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Energy Analysis of a Prototype Single-Family Detached Residence:

The Effects of Climate, House Size, Orientation, Internal Heat Release, and Natural Cooling

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ENERGY ANALYSIS OF A PROTOTYPE SINGLE-FAMILY DETACHED RESIDENCE: THE EFFECTS OF CLIMATE, HOUSE SIZE, ORIENTATION, INTERNAL HEAT RELEASE, AND NATURAL COOLING

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ABSTRACT

A computer study was done to determine how the annual heating and cooling requirements of a prototypical ranch style house are affected by changes in four energy use parameters: climate (13 locations), floor area (nominal 800 ft2, 1200 ft2 and 1800 ft2), orientation (north, south, and east/west), and internal heat generation (two different levels in the 1200 ft2 house). In addition, the effects of natural cooling on the annual cooling requirement were investigated.

The results are quantified such that the effects attributable to each variation are easily identified. Also, the heating and cooling requirements of the various sized houses are correlated to degree days.

Some of the more important findings regarding the prototypical house (as simulated in this study) are: (a) annual cooling requirements/unit area decreased with increasing floor area, while (b) annual heating requirements/unit area remained relatively constant regardless of floor area; (c) rotation of a house (with windows on only two facades) significantly affected the annual energy requirements (approximate range 20-50 percent); (d) house internal heat generation significantly affected the annual energy requirements (approximate range 10-50 percent); and (e) annual cooling requirements were significantly reduced (by as much as 48 percent) by the use of natural cooling.

Key words: Building design; building energy performance standards; computer simulation of house energy requirements; degree days; single-family detached residence; energy analysis-- variation of house energy requirements with climate, floor area, orientation, internal heat gains, and natural cooling.

PREFACE

This report is one of a series documenting NBS research and analysis efforts in developing energy and cost data to support the Department of Energy/National Bureau of Standards Building Energy Conservation Criteria Program. The work reported in this document was supported by DOE/NBS Task Order A008-BCS under Interagency Agreement No. EA 77A 01 6010.

The author wishes to acknowledge that this report benefitted greatly from the comments of Paul R. Achenbach, Jim L. Heldenbrand, and Stephen R. Petersen. Special thanks is also given to Dr. T. Kusuda for suggesting the concept of "modified" cooling degree days.

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1. INTRODUCTION

Over the past several years, the increasing cost of energy coupled with the national emphasis on energy conservation has caused building designers to carefully consider ways of designing more energy efficient buildings. Most of this work has relied heavily on computer programs that predict energy requirements of buildings. In addition, regulatory agencies faced with the task of promulgating and enforcing standards have extensively used computer programs to aid them in drafting standards and/or guidelines.

Generally, only a limited number of computer runs are made in selecting an energy-efficient building design. This is because both the computer time and the data preparation and analysis are expensive. Thus, a user can make the most effective use of his computer runs if he has some prior general knowledge of how a change in a particular variable will affect the energy requirements of a building. This report looks at several parameters affecting the energy requirements of a detached single-family house.

The prototype base house design used for the computer simulation was a single-family ranch house. The variation of annual heating and cooling requirements is presented as a function of:

1. Climate - The houses were located in Minneapolis, Chicago, Boston, Albuquerque, Portland (Oregon), Washington, DC, Atlanta, Fort Worth, Fresno, Houston, Phoenix, Los Angeles, and Tampa.

2. House size - The floor areas of the houses were 816, 1176, and 1792 square feet.

3. House orientation - The houses were rotated through three compass directions (south, west, and north).

4. Internal heat release - The 1176 square foot house was simulated with two different levels of internal heat generation.

5. Natural Cooling - The annual cooling requirements of all houses were calculated for both the "windows closed" and "windows open" cases.

2. INVESTIGATIVE PROCEDURE

The base prototype house is shown in Figure 1. The house design was taken from Reference [1] and has been used previously as the house design in several energy analysis studies [2,3,4]. The house is a 1176 ft2 (nominal 1200 ft2) slab-on-grade ranch-style house with 16.4 percent of the total north-facing wall area and 21.4 percent (including a sliding glass door) of the south-facing wall area consisting of double-pane glass. The east and west walls had no windows. The wood-frame walls were assumed to have R-19 insulation in the stud space and the ceiling to have R-30 insulation. A 1.5 ft roof overhang was assumed. Table 1 lists the areas of the various house surfaces as well as their respective air-to-air thermal conductances, absorptivities and/or shading coefficients. The wall constructions used are meant to be cost-effective (though not necessarily optimal) for a cold climate such as Minneapolis. The values for the thermal physical properties of the wall constructions were taken from Reference [5] and were meant to be typical values. Appendix A lists the materials used in the various envelope components as well as their thermal physical properties.

The internal heat gains modeled for the 1176 ft2 house were as follows:

1. Lights = 8000 Btu/day
2. Appliances/equipment = 34600 Btu/day
3. People (sensible) = 10800 Btu/day

These values were selected to give a close approximation to the internal heat generation level for residential housing found in the Department of Energy's (DOE) proposed energy performance standards (BEPS) for new buildings [4]. Appendix A gives the 24-hour lighting, appliance/equipment and occupant schedule.

The base house was operated according to the schedules given in Table 2. The temperature and humidity setpoints were derived from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers's (ASHRAE) Standard 55-74 which is currently under revision. While these conditions do not represent the widest bands that can be accommodated by variations in clothing, they are probably appropriate except during periods of emergency temperature restrictions. The winter and summer hourly air infiltration rates were held constant during their respective seasons. This approach eliminates differences in the final energy

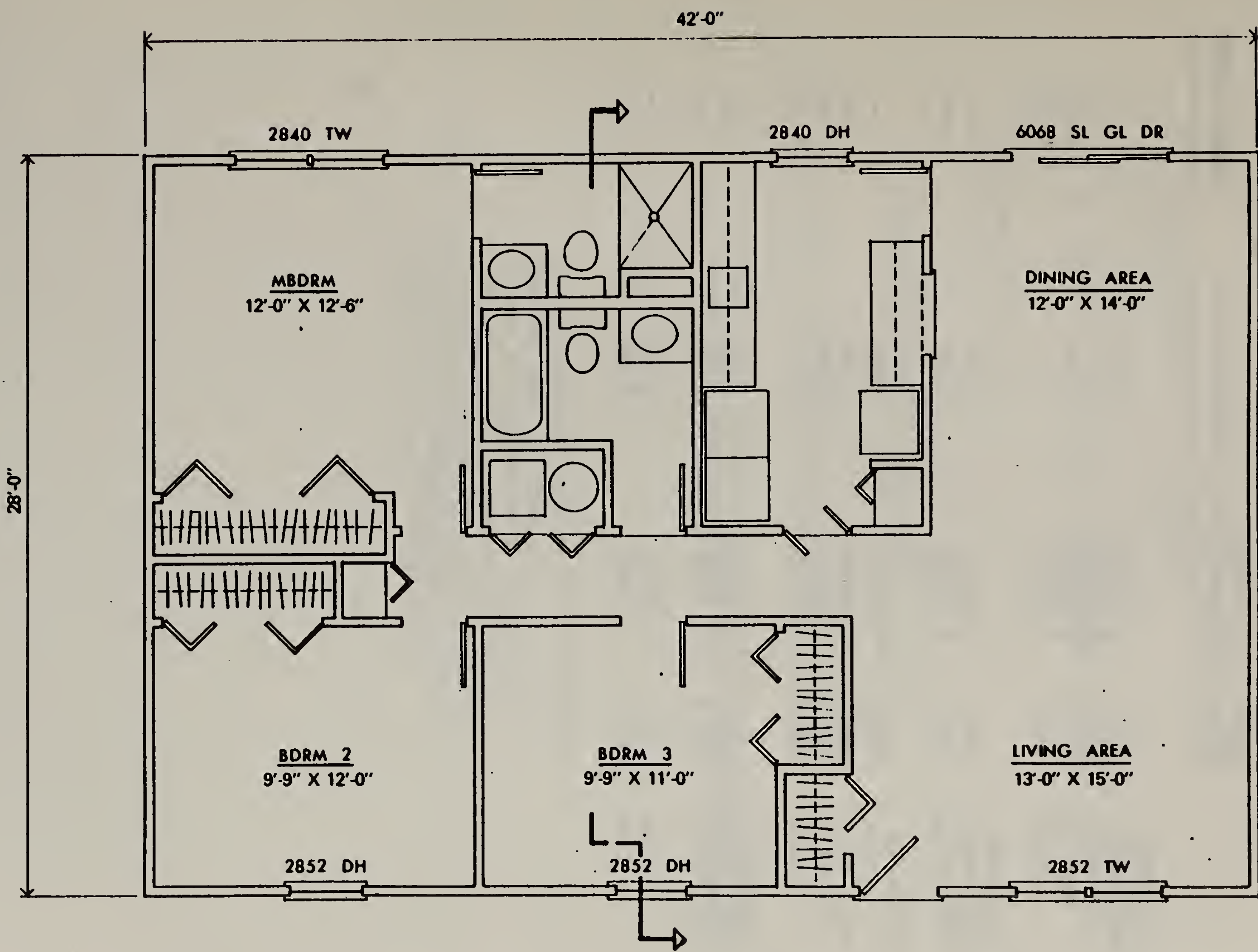

FIGURE 1. FLOOR PLAN OF A TYPICAL RANCH HOUSE

0 2 4 8
3

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TABLE 1

THERMAL PHYSICAL PROPERTIES OF 1176 FT2 HOUSE

	AREA (FT2)	U-VALUE (BTU/HR-FT2-F)	ABSORPTIVITY	SHADE COEFF
SOUTH EXPOSURE				
INSUL WALL	198.0	0.0489	0.50	---
STUD WALL	66.0	0.0736	0.50	---
WINDOW	32.0	0.5600	---	0.52
S/G-DR	40.0	0.5800	---	0.52
WEST EXPOSURE				
INSUL WALL	190.0	0.0489	0.50	---
STUD WALL	34.0	0.0736	0.50	---
NORTH EXPOSURE				
DOOR	20.0	0.4900	0.50	---
INSUL WALL	196.0	0.0489	0.50	---
STUD WALL	65.0	0.0736	0.50	---
WINDOW	55.0	0.5600	---	0.52
EAST EXPOSURE				
INSUL WALL	190.0	0.0489	0.50	---
STUD WALL	34.0	0.0736	0.50	---
CEILING	1176.0	0.0320	0.50	---
SLAB	1176.0	0.1061	0.50	---

TABLE 2

SCHEDULES OF OPERATION FOR HOUSE

A. Space Temperature Setpoints

1. 68 °F $\leq$ T $\leq$ 78 °F (from 0700 to 2300)
2. 60 °F $\leq$ T $\leq$ 78 °F (from 2400 to 0600)

B. Humidity Control

1. During cooling RH < 65%
2. During heating RH > 20%
3. If not heating or cooling RH floats

C. Design Infiltration Rates (1176 ft2 House)

1. Winter air change rate = 0.63 air changes/hour
2. Summer air change rate = 0.31 air changes/hour

D. Cooling

1. In one mode of operation no natural cooling was allowed
2. In the second mode of operation natural cooling was allowed (all cooling loads that occured when the outside temperature was at or below 78 °F were eliminated)

requirement due to transient air infiltration rates and for comparative purposes would seem to be a valid assumption. The hourly air infiltration rate for winter was selected as being adequate for condensation, combustion, respiration and odor control, and the summer value was selected as being adequate for respiration and odor control. While it is well known that a reduction in the cooling requirement can be realized by opening windows when the outside temperature is below the space temperature, it is not clear what conditions actually cause people to do this. Also, there is a lack of experimental data on how much air can be brought into a space by opening windows. For these two reasons, in this study, the cooling requirements are shown for both the "windows closed" and "windows open" cases. In the "windows open" case it was assumed that any cooling requirement that occured when the outside air temperature was at or below 78 F was eliminated by natural cooling. Thus, the "windows open" cooling savings shown in this report are near maximum for the natural cooling of these particular houses.

