Title
Methodology and Assumptions for Evaluating Heating and Cooling Energy Requirements in New Single-Family Residential Buildings. Technical Support Document for the Pear Microcomputer Program

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APPLIED SCIENCE DIVISION

METHODOLOGY AND ASSUMPTIONS FOR EVALUATING HEATING AND COOLING ENERGY REQUIREMENTS IN NEW SINGLE-FAMILY RESIDENTIAL BUILDINGS. TECHNICAL SUPPORT DOCUMENT FOR THE PEAR MICROCOMPUTER PROGRAM

Y.J. Huang, R. Ritschard, J. Bull, S. Byrne, I. Turiel, D. Wilson, C. Hsui, and D. Foley

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(TECHNICAL SUPPORT DOCUMENT FOR THE PEAR MICROCOMPUTER PROGRAM)

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TECHNICAL SUPPORT DOCUMENT FOR PEAR
(PROGRAM FOR ENERGY ENERGY ANALYSIS OF RESIDENCES)

1.0 INTRODUCTION

The influence of various energy conservation options on residential energy use in prototypical houses in the United States has been extensively analyzed over the past few years by the Building Energy Analysis Group of Lawrence Berkeley Laboratory (LBL). This research effort provided technical support for the Building Energy Performance Standards (BEPS) mandated by the Energy Conservation and Production Act of 1976. This act required analysis of building energy use for the purpose of developing mandatory energy performance standards for residences. The standards were abandoned in 1981 in favor of voluntary performance guidelines. In recent years, LBL's technical support has focused on making the relevant data available to members of the buildings industry.

Under the performance guideline approach, builders, architects and engineers are encouraged to develop innovative energy management schemes and designs that can substantially reduce energy requirements for new single-family residential buildings. From a national perspective, the implementation of energy efficiency measures in residential buildings has greater potential for assuring energy savings than programs relying only on occupant behavior, such as a permanent lowering of thermostats or operating window devices.

This report provides technical documentation for a software package called PEAR (Program for Energy Analysis of Residences) developed by LBL. PEAR offers an easy-to-use and accurate method of estimating the energy savings associated with various energy conservation measures used in site-built, single-family homes. This program was designed for use by non-technical groups such as home builders, home buyers or others in the buildings industry, and developed as an integral part of a set of voluntary guidelines entitled *Affordable Housing Through Energy Conservation: A Guide to Designing and Constructing Energy Efficient Homes.* These guidelines provide a method for selecting and evaluating cost-effective energy conservation measures based on the energy savings estimated by PEAR.

This work is part of a Department of Energy program aimed at conducting research that will improve the energy efficiency of the nation's stock of conventionally-built and manufactured homes, and presenting the results to the public in a simplified format.

The overall objectives of the *Affordable Housing Through Energy Conservation* Guide are to:

- Be easy to use and require few calculations.
- Provide sufficient information to enable home builders to construct energy-conserving homes.
- Be credible to home builders, home buyers and mortgage institutions, assuring them that estimates of energy use reductions derived from the Guide are based on reliable, state-of-the-art analysis techniques.

The microcomputer program was developed to estimate the energy savings of various conservation options. The software program, which represents a computerized version of an extensive energy database, extends the accuracy and flexibility of the slide rule that was used as the original presentation format. PEAR also offers several economic analyses and the ability to compare the energy and cost savings of different sets of conservation measures at one time.

The work described illustrates the feasibility of translating complex technical information into a simplified format that can be understandable and useful to a non-technical audience. It also demonstrates that there are significant opportunities for the buildings community as a whole to have access to a large energy database which contains a vast amount of technical information.

2.0 METHODOLOGICAL OVERVIEW

LBL has compiled a comprehensive computer-generated database on the predicted energy consumption of typical residential houses, and has used it to develop a microcomputer program. This database was assembled from a series of simulations using the DOE-2.1A computer program for several building prototypes in 45 weather locations. We also studied the relationship between climate and residential energy use in order to develop a simple method for extrapolating results from the 45 base locations to another 800 intermediate locations.

To represent the energy use characteristics of site-built single-family housing, five prototypes buildings were defined that encompass more than 90% of all new residences built in the U.S. They are: one-story, two-story, split-level, middle unit townhouse, and end unit townhouse.

For each building prototype in each of the 45 locations, a full range of energy conservation options was identified and modeled. These options include various combinations of ceiling, wall, and foundation insulation, window glazings and infiltration levels. Four types of building foundation (slab-on-grade, ventilated crawl space, heated and unheated basement) were modeled. We chose foundation types for each location on the basis of climate and current construction practices. The effects of atypical foundation types on energy consumption were estimated using statistical regressions of the database.

Standard building operating conditions were defined, including occupancy and internal load levels. Thermostat settings for both heating and cooling periods were established, including a night setback during the heating months. A schedule was determined for natural venting when feasible during the summer to remove excess heat gain. In general, these conditions were kept constant throughout the analyses of energy conservation options.

Sensitivity analyses on the effects of variations in building design and operating conditions on building energy use were also performed. We used these analyses to extend the database in order to account for design differences between individual buildings, and give accurate values for differences between conservation measures as applied to specific buildings. Sensitivity studies were conducted for the following: thermal mass in exterior walls, building floor area, building orientation, equipment efficiencies, window size, orientation, and glass types, the absence of thermostat setbacks, levels of air infiltration, and sun-tempered designs such as south-dominant window orientations and attached sunspaces.

In summary, this technical support document is organized to reflect the various phases of the research as follows:

Section 3.0 Building Energy Analysis. This section describes the simulation model used to perform the energy analysis, the building prototypes, and their building envelope conditions such as insulation, infiltration, window characteristics, and sun-tempered designs.

Section 4.0 Standard Building Operating Conditions. In this section we delineate the operational aspects of the prototype buildings, including thermostat settings, building venting schedules, window operations, internal load parameters, and space conditioning systems.

Section 5.0 Climate Analysis. This section presents the climate analyses done in support of the guidelines, including the process used to determine base locations, development of extrapolation techniques, definition of analysis of extrapolation boundaries, and determination of base locations for window sensitivity studies.

Section 6.0 Analysis of Heating and Cooling Loads. This section covers the selection of conservation options for which sensitivity analyses were performed. It describes the basic methodological approach, methods developed for extending the database and the sensitivity results, and analysis of the validity of these methods. The following areas are covered: insulation, thermal mass in exterior walls, infiltration, windows, exterior building color, night temperature setback, building floor area, and attached sunspaces.

7.0 Development of PEAR. In this section we outline the procedure used to transform the extensive database discussed in Section 6.0 into a computerized format.

8.0 Domestic Hot Water. This section provides a brief outline of the procedures developed for estimating energy savings resulting from the use of two types of conservation options: active solar panels and flow reducers.

3.0 BUILDING ENERGY ANALYSIS

3.1 Selection of a Simulation Model

In support of the BEPS project a state-of-the-art computer code (DOE-1, DOE-2) was developed at Lawrence Berkeley Laboratory and Los Alamos Scientific Laboratory under sponsorship of the Department of Energy (DOE), its predecessor, the Energy Development and Research Administration (ERDA), and the State of California. The creation of this public domain computer program made the calculation of optimal thermal design for various building types possible.

Although BEPS was canceled in favor of voluntary performance guidelines, DOE-2 is still widely used in the design and retrofit of both residential and commercial buildings. Several versions of DOE-2 are currently available, most of which are designed to work on large main-frame computers, although some minicomputer versions do exist. We used DOE-2.1A in all parts of this study with the exception of the thermal mass sensitivities, where DOE-2.1C was run. Documentation on the public domain program is available through the National Technical Information Service.

