree-day region			
					1800	3600	5400	7200
					1800	3600	5400	7200
Stucco siding/wood frame 	1. Exterior air film		0.17	R - 7	15.0%	12.5%	10.1%	7.1%
	2. 3/4 in. stucco	7.25	0.15		(31.3%)	(26.1%)	(21.0%)	(14.9%)
	3. 3/8 in. plywood	1.16	0.47	R - 11	17.6%	15.2%	12.9%	10.0%
	4. 2 x 4 in. study and insulation	1.54	----		(35.5%)	(30.7%)	(25.9%)	(20.2%)
	5. 1/2 in. gypsum wall board	4.17	0.45	R - 14	18.7%	16.3%	14.0%	11.2%
	6. Interior air film		0.68		(37.1%)	(32.5%)	(27.8%)	(22.2%)
	Total	14.12	1.92		(Percent Insulated Glass: Double, 1/2" air space)			

Table 3-2
Application of ASHRAE 90-75 Floor Insulation Requirements
Floor Types

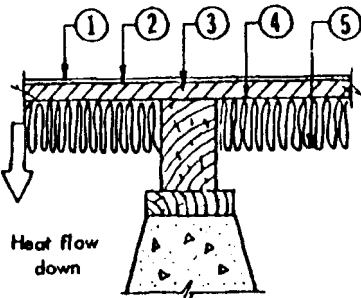
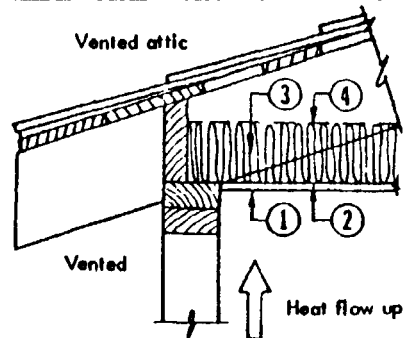
FLOOR SECTION	FLOOR COMPONENT	Thermal Resistance, R (Less Insulation)	Minimum Insulation resistance required, R_i			
			°F Degree-day region			
			1800	3600	5400	7200
Plywood Subfloor 1-1/8 in. plywd. T. & G. 	1. Interior air film (Still air) 2. Linoleum 3. 1-1/8 in. plywood combination sub-floor and underlayment 4. Insulation required 5. Exterior air film (Still air, heat flow down)	0.92 0.05 1.40 ----- 0.92 ----- R = 3.29	R - 1	R - 4	R - 10	R - 10
ROOF/CEILING SECTION	ROOF COMPONENT	Thermal Resistance, R (Less Insulation)	Minimum Insulation resistance required, R_i			
			°F Degree-day region			
			1800	3600	5400	7200
Vented attic 	1. Interior air film 2. 1/2 in. gypsum wallboard 3. Insulation required 4. Exterior air film--attic (Still air)	0.61 0.45 ----- 0.61 ----- R = 1.67	← R-19 Type A ($U_o = 0.05$) R-19 → R-19			

Table 3-3
Maximum Profile Ordinate Parameters

<u>BUILDING CATEGORY</u>	<u>MAXIMUM OCCUPANCY</u>	<u>PEAK ELECTRIC BASELOAD</u>	<u>PEAK DOMESTIC HOT WATER DEMAND</u>
RESIDENTIAL: Single Family Multi Family	4 Person/Unit 2 Person/Unit	2 W/SF	1.6 Gal/Hr/Person 1.6 Gal/Hr/Person
MOTEL:	200 SF/Person	2 W/SF	2 Gal/ Hr /Unit RM
OFFICE:	100 SF/Person	3.5 W/SF	0.15 Gal/Hr/Person
SHOPPING CENTER:	50 SF/Person	4.5 W/SF	0.20 Gal/Hr/Person
RETAIL STORE:	50 SF/Person	4.5 W/SF	0.07 Gal/Hr/Person
HOSPITAL:	120 SF/Person	3.5 W/SF	17.7 BTU/Hr/SF
SCHOOL: Elementary High School	55 SF/Person 105 SF/Person	3.0 W/SF 3.0 W/SF	0.20 Gal/Hr/Student 0.30 Gal/Hr/Student
LIGHT INDUSTRIAL:	100 SF/Person	6.0 W/SF	Not Applicable

Table 3-4
Single Family Detached
1800°F-Day

BUILDING	VOLUME V _B FT ³	UA BTU/HR °F	Q _{Base} BTU/HR	Q _{Occup} BTU/HR		Q _{Elec} BTU/HR	UA* BTU/HR °F	
				SEN	LAT			
S-1040-2 ¹ 1S-3 ² S-4 ³	8,320	427	-2,818	1,000	800	7,097	506	
1440-1S-S	11,520	517		↑	↑	9,827	621	
1440-1S-CS	11,520	804				9,827	908	
1440-1S-HB	11,520	565				9,827	669	
-UB	11,520	609				9,827	713	
1840-1S-S	14,720	596				12,557	727	
1440-1S-S/UFC	11,520	566				9,827	664	
1040-1S-CS	8,320	622				7,097	701	
1840-1S-CS	14,720	976				12,557	1,108	
2240-1S-S	17,920	667				15,286	828	
2240-1S-CS	17,920	1,145				15,286	1,306	
1600-2S-S	13,600	655				10,919	777	
W-1215-1S-S	9,720	468	-3,082			↓	8,291	555
1615-1S-S	12,920	555					11,021	671
1615-1S-CS	12,920	882					11,021	998
2015-1S-S	16,120	627					13,751	772
1615-1S-HB	12,920	606					11,021	722
-UB	12,920	664					11,021	780
1615-1S-S/UFC	12,920	603					11,021	719
2415-1S-S	19,320	697					16,481	871
1800-2S-S	15,300	697		1,000	800	12,284	835	

UA* INCLUDES INFILTRATION OF 0.5 AC/HR

Q_{DHW} = 4,250 BTU/HR = Domestic Hot Water Load

- 1 Degree Day Region: S, South; W, West; NC, North Central; NE, Northeast
- 2 Floor Area, sq. ft.
- 3 Number of Stories: 1S, One Story; 2S, Two Story
- 4 Foundation Type: S, Slab; CS, Crawl Space; UB, Unheated Basement; HB, Heated Basement

Table 3-4
Single Family Detached
(Continued)
3600°F-Day

BUILDING	VOLUME V_B FT ³	UA BTU/HR °F	Q_{Base} BTU/HR	Q_{Occup} BTU/HR		Q_{Elec} BTU/HR	UA* BTU/HR °F
				SEN	LAT		
S-1040-1S-S	8,320	383	-2,818	1,000	800	7,097	462
1440-1S-S	11,520	464		↑	↑	9,827	568
1440-1S-CS	11,520	593		↑	↑	9,827	697
1440-1S-HB	11,520	521		↑	↑	9,827	625
-UB	11,520	489		↑	↑	9,827	593
1840-1S-S	14,720	535		↑	↑	12,557	667
1440-1S-S/UFC	11,520	507		↑	↑	9,827	611
1040-1S-CS	8,320	466		↑	↑	7,097	545
1840-1S-CS	14,720	712		↑	↑	12,557	844
2240-1S-S	17,920	601		↑	↑	15,286	762
2240-1S-CS	17,920	826		↑	↑	15,286	987
1600-2S-S	13,600	590		↑	↑	10,919	712
W-1215-1S-S	9,720	419	-3,082	↓	↓	8,291	506
1615-1S-S	12,920	498		↓	↓	11,021	614
1615-1S-CS	12,920	648		↓	↓	11,021	764
2015-1S-S	16,120	565		↓	↓	13,751	710
1615-1S-HB	12,920	589		↓	↓	11,021	705
-UB	12,920	530		↓	↓	11,021	646
1615-1S-S/UFC	12,920	547		↓	↓	11,021	663
2415-1S-S	19,320	629		↓	↓	16,481	803
1800-2S-S	15,300	679		1,000	800	12,284	817

UA* INCLUDES INFILTRATION OF 0.5 AC/HR

Q_{DHW} = 4,250 BTU/HR

Table 3-4
Single Family Detached
(Continued)
5400°F-Day

BUILDING	VOLUME V_B FT ³	UA BTU/HR °F	Q_{Base} BTU/HR	Q_{Occup} BTU/HR		Q_{Elec} BTU/HR	UA* BTU/HR °F
				SEN	LAT		
NE-1240-1S-HB	9,920	429	-5,026	1,000	800	8,462	518
-UB	9,920	372				8,462	461
1640-1S-HB	13,120	517	-6,237			11,192	635
-UB	13,120	450				11,192	568
1640-1S-S	13,120	447				11,192	565
2040-1S-HB	16,320	584	-7,360			13,921	731
-UB	16,320	519				13,921	666
1800-2S-HB	15,300	611	-3,960			12,284	749
-UB	15,300	550				12,284	688
2200-2S-HB	18,700	681	-4,591			15,013	849
-UB	18,700	618				15,013	786
2600-2S-HB	22,100	755	-5,233			17,743	954
-UB	22,100	689				17,743	888
2440-1S-HB	19,520	649	-8,467			16,651	825
-UB	19,520	586				16,651	762
NC-1120-1S-HB	8,960	410	-4,652			7,643	491
-UB	8,960	347				7,643	428
1520-1S-HB	12,160	494	-5,887			10,373	603
-UB	12,160	428				10,373	537
1520-1S-CS	12,160	489				10,373	598
1920-1S-HB	15,360	564	-7,022			13,103	702
-UB	15,360	498				13,103	636
1700-2S-HB	14,450	592	-3,799			11,601	722
-UB	14,450	532				11,601	662
2100-2S-HB	17,850	664	-4,436			14,331	825
-UB	17,850	602				14,331	763
2500-2S-HB	21,250	735	-5,068			17,061	926
-UB	21,250	670				17,061	861
2320-1S-HB	18,560	633	-8,157			15,832	800
-UB	18,560	568				15,832	735
1520-1S-S	12,160	427				10,373	536
W-1215-1S-S	9,720	371				8,291	458
1615-1S-S	12,920	442				11,021	558
1615-1S-CS	12,920	510				11,021	626
2015-1S-S	16,120	503				13,751	648
1615-1S-HB	12,920	512	-6,165			11,021	628
-UB	12,920	445				11,021	561
1615-1S-S/UFC	12,920	491				11,021	607
2415-1S-S	19,320	561				16,481	735
1800-2S-S	15,300	560		1,000	800	12,284	698

UA* INCLUDES INFILTRATION OF 0.5 AC/HR

$Q_{DHW} = 4,250$ BTU/HR

Table 3-4
Single Family Detached
(Continued)
7200°F-Day

BUILDING	VOLUME V _B FT ³	UA BTU/HR °F	Q _{Base} BTU/HR	Q _{Occup} BTU/HR		Q _{Elec} BTU/HR	UA* BTU/HR °F
				SEN	LAT		
NE-1240-1S-HB	9,920	381	-7,539	1,000	800	8,462	470
-UB	9,920	338		↑	↑	8,462	427
1640-1S-HB	13,120	460	-9,356			11,192	578
-UB	13,120	410				11,192	528
1640-1S-S	13,120	394				11,192	512
2040-1S-HB	16,320	521	-11,040			13,921	668
-UB	16,320	475				13,921	622
1800-2S-HB	15,300	537	-5,940			12,284	675
-UB	15,300	489				12,284	627
2200-2S-HB	18,700	600	-6,886			15,013	768
-UB	18,700	551				15,013	719
2600-2S-HB	22,100	680	-7,849			17,743	879
-UB	22,100	614				17,743	813
2440-1S-HB	19,520	580	-12,701			16,651	756
-UB	19,520	538				16,651	714
NC-1120-1S-HB	8,960	364	-6,978			7,643	445
-UB	8,960	315				7,643	396
1520-1S-HB	12,160	440	-8,830			10,373	549
-UB	12,160	390				10,373	499
1520-1S-CS	12,160	451				10,373	560
1920-1S-HB	15,360	503	-10,533			13,103	641
-UB	15,360	456				13,103	594
1700-2S-HB	14,450	521	-5,699			11,601	651
-UB	14,450	473				11,601	603
2100-2S-HB	17,850	585	-6,654			14,331	746
-UB	17,850	536				14,331	697
2500-2S-HB	21,250	647	-7,601			17,061	838
-UB	21,250	597				17,061	788
2320-1S-HB	18,560	565	-12,236			15,832	732
-UB	18,560	521				15,832	688
1520-1S-S	12,160	376				10,373	485
W-1215-1S-S	9,720	327				8,291	414
1615-1S-S	12,920	390				11,021	506
1615-1S-CS	12,920	471				11,021	587
2015-1S-S	16,120	445				13,751	590
1615-1S-HB	12,920	456	-9,247			11,021	572
-UB	12,920	406				11,021	522
1615-1S-S/UFC	12,920	439				11,021	555
2415-1S-S	19,320	497		1,000	800	16,481	671
1800-2S-S	15,300	489				12,284	627