The National Bureau of Standards Load Determination (NBSLD) program [6], was used for the dynamic simulation of the hourly house heating and cooling requirements. The program uses ambient temperature, wind speed, solar radiation, and internal heat gains in conjunction with the various envelope response factors to calculate surface heat flows and temperatures. A detailed set of simultaneous heat balance equations are solved at the interior surfaces of the building envelope to arrive at the hourly heating or cooling requirement.

Test Reference Year (TRY) weather tapes supplied by the National Climatic Center and created in accordance with ASHRAE criteria, were used in the NBSLD simulations. There are currently TRY tapes available for over 70 cities in the United States. The tapes contain the following climatic information for each hour of the year:

1. Dry-bulb temperature
2. Wet-bulb temperature
3. Dew-point temperature
4. Wind direction
5. Wind speed
6. Barometric pressure
7. Weather conditions (e.g., fog, haze, dust, etc.)
8. Total sky cover
9. Cloud amount for each of four cloud layers
10. Type of cloud for each of four cloud layers
11. Height of base of cloud for each of four cloud layers

The NBSLD computer program uses parameters 1, 2, 3, 5, 6 and the amount and type of cloud for the lowest cloud layer from 9 and 10.

3. VARIATIONS OF SELECTED HOUSE PARAMETERS AFFECTING ENERGY REQUIREMENTS

The variations to the base house (south facing 1176 ft2 house) were analyzed in the following order:

1. Climate
2. House size
3. House orientation
4. House internal heat gains

3.1 EFFECT OF CLIMATE AND HOUSE SIZE ON HEATING AND COOLING REQUIREMENTS

The base house was run in 13 different TRY locations. The cities selected represent a fairly wide range of climates found in the United States [4]. In addition to those for the base house, runs were made for an 816 ft2 (nominal 800 ft2) and a 1792 ft2 (nominal 1800 ft2) house in each city. The aspect ratio of the three sized houses was not kept constant, since it was felt that builders commonly make the depth of a house in multliples of 4 ft. Thus, the aspect ratio of the 816 ft2 house (House S) is 1.42 (length = 34 ft and depth = 24 ft), the aspect ratio of the 1176 ft2 house (House M) is 1.5 (length = 42 ft and depth = 28 ft) and the aspect ratio of the 1792 ft2 house (House L) is 1.75 (length = 56 ft and depth = 32 ft). For all three sized houses the ratios of window to floor area were held constant at 0.11.

It is important to note that in these runs the internal heat gains from people and appliances/equipment were the same for a given hour in all three house sizes, while the internal heat gains from lights varied as the square root of the house floor area. The reason the lighting internal heat gains were not held constant for the various house sizes was that this was judged to be unrealistic, and there was no data to support such an assumption. The same reasoning applied to having the lighting heat gains vary in direct proportion to floor area. So, as a more realistc compromise, the above approach was arbitrarily taken. Likewise, it was judged to be unrealistic to hold the air infiltration (in terms of air changes/hour) constant for the various sized houses, since this would imply that air leakage (in terms of cfm) is proportional to floor area. In this study, it was assumed that air leakage is proportional to exposed wall area; therefore, the air infiltration rates (in terms of cfm) were made directly proportional to the perimeter of the various sized houses.

The results of this part of the study are shown in Table 3. The 13 cities are listed in descending order of heating degree days, base 54 °F (see Section 4). Table 3 shows what one would expect to find for a given house size: the largest heating requirements are in the colder climates and the largest cooling requirements in the warmer climates. Table 3 further reveals the following results:

1. The heating requirements in all cases increase with increasing floor area.

2. The "windows open" cooling requirements (NCOOL) increase with increasing floor area, but the "windows closed" cooling requirements (COOL) decrease for six locations (Minneapolis, Chicago, Boston, Portland, Washington, and Los Angeles)

3. For a given city, the relative size of the heating requirement compared to the cooling requirement increases with increasing floor area.

In Table 4 the results of Table 3 are normalized by floor area. Since the internal heat gains/unit area in these runs actually decreased as house size increased (which is probably the real world situation), one might expect both the absolute and the normalized heating requirement to increase with increasing house size. However, Table 4 shows the heating requirement/unit area remains almost constant with increasing house size. The reason for this is that the air infiltration heat losses were somewhat smaller in Houses M and L than they would have been if the air infiltration rates were assumed proportional to floor area rather than house perimeter (house perimeter does not increase as fast as floor area). Had the air leakage rate been directly proportional to the floor area the normalized heating requirement would have increased with increasing area.

The reason why some locations show the "windows closed" cooling requirements decreasing with increasing floor area is because of relatively light envelope loading. For these locations the house internal heat gains are by far the largest contributers to the cooling requirements. Since the internal heat gains/unit area decrease with increasing floor area, while the volume of space air being heated by these gains increases in direct proportion to the floor area, then the number of hours the house has a cooling requirement is substantially reduced. Thus, the annual cooling requirement is decreased. Those locations that show the "windows closed" cooling requirements increasing with increasing

TABLE 3
ANNUAL HEATING AND COOLING REQUIREMENTS OF HOUSES, IN MILLIONS OF BTU

CITY	ORIENTATION	816 FT2			1176 FT2			1792 FT2		
		HEAT	COOL	NCOOL	HEAT	COOL	NCOOL	HEAT	COOL*	NCOOL**
MINNEAPOLIS, MN HDD(BASE 54 °F) = 5712 CDD(BASE 58 °F) = 1769	SOUTH	29.8	3.6	2.6	40.3	3.4	2.7	57.2	3.2	2.9
CHICAGO, IL HDD=3571 CDD=1586	SOUTH	17.6	3.0	1.8	24.4	2.7	1.9	35.6	2.6	2.1
BOSTON, MA HDD=3244 CDD=1508	SOUTH	16.7	2.3	1.4	23.4	2.0	1.4	34.2	1.7	1.5
ALBUQUERQUE, NM HDD=2236 CDD=2411	SOUTH	8.0	6.2	4.5	11.3	6.5	5.0	16.4	7.1	5.9
PORTLAND, OR HDD=2173 CDD=850	SOUTH	11.9	1.3	0.9	17.5	1.1	0.9	26.8	0.9	0.9
WASHINGTON, DC HDD=2018 CDD=2595	SOUTH	10.1	5.5	4.2	14.6	5.4	4.4	21.8	5.4	4.7
ATLANTA, GA HDD=1248 CDD=2720	SOUTH	4.3	8.1	4.4	6.2	8.3	5.0	9.2	8.8	5.9
FORT WORTH, TX HDD=940 CDD=4062	SOUTH	3.0	12.7	10.0	4.4	13.9	11.4	6.7	15.9	13.8
FRESNO, CA HDD=919 CDD=2859	SOUTH	2.9	9.2	7.3	4.5	10.1	8.4	7.0	11.9	10.3
HOUSTON, TX HDD=532 CDD=4379	SOUTH	1.7	13.8	10.1	2.6	14.8	11.5	4.0	16.6	13.8
PHOENIX, AZ HDD=339 CDD=5067	SOUTH	1.0	15.7	14.0	1.6	17.6	16.3	2.6	21.0	19.9
LOS ANGELES, CA HDD=45 CDD=1488	SOUTH	0.2	3.2	0.4	0.3	2.8	0.5	0.7	2.6	0.6
TAMPA, FL HDD=44 CDD=5239	SOUTH	0.1	15.6	10.0	0.2	16.3	11.2	0.3	17.5	13.2

* COOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS CLOSED" CASE
** NCOOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS OPEN" CASE; I.E., THE NATURAL COOLING CASE

TABLE 4

ANNUAL HEATING AND COOLING REQUIREMENTS/FT2 OF HOUSES AT
13 TRY LOCATIONS, IN THOUSANDS OF BTU/FT2

CITY	ORIENTATION	816 FT2			1176 FT2			1792 FT2		
		HEAT	COOL	NCOOL	HEAT	COOL	NCOOL	HEAT	COOL*	NCOOL**
MINNEAPOLIS, MN	SOUTH	36.5	4.4	3.1	34.2	2.9	2.3	31.9	1.8	1.6
CHICAGO, IL	SOUTH	21.5	3.6	2.2	20.8	2.3	1.6	19.8	1.4	1.2
BOSTON, MA	SOUTH	20.5	2.8	1.7	19.9	1.7	1.2	19.1	1.0	0.8
ALBUQUERQUE, NM	SOUTH	9.8	7.6	5.5	9.6	5.5	4.3	9.2	4.0	3.3
PORTLAND, OR	SOUTH	14.6	1.6	1.1	14.9	0.9	0.7	15.0	0.5	0.5
WASHINGTON, DC	SOUTH	12.4	6.8	5.1	12.4	4.6	3.8	12.2	3.0	2.6
ATLANTA, GA	SOUTH	5.2	9.9	5.4	5.2	7.0	4.2	5.1	4.9	3.3
FORT WORTH, TX	SOUTH	3.7	15.6	12.2	3.8	11.8	9.7	3.8	8.9	7.7
FRESNO, CA	SOUTH	3.6	11.2	8.9	3.8	8.6	7.2	3.9	6.6	5.8
HOUSTON, TX	SOUTH	2.1	16.9	12.4	2.2	12.6	9.8	2.2	9.3	7.7
PHOENIX, AZ	SOUTH	1.3	19.2	17.2	1.4	15.0	13.9	1.5	11.7	11.1
LOS ANGELES, CA	SOUTH	0.2	4.0	0.5	0.3	2.4	0.4	0.4	1.5	0.3
TAMPA, FL	SOUTH	0.1	19.1	12.2	0.2	13.8	9.6	0.2	9.8	7.3

*COOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS CLOSED" CASE
**NCOOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS OPEN" CASE,I.E., THE NATURAL COOLING CASE

floor area experience heavy envelope loading (high ambient temperature and solar radiation). Table 4 shows quite clearly, however, the dramatic decrease in both the "windows open" and "windows closed" cooling requirements/unit area with increasing floor area. This decrease in both the "windows open" and "windows closed" normalized cooling requirements is caused by the house internal heat gains increasing much more slowly than the house floor area.