DOE-2.1A enables architects and engineers to compute the energy consumption of buildings by simulating the hour-by-hour performance of a building for each of the 8760 hours in a year. A new computer language, the Building Design Language (BDL), has been written to permit code users to instruct the computer in familiar English terminology.

The BDL was developed primarily to aid engineers and architects in the difficult and time-consuming task of designing energy efficient buildings that have low life-cycle cost. The energy consumption of a building is determined by its shape; the thermal properties of materials; the size and position of walls, floors, roofs, windows, and doors; and the transient effects of shading, occupancy patterns, lighting schedules, equipment operation, ambient conditions, temperature, and humidity controls. Energy consumption is also affected by the operation of primary and secondary HVAC (heating, ventilation and air conditioning) systems and by the type and efficiency of the fuel conversion (plant) equipment. Furthermore, the life-cycle cost of operating a building under different economic constraints can strongly influence basic design decisions. DOE-2.1A is organized into several interactive programs: LOADS, SYSTEMS, PLANT, ECONOMICS, REPORT, and WEATHER and three libraries (Schedules, Materials, and Construction).

The LOADS program simulator calculates hourly heating and cooling loads. DOE-2.1A provides a reorganization and reprogramming of many of the LOADS algorithms from previous DOE-2 versions to increase execution speed. In the LOADS program (simulator), heat gains and losses through walls, roofs, floors, windows, and doors are calculated separately. Heat transfer by conduction and radiation through the building skin is computed using response factors. The effects of thermal mass, the placement of insulation, cloud cover, building location and orientation, and architectural features are considered. Every set of response factors generated is placed in a file to be used by the LOADS and SYSTEMS (described below) programs. Infiltration loads are calculated on the basis of the difference between the inside and outside conditions and an assumed leakage rate or air-change method.

Internal use of energy for lighting and equipment is also computed, according to schedules assigned by the user for each piece of equipment that affects the energy balance of each space. The latent and sensible heat given off by the building occupants is calculated as an hour-by-hour function of the occupancy of the building.

All of the LOADS computations are performed on the basis of a fixed temperature for each space as specified by the user. It provides a baseline profile of the thermal performance of a space, given a fixed internal temperature. The SYSTEMS program then modifies the output of the LOADS program to produce actual thermal loads based on an hourly variable internal temperature.

The SYSTEMS program contains algorithms for simulating the performance of the heating, ventilation, and air conditioning (HVAC) equipment used to control the temperature and humidity of each zone within the building. The SYSTEMS program uses the output information from the LOADS program and a list of user-defined system characteristics (e.g., air flow rates, thermostat settings, and schedules of equipment operation or temperature setback schedules) to calculate the hourly energy requirements of the HVAC system. The SYSTEMS program calculates thermal loads based on variable temperature conditions for each zone.

The ECONOMICS program may be used to compute the life-cycle costs of various building components and to generate investment statistics for economic comparison of alternative projects. This program was not used in this research effort.

The REPORT program is used to collect information from the output files from the programs discussed above. Output data is arranged in lists or tables according to the format of a standard output report. If the user wishes to examine a particular variable that is not available in a standard output report, he may select the variable and print its hourly values through the REPORT program. In this research, we used a custom DOE-2.1A program that produced, in addition to the standard DOE-2.1A outputs, yearly and monthly values for different parameters such as temperatures, loads, peak loads, and energies, as well as short two-line outputs giving only annual loads and energies. We saved complete copies of DOE-2.1A outputs for every simulation on microfilm, while the monthly and annual outputs have been kept on more easily accessible computer files and tapes.

Manipulation of weather data is a separate activity independent of the other programs. For this analysis the WEATHER program utilizes NOAA Test Reference Year (TRY) weather tapes for all locations except Juneau, AK, Medford, OR, Reno and Las Vegas, NV. For these four locations, Typical Meteorological Year (TMY) weather tapes were used. The climatic data used included dry and wet bulb temperatures, wind speed and direction, barometric pressure, cloud cover, and an atmospheric clearness index.

Schedules Library data include graphs of various schedules that may be entered to calculate the hour-by-hour heat input to a space from lighting, equipment, or occupants. Various changes may be made in the schedule data, to customize it to particular requirements. Schedule data, however, are not machine readable.

Both the Materials Library and the Construction Library are directly addressable by the DOE-2.1A program. The Materials Library contains data on the thermal properties of materials to be used in the calculation of heat transfer through space boundaries. Thermal performance of a wall or roof, for example, may be modeled by: (1) selecting and mathematically laminating various materials or (2) specifying the desired construction from the Construction Library by code word.

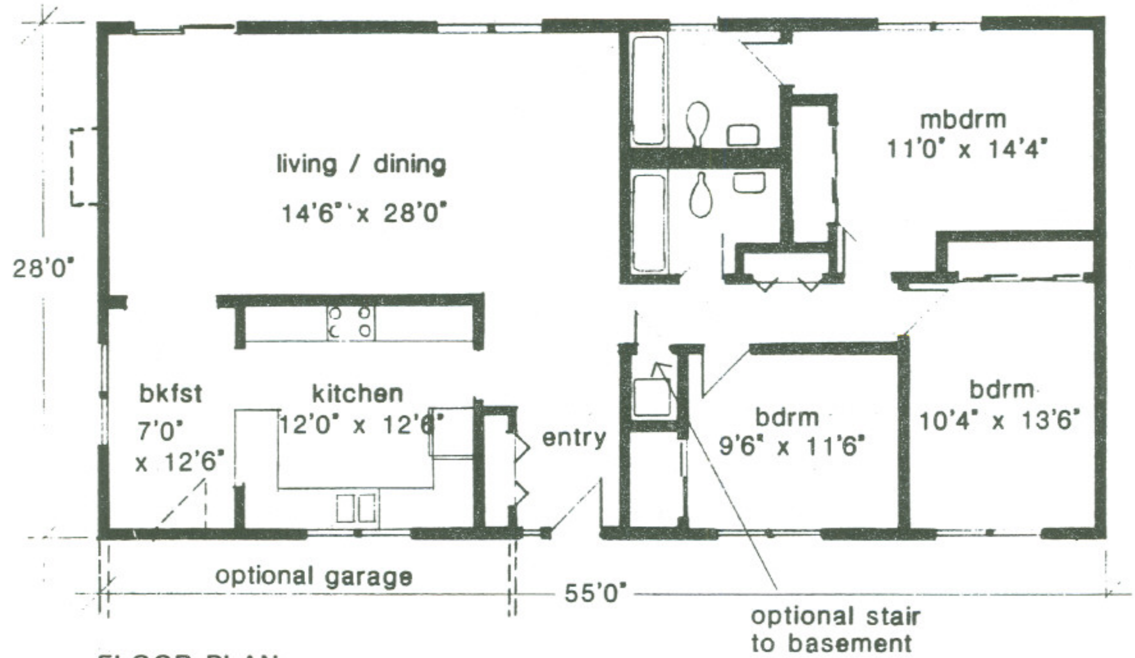
The tasks required for performing a DOE-2.1A building energy analysis include: (1) preparing the building description from conceptual or as-built drawings, (2) preparing an input deck using drawings and notes of operation and the user worksheets given in the DOE-2.1A manual (e.g., writing a BDL file), (3) making preliminary computer runs to test the system, (4) adjusting the various parameters as necessary, (5) re-running the computer program, and (5) examining the results.