UA* INCLUDES INFILTRATION OF 0.5 AC/HR

Q_{DHW} = 4,250 BTU/HR

Table 3-5
Apartment Buildings

BUILDING	VOLUME	UA	Q _{Base}	Q _{Occup}		Q _{Elec}	Q _{DHW} ⁷	UA*
	FT ³	BTU/HR °F	BTU/HR	SEN	LAT	BTU/HR	BTU/HR	BTU/HR °F
1800°F-DAY								
S-C-16U ¹ -900 ² -2S ³ -S ⁴ -S ⁵ ⁶	122,400	3,799		8,000	6,400	98,269	34,000	4,811
B-12U-900-2S-S	91,800	2,574		6,000	4,800	73,702	25,500	3,400
C-16U-1100-2S-S	149,600	4,242		8,000	6,400	120,106	34,000	5,583
B-12U-1100-2S-S	112,200	2,878		6,000	4,800	90,080	25,500	3,888
D-24U-900-3S-S	187,200	4,368		12,000	9,600	147,404	51,000	6,052
B-12U-900-3S-S	93,600	2,721		6,000	4,800	73,702	25,500	3,563
D-24U-1100-3S-S	228,800	4,871		12,000	9,600	180,160	51,000	3,930
B-12U-1100-3S-S	114,400	3,030		6,000	4,800	90,080	25,500	4,060
W-B-16U-910-2S-S	123,760	3,268		8,000	6,400	99,361	34,000	4,382
D-16U-910-2S-S	123,760	3,093		8,000	6,400	99,361	34,000	4,207
B-16U-1110-2S-S	150,960	3,651		8,000	6,400	121,200	34,000	5,010
D-16U-1110-2S-S	150,960	3,455		8,000	6,400	121,200	34,000	4,814
3600 °F-DAY								
S-C-16U-900-2S-S	122,400	3,419		8,000	6,400	98,269	34,000	4,431
B-12U-900-2S-S	91,800	2,320		6,000	4,800	73,702	25,500	3,146
C-16U-1100-2S-S	149,600	3,822		8,000	6,400	120,106	34,000	5,168
B-12U-1100-2S-S	112,200	2,596		6,000	4,800	90,080	25,500	3,606
D-24U-900-3S-S	187,200	3,941		12,000	9,600	147,404	51,000	5,625
B-12U-900-3S-S	93,600	2,453		6,000	4,800	73,702	25,500	3,295
D-24U-1100-3S-S	228,800	4,398		12,000	9,600	180,160	51,000	6,457
B-12U-1100-3S-S	114,400	2,730		6,000	4,800	90,080	25,500	3,760
W-B-16U-910-2S-S	123,760	2,947		8,000	6,400	99,361	34,000	4,061
D-16U-910-2S-S	123,760	2,791		8,000	6,400	99,361	34,000	3,905
B-16U-1110-2S-S	150,960	3,298		8,000	6,400	121,200	34,000	4,657
D-16U-1110-2S-S	150,960	3,122		8,000	6,400	121,200	34,000	4,481

- 1 Degree Day Region: S, South; W, West; NC, North Central; NE, Northeast
- 2 Layout Type: Table 2-12
- 3 Number of Units: nU
- 4 Unit Floor Area, sq. ft.
- 5 Number of Stories: 2S, Two Stories; 3S, Three Stories
- 6 Foundation Type: S, Slab; UB, Unheated Basement; HB, Heated Basement
- 7 Domestic Hot Water Load

Table 3-5
Apartment Buildings
(Continued)

BUILDING	VOLUME FT ³	UA BTU/HR °F	Q _{Base} BTU/HR	Q _{Occup} BTU/HR		Q _{Elec} BTU/HR	Q _{DHW} BTU/HR	UA* BTU/HR °F
				SEN	LAT			
5400 °F-DAY								
NE-D-16U-880-2S-S	119,680	2,478	-21,288	8,000	6,400	96,086	34,000	3,555
B-12U-880-2S-S	89,760	2,069		6,000	4,800	72,064	25,500	3,146
D-16U-880-2S-HB	119,680	2,733		8,000	6,400	96,086	34,000	3,810
-UB	119,680	2,608		8,000	6,400	96,086	34,000	3,685
B-12U-880-2S-HB	89,760	2,285	-16,680	6,000	4,800	72,064	25,500	3,093
-UB	89,760	2,152		6,000	4,800	72,064	25,500	2,860
D-16U-1080-2S-HB	146,880	3,070	-25,267	8,000	6,400	117,923	34,000	4,392
-UB	146,880	2,965		8,000	6,400	117,923	34,000	4,287
B-12U-1080-2S-HB	110,160	2,563	-19,743	6,000	4,800	88,442	25,500	3,554
-UB	110,160	2,440		6,000	4,800	88,442	25,500	3,431
NC-D-24U-860-2S-S	175,440	3,430	-30,519	12,000	9,600	140,852	51,100	5,009
C-16U-860-2S-S	116,960	3,007		8,000	6,400	93,902	34,000	4,060
D-24U-860-3S-S	178,880	3,479		12,000	9,600	140,852	51,100	5,089
D-24U-860-2S-HB	175,440	3,779		12,000	9,600	140,852	51,100	5,358
-UB	175,440	3,635	-22,789	12,000	9,600	140,852	51,100	5,214
C-16U-860-2S-HB	116,960	3,326		8,000	6,400	93,902	34,000	4,379
-UB	116,960	3,092	-20,886	8,000	6,400	93,902	34,000	4,145
D-24U-860-3S-HB	178,880	3,730		12,000	9,600	140,852	51,100	5,340
-UB	178,880	3,604		12,000	9,600	140,852	51,100	5,214
D-24U-1060-2S-S	216,240	3,871		12,000	9,600	173,609	51,100	5,817
C-16U-1060-2S-S	144,160	3,380	D-24U-1060-3S-S	8,000	6,400	115,739	34,000	4,677
D-24U-1060-3S-S	220,480	3,904		12,000	9,600	173,609	51,100	5,888
W-B-16U-910-2S-S	123,760	2,664	D-16U-910-2S-S	8,000	6,400	99,361	34,000	3,778
D-16U-910-2S-S	123,760	2,525		8,000	6,400	99,361	34,000	3,639
B-16U-1110-2S-S	150,960	2,985		8,000	6,400	121,200	34,000	4,344
D-16U-1110-2S-S	150,960	2,829		8,000	6,400	121,200	34,000	4,188

Table 3-5
Apartment Buildings
(Continued)

BUILDING	VOLUME	UA	Q _{Base}	Q _{Occup} BTU/HR		Q _{Elec}	Q _{DHW}	UA*
	FT ³	BTU/HR °F	BTU/HR	SEN	LAT	BTU/HR	BTU/HR	BTU/HR °F
7200 °F-DAY								
NE-D-16U-880-2S-S	119,680	2,207		8,000	6,400	96,086	34,000	3,284
B-12U-880-2S-S	89,760	1,839		6,000	4,800	72,064	25,500	2,647
D-16U-880-2S-HB	119,680	2,445	-31,932	8,000	6,400	96,086	34,000	3,523
-UB	119,680	2,370		8,000	6,400	96,086	34,000	3,447
B-12U-880-2S-HB	89,760	2,041	-25,021	6,000	4,800	72,064	25,500	2,849
-UB	89,760	1,949		6,000	4,800	72,064	25,500	2,757
D-16U-1080-2S-HB	146,880	2,752	-37,900	8,000	6,400	117,923	34,000	4,074
-UB	146,880	2,701		8,000	6,400	117,923	34,000	4,023
B-12U-1080-2S-HB	110,160	2,293	-29,614	6,000	4,800	88,442	25,500	3,284
-UB	110,160	2,216		6,000	4,800	88,442	25,500	3,207
NC-D-24U-860-2S-S	175,440	3,059		12,000	9,600	140,852	51,100	4,638
C-16U-860-2S-S	116,960	2,668		8,000	6,400	93,902	34,000	3,721
D-24U-860-3S-S	178,880	3,087		12,000	9,600	140,852	51,100	4,697
D-24U-860-2S-HB	175,440	3,385	-45,779	12,000	9,600	140,852	51,100	4,964
-UB	175,440	3,308		12,000	9,600	140,852	51,100	4,887
C-16U-860-2S-HB	116,960	2,964	-34,183	8,000	6,400	93,902	34,000	4,019
-UB	116,960	2,791		8,000	6,400	93,902	34,000	3,846
D-24U-860-3S-HB	178,880	3,321	-31,329	12,000	9,600	140,852	51,100	4,932
-UB	178,880	3,24		12,000	9,600	140,852	51,100	4,854
D-24U-1060-2S-S	216,240	3,45		12,000	9,600	173,609	51,100	5,405
C-16U-1060-2S-S	144,160	3,00		8,000	6,400	115,739	34,000	4,301
D-24U-1060-3S-S	220,480	3,46		12,000	9,600	173,609	51,100	5,453
W-B-16U-910-2S-S	123,760	2,371		8,000	6,400	99,361	34,000	3,485
D-16U-910-2S-S	123,760	2,251		8,000	6,400	99,361	34,000	3,365
B-16U-1110-2S-S	150,960	2,661		8,000	6,400	121,200	34,000	4,020
D-16U-1110-2S-S	150,960	2,526		8,000	6,400	121,200	34,000	3,885

Table 3-6
Townhouse, Highrise Apartment, and Motel

BUILDING	VOLUME	UA	Q _{Base}	Q _{Occup} BTU/HR		Q _{Elec}	Q _{DHW}	UA*
	FT ³	BTU/HR °F	BTU/HR	SEN	LAT	BTU/HR	BTU/HR	BTU/HR °F
1800°F-DAY								
TH-4U ² -1300 ³ -2S ⁴	44,200	1,607	-2,106	4,000	3,200	35,486	17,000	2,005
TH-8U-1300-2S	88,400	2,756		8,000	6,400	70,972	34,000	3,552
TH-4U-1500-2S	51,000	1,737		4,000	3,200	40,946	17,000	2,196
TH-8U-1500-2S	102,000	2,981		8,000	6,400	81,891	34,000	3,899
MOT-32U-422-2S	135,000	2,348		17,000	13,600	92,127	42,496	3,763
APT-13U-1076-4S	173,160	6,006		10,750	8,600	95,478	45,683	7,564
3600 °F-DAY								
TH-4U-1300-2S	44,200	1,444	-2,106	4,000	3,200	35,486	17,000	1,842
TH-8U-1300-2S	88,400	2,480		8,000	6,400	70,972	34,000	3,276
TH-4U-1500-2S	51,000	1,561		4,000	3,200	40,946	17,000	2,020
TH-8U-1500-2S	102,000	2,684		8,000	6,400	81,891	34,000	3,602
MOT-32U-422-2S	135,000	2,491		17,000	13,600	92,127	42,496	3,706
APT-13U-1076-4S	173,160	5,268		10,750	8,600	95,478	45,683	6,826
5400 °F-DAY								
TH-4U-1300-2S	44,200	1,300	-4,212	4,000	3,200	35,486	17,000	1,698
TH-8U-1300-2S	88,400	2,237		8,000	6,400	70,972	34,000	3,033
TH-4U-1500-2S	51,000	1,407		4,000	3,200	40,946	17,000	1,866
TH-8U-1500-2S	102,000	2,424		8,000	6,400	81,891	34,000	3,342
MOT-32U-422-2S	135,000	2,435		17,000	13,600	92,127	42,496	3,650
APT-13U-1076-4S	173,160	4,635		10,750	8,600	95,478	45,683	6,193
7200 °F-DAY								
TH-4U-1300-2S	44,200	1,151	-6,318	4,000	3,200	35,486	17,000	1,549
TH-8U-1300-2S	88,400	1,985		8,000	6,400	70,972	34,000	2,781
TH-4U-1500-2S	51,000	1,266		4,000	3,200	40,946	17,000	1,725
TH-8U-1500-2S	102,000	2,154		8,000	6,400	81,891	34,000	3,072
MOT-32U-422-2S	135,000	2,404		17,000	13,600	92,127	42,496	3,619
APT-13U-1076-4S	173,160	3,979		10,750	8,600	95,478	45,683	5,537

- 1 Building Type: TH, Town House; MOT, Motel; APT, Multi Family (High Rise)
- 2 Number of Units: nU
- 3 Unit Floor Area, sq. ft.
- 4 Number of Stories: 2S, Two Stories; 4S, Four Stories

Table 3-7
Solar Heat Gain Factors, SHGF (SC = 1.0)

40° N LATITUDE		SOLAR HEAT GAIN FACTORS, SHGF (SC = 1.0) (BTU/HR/SF)		
DATE	HR	AVERAGE SHGF $[A = \frac{1}{4} (N+E+S+W)]$	SOUTH SHGF [S]	RATIO $\frac{S}{A}$
Jan. 21	8	49	75	1.5
	9	84	160	1.9
	10	92	213	2.3
	11	85	244	2.9
	12	78	254	3.3
	1	85	244	2.9
	2	92	213	2.3
	3	84	160	1.9
	4	49	75	1.5
	Total	691	1630	2.4
Jul. 21	6	48	10	0.2
	7	68	20	0.3
	8	75	29	0.4
	9	77	52	0.7
	10	74	80	1.1
	11	64	102	1.6
	12	57	109	1.9
	1	64	102	1.6
	2	74	80	1.1
	3	77	52	0.7
	4	75	29	0.4
	5	68	20	0.3
	6	48	10	0.2
	Total	860	694	0.8

* Ref. ASHRAE Handbook (1972), pp. 388-391.
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Table 3-8
Reference Non-Residential HVAC Systems

OCCUPANCY	PERIMETER ZONE	INTERIOR ZONE	OUTSIDE AIR REQUIREMENTS (OSA)
OFFICE	VAV + RHT	VAV	5 CFM/PERSON
RETAIL STORE	SC/ACU	SC/ACU	5 CFM/PERSON
SHOPPING CENTER	VAV + RHT	VAV	5 CFM/PERSON
SCHOOL	SC/MZU	SC/MZU	5 CFM/PERSON
HOSPITAL	VAV + RHT	VAV	25% x SUPPLY AIR RATE
LIGHT INDUSTRIAL	SC/ACU	SC/ACU	5 CFM/PERSON

VAV: VARIABLE AIR VOLUME

RHT: REHEAT

SC/ACU: SELF CONTAINED AIR CONDITIONING UNIT (ROOF MOUNTED WITH HEATING ELEMENT, DX REFRIGERATION, AND ECONOMIZER CYCLE)