Result (3) above is a consequence of (1) and (2) but is the more important result as far as its implications for effective energy analysis of detached single-family housing is concerned. Using Atlanta as an example, one sees from Table 3 that the ratio of heating to cooling requirement goes from approximately 0.53 (for House S) to approximately 1.05 (for House L). These substantial changes in the relative size of the heating and cooling requirements will influence the choice of energy conserving modifications made for each sized house. For example, one might opt for a whole-house fan or external awnings to reduce the cooling requirement of House S while the choice for House L might be increased insulation or storm windows to reduce the heating requirement which is now as large as the cooling requirement. Other factors also influence the choice of house modifications (e.g., seasonal efficiencies of heating and cooling equipment, cost of heating and cooling energy, etc.), but the relative size of heating and cooling requirements for a given house plays an important role in the choice of energy conserving options. This example also illustrates the potential error of generalizing the results of one house size to another house size.

3.2 VARIATION OF HEATING AND COOLING REQUIREMENTS DUE TO HOUSE ROTATION

The three differently sized houses were originally oriented as shown in Figure 1. For purposes of reference the base orientation of the houses is taken to be south (this is the direction the facade with the most glass area is facing). The houses were then rotated to face west, and then to north. The houses were not run with an east-facing orientation since a sensitivity analysis showed the annual heating and cooling requirements for the east and west orientations to be virtually identical (this would not be necessarily true for peak hourly requirements). The results of these runs are shown in Tables 5 and 6. An analysis of those tables show the following:

1. For all locations the lowest heating requirements are found for a south-facing orientation.

TABLE 5

ANNUAL HEATING AND COOLING REQUIREMENTS OF ROTATED HOUSES
IN MILLIONS OF BTU

CITY	ORIENTATION	816 FT2			1176 FT2			1792 FT2		
		HEAT	COOL	NCOOL	HEAT	COOL	NCOOL	HEAT	COOL*	NCOOL**
MINNEAPOLIS, MN	EAST/WEST	30.9	4.9	3.2	41.8	5.1	3.6	59.5	5.6	4.3
	NORTH	30.4	3.4	2.5	41.2	3.2	2.6	58.7	3.1	2.8
CHICAGO, IL	EAST/WEST	18.5	4.3	2.3	25.7	4.5	2.6	37.4	4.9	3.1
	NORTH	18.1	2.9	1.8	25.3	2.6	1.9	36.8	2.5	2.0
BOSTON, MA	EAST/WEST	17.8	3.4	1.8	24.8	3.4	2.0	36.3	3.5	2.3
	NORTH	17.3	2.2	1.4	24.3	1.9	1.4	35.7	1.6	1.4
ALBUQUERQUE, NM	EAST/WEST	8.9	8.2	5.4	12.6	9.2	6.5	18.5	11.0	8.1
	NORTH	8.5	6.1	4.4	12.0	6.4	5.0	17.7	7.0	5.8
PORTLAND, OR	EAST/WEST	12.6	2.2	1.2	18.5	2.2	1.4	28.2	2.4	1.7
	NORTH	12.3	1.3	0.8	18.1	1.0	0.8	27.7	0.9	0.8
WASHINGTON, DC	EAST/WEST	10.8	7.1	5.1	15.6	7.6	5.8	23.5	8.4	6.8
	NORTH	10.5	5.4	4.1	15.2	5.3	4.4	22.8	5.3	4.7
ATLANTA, GA	EAST/WEST	4.8	10.3	5.4	6.9	11.3	6.5	10.4	13.2	8.2
	NORTH	4.6	7.9	4.3	6.6	8.1	4.9	10.0	8.6	5.9
FORT WORTH, TX	EAST/WEST	3.5	15.1	11.6	5.2	17.3	13.9	7.9	21.0	17.5
	NORTH	3.3	12.5	9.8	4.8	13.6	11.3	7.4	15.5	13.6
FRESNO, CA	EAST/WEST	3.4	11.8	8.9	5.3	13.8	10.8	8.2	17.3	13.9
	NORTH	3.1	8.9	7.1	4.9	9.8	8.3	7.7	11.5	10.1
HOUSTON, TX	EAST/WEST	2.0	16.2	11.8	3.1	18.2	14.0	4.8	21.6	17.5
	NORTH	1.9	13.6	10.0	2.9	14.5	11.4	4.5	16.3	13.6
PHOENIX, AZ	EAST/WEST	1.3	18.4	16.4	2.0	21.5	19.7	3.4	26.9	25.1
	NORTH	1.1	15.3	13.9	1.8	17.2	16.1	3.0	20.5	19.6
LOS ANGELES, CA	EAST/WEST	0.2	5.0	0.5	0.4	5.1	0.6	1.0	5.7	0.7
	NORTH	0.2	3.0	0.4	0.4	2.5	0.5	0.9	2.3	0.6
TAMPA, FL	EAST/WEST	0.1	17.6	11.5	0.3	19.2	13.4	0.5	22.0	16.4
	NORTH	0.1	15.2	9.8	0.2	15.8	11.1	0.4	17.0	12.9

*COOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS CLOSED" CASE
**NCOOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS OPEN" CASE, I.E., THE NATURAL COOLING CASE

TABLE 6

ANNUAL HEATING AND COOLING REQUIREMENTS/FT2 OF ROTATED HOUSES, IN THOUSANDS OF BTU/FT2

CITY	ORIENTATION	816 FT2			1176 FT2			1792 FT2		
		HEAT	COOL	NCOOL	HEAT	COOL	NCOOL	HEAT	COOL*	NCOOL**
MINNEAPOLIS, MN	EAST/WEST	37.8	6.0	3.9	35.6	4.3	3.1	33.2	3.1	2.4
	NORTH	37.2	4.2	3.1	35.0	2.7	2.2	32.7	1.7	1.5
CHICAGO, IL	EAST/WEST	22.7	5.2	2.8	21.9	3.8	2.2	20.9	2.7	1.7
	NORTH	22.2	3.5	2.2	21.5	2.3	1.6	20.6	1.4	1.1
BOSTON, MA	EAST/WEST	21.8	4.2	2.2	21.1	2.9	1.7	20.3	2.0	1.3
	NORTH	21.2	2.7	1.7	20.7	1.6	1.2	19.9	0.9	0.8
ALBUQUERQUE, NM	EAST/WEST	10.9	10.1	6.7	10.7	7.8	5.5	10.3	6.1	4.5
	NORTH	10.4	7.5	5.4	10.2	5.4	4.2	9.8	3.9	3.3
PORTLAND, OR	EAST/WEST	15.4	2.7	1.5	15.7	1.9	1.2	15.7	1.3	0.9
	NORTH	15.0	1.6	1.0	15.4	0.9	0.7	15.4	0.5	0.5
WASHINGTON, DC	EAST/WEST	13.3	8.7	6.2	13.3	6.4	4.9	13.1	4.7	3.8
	NORTH	12.9	6.7	5.0	12.9	4.5	3.7	12.7	3.0	2.6
ATLANTA, GA	EAST/WEST	5.9	12.6	6.6	5.9	9.6	5.5	5.8	7.4	4.6
	NORTH	5.6	9.7	5.3	5.6	6.9	4.2	5.6	4.8	3.3
FORT WORTH, TX	EAST/WEST	4.3	18.5	14.3	4.4	14.7	11.8	4.4	11.7	9.8
	NORTH	4.0	15.3	12.0	4.1	11.5	9.6	4.1	8.7	7.6
FRESNO, CA	EAST/WEST	4.2	14.4	10.9	4.5	11.7	9.1	4.6	9.6	7.8
	NORTH	3.9	10.9	8.7	4.1	8.4	7.0	4.3	6.4	5.7
HOUSTON, TX	EAST/WEST	2.5	19.8	14.5	2.6	15.4	11.9	2.7	12.1	9.8
	NORTH	2.3	16.6	12.3	2.4	12.3	9.7	2.5	9.1	7.6
PHOENIX, AZ	EAST/WEST	1.6	22.5	20.1	1.7	18.3	16.7	1.9	15.0	14.0
	NORTH	1.4	18.8	17.0	1.5	14.6	13.7	1.7	11.4	10.9
LOS ANGELES, CA	EAST/WEST	0.2	6.1	0.6	0.4	4.4	0.5	0.5	3.2	0.4
	NORTH	0.2	3.6	0.5	0.3	2.2	0.4	0.5	1.3	0.3
TAMPA, FL	EAST/WEST	0.2	21.6	14.0	0.2	16.3	11.4	0.3	12.3	9.2
	NORTH	0.2	18.6	12.1	0.2	13.4	9.4	0.2	9.5	7.2

*COOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS CLOSED" CASE
**NCOOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS OPEN" CASE,I.E., THE NATURAL COOLING CASE

2. For all locations the lowest cooling requirements are found for a north-facing orientation.

3. For all locations both the heating and cooling requirements for the east/west facing house are always larger than for the south- and north-facing houses.

It is instructive to look at the results of Tables 5 and 6 as percent changes in the respective heating and cooling requirements of the three sized houses, as they are rotated form south to west to north. This is done in Table 7. An analysis of Table 7 yields the following results:

1. The percent change in the heating requirement, due to house rotation, can be significant depending on the location of the house (the range is 2 to 20 percent, neglecting the large percentage changes for locations having very small heating requirements).

2. The percent change in the cooling requirement can be very significant depending on the location and house size (the range is -1 to 56 percent for the "windows closed" case, and -1 to 45 percent for the "windows open" case, neglecting the large percentage changes for locations having very small cooling requirements).

3. For a given location the rotational effect on the heating requirement remains relatively constant, regardless of house size (neglecting abrupt changes for locations having very small heating requirements).

4. For a given location the north-facing orientation has little effect on the cooling requirements (the average decrease is about 3 percent).