3.2 Building Prototypes

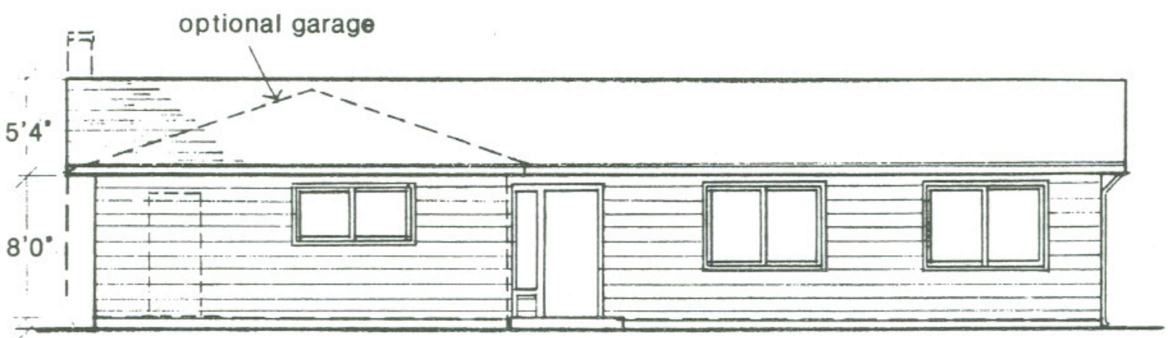
This study covers the four major building types found by the National Association of Home Builders Research Foundation Survey of 1979 to represent 90% of all new single family construction in the United States.[1] For each building type, size and design are meant to reflect average current construction practices. The building prototypes are one-story ranch, two-story, split-level, and two-story townhouse. We modeled end unit townhouses separately from middle units because of their differing thermal characteristics. Dimensions used for each building type are given in Table 3.2a. Representative floor plans and elevations for these prototypes are shown in Figures 3.2.1 through 3.2.6. These are the closest architectural representations of the buildings modeled. It must be noted, however, that the actual computer model does not contain all of the details shown, and differs in some ways due to the use of mathematical approximations and special analysis techniques.

1. NAHB Research Foundation, Inc., "Sustained Builder Survey Responses Result in Data Bank of Over One Million Houses." NAHB Research Foundation, Inc., Rockville MD (1981).

FLOOR PLAN AND ELEVATION OF 1-STORY RANCH HOUSE



FLOOR PLAN



FRONT ELEVATION

Scale 1/8" = 1'0"
JH 14 8 81

Total floor area 1540 sq ft
Total glazing 154 sq ft

XBL 8110-11932

Fig. 3.2.1

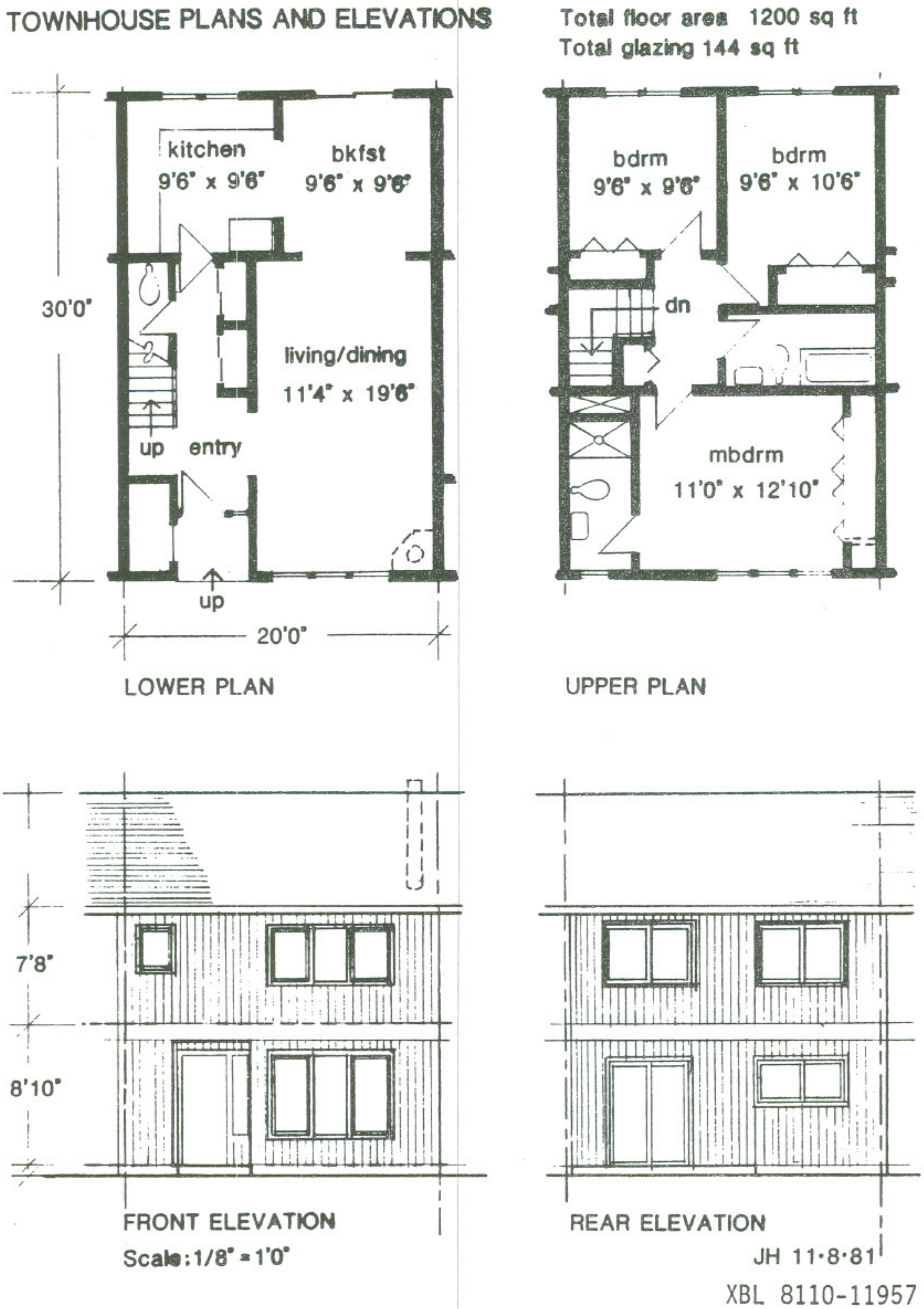

TOWNHOUSE PLANS AND ELEVATIONS
Total floor area 1200 sq ft
Total glazing 144 sq ft
kitchen
9'6" x 9'6"
bkfst
9'6" x 9'6"
30'0"
living/dining
11'4" x 19'6"
up
entry
up
20'0"
LOWER PLAN
bdrm
9'6" x 9'6"
bdrm
9'6" x 10'6"
dn
mbdrm
11'0" x 12'10"
UPPER PLAN
7'8"
8'10"
FRONT ELEVATION
Scale: 1/8" = 1'0"
REAR ELEVATION
JH 11·8·81
XBL 8110-11957