SC/MZU: SELF CONTAINED MULTI ZONE UNIT (ROOF MOUNTED WITH HEATING ELEMENTS, DX REFRIGERATION, AND ECONOMIZER CYCLE)

Table 3-9
Design Conditions

SUMMER DESIGN CONDITIONS

T_{ID} = INDOOR TEMPERATURE = 78 °F (ASHRAE 90-75)

<u>REGION (DD AND LATITUDE)</u>	<u>OUTDOOR TEMPERATURE, T_{OD}</u>	<u>$\Delta T = T_{ID} - T_{OD}$</u>
1800 °FHDD; 27.5 °N, 32.5 °N	103 °F	25 °F
3600 °FHDD; 37.5 °N, 42.5 °N	98 °F	20 °F
5400 °FHDD; 37.5 °N, 42.5 °N	98 °F	20 °F
7200 °FHDD; 47.5 °N	93 °F	15 °F

T_{SUP} = SUPPLY AIR TEMPERATURE

- OSA SENSIBLE HEAT GAIN = OSA LATENT HEAT GAIN
- $T_{ID} - T_{SUP} = 20$ °F

WINTER DESIGN CONDITIONS

T_{ID} = INDOOR TEMPERATURE = 72 °F (ASHRAE 90-75)

<u>REGION</u>	<u>OUTDOOR TEMPERATURE, T_{OD}</u>	<u>$\Delta T = T_{ID} - T_{OD}$</u>
1800 °FHDD	37 °F	35 °F
3600 °FHDD	17 °F	55 °F
5400 °FHDD	7 °F	65 °F
7200 °FHDD	-3 °F	75 °F

Table 3-10
Non-Residential Buildings

Building Type		3-Story Office	10-Story Office	Hospital	Elementary School
Exterior Zone	Floor area, SF	24,750	68,984	40,200	8,100
	Volume, ft ³	198,000	551,872	321,600	81,000
	Wall type	6 in. concrete tiltup wall	Curtain wall/spandrel glass	8 in. reinforced concrete	Face brick/concrete block
	Insulation				
	1800DD	R-7	R-4	R-7	R-7
	3600DD	R-7	R-4	R-7	R-7
	5400DD	R-7	R-4	R-7	R-7
	7200DD	R-7	R-4	R-7	R-7
	Gross wall area, SF	17,280	60,000	31,000	6,000
	Roof type	Concrete/steel deck	Concrete/steel deck	Concrete/steel deck	Steel deck/builtup roof
	Insulation				
	1800DD	R-9	R-9	R-9	R-9
	3600DD	R-9	R-9	R-9	R-10
	5400DD	R-11	R-11	R-11	R-12
	7200DD	R-14	R-14	R-14	R-14
	Roof area, SF	12,150	12,284	15,000	8,100
	Percent glass	30%	30%	30%	20%
	U-value/SC (BTU/HR-SF-°F)				
	1800DD	0.55/0.56	0.60/0.56	1.00/0.43	1.13/0.93
	3600DD	0.55/0.56	0.60/0.56	1.00/0.43	1.13/0.93
	5400DD	0.55/0.56	0.60/0.56	0.60/0.56	1.13/0.93
	7200DD	0.55/0.56	0.60/0.56	0.60/0.56	0.60/0.79
Interior	Door area, SF	32	32	32	32
	Equivalent Perimeter, ft	(1)	(1)	(1)	(1)
	Maximum No. of people	247	690	335	147
	Peak electric, BTU/HR	295,576	823,838	480,086	82,915
Interior	Floor area, SF	11,700	53,856	19,800	11,900
	Volume, ft ³	93,600	430,848	158,400	119,000
	Roof area, SF	-----	-----	-----	11,900
	No. of people	117	538	165	216
	Peak electric, BTU/HR	139,727	643,173	236,460	121,823
Building	Domestic hot water, BTU/HR	36,254	122,308	1,062,000	48,206
	Max. cooling cap., BTU/HR				
	1800DD	1,444,194	4,657,221	3,265,287	830,641
	3600DD	1,403,109	4,597,634	3,092,689	787,424
	5400DD	1,362,025	4,538,045	2,920,089	744,207
	7200DD	1,320,940	4,478,458	2,747,491	700,990
	Overall thermal conductance (UA), BTU/HR °F				
	1800DD	10,209	27,185	39,663	6,140
	3600DD	8,994	25,956	38,163	5,873
	5400DD	8,058	25,011	33,226	5,393
	7200DD	7,887	24,839	33,016	4,509

(1) Refer to Table 3-11

Table 3-10
Non-Residential Buildings (Continued)

Building Type		High school	Retail Store	Shopping Center	Industrial
Exterior Zone	Floor area, SF	34,200	14,100	63,300	22,320
	Volume, ft ³	342,000	169,200	1,083,000	401,774
	Wall type	Face brick/ concrete block	Face brick/ concrete block	Face brick/ concrete block	Metal siding/ insulation
	Insulation				
	1800DD	R-7	R-7	R-7	R-2
	3600DD	R-7	R-7	R-7	R-2
	5400DD	R-11	R-7	R-7	R-3
	7200DD	R-11	R-7	R-7	R-3
	Gross wall area, SF	24,000	12,000	75,200	23,220
	Roof type	Steel deck/ builtup roof	Non-vented, flat roof	Steel deck/ builtup roof	Steel deck/ builtup roof
	Insulation				
	1800DD	R-9	R-7	R-9	R-9
	3600DD	R-10	R-8	R-10	R-10
	5400DD	R-12	R-10	R-12	R-12
	7200DD	R-14	R-13	R-14	R-14
	Roof area, SF	18,000	14,100	43,200	22,320
	Percent glass	20%	16%	9.6%	2%
	U-value/SC (BTU/HR·SF·°F)				
	1800DD	1.13/0.93	1.13/0.93	1.13/0.93	1.13/0.93
	3600DD	1.13/0.93	1.13/0.93	1.13/0.93	1.13/0.93
	5400DD	1.13/0.93	1.13/0.93	1.13/0.93	1.13/0.93
	7200DD	0.60/0.79	0.60/0.79	1.13/0.93	1.13/0.93
Interior	Door area, SF	32	32	32	32
	Equivalent Perimeter, ft	(1)	(1)	(1)	(1)
	Maximum No. of people	326	231	1,266	223
	Peak electric, BTU/HR	350,084	177,345	971,945	266,555
Interior	Floor area, SF	65,800	25,900	326,700	119,880
	Volume, ft ³	658,000	310,800	5,697,000	2,157,840
	Roof area, SF	31,900	25,900	226,800	119,880
	No. of People	627	469	6,534	1,198
	Peak electric, BTU/HR	673,554	360,065	5,016,340	1,431,661
Building	Domestic hot water, BTU/HR	191,829	92,960	1,035,840	-----
	Max. cooling cap., BTU/HR				
	1800DD	2,919,046	1,752,735	15,623,997	4,759,011
	3600DD	2,792,893	1,684,391	15,104,807	4,670,540
	5400DD	2,666,741	1,616,046	14,565,612	4,581,169
	7200DD	2,540,588	1,547,702	14,066,428	4,491,798
	Overall thermal conduc- tance (UA), BTU/HR °F				
	1800DD	18,096	18,591	85,040	31,027
	3600DD	17,471	17,630	82,259	28,708
	5400DD	16,145	16,297	78,139	25,801
	7200DD	13,004	13,484	75,244	23,440

(1) Refer to Table 3-11

Table 3-11
Equivalent Slab Perimeter for TRNSYS Type 19

Building Type	Equivalent Perimeter (FT.)			
	Degree Day Region			
	1800DD	3600DD	5400DD	7200DD
3-Story office (1)	9,291	5,404	2,956	2,956
10-Story office (1)	8,455	4,918	2,690	2,690
Hospital (1)	10,325	6,004	3,281	3,281
Retail store (2)	1,923	1,499	1,093	860
Elementary school (2)	1,152	899	656	515
High school (2)	2,306	1,801	1,309	1,030
Industrial (2)	2,976	2,323	1,690	1,329
Shopping center (2)	4,405	3,602	2,621	2,060

(1) Over unheated space

(2) Slab with different insulation at edges

Table 3-12

Non-Residential Space Heating and Cooling Load Summary

Building type	Gross floor area (SF)	Perimeter zone floor area (%)	Interior zone floor area (%)	Cooling peak requirement (SF/Ton)		Heating peak requirement (BTU/HR/SF)	
				1800 HDD (F°)	7200 HDD (F°)	1800 HDD (F°)	7200 HDD (F°)
Office							
3 story	40,500	61	29	303	331	10.1	16.4
10 story	144,000	48	37	316	329	7.9	15.3
Retail store	40,000	35	65	274	310	9.6	16.1
Shopping center	390,000	16	84	307	341	7.4	14.5
School							
Elementary	20,000	41	59	289	342	10.0	13.9
High school	100,000	34	66	411	472	6.1	9.5
Hospital	60,000	67	33	220	262	14.7	23.4
Light industrial	142,000	16	84	367	387	7.4	12.1

1 Ton = 12,000 Btuh

REFERENCE SOLAR HEATING AND COOLING SYSTEMS

The design and selection of a solar heating and cooling system is heavily influenced by economics (first or capital costs) and local climatology. The available literature was reviewed in an attempt to obtain a specific classification of solar system configurations for establishment of preferred concepts to be utilized in the impact study simulations. This review indicated a widely diverse population of existing designs and concepts. Thus, it was concluded that in view of the traditional wide diversity of building architecture and construction techniques within the building industry, most of the basic solar system configuration could be considered for application to future construction.

4.1 CLASSIFICATION OF SOLAR SYSTEMS

Four generic solar heating and cooling systems are illustrated in Figure 4-1, being distinguished by the solar heat transfer media (liquid or air) and coupling of specific thermodynamic cycles (heat pump or absorption refrigeration) with the collector/storage tank subsystem. This classification was selected to aid the subsequent simulations and does not necessarily represent all possible configurations. It was assumed that the auxiliary (backup) source is provided by electric power. These four generic systems, plus solar domestic water heating, are discussed briefly below.

Direct Liquid Solar Heating Systems. This system configuration may require the use of a heat exchanger between the collector array and storage tank depending upon the choice of collector heat transfer fluid. The preheating of domestic hot water is optional. The point of auxiliary energy input can be either a resistance element within the storage tank (for the load management option), a series auxiliary heater (boiler) in the heating water supply, or direct auxiliary input to the heated space. Average operating temperatures typically range from 120°F to 140°F. It should be noted that the auxiliary input to the space could be a parallel configuration heat pump, as well as a resistance heating element, within an air duct.

Direct Air Solar Heating Systems. The system configuration represented in Figure 4-1 may include the option of domestic water preheated by use of coil element buried in the rock bin. Auxiliary input may be input directly to the rock storage bin by the use of resistance wire in the rock bin for a load management option. Resistance heaters may be used to boost the heated air stream temperature or auxiliary energy may be input directly to the heated space by other means.

Heat Pump/Solar Heating Systems. The system represented in Figure 4-1 is a series configuration solar augmented heat pump. Auxiliary energy may be input directly to storage for load management or to the heated space. The auxiliary input to the space may be an air source heat pump, thus creating a dual-source heat pump. Recent studies (Ref. 50-53) have indicated that parallel (or dual-source) solar augmented heat pumps perform significantly better than series (or single-source) solar augmented heat pumps. However, the conclusions have been based upon long-term seasonal performance and not upon short-term demand characteristics. Since air source heat pumps require increasing auxiliary energy input as outside air temperature decreases below the balance point of the particular application, significant differences in demand profile might result, thus both systems must be considered. Typical storage tank operating temperatures are between 80°F and 100°F for the series mode of operation.

The use of a bypass mode, converting the system to a direct solar heating system if the tank fluid temperature can meet the load, is optional. Simulation studies (Ref. 50) have not conclusively demonstrated that inclusion of this mode significantly increases performance.

Solar Absorption Cooling Systems. Several different solar assisted refrigeration cycles are currently under development such as Rankine cycle chillers, ammonia absorption cycle chillers, and desiccant absorption cycle equipment. However, current technology and commercial applications are using LiBr absorption cycle chillers. Since these machines are the only nonresearch items available to interface with a solar system, it was assumed that the LiBr absorption chillers will be the only refrigeration equipment compatible with solar systems for the impact study period.

Referring to Figure 4-1, several operating options exist such as direct input of collector fluid to the absorption unit, auxiliary input to the heating water supply, or parallel operation with conventional cooling equipment. The input of energy to the tank, while feasible, is not recommended due to the high temperatures (180°F to 200°F) required for the cycle.

A summary of the expected viability of the generic SHAC systems and various backup systems is given in Table 4-1. The backup systems are differentiated primarily by where the backup energy is inserted (storage, heating fluid, or heated space) and how it is generated (resistive or heat pump). Essentially all applicable combinations are considered viable except for resistive heating of the storage fluid in solar absorption cooling.

Domestic Water Heating. As mentioned in Section 1.0, solar domestic water heating is considered viable for both retrofit applications and new construction. However, the combination of solar space heating and solar hot water heating is not likely to have a large retrofit penetration.

Solar domestic water heating designs often include two tanks. The solar system acts as a preheater providing hot water at temperatures determined by the collected solar energy in the first tank. The preheated water is fed as required to the second tank which is maintained at the required temperature (typically, 140°F).

4.2 SYSTEM DESIGN CONSIDERATIONS

The following items are representative of the factors which influence system configuration.

Regional Climate. A regional factor which influences system configuration is the minimum winter temperature to be expected. For minimum temperatures less than 30°F, an antifreeze solution is recommended as the collector heat transfer fluid. The introduction of antifreeze requires the use of a collector/tank heat exchanger. Another regional factor would be the incidence of long, high temperature weather associated with clear skies. This combination would assist solar absorption cooling.