The above points deserve some additional discussion. House orientation effects on the annual heating and cooling requirements are totally due to the changes in solar loading on the house (primarily the solar heat gain through glazed surfaces). Therefore, the direction in which the glazed surfaces face has a great impact on the house energy requirements. One can see from the results presented in this study that reorienting window area from the south and

TABLE 7

PERCENT CHANGE IN THE ANNUAL HEATING AND COOLING REQUIREMENTS OF HOUSES DUE TO ROTATION FROM SOUTH-FACING DIRECTION

CITY	ORIENTATION	816 FT2			1176 FT2			1792 FT2		
		HEAT	COOL	NCOOL	HEAT	COOL	NCOOL	HEAT	COOL*	NCOOL**
MINNEAPOLIS, MN	EAST/WEST	4	36	23	4	50	33	4	75	48
	NORTH	2	-6	-4	2	-6	-4	3	-3	-3
CHICAGO, IL	EAST/WEST	5	43	28	5	67	37	5	88	48
	NORTH	3	-3	0	4	-4	0	3	-4	-5
BOSTON, MA	EAST/WEST	7	48	29	6	70	43	6	106	53
	NORTH	4	-4	0	4	-5	0	4	-6	-7
ALBUQUERQUE, NM	EAST/WEST	11	32	20	12	42	30	13	55	37
	NORTH	6	-2	-2	6	-2	0	8	-1	-2
PORTLAND, OR	EAST/WEST	6	69	33	6	100	56	5	167	89
	NORTH	3	0	-11	3	-9	-11	3	0	-11
WASHINGTON, DC	EAST/WEST	7	29	21	7	41	32	8	56	45
	NORTH	4	-2	-2	4	-2	0	5	-2	0
ATLANTA, GA	EAST/WEST	12	27	23	11	36	30	13	50	39
	NORTH	7	-2	-2	6	-2	-2	9	-2	0
FORT WORTH, TX	EAST/WEST	17	19	16	18	24	22	18	32	27
	NORTH	10	-2	-2	9	-2	-1	10	-3	-1
FRESNO, CA	EAST/WEST	17	28	22	18	37	29	17	45	35
	NORTH	7	-3	-3	9	-3	-1	10	-3	-2
HOUSTON, TX	EAST/WEST	18	17	17	19	23	22	20	30	27
	NORTH	12	-1	-1	12	-2	-1	13	-2	-1
PHOENIX, AZ	EAST/WEST	30	17	17	25	22	21	31	28	26
	NORTH	10	-3	-1	13	-2	-1	15	-2	-2
LOS ANGELES, CA	EAST/WEST	0	56	25	33	82	20	43	119	17
	NORTH	0	-6	0	33	-11	0	29	-12	0
TAMPA, FL	EAST/WEST	0	13	15	50	18	20	67	26	24
	NORTH	0	-3	-2	0	-3	-1	33	-3	-2

*COOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS CLOSED" CASE
**NCOOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS OPEN" CASE,I.E., THE NATURAL COOLING CASE

north to the east and west increases both the annual heating and cooling requirements. The annual heating requirements are increased because the winter window solar heat gains through the southern exposure have been removed, and the annual cooling requirements have been increased due to substantial summer window solar heat gains through east/west exposures. The rotational effect on the annual heating requirements remains almost constant because the ratio of window area to floor area, for all sized houses, was held constant.

A south to north rotation of these houses resulted in a relatively small decrease in the cooling requirements. This seems to indicate that only a small part of the annual cooling requirements were due to solar heat gains through south-facing windows. However, a shift in window area from south to north might be considered as an energy saving option in very warm climates.

3.3 VARIATION OF HEATING AND COOLING REQUIREMENTS DUE TO INCREASES IN HOUSE INTERNAL HEAT GAINS

In this part of the study, the internal heat gains for House M (1176 ft2, south facing)) were increased by 50 percent. This was thought to be a reasonable upper limit for house internal heat gains [7]. These results are shown in Table 8. It is useful to show the results of Table 8 as percentage changes in comparison with the corresponding results of Table 3. This is done in Table 9. For all locations the percent change in the heating and cooling requirements is very significant. For those locations having substantial heating requirements the decreases in the heating requirements vary from 13 to 46 percent. For those locations having substantial cooling requirements, the increases in the cooling requirements vary from 30 to 57 percent for the "windows closed" case and from 21 to 36 percent for the "windows open" case. The reason the "windows open" increases are less than the corresponding "windows closed" increases is that internal heat gains are less important in the "windows open" case where conduction, air infiltration, and solar heat gains dominate because of the high ambient temperature (always above 78 °F).

It is interesting to normalize the results of Table 8 to floor area. This is done in Table 10. Comparing the results of Table 10 to the House S results in Table 4, one sees that the cooling requirements for a given location are now nearly proportional to floor area. This result is not surprising since the internal heat gains/unit area for House M in Table 10 are about equal to the internal heat gains/unit area for House S in Table 4. The fact that the

TABLE 8

ANNUAL HEATING AND COOLING REQUIREMENTS OF SOUTH-FACING 1176 FT2 HOUSE WITH 50% INCREASE IN INTERNAL HEAT GAINS IN MILLIONS OF BTU

CITY	HEAT	COOL*	NCOOL**
MINNEAPOLIS, MN	35.1	5.6	3.7
CHICAGO, IL	19.8	4.8	2.6
BOSTON, MA	18.7	3.8	2.1
ALBUQUERQUE, NM	7.7	9.7	6.4
PORTLAND, OR	12.8	2.3	1.3
WASHINGTON, DC	10.7	8.5	6.0
ATLANTA, GA	3.9	12.7	6.2
FORT WORTH, TX	2.6	18.9	14.1
FRESNO, CA	2.3	13.9	10.4
HOUSTON, TX	1.4	20.5	14.3
PHOENIX, AZ	0.7	22.8	19.7
LOS ANGELES, CA	0.1	6.1	0.6
TAMPA, FL	0.1	23.4	14.1

*COOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS CLOSED" CASE
**NCOOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS OPEN" CASE,I.E., THE NATURAL COOLING CASE

TABLE 9

PERCENT CHANGE IN THE ANNUAL HEATING AND COOLING REQUIREMENTS OF 1176 FT2 HOUSE DUE TO 50% INCREASE IN INTERNAL HEAT GAINS

CITY	HEAT	COOL*	NCOOL**
MINNEAPOLIS, MN	-13	65	37
CHICAGO, IL	-19	78	37
BOSTON, MA	-20	90	50
ALBUQUERQUE, NM	-32	49	28
PORTLAND, OR	-27	109	44
WASHINGTON, DC	-27	57	36
ATLANTA, GA	-37	53	24
FORT WORTH, TX	-41	36	24
FRESNO, CA	-49	38	24
HOUSTON, TX	-46	39	24
PHOENIX, AZ	-56	30	21
LOS ANGELES, CA	-67	118	20
TAMPA, FL	-50	44	26

*COOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS CLOSED" CASE
**NCOOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS OPEN" CASE, I.E., THE NATURAL COOLING CASE

TABLE 10

ANNUAL HEATING AND COOLING REQUIREMENTS/FT2 OF 1176 FT2 HOUSE WITH 50% INCREASE IN INTERNAL HEAT GAINS, IN THOUSANDS OF BTU/FT2

CITY	HEAT	COOL*	NCOOL**
MINNEAPOLIS, MN	29.8	4.7	3.2
CHICAGO, IL	16.8	4.1	2.2
BOSTON, MA	15.9	3.2	1.7
ALBUQUERQUE, NM	6.5	8.3	5.4
PORTLAND, OR	10.9	2.0	1.1
WASHINGTON, DC	9.1	7.1	5.1
ATLANTA, GA	3.4	10.8	5.3
FORT WORTH, TX	2.1	16.1	11.9
FRESNO, CA	2.0	11.8	8.8
HOUSTON, TX	1.2	17.4	12.1
PHOENIX, AZ	0.6	19.4	16.7
LOS ANGELES, CA	0.0	5.2	0.5
TAMPA, FL	0.0	19.9	12.0

*COOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS CLOSED" CASE
**NCOOL = ANNUAL COOLING REQUIREMENT FOR "WINDOWS OPEN" CASE, I.E., THE NATURAL COOLING CASE

annual cooling requirements in Table 9 are almost directly proportional to floor area serves to illustrate the fact that the internal heat gains can be the prime drivers for the cooling requirements of a well-insulated house with glazing on the east and west facades only. However, one sees by comparing the heating requirements/unit area of Table 10 with the heating requirements/unit area for House S of Table 4 that the heating requirements are no longer almost directly proportional to floor area. This result was caused by the air infiltration rate varying with house perimeter rather than area. This fact illustrates the point that air infiltration is a major contributor to well insulated house heating requirements.

The results in Tables 8-10 point out the need for having standard internal heat gains. If researchers use different internal heat gains it will be difficult, if not impossible, to compare the results of their work. Heating and cooling variations in the 5 to 10 percent range can be partially or totally masked by an inappropriate choice for house internal heat gains.

3.4 REDUCTION IN COOLING REQUIREMENTS DUE TO USE OF NATURAL COOLING

Tables 3 and 5 show both the annual cooling requirements for the "windows closed" and "windows open" conditions. Table 11 displays these results as a percent decrease in the respective "windows closed" annual cooling requirement. In other words, Table 11 shows the potential savings in the annual cooling requirement attainable through the use of natural cooling (the introduction into the space of cool outside air by non-mechanical means). One sees that the percent savings possible in almost all cases are quite significant. The savings range from 4 percent (for the 1792 ft2 north-facing Phoenix house) to 48 percent (for the 816 ft2 south-facing Atlanta house), for houses having an appreciable annual cooling requirement.

The percent savings are least for the Phoenix houses since much of the time the ambient temperature there is very high and, thus, much of the cooling requirement occurs when the ambient temperature is above 78 °F. The percent savings are greatest for House S in all cities because the internal heat gains per unit floor area are greatest. This causes a larger portion of the cooling requirement to occur when the ambient temperature is at or below 78 °F, resulting in a larger percent savings than in the larger houses. This same reasoning applies in comparing the percent savings of House M to House L.