Fig. 3.2.2

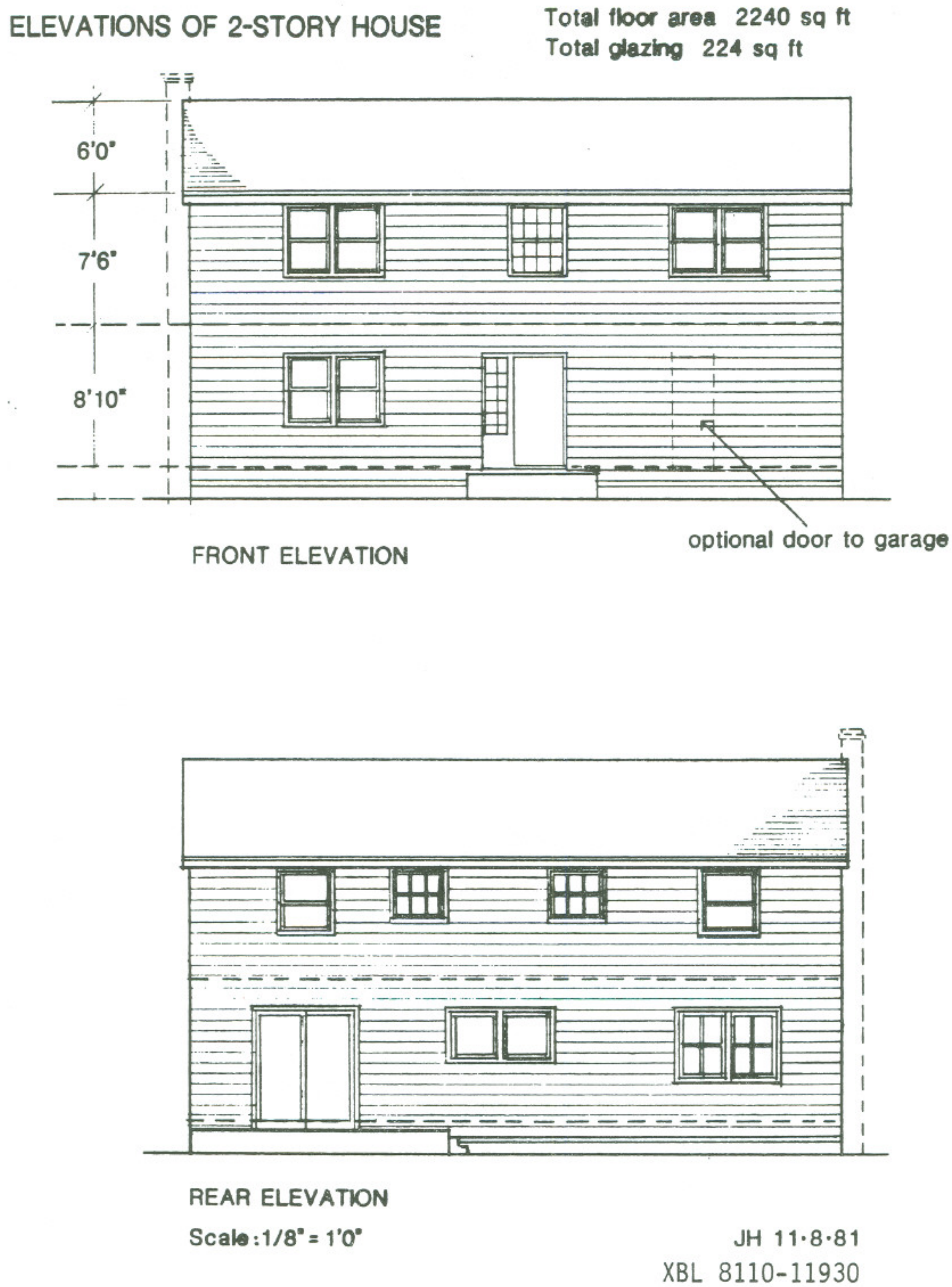
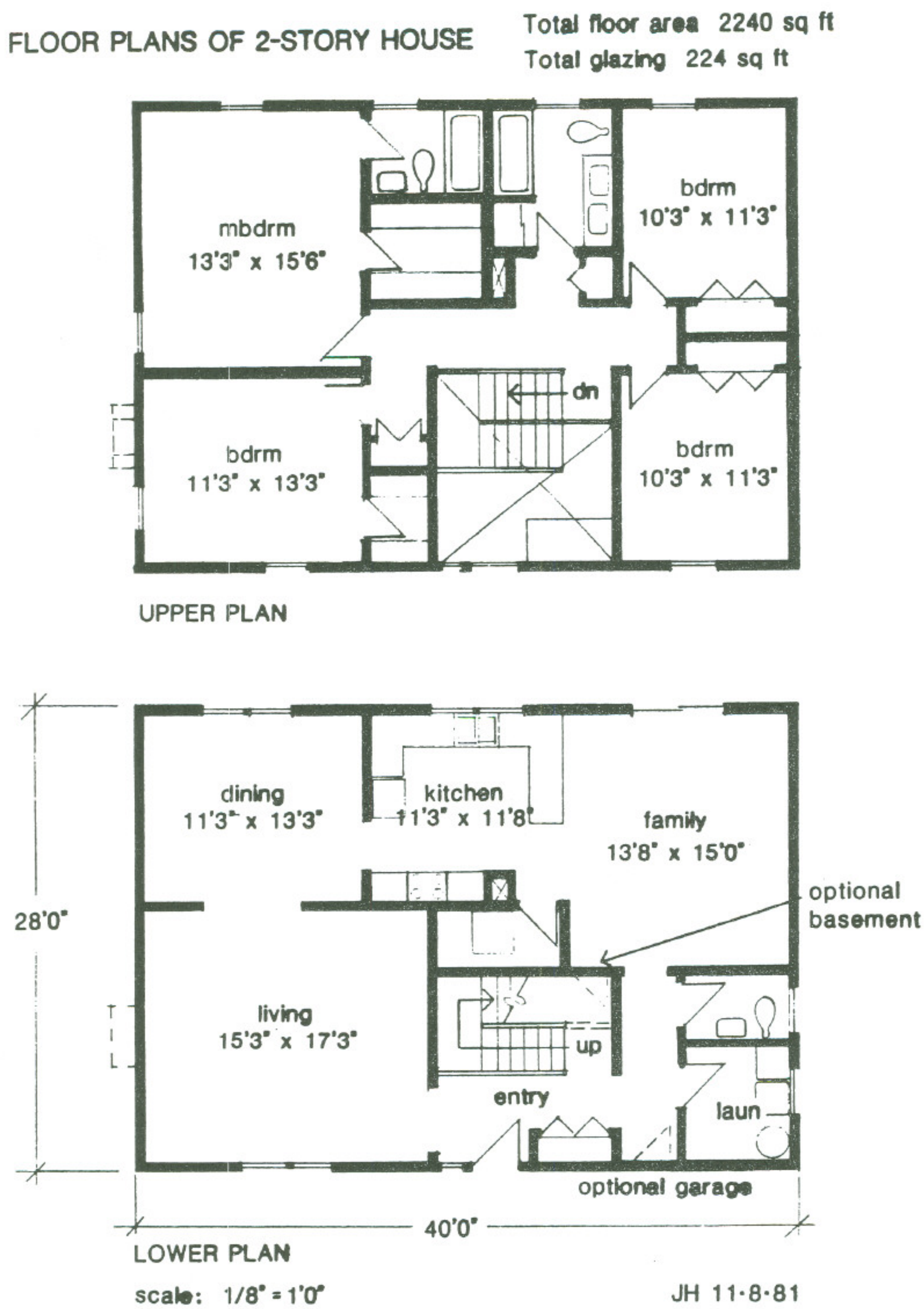
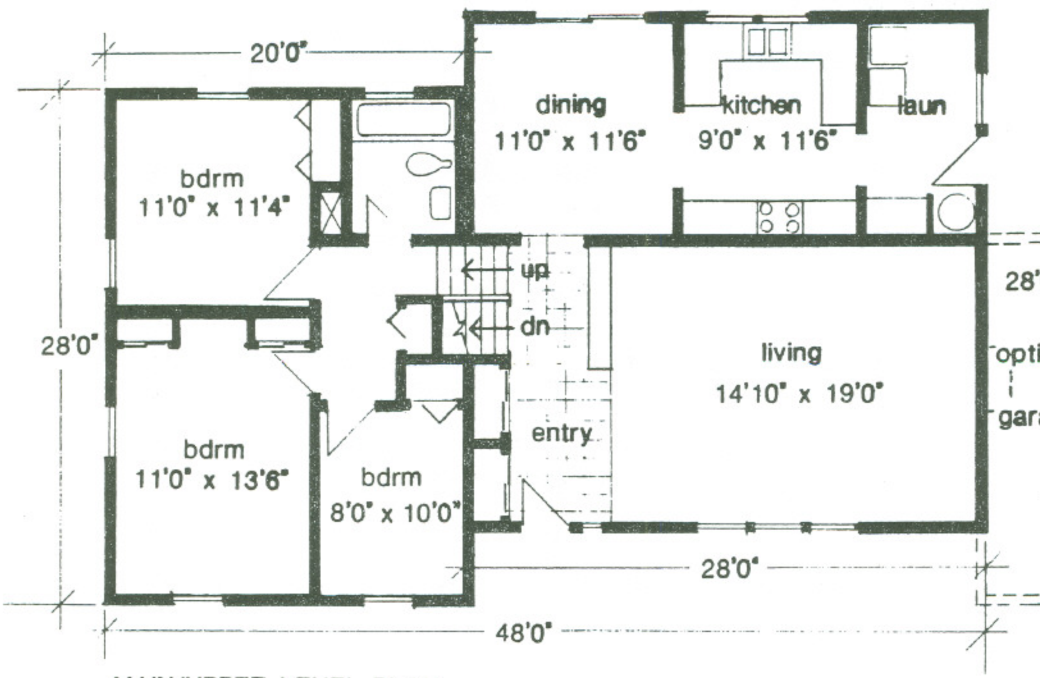