Compatibility with Building Type and HVAC System. Large buildings with requirements for HVAC zone control would not be candidates for direct air heating systems due to storage volume requirements and the fan sizes required to move air large distances. Building architecture and specific site location restrictions can inhibit placement of collector arrays.

Engineering and Control Complexity. Simple direct liquid and air solar systems for small buildings require a minimum of engineering input to assure performance but the interface of a solar system with large HVAC distribution systems requires considerable engineering effort. The dominant engineering effort is concerned with the controls and control logic necessary to achieve the performance objectives.

Economic Factors. The major factors concerning system configuration are economic tradeoffs made during design. A solar system configuration should be optimized on a life-cycle cost basis. However, the constraints such as available capital and physical building configuration limit the design of an optimized system. For example, the results of a life-cycle analysis might dictate a given tank size which cannot be accommodated within a given building configuration without building enlargement. Thus, rather than increase the building structural costs, the tank might be buried outside the building. In this case, additional piping and exterior quality insulation would be required thus increasing solar system costs. This, in turn, might influence the control system design by using lower cost control elements. System performance would also be affected since the buried tank heat loss is an additional thermal system load rather than a heat gain to the space.

4.3 SYSTEM COMPONENT SIZING PROCEDURES

Solar systems cannot be economically sized to supply 100% heating or cooling. Rather some fraction of the required heating or cooling load should be selected on the basis of a life-cycle cost analysis. Since future economic behavior is uncertain, the approach adopted for the simulation study is to arbitrarily vary the solar fraction for SHAC systems by 25%, 50%, and 75% solar fractions and then define three separate solar systems which each meet one of the required solar fractions.

Simulation of each solar system then established the demand differential as a function of solar fraction. For solar domestic water heating, solar fractions of 50% and 80% were chosen.

Several simplified collector area sizing procedures are the subject of current research (Ref. 39-49). The purpose of these procedures is to provide quick, approximate estimates of solar system performance for preliminary design purposes. Once the collector area is specified (for a given solar fraction), the remainder of the system descriptive parameters may be determined from simple normalized (collector area as normalization base) coefficients. These simplified sizing procedures were used for the definition of the solar systems for the simulation study.

Direct solar space heating systems may be sized by either the methods of References 40 or 41. The joint conclusion of References 40, 41, 43, and 44 are that the performance of either the liquid or air solar systems are identical for the same solar fraction. The method of Reference 41 was applied in the numerical definition of the solar heating systems used in the simulation study since the results have been presented (Ref. 40) on a wide geographic base. Values of load/collector ratio, LC, defined as the overall thermal conductance per sq ft of collector area are listed in Table 4-2. Figure 4-2 is an example of the same information in terms of geographic contour plots for 50% solar fractions.

The overall thermal conductances required in the collector sizing were given in Tables 3-6, 3-7, and 3-8.

The sizing method of Reference 46 is the only one available for both solar heating and cooling. The procedure is the result of simulation studies as shown in Figure 4-3. A basic input parameter is an estimate of the total annual energy requirements (both heating and absorption cooling). The cooling input energy was determined from the estimated equivalent rated full-load hours tabulated in Reference 18 while the annual heating requirement was estimated by the degree-day method.

The method of Reference 41 may be utilized for series heat pump collector sizing. The use of the series heat pump configuration results in a 25% reduction in collector

area, however, the solar fractions are limited to less than 60%. Parallel heat pumps may be considered as using conventional air source units (including resistive backup to the heat pumps) as the auxiliary. The usual design practice for air-air heat pumps is to size on the basis of peak cooling requirement and let the peak heating requirement be satisfied by the resulting size heat pump and auxiliary electric resistance heating. A heat pump sized for peak cooling in Columbia, Missouri, will easily satisfy a large portion of the peak heating load; however, a system sized for peak cooling in Madison, Wisconsin, meets less of the peak heating load, but the selection of the next larger heat pump cannot be justified on a cost basis.

Reference 46 also presents a universal curve (shown in Figure 4-4) for determining collector size when the annual hot water requirements, annual insolation available, and the desired solar fraction for hot water heating are given. For this study design solar fractions of 50% and 80% were considered.

The normalized system parameters associated with the "standard" systems of Reference 40 are given in Table 4-3 for the direct liquid system and Table 4-4 for the air system. As shown in the example of Figure 4-5, the performance of air and liquid systems are very similar. Comments on the selection of the direct liquid SHAC system components parameters follow:

Collector. The effects of collector tilt and orientation have been analyzed frequently (Ref. 39, 40, 41). The resulting optima have been shown to be relatively insensitive within $\pm 10^\circ$. For this study a tilt of latitude plus 10° was used for space heating and a tilt equal to the latitude for year-round requirements. The orientation was due south in both cases. The curves used for determining collector performance parameters are given in Figure 4-6 from Reference 41 and the assumed effect of wind speed is shown in Figure 4-7.

Storage. The effect of variance in the amount of solar storage (above minimum values) for heating and/or cooling is small. The commonly used value of 15 lbs of water for each sq ft of equivalent single-glazed collector was used here. Storage for load management systems was sized to provide 24 hrs of design-day energy

requirements. For space heating systems the heating coil was sized to provide this energy in an eight-hour period. For solar domestic water heating-only systems, the heating coil used in conventional systems is generally adequate.

Heat Exchangers and Coils. A solar heating system using a liquid medium requires a heat exchanger as interface with the warm air distribution system. A constant effectiveness coil model was used for simplicity in the simulation. The minimum heating coil capacitance rate for the residential reference building set was defined in Section 3.0. The design conditions and procedures used for calculation are given in Table 4-5.

Absorption Chillers. The capacity of conventional absorption chillers must be derated to the 180°F to 200°F generator operating temperatures for solar cooling applications. At least one manufacturer (Arkla) now has commercially available units designed and rated for solar cooling.

4.4 SOLAR PERFORMANCE MODELING

The SHAC systems simulated were selected as representative of the various possible configurations of the generic systems discussed in Section 4.2. The configurations of the solar heating systems selected are shown in Figure 4-8. Since as indicated in Section 4.1, the performance of air and liquid solar heating systems are very similar; only the liquid based systems were simulated. Direct solar system heating was considered with and without a thermostatically controlled nighttime storage capability for load management. The solar assisted heat pump system selected was the parallel system discussed in Section 4.1. As pointed out in that Section, the parallel heat pump system may be superior to the series configuration in terms of performance and it is definitely much simpler to simulate. The simulation results should be representative of either system.

The conventional space heating systems selected for comparison with the SHAC systems were resistive heating and conventional heat pumps. Conventional air conditioning was simulated with the heat pump models in the cooling mode.

Thermostatically-controlled load management systems without solar input were also simulated. For domestic hot water heating the only systems simulated were resistive heating, direct solar, and load management. For meeting cooling loads the systems simulated were solar absorption cooling with electric backup and conventional heat pumps in the cooling mode.

4.4.1 Conventional System Performance Models

The resistive heating systems were assumed to be nearly 100% efficient. Thus the thermal load also represented the demand and no simulations were required.

The standard TRNSYS heat pump module requires the user to supply performance data for a particular manufacturer's device. At each timestep of the simulation, the ambient wet- and dry-bulb temperatures are used to compute a nominal capacity from the manufacturer's table of values to provide a more flexible, parametric heat pump model independent of specifications and sizing for specific hardware. A new module was designed incorporating the same control logic as the original TRNSYS heat pump, but substituting a series of equations for the tabulated manufacturer's data. The equations were adapted from Reference 54 and include differences between commercial size devices and residential machines. These models also reflect changes in performance between the heating, the heating with defrosting of evaporator coils, and the cooling modes.

The load management simulation assumed a thermostatically-controlled tank that stores sufficient energy during the nighttime hours to offset loads on a design day. The particular control scheme adopted was: if the storage tank temperature drops below 140°F between the hours of 10PM and 6AM, then an electric heating coil boosts the temperature back up to 140°F. The tank was assumed to be located in a heated space so that tank losses were given up to the space. The purpose of this system is to significantly reduce daily peak period utility demands and to take advantage of the usually lower off-peak costs of production.

Conventional domestic hot water heating assumed a 100% efficient resistive system meeting the hot water load plus tank losses. The load management simulation was similar to that used in the space heating load management simulation.

Conventional cooling was simulated by heat pumps in the cooling mode.

4.4.2 SHAC System Performance Models

The essential ingredients of the direct solar heating system were the following TRNSYS modules: a processor to compute the amount of insolation impacting the collector, the collector, a pump for circulating the collector fluid, a heat exchanger, a pressure relief valve, a pump controller, a storage tank, and a pump for circulating fluid from the cold side of the heat exchanges to the tank.

The solar processor uses the input insolation falling on a horizontal plate to compute the insolation on a tilted collector facing a given direction. The processor takes into account the day of year and time of day in order to make the correction from horizontal values of insolation to the tilted value.

The collector module chosen in TRNSYS was modified by adding a variable loss coefficient capability to accommodate collector loss coefficient variability with wind speed.

The pump module operates in an on/off fashion, the signal coming from a controller to be described later. The first pump in the system circulates the collector fluid through a heat exchanger and back to the collector. It is sized according to the collector area. The circulating fluid was assumed to contain ethylene glycol, and as such, could not contact the potable water supply. A heat exchanger was therefore inserted into the system to provide a method of transferring the collected energy to the storage tank. In heat exchanger model utilized in the simulations, the effectiveness is taken as a constant and the energy transferred across the heat exchanger is the effectiveness (0.5) times the maximum energy transfer possible. Thermal flow rates on both sides of the exchanger were equal.

In order to simulate an actual solar installation as closely as possible, a pressure relief module was inserted in the system to prevent temperatures from reaching the boiling point of the collector fluid. The module is designed to vent enough energy from the system so that the fluid will not boil away.

An essential component of the system is the controller which regulates the circulation of the collector fluid. TRNSYS provides a module which compares the collector temperature to the tank temperature, turning the pumps on only when the collector temperature reaches a tank temperature of 18°F and turning the pumps off when the collector temperatures is within 1°F of the tank temperature. Both pumps are controlled by the same module since no exchange of energy takes place if either side of the heat exchanger has no flow.

The storage tanks tend to be of moderate size and the tanks were modeled with one node (i.e., one differential equation). In most cases these tanks were assumed to be in the heated space during the heating season so the losses from the tank contribute to the heating of the structure.

A second pump was required in our design to circulate fluid from the tank to the heat exchanger. This flow rate to the tank was chosen to maximize the amount of energy removed from the collector side of the heat exchanger. The pump was controlled in the same fashion as the collector pump.

The operational mode chosen for this study was that the maximum energy possible was extracted from the tank and auxiliary energy was added to just meet the thermal load (heating). For the water-air heat exchanger that provides energy to the heated space, an effectiveness of 0.8 was used. The model then computes the return temperature of the fluid to the tank after it has heated the space. The auxiliary energy computed was that energy required to backup the solar system.

For simulating a direct solar heating system that would have the capability to store backup energy requirements during the nighttime, the conventional load management tank and coil sized for nonsolar application replaced the solar energy storage

tank. Because of the higher tank temperatures maintained by this approach, the collector performance was reduced. Optimization of the overall system would have improved this performance somewhat, but was not included in this study.

For the solar assisted heat pump system simulation a heat pump module was added in parallel to the direct solar heating system described above. The load which the heat pump met was that auxiliary energy required by the solar heating system.

The solar domestic hot water system simulations were patterned after the direct solar space heating simulations except that tank losses were system losses. The backup system was resistive.

The solar absorption cooling simulation was based directly on the TRNSYS module for such systems.