TABLE 11

PERCENT REDUCTION IN THE ANNUAL COOLING REQUIREMENTS OF HOUSES DUE TO NATURAL COOLING

CITY	ORIENTATION	816 FT2	1176 FT2	1792 FT2
MINNEAPOLIS, MN	SOUTH	28	21	9
	EAST/WEST	35	29	23
	NORTH	26	19	10
CHICAGO, IL	SOUTH	40	30	19
	EAST/WEST	47	42	37
	NORTH	38	27	20
BOSTON, MA	SOUTH	39	30	12
	EAST/WEST	47	41	34
	NORTH	36	26	13
ALBUQUERQUE, NM	SOUTH	27	23	17
	EAST/WEST	34	29	26
	NORTH	28	22	17
PORTLAND, OR	SOUTH	31	18	0
	EAST/WEST	45	36	29
	NORTH	38	20	11
WASHINGTON, DC	SOUTH	24	19	13
	EAST/WEST	28	24	19
	NORTH	24	17	11
ATLANTA, GA	SOUTH	46	40	33
	EAST/WEST	48	42	38
	NORTH	46	40	31
FORT WORTH, TX	SOUTH	21	18	13
	EAST/WEST	23	20	17
	NORTH	22	17	12
FRESNO, CA	SOUTH	21	17	13
	EAST/WEST	25	22	20
	NORTH	20	15	12
HOUSTON, TX	SOUTH	27	22	17
	EAST/WEST	27	23	19
	NORTH	26	21	17
PHOENIX, AZ	SOUTH	11	7	5
	EAST/WEST	11	8	7
	NORTH	9	6	4
LOS ANGELES, CA	SOUTH	88	82	77
	EAST/WEST	90	88	88
	NORTH	87	80	74
TAMPA, FL	SOUTH	36	31	25
	EAST/WEST	35	30	25
	NORTH	36	30	24

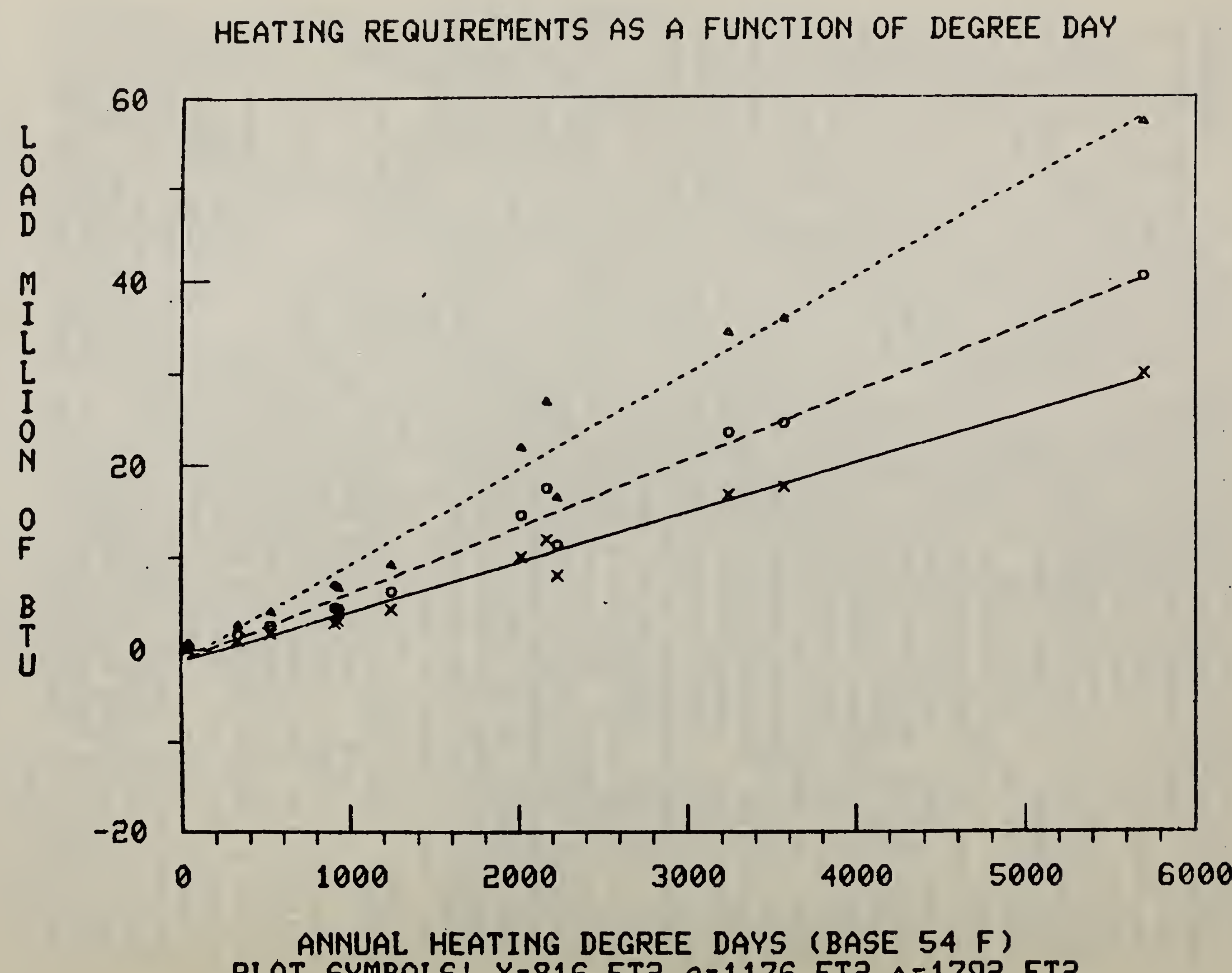
The percent savings for the east/west orientation, for a given location, are always greatest because the increased window solar heat gains cause more of the cooling requirement to occur when the ambient temperature is at or below 78 °F. Generally, the south orientation gives a larger percent savings than the north for this same reason.

It should be remembered that the percent savings shown in Table 11 do not reflect the effect natural cooling would have on the cooling requirement if substantial amounts of "thermal mass" were present in the house and nighttime flushing were used. In certain locations (e.g., Phoenix) because of the large diurnal temperature cycle it would be expected that "thermal mass" and nighttime flushing would substantially increase the percent savings in Table 11. However, the percent savings in Table 11 are probably very near the maximum possible for the houses modeled here for natural cooling. The reason is because of the natural cooling mode of operation assumed in this study. It was assumed that the entire cooling requirement could be eliminated when the ambient temperature was at or below 78 °F. This would not be possible when there is a large cooling requirement and the ambient temperature is very close to 78 °F. Thus savings due to natural cooling were overestimated. This overestimate was partially compensated for by not allowing the house to be cooled below 78 °F and therefore neglecting these potential savings. If, in addition to natural cooling a whole-house fan were employed, the savings in Table 11 would be increased because a higher ambient air temperature could be used to cool with (due to higher air velocities) and the house could be more frequently cooled below 78 °F (because larger amounts of cool air could be brought into the house).

4. CORRELATION OF ANNUAL HEATING AND COOLING REQUIREMENTS TO DEGREE DAYS

The heating and cooling requirements (Table 3, "windows closed" case) were plotted as a function of heating degree days (base 54 °F) and cooling degree days (base 58 °F) in Figures 2 and 3 (the straight lines in the figures are least square fits to the points). As can be seen from the figures, both the total annual heating and cooling requirements of the three sized houses lie roughly on straight lines, with the heating requirements showing a better correlation with degree days than the cooling requirements. This fact is not surprising since cooling degree days only indirectly reflect solar radiation intensity and do not reflect latent requirements at all. Taking this into account, it is interesting that the correlation between cooling requirements and cooling degree days is as good as it appears to be. Another point that should be made is that the heating and cooling degree day bases actually change when the house size changes. This is because the "balance point" temperatures of the house are affected by changes in air leakage rate, internal heat gains, and to some extent envelope area. The "balance point" temperatures of the house are taken here to mean those ambient temperatures above which or below which no heating or cooling is required, respectively. Since in theory the degree day base temperatures should equal the "balance point" temperatures of the house, then a change in one should produce an identical change in the other [2]. Thus, there is an inherent error in the correlation that is caused by using the same degree day base for all three sized houses. But this shortcoming may be acceptable (providing the error remains small) if it avoids the awkwardness of having different degree day bases for different sized houses. The reason for choosing the heating degree day base of 54 °F and the cooling degree day base of 58 °F is that these two degree day bases gave the best fits for all the points for the three different sized houses. Figures 2 and 3 show that Albuquerque and Portland have a poor fit for heating degree days and that Washington, DC and Fresno have a poor fit for cooling degree days. Albuquerque most probably shows a poor correlation to heating degree days because of its large diurnal temperature cycle (daylight hours considerably warmer than nighttime hours) and a high level of incident solar radiation. The reasons why Portland does not have better correlataion to heating degree days and Washington, DC and Fresno to cooling degree days are unclear at this time.

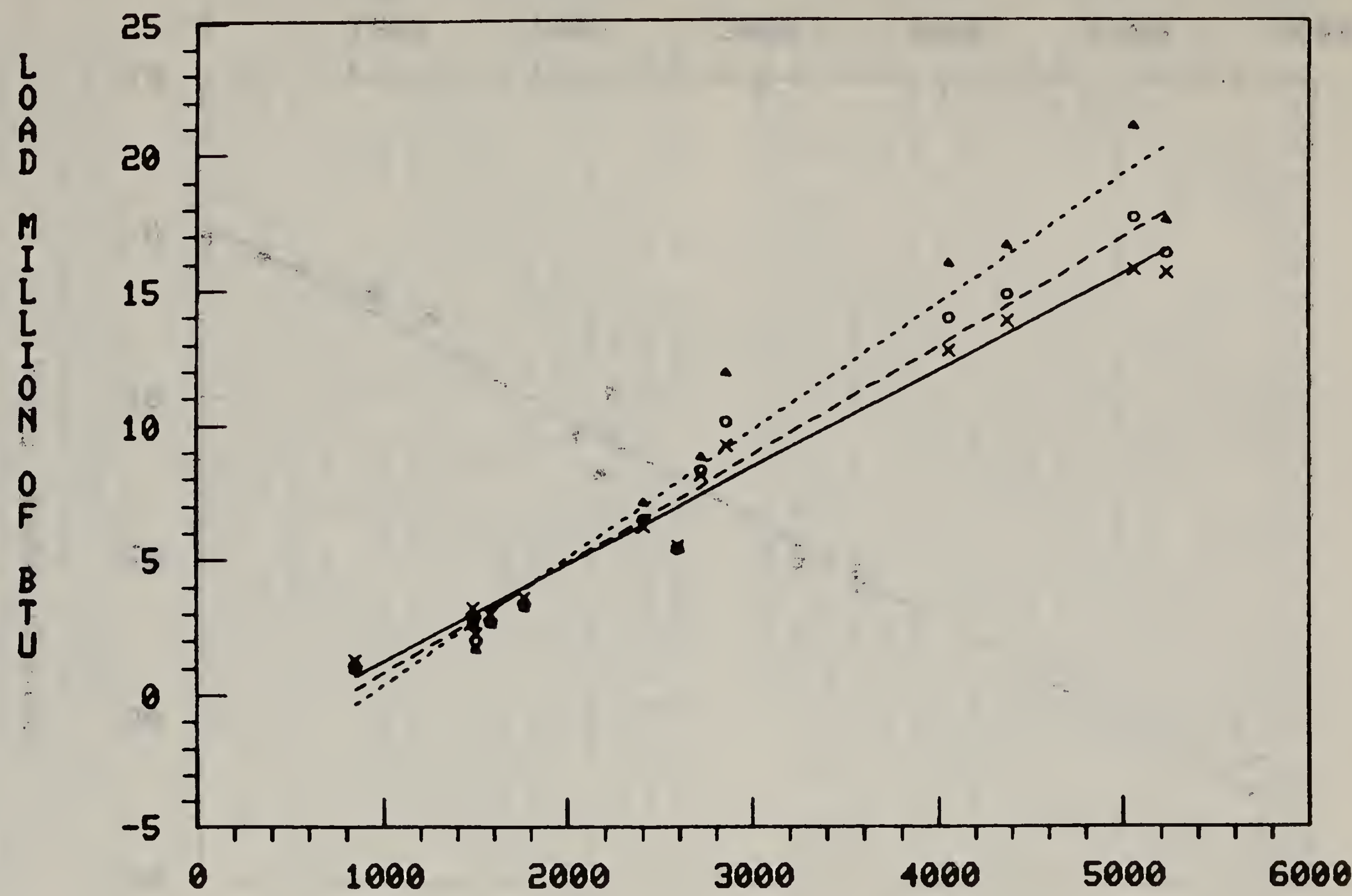
In Figure 4 the annual heating requirements of Figure 2 have been divided by their respective floor areas and plotted against heating degree days. The solid line is a least



HEATING REQUIREMENTS AS A FUNCTION OF DEGREE DAY
LOAD MILLION OF BTU
60
40
20
0
-20
0
1000
2000
3000
4000
5000
6000
ANNUAL HEATING DEGREE DAYS (BASE 54 F)
PLOT SYMBOLS! X=816 FT2,○=1176 FT2,△=1792 FT2

FIGURE 2.