ELEVATIONS OF 2-STORY HOUSE
Total floor area 2240 sq ft
Total glazing 224 sq ft
6'0"
7'6"
8'10"
optional door to garage
FRONT ELEVATION
REAR ELEVATION
Scale: 1/8" = 1'0"
JH 11·8·81
XBL 8110-11930

Fig. 3.2.3

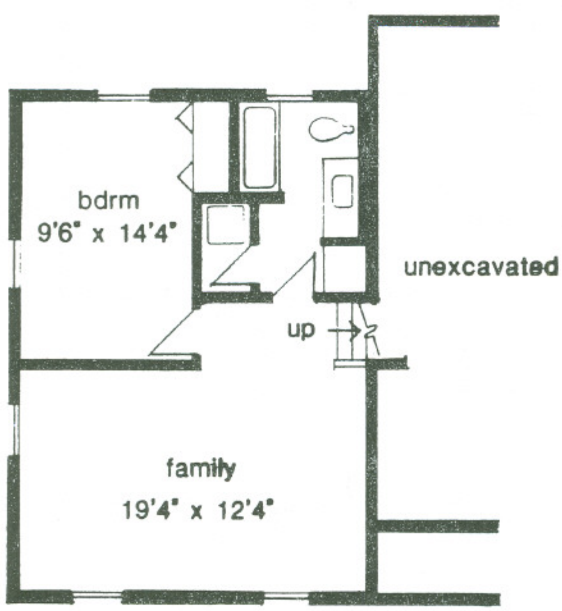


XBL 8110-11929

Fig. 3.2.4



MAIN/UPPER LEVEL PLAN



LOWER LEVEL PLAN

FLOOR PLANS OF
SPLIT-LEVEL HOUSE

Total floor area 1904 sq ft
Total glazing 210 sq ft
Scale 1/8" = 1'0" JH 11·8·81

XBL 8110-11931

Fig. 3.2.5

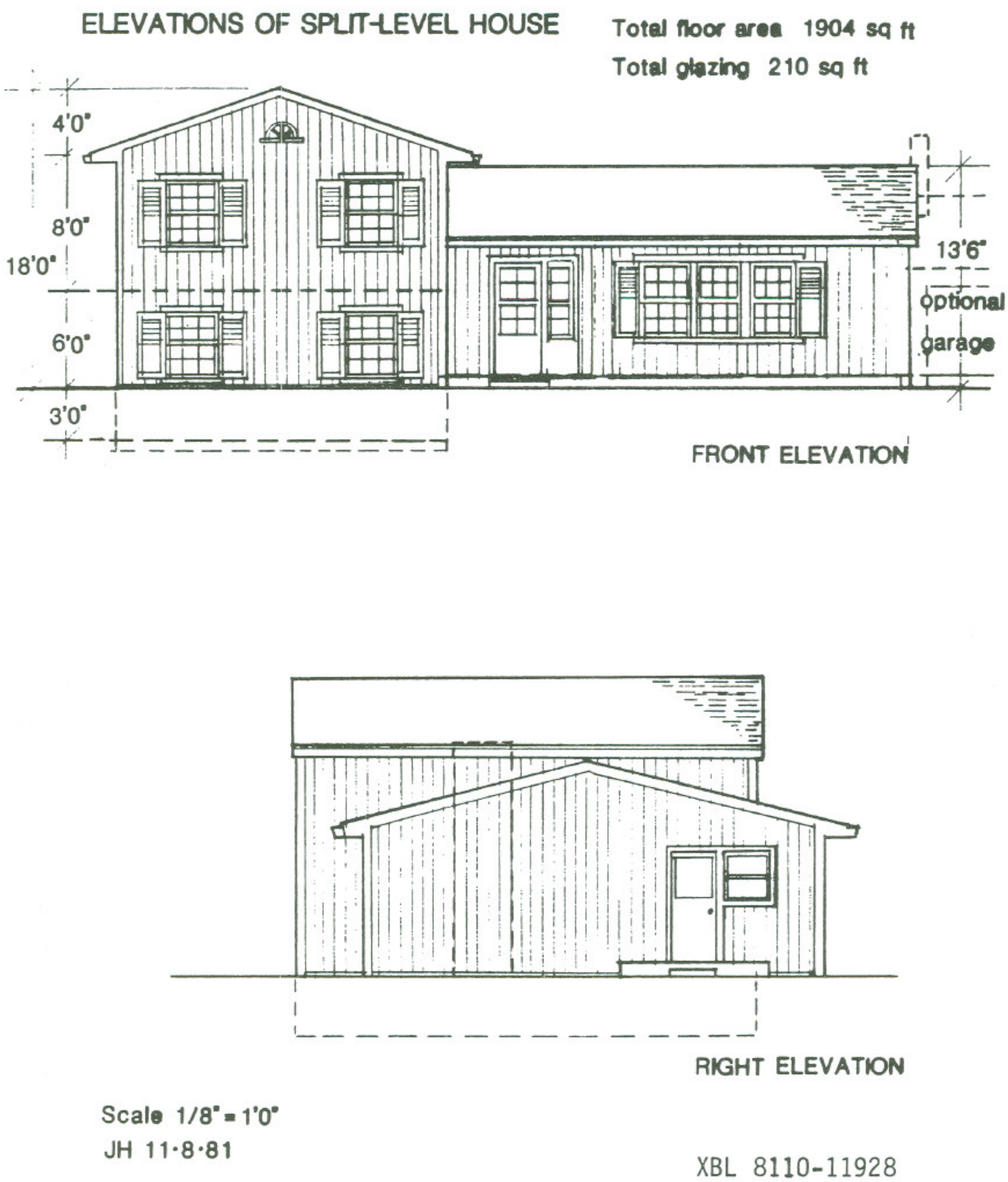

ELEVATIONS OF SPLIT-LEVEL HOUSE
Total floor area 1904 sq ft
Total glazing 210 sq ft
4'0"
8'0"
18'0"
6'0"
3'0"
13'6"
optional
garage
FRONT ELEVATION
RIGHT ELEVATION
Scale 1/8" = 1'0"
JH 11·8·81
XBL 8110-11928