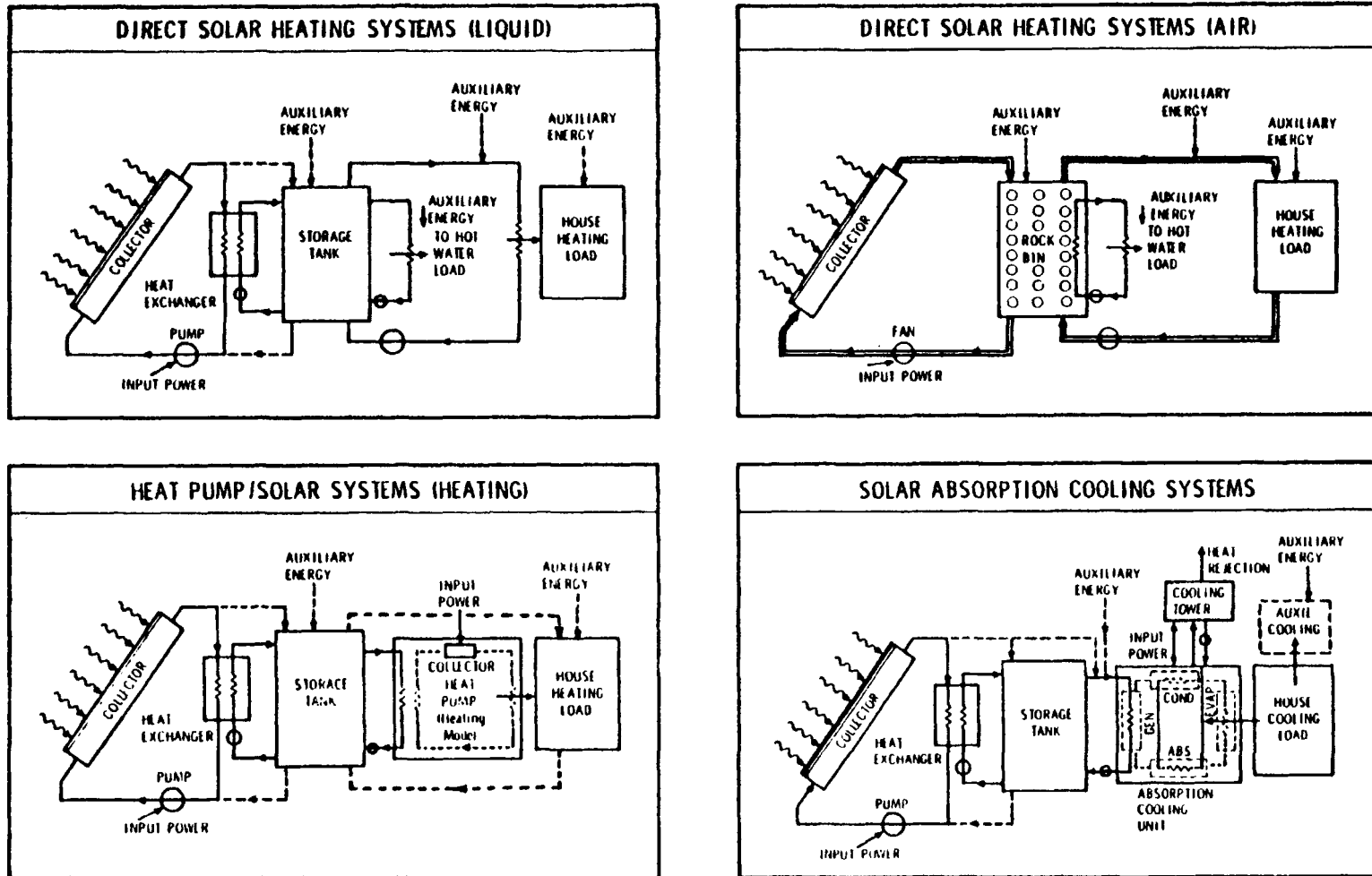
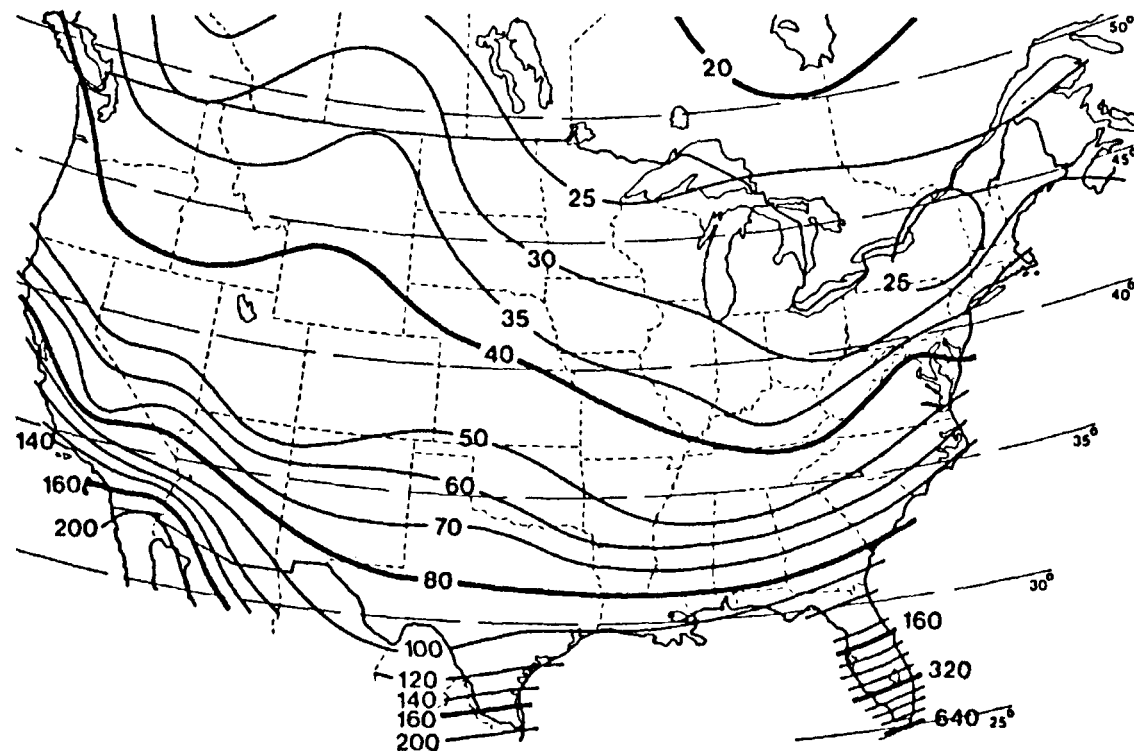


Figure 4-1
Generic Solar Heating and Cooling Systems



building load (btu/dd)
collector area (sq.ft.)