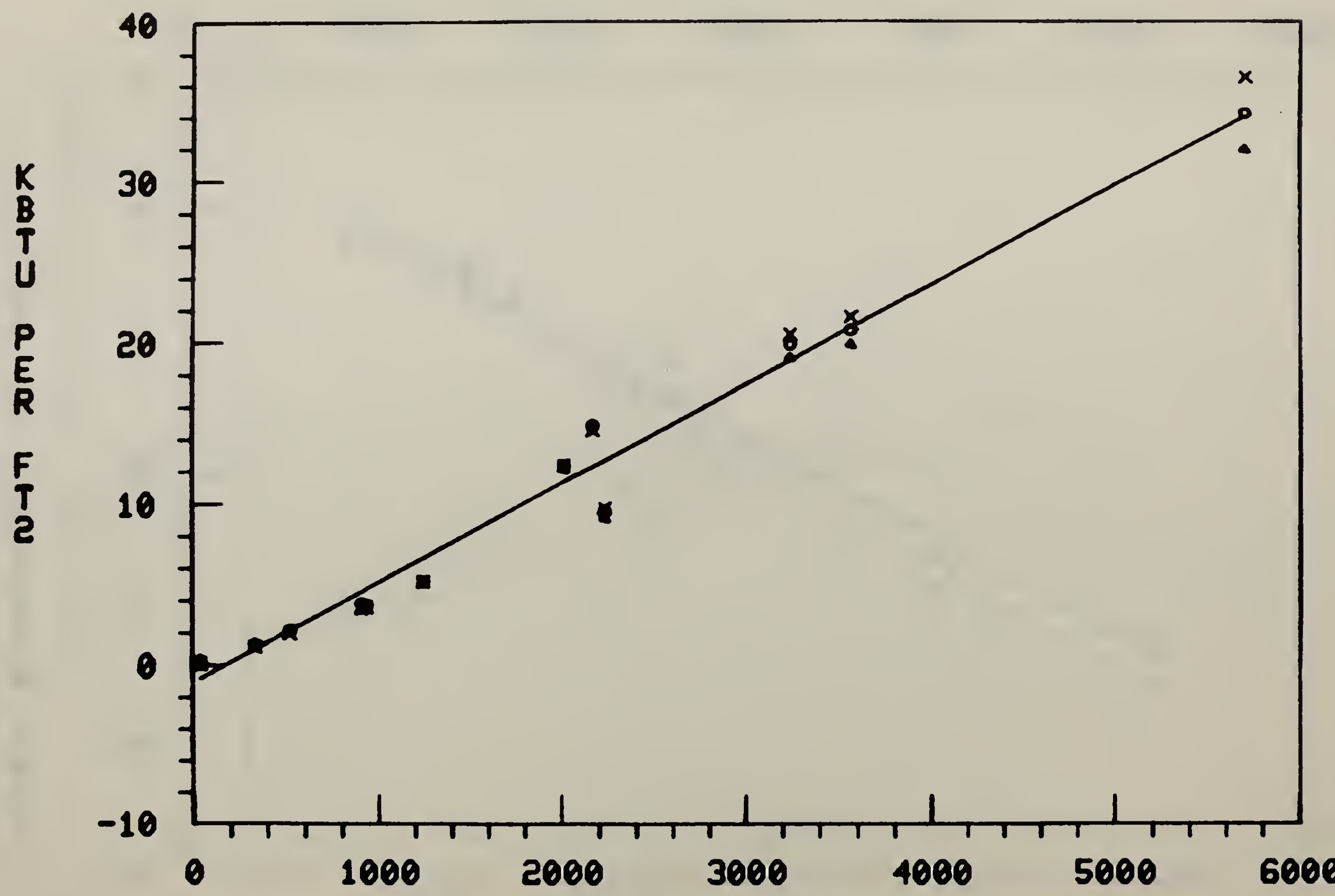
COOLING REQUIREMENTS AS A FUNCTION OF DEGREE DAY



PLOT SYMBOLS! X=816 FT2,o=1176 FT2,Δ=1792 FT2

FIGURE 3.

HEATING/FT2 AS A FUNCTION OF DEGREE DAY



ANNUAL HEATING DEGREE DAYS (BASE 54 F)
PLOT SYMBOLS: X=816 FT2, ○=1176 FT2, △=1792 FT2
FIGURE 4.

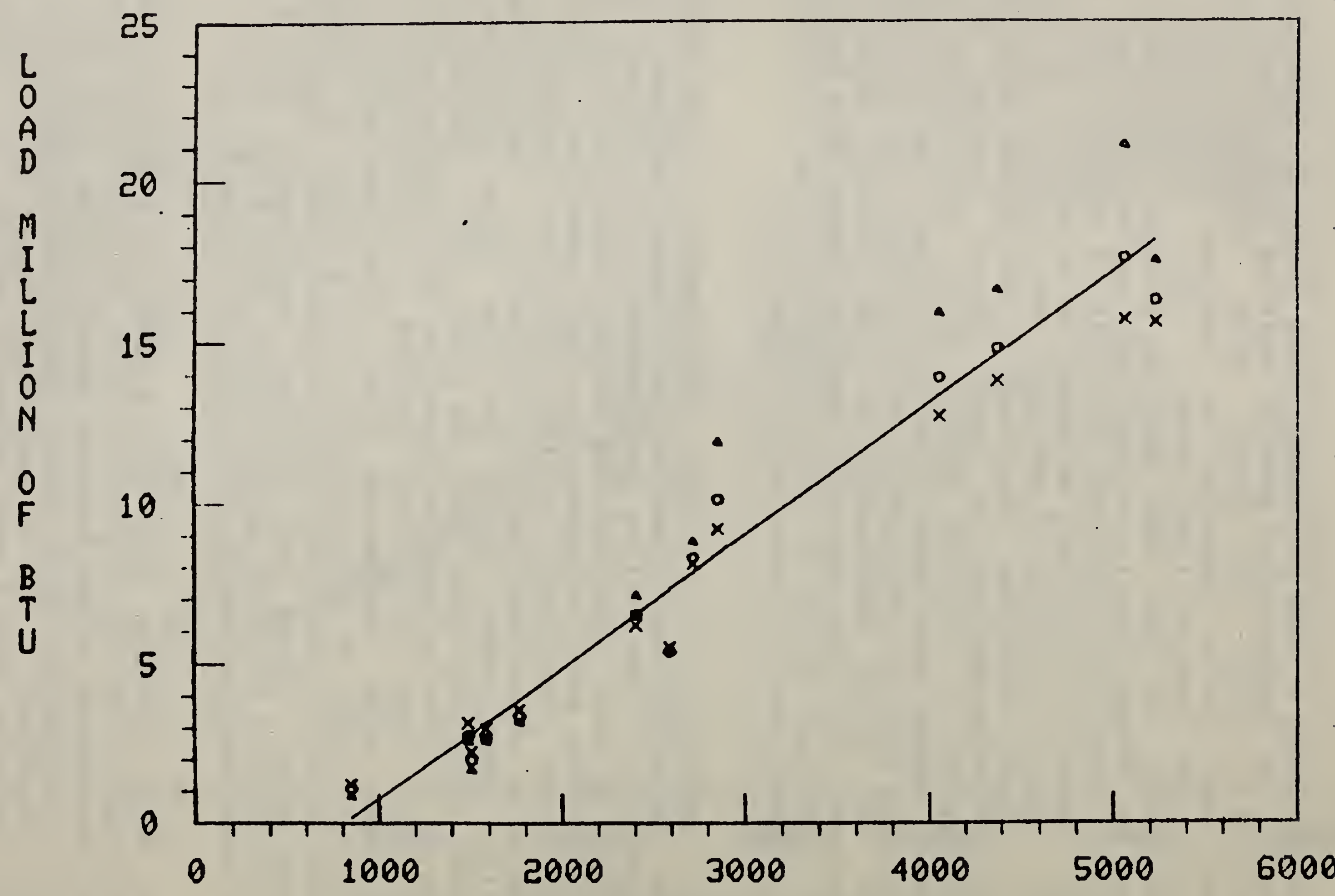
squares fit of the points. One can see from the figure that the fit is fairly good for all locations with the exception of Albuquerque and Portland (this result was to be expected from the poor fits these two cities showed in Figure 2).

Figures 2 and 4 tend to suggest that it may be possible to develop an equation to predict heating requirements, for a particular style of house with standard operating conditions, as a function of heating degree days for a fairly wide range of floor areas. This possibility is a consequence of the fact that the heating requirement of a house is assumed nearly proportional to the floor area. For a large number of locations with heating degree days above 1000 (base 54 °F) it may be possible to predict the heating requirements to within 10 percent. There will, of course, be certain locations that need to be handled individually (e.g., Albuquerque) or in small groups because of poor correlation to heating degree days. For locations with heating degree days above 2500 it is likely the error in the predicted heating requirement will be less than 10 percent, with the error decreasing as the heating degree days increase. For locations with heating degree days between 0 and 1000 (base 54 °F) it will probably be best to handle them as a subset and fit these points separately.

The prediction of cooling requirements is more difficult than the prediction of heating requirements because of the behavior of the cooling requirements as calculated in this study. In some locations the cooling requirement decreases as the floor area increases, in other locations, the cooling requirement increases as the floor area increases. This problem is shown graphically in Figure 3 . One can see the cooling requirement lines for the three different sized houses cross over each other at about 1700 cooling degree days. It does no good to normalize the cooling requirement to floor area since the cooling requirement/unit area decreases with increasing floor area (see Table 4). One simple solution to this problem is to perform a regression analysis on all the cooling requirement points regardless of house size, since the cooling requirement for a given location does not vary significantly with floor area. This was done and the results are shown in Figure 5.

The major problem with this method for predicting cooling requirements is that the difference between the predicted and calculated values becomes larger at the high end of the cooling degree day scale where the cooling requirements are most important. It is suggested, though not attempted in this analysis, that a more accurate method for predicting cooling requirements would take into account solar radiation, latent requirement, and internal heat generation as well as cooling degree days.