Fig.3.2.6

Table 3.2a. Dimensions of Building Prototypes

Building Type	Floor Area (sq.ft.)	Window Area (sq.ft.)	(% floor area)	Dimensions (ft.)
One-story	1540	154	10	28x55x8
Two-story	2240	224	10	28x40x16
Split-level	1904	210	11	28x48x16
Mid-townhouse	1200	144	12	20x30x16
End-townhouse	1200	144	12	20x30x16

NAHB survey data was used to determine which foundation types are being constructed in the U.S. A complete set of simulations was done for all five prototypes in any base city for those foundation types that comprise more than 25% of all new house construction. A shorter set of simulations was done for alternate foundation types comprising from 10 to 25% of new construction (see Table 3.2b). For uncommon foundation conditions such as slab foundations in cold locations, we developed interpolated energy budgets using regression analysis of the existing data. We did not consider basements in warm locations.

3.3 Building Envelope

3.3.1 Insulation

Wood-frame construction was assumed as the base case for all five prototype houses.* Wall framing is either 2 x 4's 16" O.C. occupying 25% of the wall area (including fire breaks and window framing) or, for houses with wall insulation of R-19 or above, 2 x 6's 24" O.C. occupying 20% of the wall area. The wall exterior has aluminum siding and 1/2" fiberboard sheathing in all locations except California, where the wall exteriors are assumed to be 1/2" stucco. Walls with greater than R-19 insulation have rigid board insulation of the desired R-value instead of the fiberboard. It was assumed that the R-19 batts will have an effective R-value of 18.0 when installed due to insulation compression.[2] Four levels of wall insulation were modeled: (1) no insulation, (2) R-11, (3) R-19, and (4) R-27 (R-19 plus R-8 rigid insulation). We show schematic drawings of the wall sections for illustrative purposes in Figures 3.3.1 through 3.3.6.

Roof construction was assumed to be 2 x 6 rafters 24" O.C., with 1/2" plywood finish covered by 1/8" asphalt shingles. There are roof overhangs of 2 ft on the eaves and 1 1/2 ft on the gable sides. We modeled a pitched roof design with a 4:12 pitch for the one-story and split-level, a 5:12 pitch for the two-story, and a 7.7:12 pitch for the townhouses.

* Masonry and other types of mass wall construction were treated in an extensive series of sensitivity analyses. The wall construction and analytical techniques used for the mass wall study are given in Section 6.2.

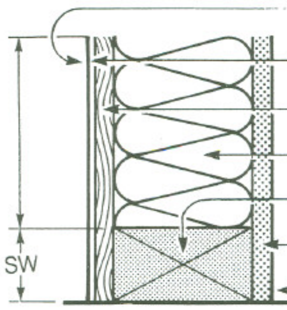
2. Art Johnson, NAHB Research Foundation, private communication (1983).

Table 3.2b. Foundation Types Modeled In Base Cities

(X = complete set, S = short set, other foundation types estimated using statistical regressions)

City	Slab	Basement	Vent. Crawl
1. Albuquerque NM	X		
2. Atlanta GA	X	X	X
3. Birmingham AL	X	S	
4. Bismarck ND		X	
5. Boise ID		X	X
6. Boston MA		X	
7. Brownsville TX	X		
8. Buffalo NY		X	
9. Burlington VT		X	
10. Charleston SC	S		X
11. Cheyenne WY		X	
12. Chicago IL	S	X	
13. Cincinnati OH	S	X	S
14. Denver CO		X	
15. El Paso TX	X		
16. Fort Worth TX	X		
17. Fresno CA	X		S
18. Great Falls MO		X	
19. Honolulu HA	X		
20. Jacksonville FL	X		
21. Juneau AK		X	
22. Kansas City MO		X	
23. Lake Charles LA	X		
24. Las Vegas NV	X		X
25. Los Angeles CA	X		S
26. Medford OR		S	X
27. Memphis TN	X	S	X
28. Miami FL	X		
29. Minneapolis MN		X	
30. Nashville TN	X	S	X
31. New York NY	S	X	
32. Oklahoma City OK	X		
33. Omaha NB		X	
34. Philadelphia PA		X	
35. Phoenix AZ	X		
36. Pittsburgh PA		X	
37. Portland ME		X	
38. Portland OR		S	X
39. Reno NV	X	X	
40. Salt Lake City UT		X	
41. San Antonio TX	X		S
42. San Diego CA	X		S
43. San Francisco CA	X		S
44. Seattle WA		X	X
45. Washington DC		X	

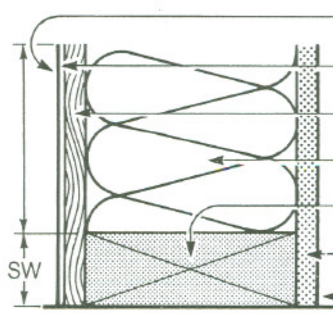
R-0 and R-11 Standard Wood Frame Wall



No Stud Section (NSW) (75%)		Stud Section (SW) (25%)
0.17	Outside Air Film	0.17
0.61	1/8″ Siding	0.61
1.22	1/2″ Sheathing	1.22
0.91 (Air Film) or 11.00	Insulation	—
—	2 X 4 16 O.C.	4.37
0.45	1/2″ Drywall	0.45
0.68	Inside Air Film	0.68
4.04 or 14.13	Total Resistance	7.50
Composite R-0 Regular Wall Resistance		4.57
Composite R-11 Regular Wall Resistance		11.57

Fig. 3.3.1

R-19 Standard Wood Frame Wall

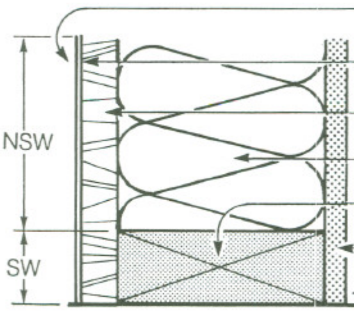


No Stud Section (NSW) (80%)		Stud Section (SW) (20%)
0.17	Outside Air Film	0.17
0.61	1/8″ Siding	0.61
1.22	1/2″ Sheathing	1.22
18.00	R-19 Insulation	—
—	2 × 6 24 O.C.	6.87
0.45	1/2″ Drywall	0.45
0.68	Inside Air Film	0.68
21.13	Total Resistance	10.00
Composite R-19 Regular Wall Resistance		17.28

-- XBL 8312-2451 --

Fig. 3.3.2

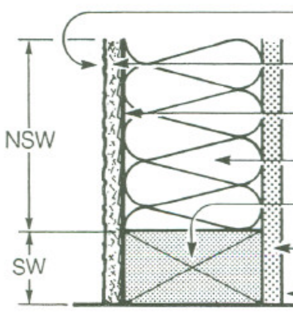
R-27 Standard Wood Frame Wall



No Stud Section (NSW) (80%)		Stud Section (SW) (20%)
0.17	Outside Air Film	0.17
0.61	1/8″ Siding	0.61
8.00	Rigid Insulation	8.00
18.00	R-19 Insulation	—
—	2 X 6 24 O.C.	6.87
0.45	1/2″ Drywall	0.45
0.68	Inside Air Film	0.68
27.91	Total Resistance	16.78
Composite R-27 Regular Wall Resistance		24.64