50 %
solar fraction

los alamos scientific laboratory

SOURCE: Reference 40

Figure 4-2
 Load-Collector Ratio

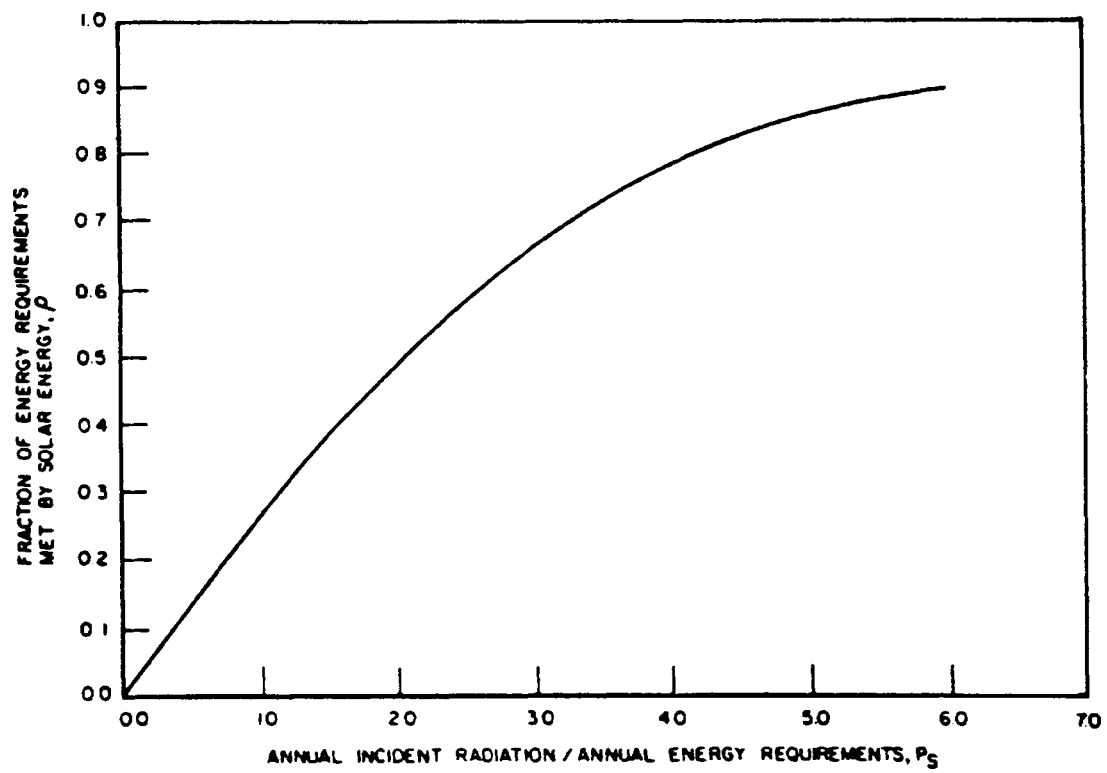


Figure 4-3
Universal Curve for Solar Heating and Cooling Systems

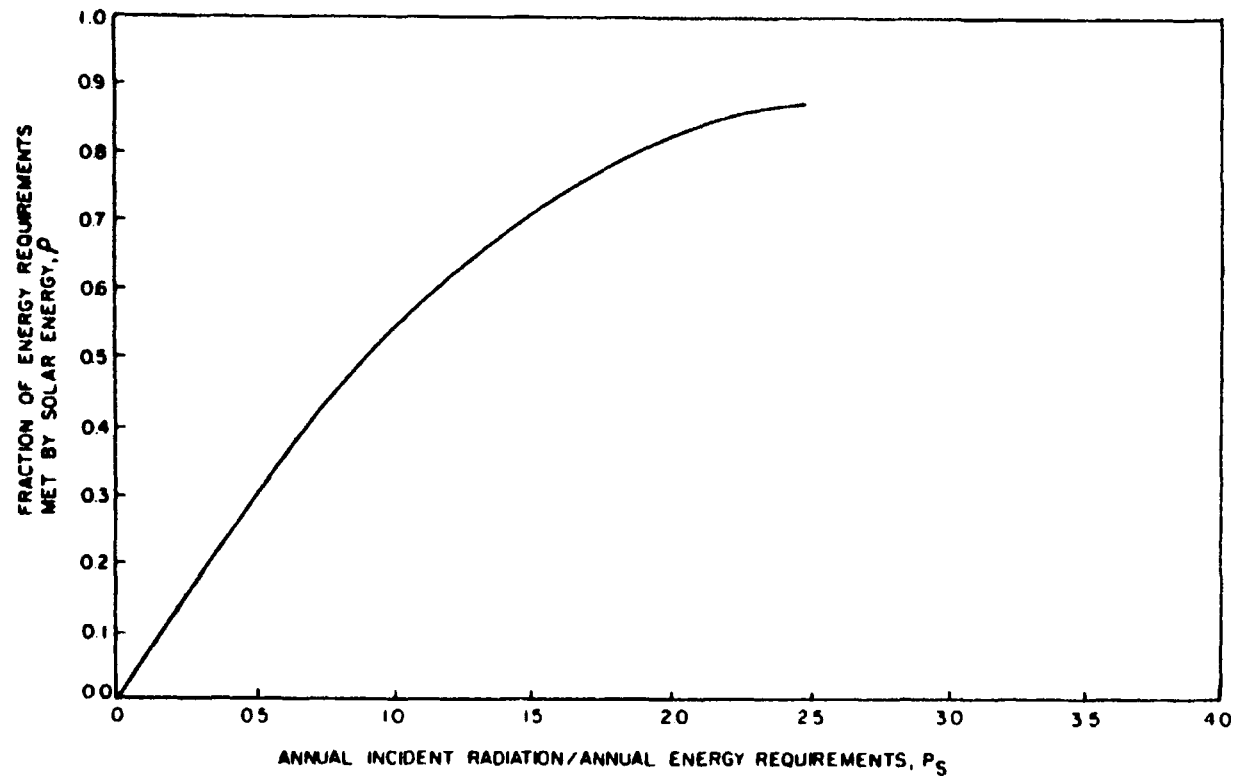


Figure 4-4
Universal Curve for Hot Water Heating with Solar Energy

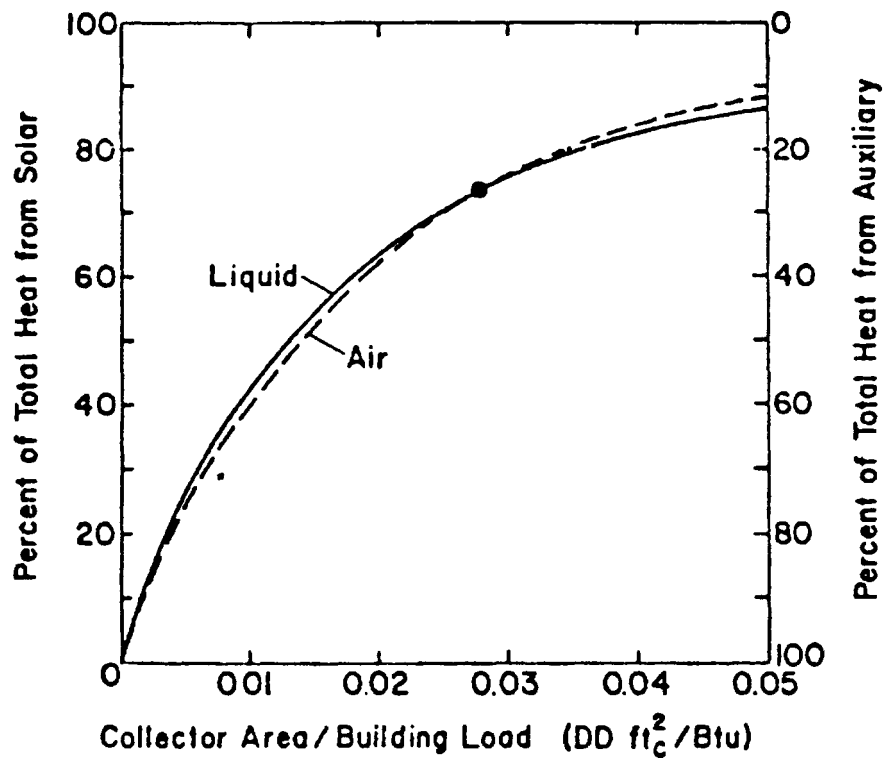


Figure 4-5
Comparison of Air and Liquid Space Heating Systems in Fresno

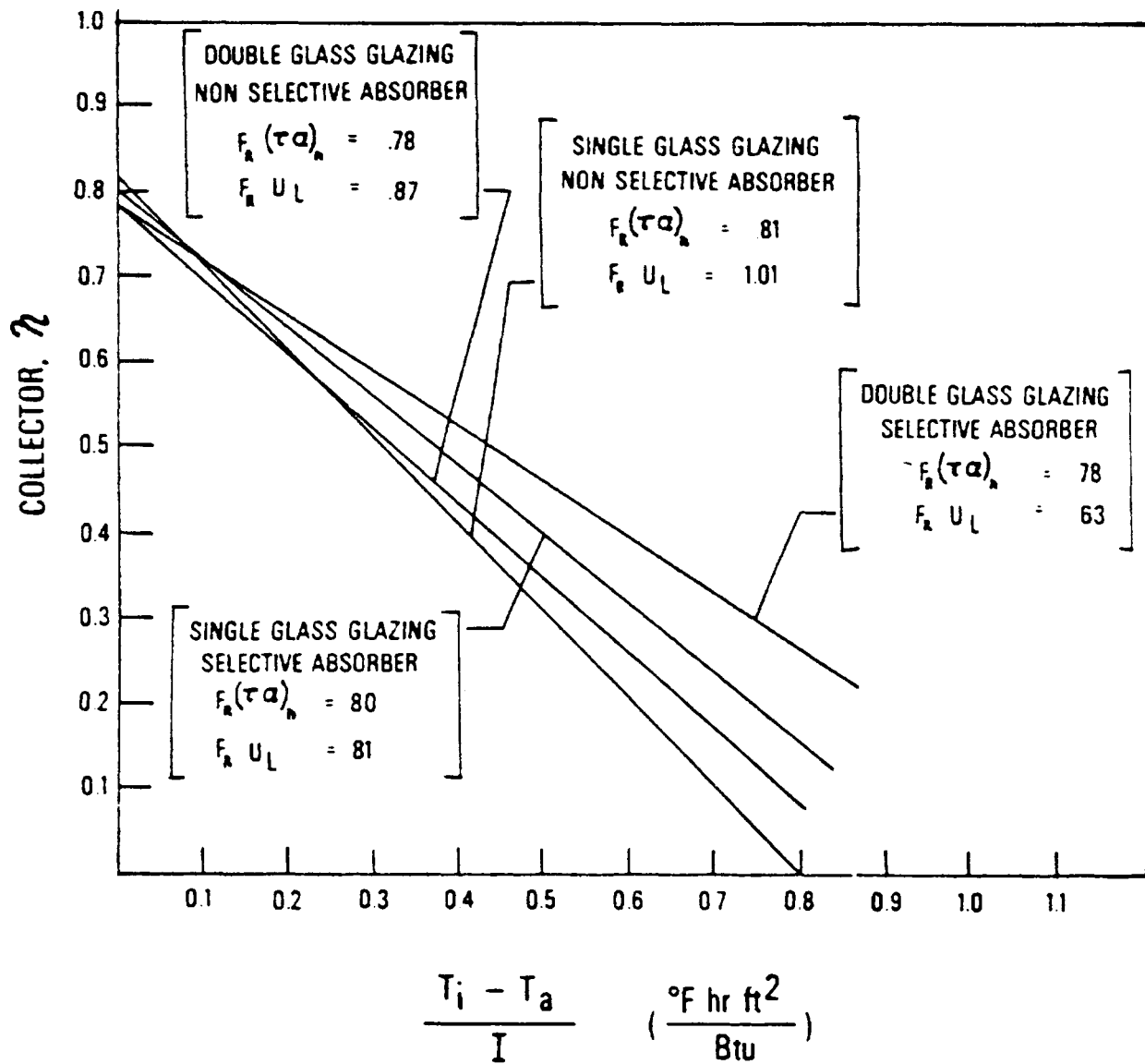


Figure 4-6
Efficiency Curves for Typical Flat Plate Collectors (Liquid)

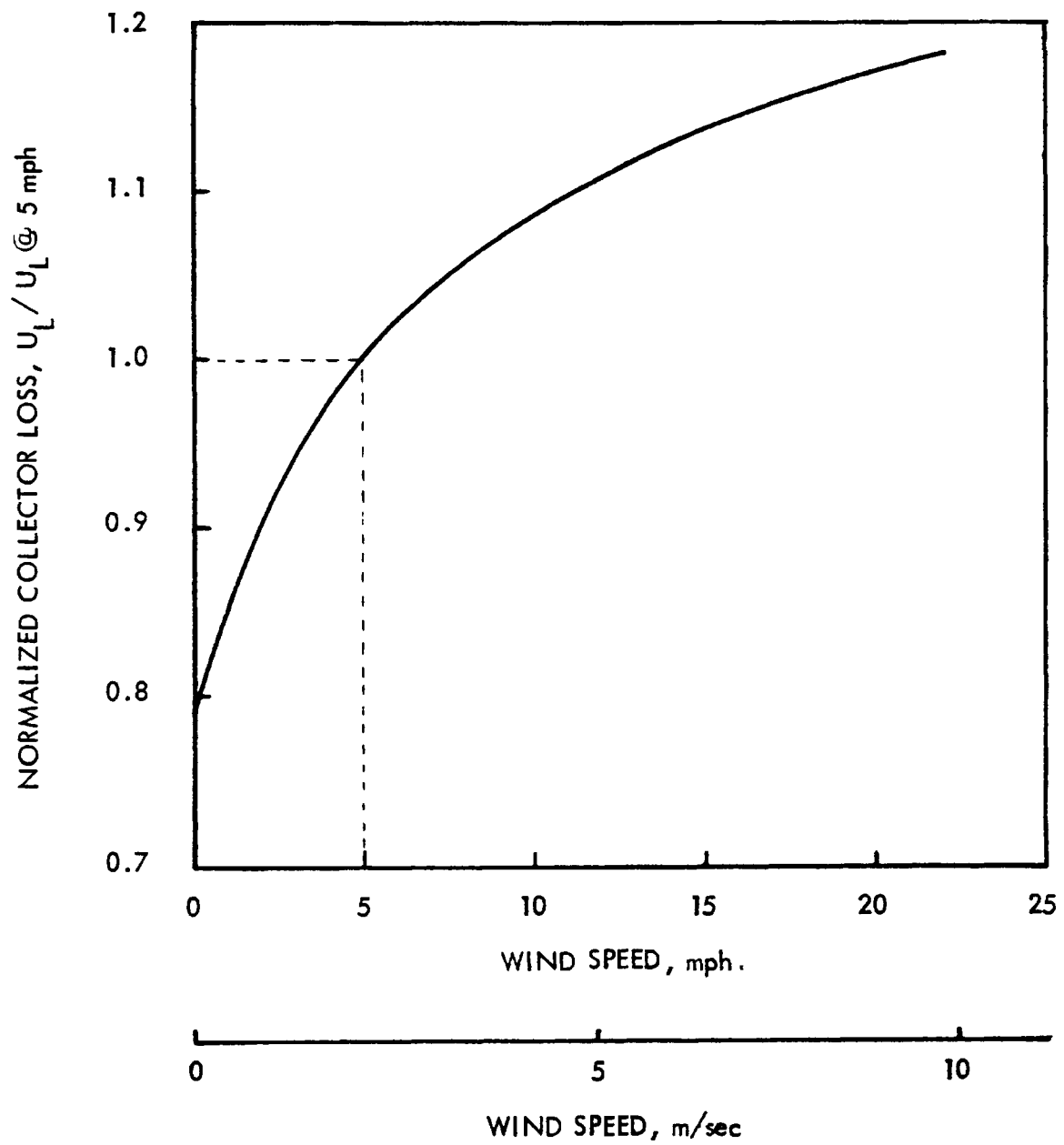
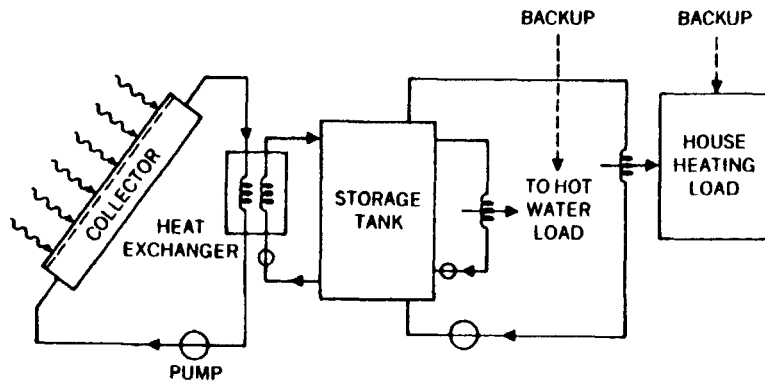
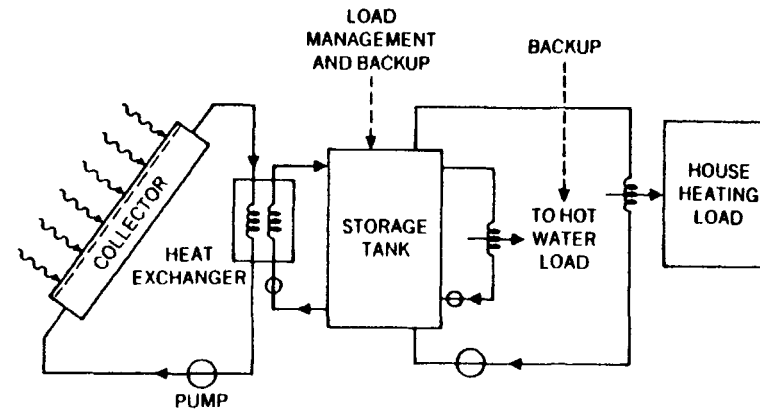


Figure 4-7
Collector Loss Coefficient
Correction for Wind Speed

DIRECT SOLAR HEATING SYSTEMS (liquid) WITHOUT LOAD MANAGEMENT



DIRECT SOLAR HEATING SYSTEMS (liquid) WITH LOAD MANAGEMENT



SOLAR-ASSISTED HEAT PUMP (parallel configuration)

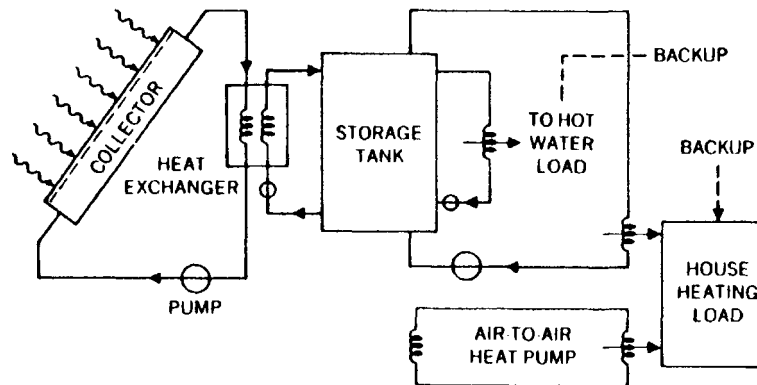


Figure 4-8
Solar Heating Systems Considered

Table 4-1
SHAC System Configurations

		AUXILIARY SYSTEM			
		RESISTIVE HEATING (AIR SUPPLY)	RESISTIVE HEATING (HEATING FLUID)	RESISTIVE HEATING (STORAGE)	AIR-AIR HEAT PUMP (with resistive heating)
SHAC SYSTEM	DIRECT LIQUID	Viable concept	Viable concept for central hydronic heating systems	Viable concept for load management; needs study and validation	Viable concept; studies indicate is preferred option
	DIRECT AIR	Viable concept	Not applicable	Viable concept for load management; needs study and validation	Viable concept; requires further development but studies indicate is preferred option
	SOLAR ASSISTED HEAT PUMP (SERIES)	Viable concept; Single source (Water-air) heat pumps that operate over a wide range of water temperature require further development	Viable concept for water-water heat pump systems; operational temperature range requires further development	Viable concept for load management; needs study and validation	Viable concept; dual source equipment requires further development; studies indicate is preferred option
	ABSORPTION COOLING	Not applicable	Viable concept; not cost effective for current economics	Not recommended ----- Cold storage for off-peak chilled water generation recommended	Viable concept; requires further study ----- Electric chiller back-up recommended

Table 4-2
Values of LC for 85 Selected Cities

City, State	Latitude °N	Elevation ft	Degree Days	LC, BTU/degree-day-ft ² where solar provides 25%,50%,75% of total heat		
				25%	50%	75%
Los Alamos, NM	36	7200	6600	107	41	21
Columbus, OH	40	760	5211	77	29	13
Corvallis, OR	45	236	4726	120	42	18
Davis, CA	39	50	2502	198	72	33
East Lansing, MI	43	878	6909	76	28	13
East Wareham, MA	42	50	5891	97	37	18
El Centro, CA	33	12	1458	547	206	97
Flaming Gorge, UT	41	6273	6929	111	43	21
Granby, CO	40	8340	5524	119	47	23
Toronto, Canada	44	443	6827	72	27	13
Griffin, GA	33	1001	2136	217	84	42
Winnipeg, Canada	50	820	10629	63	23	11
Ithaca, NY	42	951	6914	68	24	11
Inyokern, CA	36	2186	3528	232	88	42
ANL, Lemont, IL	42	750	6155	79	30	14
Newport, RI	41	50	5804	97	37	18
Laramie, WY	41	7240	7381	106	42	21
Page, AZ	37	4280	6632	128	48	23
Prosser, WA	46	840	4805	117	41	18
Pullman, WA	47	2583	5542	100	36	16
Put-In-Bay, OH	42	580	5796	68	24	11
Richland, WA	47	731	5941	100	35	15
Raleigh, NC	36	440	3393	133	52	25
Riverside, CA	34	1050	1803	391	152	74
Seattle, WA	48	110	4785	94	33	13
Sayville, NY	41	56	4811	98	38	18
Schenectady, NY	43	490	6650	63	24	11
Seabrook, NJ	39	110	4812	97	37	18
Schreveport, LA	32	220	2184	179	70	35
State College, PA	41	1230	5934	78	29	14
Stillwater, OK	36	910	3725	132	52	25
Tallahassee, FL	30	64	1485	283	113	57
Tucson, AZ	32	2440	1800	301	118	59
Oak Ridge, TN	36	940	3817	111	42	20
Fort Worth, TX	33	574	2405	186	73	37
Lake Charles, LA	30	60	1459	244	96	48
Apalachicola, FL	30	46	1308	324	129	65
Brownsville, TX	26	48	600	517	218	110
San Antonio, TX	30	818	1546	262	103	52
Greensboro, NC	36	914	3805	128	50	24
Hatteras, NC	35	27	2612	204	79	39
Atlanta, GA	34	1018	2961	154	59	29
Charleston, SC	33	69	2033	210	82	41