COOLING REQUIREMENTS AS A FUNCTION OF DEGREE DAY



ANNUAL COOLING DEGREE DAYS (BASE 58 F)
PLOT SYMBOLS! X=816 FT2, o=1176 FT2, Δ=1792 FT2
FIGURE 5.

In Figure 6 the annual cooling requirements for the "windows open" condition are plotted against cooling degree days (base 78 °F). At first, one might think this should yield a "good" fit since the "windows open" requirements are only made up of cooling requirements that occured when the ambient temperature was above 78 °F. However, a glance at Figure 6 shows this is not the case. The reason for this "poor" fit is that the cooling requirements for the "windows open" case actually occur when the windows are closed (the windows are opened to eliminate the cooling requirements that occur when the ambient temperature is at or below 78 °F). As mentioned previously, a regression analysis showed that the cooling "balance point" temperature for these houses was 58 °F with the windows closed. However, one would not expect a good correlation between the "windows open" case cooling requirements and cooling degree days (base 58 °F) since the cooling requirements that occured when the ambient temperature was between 58 °F and 78 °F have been eliminated by natural cooling. What one needs to calculate are "modified" cooling degree days defined as follows:

$$MCDD_{T1/T2} = \sum_{n=1,365} (TAVG_n - T1) \text{ for } TAVG_n > T2$$

where TAVG = average daily temperaure
T1 = cooling "balance point" temperature
T2 = ambient temperature above which no natural cooling is used

For our case T1 equals 58 °F and T2 equals 78 °F. In Figure 7 the "windows open" cooling requirements are plotted against "modified" cooling degree days (base 58 °F / 78 °F). The line is a least squares fit of all the points. The fit in Figure 7 is a vast improvement over the fit found in Figure 6. This suggests that in the future with more and more homes using some form of natural cooling that "modified" cooling degree days may prove useful in predicting annual cooling requirements.

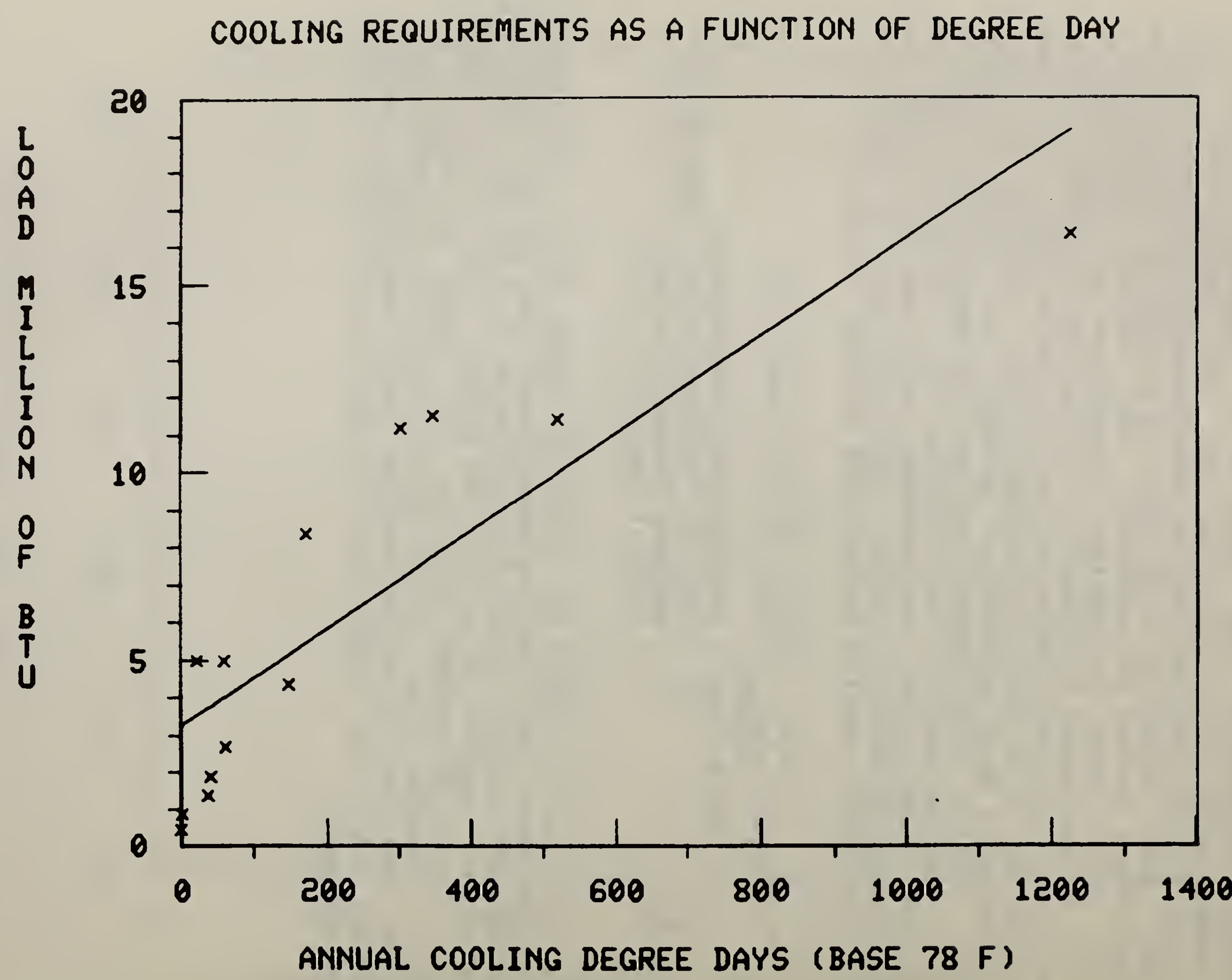

COOLING REQUIREMENTS AS A FUNCTION OF DEGREE DAY
LOAD MILLION OF BTU
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
ANNUAL COOLING DEGREE DAYS (BASE 78 F)

FIGURE 6.

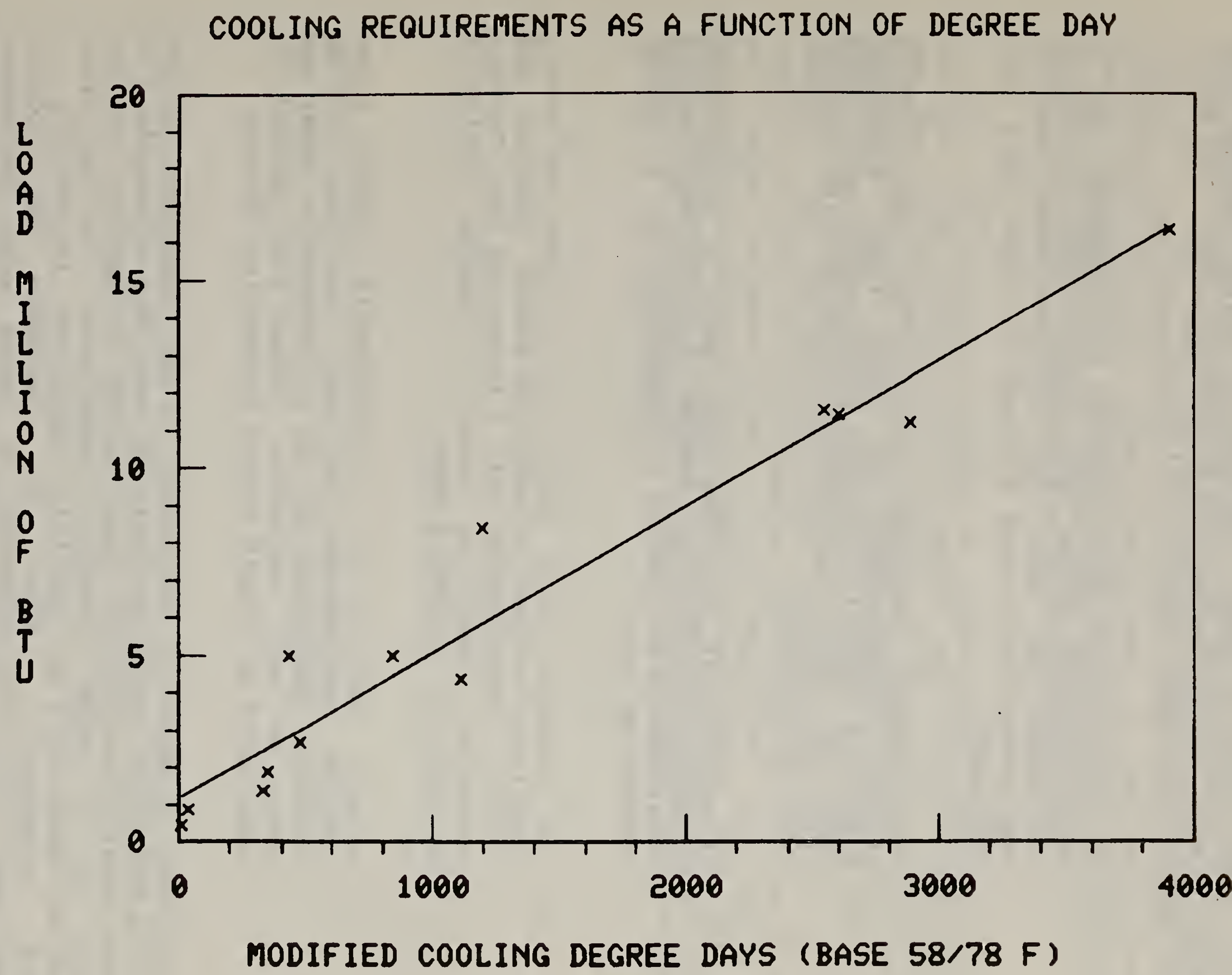

COOLING REQUIREMENTS AS A FUNCTION OF DEGREE DAY
LOAD MILLION OF BTU
20
15
10
5
0
0
1000
2000
3000
4000
MODIFIED COOLING DEGREE DAYS (BASE 58/78 F)

FIGURE 7.

5. CONCLUSIONS

The annual heating and cooling requirement trends, due to parametric variations made to a base house, provide a useful guide from which to select the initial energy options that are to be made to a detached single-family house. The major findings of this report are as follows:

1. It appears that annual cooling requirements for a well-insulated house show only a small variation with house floor area, and therefore annual cooling requirements/unit area decrease as house floor area increases.

2. House annual heating requirements are almost directly proportional to house floor area, and therefore annual heating requirements/unit area tend to remain relatively constant with varying house floor area.

3. Orientation of a house can have a significant effect on both the annual heating and cooling requirements and should be considered as a energy conserving option.

4. The internal heat gains of a house can have a significant effect on both the annual heating and cooling requirements of a house and thus careful attention should be given to making realistic assumptions regarding them.

5. Natural cooling can significantly reduce house cooling requirements in most locations in the country, therefore the use of screened windows and doors as well as whole house fans should be considered as viable energy conserving options.