Fig. 3.3.3

R-0 and R-11 Stucco Wall

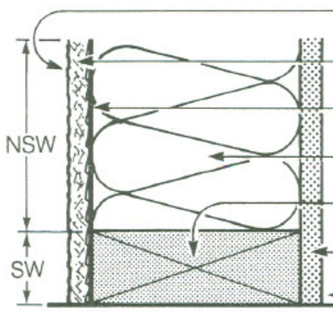


No Stud Section (NSW) (75%)		Stud Section (SW) (25%)
0.17	Outside Air Film	0.17
0.10	1/2″ Stucco	0.10
0.06	Paper	0.06
0.91 (Air Film) or 11.00	Insulation	—
—	2 X 4 16 O.C.	4.37
0.45	1/2″ Drywall	0.45
0.68	Inside Air Film	0.68
2.37 or 12.46	Total Resistance	5.83
Composite R-0 Stucco Wall Resistance		2.78
Composite R-11 Stucco Wall Resistance		9.70

-- XBL 8312-2452 --

Fig. 3.3.4

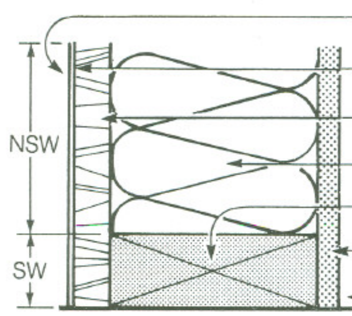
R-19 Stucco Wall



No Stud Section (NSW) (80%)		Stud Section (SW) (20%)
0.17	Outside Air Film	0.17
0.10	1/2″ Stucco	0.10
0.06	Paper	0.06
18.00	R-19 Insulation	—
—	2 × 6 24 O.C.	6.87
0.45	1/2″ Drywall	0.45
0.68	Inside Air Film	0.68
19.46	Total Resistance	8.33
Composite R-19 Stucco Wall Resistance		15.36

Fig. 3.3.5

R-27 Stucco Wall



No Stud Section (NSW) (80%)		Stud Section (SW) (20%)
0.17	Outside Air Film	0.17
0.10	1/2″ Stucco	0.10
8.00	Rigid Insulation	8.00
18.00	R-19 Insulation	—
—	2 × 6 24 O.C.	6.87
0.45	1/2″ Drywall	0.45
0.68	Inside Air Film	0.68
27.40	Total Resistance	16.27
Composite R-27 Stucco Wall Resistance		24.10

-- XBL 8312-2453 --

Fig. 3.3.6

The ceiling was modeled as 1/2" drywall with 2 x 6's 24" O.C. framing covering 10% of the area. Ceiling insulation was assumed to be fiberglass batts placed both between (R-19 and below) and on top (R-30 and above) of the ceiling joists. For highly insulated ceiling options, we assumed that the roof trusses were raised to accommodate the ceiling batt insulation at its full thickness up to the exterior surface of the walls below. We modeled seven levels of ceiling insulation: (1) no insulation, (2) R-11, (3) R-19, (4) R-30, (5) R-38, (6) R-49, and (7) R-60. Schematic ceiling and roof sections are shown in Figures 3.3.7 through 3.3.9.

We approximate the various heat transfer mechanisms in the attic without significantly compromising accuracy by calculating the net heat transfer between the interior space and the outside.* The roof-ceiling building component was modeled as a single construction section with the following layers starting from the interior: (1) an underceiling surface air-film, (2) ceiling drywall, (3) ceiling joists and/or insulation, (4) a pure resistance representing the air-layer in the attic ("attic resistance"), and (5) the roof construction consisting of rafters, plywood and asphalt shingles. The thermal effects of the attic were therefore taken care of as an added air film with a resistance equal to the average of ASHRAE values for heat flow up and for heat flow down. To simulate correctly the amount of sunshine absorbed by this combined roof-ceiling component, the tilts and areas of the roof sections were kept identical to those of the actual roof. We modeled end gables separately from the main gabled roofs. All roof were modeled in parallel and then scaled by the ratio of the attic envelope area to ceiling area.

The three foundation types modeled were slab-on-grade, basement and ventilated crawl space. For the split-level building prototype, the lower level foundation was always assumed to be slab-on-grade, while that of the upper level was either of the three foundation types mentioned.

We assumed the slab-on-grade foundation was a 4-in concrete slab with a polyethylene film on the bottom, resting on a 4-in gravel bed. The top of the slab was covered by carpet and pad.

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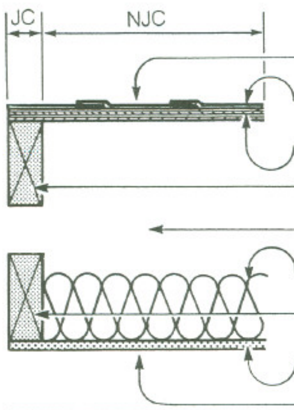
* Accurate modeling of attics is a more difficult problem than it first appears. The attic is an unconditioned space with significant thermal mass, high temperature swings, and irregular ventilation rates. Moreover, the typical triangular attic geometry invalidates one-dimensional heat transfer assumptions, as well as causing temperature stratification.

There are two reasonable choices of modeling an attic on DOE-2.1A, each of which omits some significant aspect of the problem but has advantages in terms of accurately modeling other aspects. The simplest conceptually is to model the attic as an unconditioned zone. The other is to model the ceiling and attic as a single-layered construction (This is the model used.). The first model may superficially seem more detailed based on its input file, but it ignores thermal delay of the ceiling mass and incorrectly calculates the radiant heat transfer between roof and ceiling (DOE-2 uses air, not radiant, temperatures), and the attic weighting factor (calculated based on square geometry). The second approach models correctly the time-dependence and overall magnitude of attic heat flow, but assumes parallel heat flow and ignores variations in attic ventilation rates and radiant heat transfer. The errors from the first assumption should be small, while those from the second are significant only in very poorly insulated or power-ventilated attics. For ceilings with R-19 insulation or better, the energy impact of ventilation and radiant heat transfer are negligible and can be ignored. Since attic ventilation rates are very difficult to quantify, we believe that the modeling technique described represents the most reliable method using the DOE-2.1A code.