SOURCE: Reference 40

Table 4-2
Values of LC for 85 Selected Cities
(Continued)

City, State	Latitude °N	Elevation ft	Degree Days	LC, BTU/degree-day-ft ² where solar provides 25%,50%,75% of total heat		
				25%	50%	75%
Nashville, TN	36	614	3578	117	44	21
Lake Charles, LA	30	39	1459	261	104	53
Little Rock, AR	35	276	3219	126	48	24
Oklahoma City, OK	35	1317	3725	134	53	26
Columbia, MO	39	814	5046	102	38	18
Dodge City, KA	38	2625	4986	126	49	24
Caribou, ME	47	640	9767	68	26	12
Burlington, VT	44	385	8269	63	24	11
Blue Hill, MA	42	670	6368	82	31	15
Cleveland, OH	41	871	6351	71	26	12
Madison, WI	43	889	7863	76	28	13
Sault Ste. Marie, MI	46	724	9048	74	27	12
Saint Cloud, MN	46	1062	8879	71	27	13
Lincoln, NE	41	1316	5864	104	39	19
Midland, TX	32	2885	2591	202	79	39
El Paso, TX	32	3954	2700	228	88	44
Albuquerque, NM	35	5327	4348	161	64	31
Grand Junction, CO	39	4832	5641	119	46	22
Ely, NV	39	6279	7733	119	47	23
Las Vegas, NV	36	2188	2709	218	84	42
Phoenix, AZ	33	1139	1765	300	118	59
Reno, NV	39	4400	6632	125	47	22
Santa Maria, CA	35	289	2967	353	142	67
Bismark, ND	47	1677	8851	78	29	14
Lander, WY	43	5574	7870	108	42	21
Glasgow, MT	48	2109	2996	105	41	20
Rapid City, SD	44	3180	7345	97	37	18
Salt Lake City, UT	41	4238	6052	107	40	19
Boise, ID	44	2895	5809	108	39	17
Great Falls, MT	47	3692	7750	93	35	16
Spokane, WA	48	2356	6655	90	31	14
Medford, OR	42	1321	5008	107	38	16
Los Angeles, CA	34	540	2061	416	157	75
Fresno, CA	37	336	2492	195	70	32
Silver Hill, MD	39	292	4224	111	43	21
Cape Hatteras, NC	35	27	4612	189	74	36
Sterling, VA	39	276	4224	111	43	21
Indianapolis, IN	40	819	5699	86	32	15
Astoria, OR	46	22	5186	127	45	19
Boston, MA	42	157	5624	86	33	16
New York, NY	41	187	4871	88	34	16
North Omaha, NE	41	1323	6612	89	34	16

SOURCE: Reference 40

Table 4-3
Standard Liquid System Parameters

Values of parameters used for the "standard" solar heating system using liquid-cooled solar collectors, a heat exchanger, water tank thermal storage, and a forced air heat distribution system to the building. The values are normalized to one square foot of collector (ft_c^2).

Solar Collectors

Number of glazings	1	
Glass transmissivity (at normal incidence)	0.86	(6% absorption, 8% reflection)
Surface absorptance (solar)	0.98	
Surface emittance (IR)	0.89	
Back insulation U-value	0.083	$\text{BTU/hr-}^\circ\text{F-ft}_c^2$
Coolant flow rate	20	$\text{BTU/hr-}^\circ\text{F-ft}_c^2$
Heat capacity	1	$\text{BTU/}^\circ\text{F-ft}_c^2$
Heat transfer coefficient to liquid coolant	30	$\text{BTU/}^\circ\text{F-ft}_c^2$
Tilt (from horizontal)	Latitude + 10 degrees	
Orientation	Due south	

Collector Plumbing

Heat loss coefficient (to ambient)	0.04	$\text{BTU/hr-}^\circ\text{F-ft}_c^2$
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Heat Exchanger

Heat transfer effectiveness	10	$\text{BTU/}^\circ\text{F-hr-ft}_c^2$
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Thermal Storage

Heat capacity	15	$\text{BTU/}^\circ\text{F-ft}_c^2$
Heat loss coefficient (i.e. assuming all heat loss is to heated space)	0	$\text{BTU/}^\circ\text{F-hr-ft}_c^2$

Heat Distribution System

Design air distribution temperature*	120°F
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Controls

Building maintained at 68°F
Collectors on when advantageous

* The coil and air circulation are sized to meet the building load with an outside temperature of -2°F with 133°F water and an air flow rate adequate to make up the space heat losses at an air discharge temperature of 120°F. This corresponds to a finned-tube coil effectiveness of 80%.

SOURCE: Reference 40

Table 4-4
Standard Air System Parameters

Values of parameters used for the "standard" solar heating system using air heating collectors, a rock bed thermal storage, and a forced air heat distribution to the building. Values are normalized to one square foot of collector (ft_c^2).

Solar Collectors

Number of glazings	1	
Glass transmissivity (at normal incidence)	0.86	(6% absorption 8% reflection)
Glass absorptance	0.98	
Glass emittance	0.89	
Back-insulation U-value	0.083	$\text{BTU/hr-}^\circ\text{F-ft}_c^2$
Heat capacity	0.5	$\text{BTU/}^\circ\text{F-ft}_c^2$
Air flow rate	2	CFM/ft_c^2
Heat transfer coefficient to air	4	$\text{BTU/hr-}^\circ\text{F-ft}_c^2$
Tilt	Latitude + 10 degrees	
Orientation	Due south	

Collector Air Ducts

Heat loss coefficient (to ambient)	0.1	$\text{BTU/hr-}^\circ\text{F-ft}_c^2$
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Thermal Storage

Heat capacity	15	$\text{BTU/}^\circ\text{F-ft}_c^2$
Heat loss coefficient (i.e. assuming all heat is lost to heated space)	0	$\text{BTU/}^\circ\text{F-hr-ft}_c^2$
Dimensionless rock-bed heat transfer length*	10	

Heat Distribution System

Air flow rate	2	CFM/ft_c^2
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Controls

Building maintained at 68°F
Collectors on when advantageous

* The rock-bed length (distance in the direction of flow) is greater than 5 times the relaxation length for heat transfer (15 was used in the model). Physically this means that the bed is at least 12 times as long as the rock diameter. It is important to note that the flow direction is reversed in the rock bed, being in one direction during the charging period and in the opposite direction during discharging.

SOURCE: Reference 40

Table 4-5
Winter Design Conditions

T_{ID} = INDOOR TEMPERATURE = 72 °F (ASHRAE 90-75)

REGION	OUTDOOR TEMPERATURE, T_{OD}	$\Delta T = T_{ID} - T_{OD}$	$T_{SUP} - T_{ID}$	$\frac{\epsilon C_{min}}{UA^*}$ ($\epsilon = 0.8$)
1800 °FHDD	37 °F	35 °F	20 °F	1.40
3600 °FHDD	17 °F	55 °F	30 °F	1.47
5400 °FHDD	7 °F	65 °F	35 °F	1.49
7200 °FHDD	-3 °F	75 °F	40 °F	1.50

HEATING COIL SELECTION

T_{SUP} = SUPPLY AIR TEMPERATURE

ϵ = HEATING COIL EFFECTIVENESS

C_{min} = MINIMUM HEATING COIL CAPACITANCE RATE

UA^* = OVERALL THERMAL CONDUCTANCE (INCLUDING INFILTRATION OR OSA)

- HEATING LOAD = $UA^* (T_{ID} - T_{OD}) = C_{min} (T_{SUP} - T_{ID})$
- $C_{min} = UA^* \frac{T_{ID} - T_{OD}}{T_{SUP} - T_{ID}}$
- $\frac{\epsilon C_{min}}{UA^*} = \epsilon \frac{(T_{ID} - T_{OD})}{T_{SUP} - T_{ID}}$

5.0

SIMULATION AND DATA PROCESSING

In Sections 3.0 and 4.0 the reference configurations for buildings and SHACOB systems were given and their simulation models defined. In this Section the overall simulation process is reviewed. This process is depicted in Figures 5-1 and 5-2, beginning with weather data inputs, applying the simulation models, and ending with SHACOB and conventional system demands. The elements of this process, other than the simulation models for the reference systems, are summarized in this Section. Additional details and results are presented in Volume 2.

5.1 WEATHER DATA PROCESSING

The following discussion refers to Items 1, 2, and 3 of Figure 5-1. Weather data tapes from the National Climatic Center were obtained for the Test Reference Year (TRY) for each city in the study (see Volume 1). The data were processed and reformatted with hourly insolation values being synthesized from cloud-cover data as required. A TRNSYS simulation was designed to convert the hourly insolation on a horizontal plate to the average insolation over north, east, south, and west walls. This average insolation was subsequently used to compute changes in wall surface temperature and heating gains through windows.

The results of this simulation were stored on three data files: one representing the weather, insolation and average vertical insolation for a nominal heating season (16 November through 15 March); the second representing the same types of information for a nominal cooling season; and the third representing weather data for the whole year for use in the domestic hot water heating (without space heating) simulations. The use of weather and insolation values will be described in the loads and SHAC simulations discussions below. The average insolation value is used only in the loads processing.

The simulation of building loads was carried out using the models discussed in Section 3.0. These loads were generated at hourly intervals for the season(s) of

interest. The data processing approach used depended on whether residential or nonresidential buildings were being addressed.

Residential. The following refers to Items 5 through 9 in Figure 5-1. The computation of the thermal loads on a residence uses TRNSYS models described in Section 3.0. The computation of the loads requires a thermal loss coefficient for each structure, as well as the volume and set-point room temperature for the structure. Since TRNSYS operates with a specific set of control cards of particular format, a program was created to read in fundamental data about a structure (e.g., floor area, number of stories, foundation type, aspect ratio) and compute the loss coefficient and volume based on these fundamental data. The program writes a file which has all the necessary control cards for one TRNSYS simulation to compute the thermal loads on one structure. This process was repeated as often as necessary to create simulation control data for every type of residence being studied in a particular city.

Another TRNSYS simulation was then designed to use this set of control cards for one building and the appropriate heating or cooling data described in Section 5.1 to produce the hourly heating or cooling loads on the residence considered. This simulation was automated to compute the residential loads for all the building types in a given city with one execution of the program. The insolation and weather inputs were included with the loads output since these weather values were required in subsequent SHAC simulations.

The outputs of the loads simulations were combined with the weather data to produce a single input tape for the SHACOB and conventional system simulations. The components of this tape were:

- Insolation on a Horizontal Plate
- Ambient Dry-Bulb Temperature
- Ambient Wet-Bulb Temperature
- Wind Speed
- Heating Load

- Cooling Load
- Hot Water Load

Nonresidential. Items 10 through 14 of Figure 5-1 cover this category. As discussed above in Section 3.0, the computation of the thermal loads for nonresidential buildings was carried out using the AXCESS program. The loads generated by AXCESS were modified to make them compatible with the TRNSYS format and suitable for the SHAC simulation. The modification process included the addition of necessary weather and insolation values to the AXCESS loads so that the nonresidential SHAC simulation would not require auxiliary weather data tapes. It also included printouts of the hourly primary HVAC system demands.

The time-varying hourly output from AXCESS and the accompanying weather data are:

- Perimeter Cooling Load
- Interior Cooling Load
- North Zone Heating Load
- East Zone Heating Load
- South Zone Heating Load
- West Zone Heating Load
- Ambient Dry Bulb
- Ambient Wet Bulb
- Insolation on Horizontal Plate
- Wind Velocity

5.2 HVAC SYSTEM SIMULATIONS

The component models for the residential and nonresidential (heating, ventilation, and cooling) simulations have been described in detail in Section 4.0. This Section describes the types of data required to execute a simulation, the assumptions concerning the simulation itself, and the types of data retained at the conclusion of a simulation.

The information in Figure 5-2 gives an overview of the HVAC systems simulation program as it was exercised for one structure. This simulation process was repeated three times for every building type in the city since there are three solar fractions (25, 50 and 75%) to be studied for each structure. One execution of the simulation package gives the hourly performance of the six HVAC systems given below.

- Conventional Resistive
- Direct Solar
- Heat Pump
- Solar Assisted Heat Pump
- Conventional Load Management
- Direct Solar with Load Management

As with any TRNSYS application, a HVAC system simulation required a specific set of control cards which describe the order along which the simulation must proceed, as well as describe the parameters and sizing of the modules in the simulation. The sizing algorithms described earlier were combined with a routine which created all the required simulation input for each of the six HVAC systems. This procedure was repeated for each building and each solar fraction.

To maintain integration stability of differential equations describing storage fluid temperature and the nonlinearities arising from system controls, an integration time step of 15 minutes was generally required.

At the conclusion of each simulation for each building and solar fraction, a file was created to store the hourly outputs of the six HVAC systems. For heating computations these variables are the backup demands each SHAC system makes at a particular hour on the electric utility.

5.3 OUTPUT PROCESSING

The simulations described in the previous Section were carried out for each city, building, and solar fraction considered. To assess the impact that these solar

systems would have on a electric utility, three processes were utilized to collect and merge the data from the individual building simulations. These processes can be categorized as:

- Aggregation
- Diversification
- Delta Demand Analysis

For a given year and utility service the aggregate demand from all buildings within a service area having a particular HVAC system was constructed. Data supplied by each participating utility provided the total number of residences (single family and multi-family) in the new construction market that are projected to have resistive heating, heat pumps, and air conditioning. Within these potential markets, the number of residences represented by each of the selected representative buildings was obtained by using the new building construction data presented in Section 2.0. Ratios of building types within each building category (single family, multi-family) were assumed to be independent of the HVAC market addressed. Market data are presented in Volume 2.