Conclusion 1 above, if confirmed, is very important because of its potential impact on building codes and standards. If these regulations allocate house energy consumption on the basis of it being directly proportional to floor area, smaller houses will be unfairly penalized (especially in warm climates). This is because the cooling requirement/unit area decreases as house size increases. Therefore, larger houses would receive an implicit energy "credit" that would allow them to meet their required energy levels more easily than smaller houses.

As mentioned earlier in this report air infiltration rates and internal heat generation are major contributors to the annual heating and cooling requirements. In this report what were thought to be realistc assumptions were made concerning these two variables. It should be stressed that if these assumptions should prove to be partially or totally incorrect then many of our results would be substantially changed. The assumptions one makes regarding these two paramenters are of prime importance in determing house energy requirements. Currently there exists a pressing need to get measured data for these two parameters, especially data on how these parameters vary with house size.

A note of caution should be made about applying these results. The results of this report apply in detail only to the houses modeled here along with their operating assumptions (e.g., air infiltration rates,internal heat gain schedules, etc.) and while the results should apply in general to similar houses, discretion is advised. For example, it is obvious that the rotation effects on the heating and cooling requirements would not apply to a house with equal window areas on all exposures. What might be overlooked is that the rotation findings would have to be modified somewhat if applied to houses where the window area varied as the exposed wall area (in this study, window area varied as the floor area).

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APPENDIX A - Basic House Data Set Used In This Study

This appendix is intended to describe the computer input data set used in this study. The appendix is divided into three sections:

1. House Envelope Data
2. House Internal Heat Gain Data
3. House Operational Data

Within each section the value of the appropriate parameters are listed along with the reasons for the selection of these values.

House Envelope Data

T=THICKNESS(FT), C=CONDUCTIVITY(BTU/HOUR-FT-F), D=DENSITY(LB/FT3), SH=SPECIFIC HEAT(BTU/LB-F), R=RESISTANCE(HOUR-FT2-F/BTU), U=THERMAL CONDUCTANCE(BTU/HOUR-FT2-F)

ROOF COMPOSITION

LAYER	T	C	D	SH	R	DESCRIPTION
1	0.000	0.000	0.00	0.000	0.60	INSIDE SURF. RES. (ROOF)
2	0.042	0.070	34.00	0.290	0.00	1/2 IN. PLYWOOD
3	0.000	0.000	0.00	0.000	0.50	BUILD. PAP.+ASPH. SHIG.
			THERMAL CONDUCTANCE			U= 0.590

WALL(INSULATED PORTION) COMPOSITION

LAYER	T	C	D	SH	R	DESCRIPTION
1	0.042	0.094	50.00	0.200	0.00	1/2 IN. GYPBOARD
2	0.292	0.026	2.00	0.200	0.00	3 1/2 IN. INSUL R11
3	0.125	0.017	2.20	0.290	0.00	1 1/2 IN RIGID INSUL R7
4	0.031	0.050	37.00	0.290	0.00	3/8 IN. WOOD SIDING
			THERMAL CONDUCTANCE			U= 0.051

WALL(STUD PORTION) COMPOSITION

LAYER	T	C	D	SH	R	DESCRIPTION
1	0.042	0.094	50.00	0.200	0.00	1/2 IN. GYPBOARD
2	0.292	0.070	32.00	0.330	0.00	2X4 STUD
3	0.125	0.017	2.20	0.290	0.00	1 1/2 IN RIGID INSUL
4	0.031	0.050	37.00	0.290	0.00	3/8 IN. WOOD SIDING
			THERMAL CONDUCTANCE			U= 0.078

FLOOR COMPOSITION

LAYER	T	C	D	SH	R	DESCRIPTION
1	0.000	0.000	0.00	0.000	1.50	CARPET&PADDING
2	0.333	1.000	140.00	0.200	0.00	4 IN. CONCRETE SLAB
3	0.000	0.000	0.00	0.000	5.00	1 IN. POLYSTYRENE INSUL
4	0.333	0.200	100.00	0.400	0.00	4 IN. EARTH

THERMAL CONDUCTANCE U= 0.118

BASE 1176 FT2 HOUSE

	AREA	U-VALUE	ABS.	S.C.
SOUTH EXPOSURE				
INSUL WALL	198.0	0.0489	0.50	---
STUD WALL	66.0	0.0736	0.50	---
WINDOW	32.0	0.5600	---	0.52
S/G-DR	40.0	0.5800	---	0.52
WEST EXPOSURE				
INSUL WALL	190.0	0.0489	0.50	---
STUD WALL	34.0	0.0736	0.50	---
NORTH EXPOSURE				
DOOR	20.0	0.4900	0.50	---
INSUL WALL	196.0	0.0489	0.50	---
STUD WALL	65.0	0.0736	0.50	---
WINDOW	55.0	0.5600	---	0.52
EAST EXPOSURE				
INSUL WALL	190.0	0.0489	0.50	---
STUD WALL	34.0	0.0736	0.50	---
CEILING	1176.0	0.0320	0.50	---
SLAB	1176.0	0.1061	0.50	---

The design of this house is taken from Reference [1]. This style of ranch house represents 30% of current U.S. detached single-family housing. The actual wall constructions shown are meant to be cost effective (though not necessarily optimal) for a cold climate (such as Minneapolis, MN). The values for the thermal physical properties were taken from the ASHRAE Guide and Data Handbook of Fundamentals (1977). The values selected for absorptivity of wall/roof and shading coefficient of double pane glass are meant to be typical values. An off-white paint would have an absorptivity of approximately 0.5 while a double pane window with average weight draperies has a shading coefficient of about 0.52. The windows and wall were assumed to be shaded by a 1.5 ft over hang.

Internal Heat Gain Data

Lighting:

24-Hour Profile

1.	0.0	7.	1.0	13.	0.023	19.	0.023
2.	0.0	8.	1.0	14.	0.023	20.	0.5
3.	0.0	9.	0.023	15.	0.023	21.	0.5
4.	0.0	10.	0.023	16.	0.023	22.	1.0
5.	0.0	11.	0.023	17.	0.023	23.	0.0
6.	0.0	12.	0.023	18.	0.023	24.	0.0

Normalization Factor = 0.38 watts/sq. ft

In the absence of any published studies of actual hourly use of lighting in single-family detached housing as well as a lack of established guidelines, the hourly lighting profile found in Reference [8] was used. While this profile may not necessarily reflect actual lighting schedules, it still seems to be a reasonable representation of hourly lighting use.

Equipment/Appliance:

24-Hour Profile

1.	0.25	7.	0.33	13.	0.42	19.	0.92
2.	0.25	8.	0.46	14.	0.25	20.	0.68
3.	0.25	9.	0.63	15.	0.25	21.	0.68
4.	0.25	10.	0.88	16.	0.58	22.	0.68
5.	0.25	11.	0.35	17.	0.58	23.	0.51
6.	0.25	12.	0.88	18.	1.0	24.	0.23

Normalization Factor = 0.75 watts/sq. ft

As with lighting use there are no published data or guidelines for hourly equipment/appliance use in detached housing. This schedule was taken from Reference [9]. It was chosen because there is an hourly breakdown given of the appliance being used and it correlated well with annual values given in Reference [7].

Occupants:

24-Hour Profile

1.	1.0	7.	1.0	13.	0.4	19.	1.0
2.	1.0	8.	1.0	14.	0.4	20.	1.0
3.	1.0	9.	0.4	15.	0.4	21.	1.0
4.	1.0	10.	0.4	16.	0.69	22.	1.0
5.	1.0	11.	0.4	17.	0.69	23.	1.0
6.	1.0	12.	0.4	18.	1.0	24.	1.0

Normalization Factor = 2 adults and 2 children

This profile was taken from Reference [8] since there is at present inadequate data for determining a typical profile. This profile appears to be reasonable.

House Operational Data

A. Space Temperature Setpoints

1. 68 °F < T < 78 °F (from 0700 to 2300)
2. 60 °F < T < 78 °F (from 2400 to 0600)

B. Humidity Control

1. During cooling RH < 65%
2. During heating RH > 20%
3. If not heating or cooling RH floats

C. Design Infiltration Rates (1176 ft2 House)

1. Winter air change rate = 0.63 air changes per hour
2. Summer air change rate = 0.31 air changes per hour

D. Cooling

1. In one mode of operation no natural cooling was allowed
2. In the second mode of operation natural cooling was allowed (all cooling loads that occured when the outside temperature was at or below 78 °F were eliminated)

APPENDIX B. SI Conversion

In view of the presently accepted practice of the building industry in the United States and the structure of the NBS Load Determination computer program used in this report, common U.S. units of measurement have been used throughout this report. In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units in 1960, appropriate conversion factors have been provided in the table below. The reader interested in making further use of the coherent system of SI units is referred to:

NBS SP330, 1972 Edition, "The International System of Units"
E380-72 ASTM Metric Practice Guide (American National Standard 2210.1).

Metric Conversion Factors

Length:	1 inch (in) = 25.4 millimeters (mm) 1 foot (ft) = 0.3048 meter (m)
Area:	1 ft2 = 0.092903 m2
Volume:	1 ft3 = 0.028317 m3
Temperature:	F = 9/5 C + 32
Temperature Interval:	1 F = 5/9 C or K
Mass:	1 pound (lb) = 0.453592 kilogram (kg)
Mass per unit volume:	1 lb/ft3 = 16.0185 kg/m3
Energy:	1 Btu = 1.05506 kilojoules (kJ)
Specific heat:	1 Btu/(lb)(F) = 4.1868 kJ/(kg)(K)
U-value:	1 Btu/(ft2)(h)(F) = 5.67826 W/(m2)(K)
R-value:	1(ft2)(h)(F)/Btu = 0.176110(m2)(K)/W

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A computer study was done to determine how the annual heating and cooling requirements of a prototypical ranch-style house are affected by changes in four energy use parameters: climate (13 locations), floor area (nominal 800 ft^2, 1200 ft^2, and 1800 ft^2), orientation (north, south, and east/west), and internal heat generation (two different levels in the 1200 ft^2 house). In addition, the effects of natural cooling on the annual cooling requirement were investigated.

The results are quantified such that the effects attributable to each variation are easily identified. Also, the heating and cooling requirements of the various sized houses are correlated to degree days.

Some of the more important findings regarding the prototypical house (as simulated in this study) are: (a) annual cooling requirements/unit area decreased with increasing floor area, while (b) annual heating requirements/unit area remained relatively constant regardless of floor area; (c) rotation of a house (with windows on only two facades) significantly affected the annual energy requirements (approximate range 20-50 percent); and (e) annual cooling requirements were significantly reduced (by as much as 48 percent) by the use of natural cooling.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

building design; building energy performance standards; computer simulation of house energy requirements; degree days; energy analysis--variation of house energy requirements with climate, floor area, orientation, internal heat gain, and natural cooling; single-family detached residence.

13. AVAILABILITY

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