The actual aggregation process applied is depicted in Figure 5-3. For a given utility, reference building, solar design fraction, and the corresponding six demand simulations, the demands are multiplied by the number of those reference buildings in the simulated market. The demands are then summed over each building type to get the demands for complete saturation of the new construction market.

The results at this point were then diversified. The SHAC system simulations do not directly account for varying life styles and energy-use patterns of families in the various reference buildings. The effects of this diversity on the aggregate utility demand is significant in terms of the lowering of peaks and raising of valleys. This factor is accounted for by smoothing out the simulated demands with a normal distribution curve that acts as a running average, with points near the time of interest weighted more heavily than those farther away. The equation for this smoothing process is

$$D(t) = \frac{1}{\sqrt{2\pi}\sigma} \int_{t-12}^{t+12} e^{-\tau^2/2\sigma^2} D^*(t+\tau) d\tau$$

where

$D(t)$ = diversified demand, MW

$D^*(t)$ = simulated demand, MW

t = time, hrs

σ = standard deviation, hrs

A one-hour spread or standard deviation of this distribution has been selected as representative of the typical variation energy use. This spread is used in smoothing demands for all the heating systems investigated. The resulting diversity factor (noncoincident peak/coincident peak) is estimated at 1.3 for resistance heating. The 24-hr average demands are essentially unaffected by this smoothing process.

After diversification the alternate advanced system (i.e., SHAC or load management) demands in each conventional market as well as the conventional demand itself was obtained by multiplying the total new construction market demand by the percent saturation of the given conventional system. Load management was considered as both a conventional and advanced alternate system. The latter category includes both load management and SHAC systems.

The resulting demand differences or delta demands were then stored on tape, identified by city, solar fraction, and systems compared.

Two types of summary data were generated for the delta demands. The delta demand profiles provide the maximum, minimum and average values of delta demand for each hour of the day over the season of interest. The delta demand distributions provide the cumulative probability distributions for delta demands at the time of day for the utility system peak.

The delta demand results for each city and utility analyzed are given in Volume 2. In addition, Volume 2 describes the overall delta demand analysis process and provides details on the input data used.

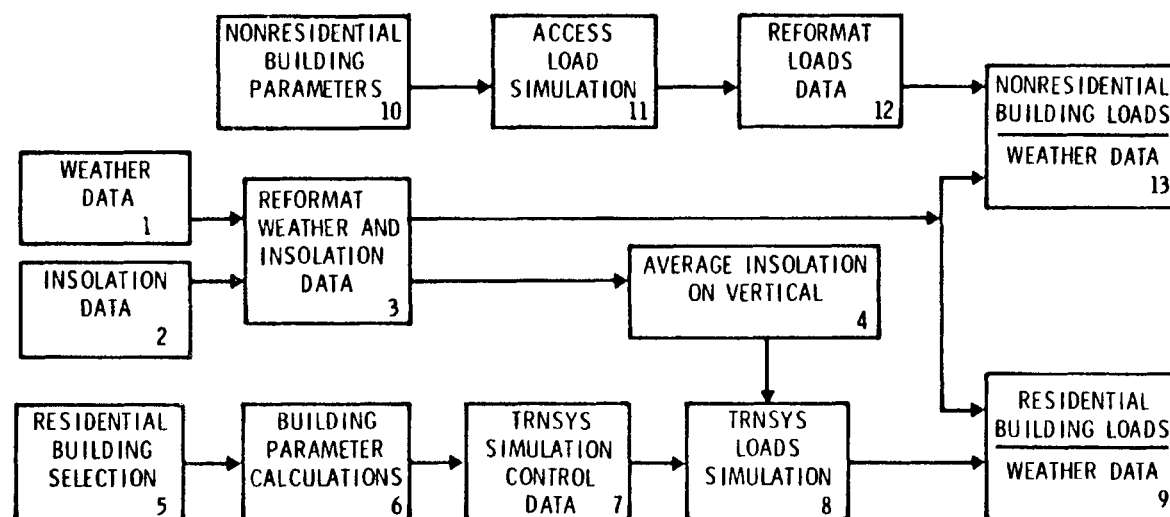


Figure 5-1
Simulation Logic Flow for Building Loads

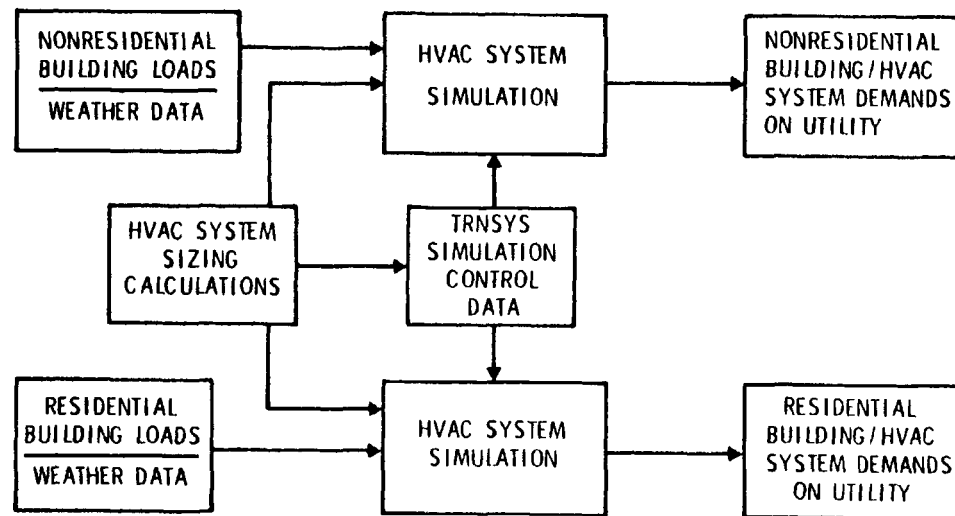


Figure 5-2
Systems Simulation Logic Flow

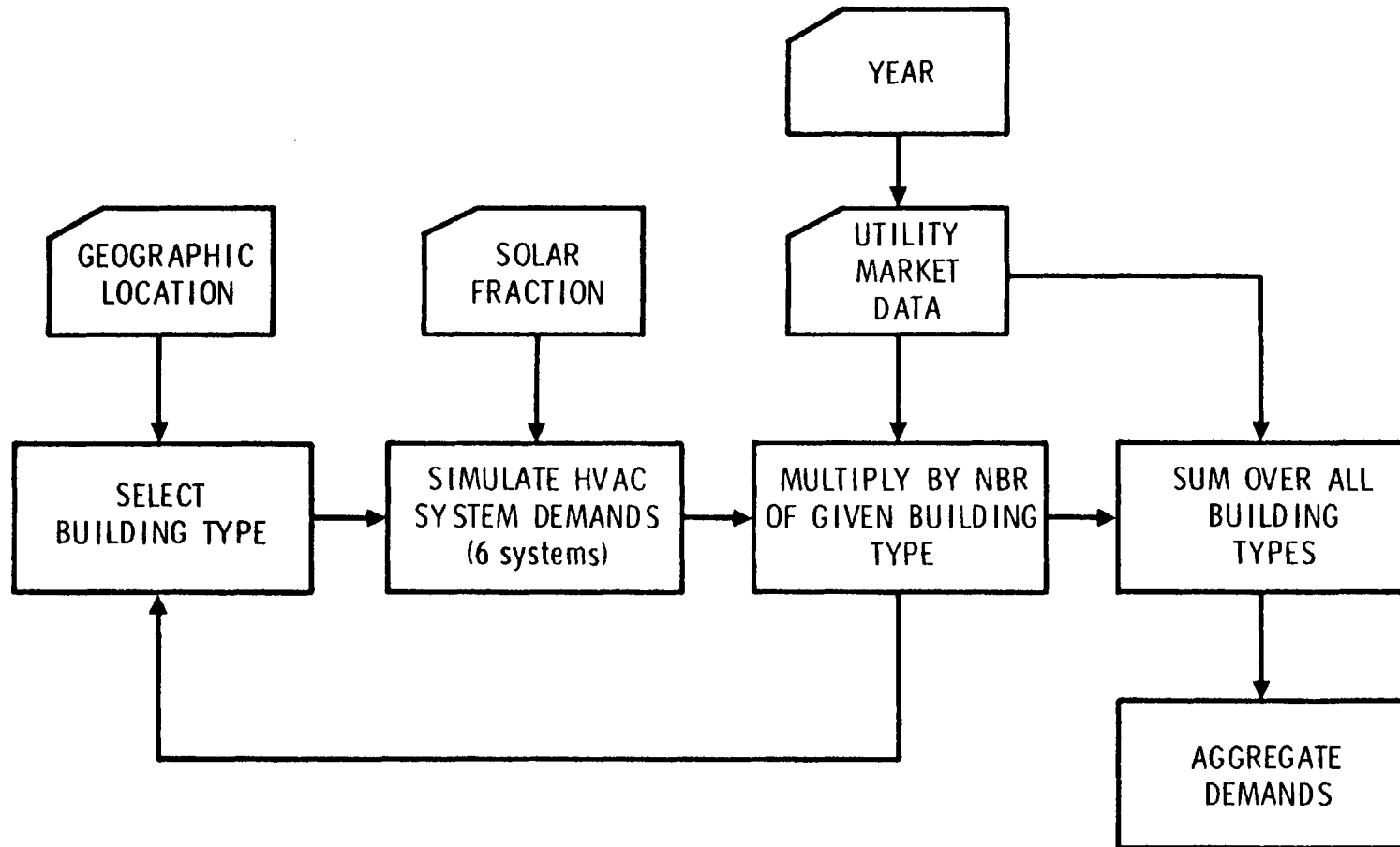


Figure 5-3
Logic Flow for Computing Aggregate Demands

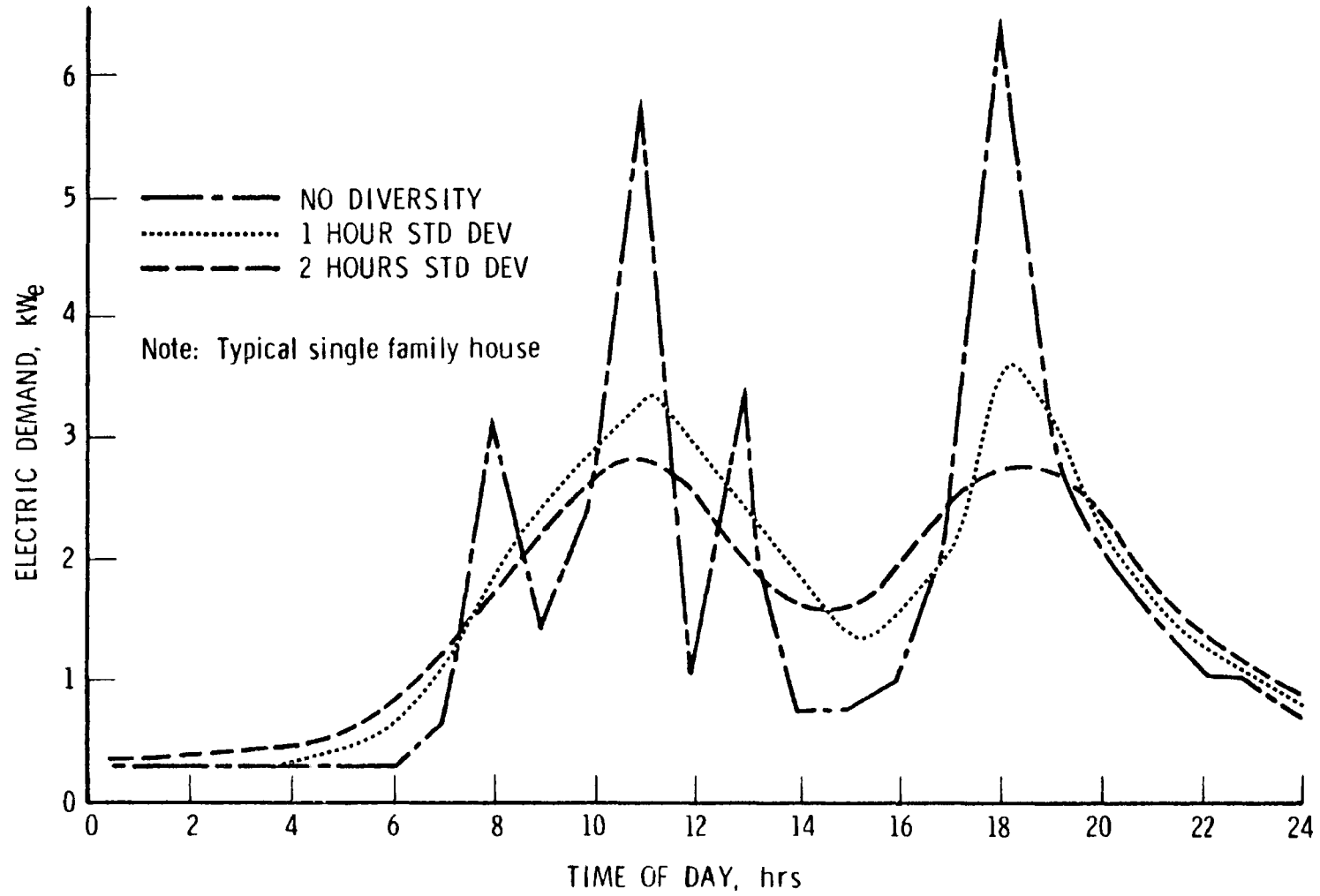


Figure 5-4
Effects of Diversity Model on Demand

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