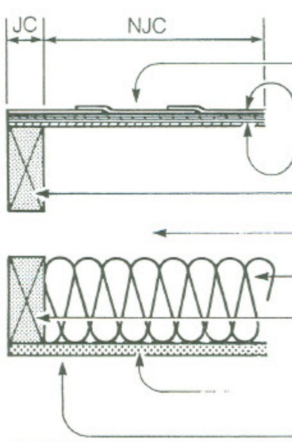
R-0 and R-11 Ceiling and Roof



No Joist Section (NJC) (90%)		Joist Section (JC) (10%)
0.17	Outside Air Film	0.17
0.44	1/4" Asphalt Shingle	0.44
0.62	1/2" Plywood	0.62
—	2 × 6 Rafters 24 O.C.	—
1.46	Attic	1.46
0 or 11.00	Insulation	—
—	2 × 6 Joists 24 O.C.	6.87
0.45	1/2" Drywall	0.45
0.77	Inside Air Film	0.77
3.90 or 14.90	Total Resistance	10.78
Composite R-0 Ceiling Resistance		4.17
Composite R-11 Ceiling Resistance		14.35

Fig. 3.3.7

R-19 Ceilings and Roofs

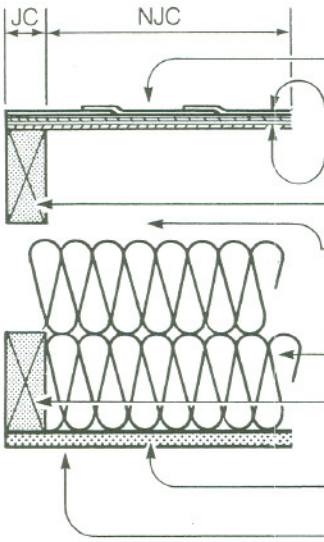


No Joist Section (NJC) (90%)		Joist Section (JC) (10%)
0.17	Outside Air Film	0.17
0.44	1/4" Asphalt Shingle	0.44
0.62	1/2" Plywood	0.62
—	2 × 6 Rafters 24 O.C.	—
1.46	Attic	1.46
19.00	Insulation	0
—	2 × 6 Joists 24 O.C.	6.87
0.45	1/2" Drywall	0.45
0.77	Inside Air Film	0.77
22.91	Total Resistance	10.78
Composite R-19 Resistance		20.59

Fig .3.3.8

-- XBL 8312-2456 --

R-30, R-38, R-49 and R-60 Ceilings and Roofs



No Joist Section (NJC) (90%)		Joist Section (JC) (10%)
0.17	Outside Air Film	0.17
0.44	1/4″ Asphalt Shingle	0.44
0.62	1/2″ Plywood	0.62
—	2 × 6 Rafters 24 O.C.	—
1.46	Attic	1.46
30,38,49, or 60	Insulation	11,19,30, or 41
—	2 × 6 Joists 24 O.C.	6.87
0.45	1/2″ Drywall	0.45
0.77	Inside Air Film	0.77
33.91,41.91,52.91, or 63.91	Total Resistance	21.78,29.78,40.78, or 51.78

Composite R-30 Ceiling Resistance	32.12
Composite R-38 Ceiling Resistance	40.27
Composite R-49 Ceiling Resistance	51.38
Composite R-60 Ceiling Resistance	62.45

-- XBL 8312-4777 --

Fig. 3.3.9

We assumed insulation was rigid panels placed on the outside of the slab perimeter and extending either down two ft or down one ft and out one ft. An 8-in grade was assumed from the top of the slab to the exterior level. Perimeter insulation measures modeled include no insulation, and two ft of R-5 or R-10 rigid boards.

Basement foundations were assumed to have concrete walls 8 ft high, extending 12 in above ground level. Insulation measures included rigid insulation on either side of the walls for heated basements, or batts placed between the floor joists for unheated basements. We modeled five insulation options: (1) uninsulated basements, (2) heated basements with R-5 rigid boards extending down 4 ft, (3) R-5 down 8 ft, (4) R-10 down 8 ft, and (5) unheated basements with R-19 floor insulation and no basement wall insulation.

We assumed crawl space foundations to be well ventilated, with the building thermally decoupled from the soil. Air temperatures in the vented crawl space were assumed to be close to ambient air temperatures. This is a generally accepted approximation when doing loads calculations for buildings with vented crawl space foundations.[3] Insulation was assumed to be batts placed between the floor joists. We modeled three levels of insulation: (1) uninsulated, (2) R-11 batts, and (3) R-19 batts.

Figure 3.3.10 illustrates the various foundation configurations that were modeled. Table 3.3a shows a list of the conservation options for each foundation type and the coding system developed to simplify identification of these option types.

Table 3.3a. Foundation Insulation Levels

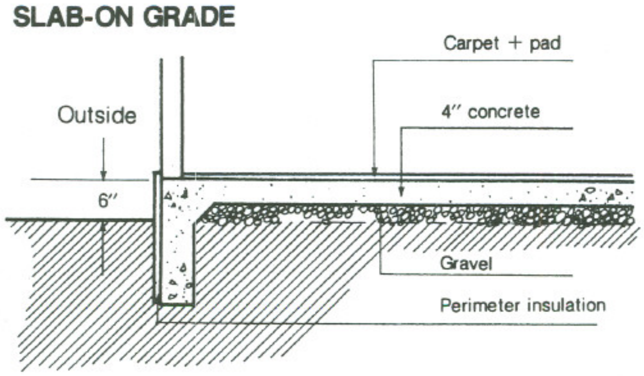
	Level of Insulation		
Floor Measure	Slab-on grade	Ventilated Crawl Space	Basement
FM0	No Insulation	No Insulation	No Insulation
FM1	R-5 2ft	R-11 Floor	R-5 4ft.
FM2	R-10 2ft †	R-19 Floor	R-10 4ft †
FM3	R-5 4ft	R-30 Floor †	R-5 8ft
FM4	R-10 4ft †	R-49 Floor †	R-10 8ft
FM5			R-0 Bsmt Wall, R-19 Floor

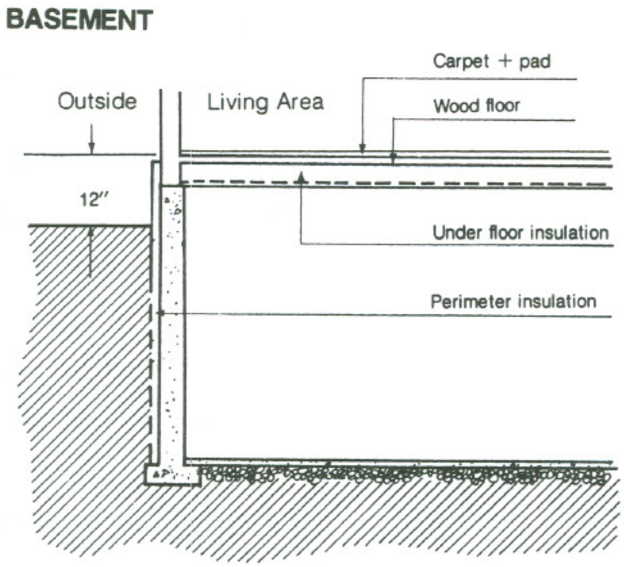
† not used in generating data base

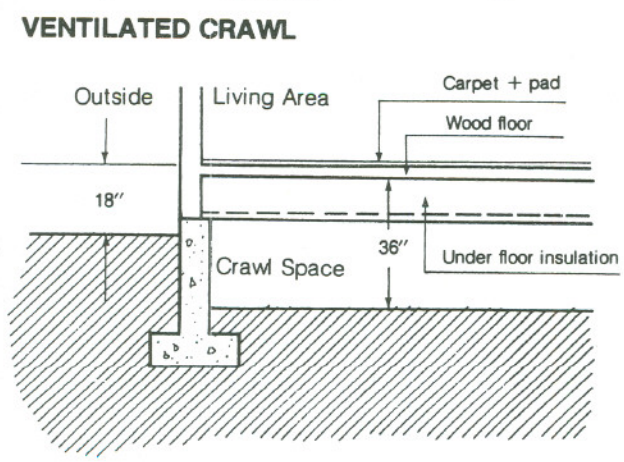
Accurate modeling of foundation heat losses is quite difficult because of the complex thermal coupling between the building and the ground, and the absence of reliable data on underground

3. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, *ASHRAE Handbook of Fundamentals* (1981).

Schematic Drawing of Foundation Models







XBL 8312-4776

Fig. 3.3.10

temperatures and soil properties. In 1981, when the residential database was created, this task was well beyond the capabilities of DOE-2.1A. Consequently, the Building Energy Analysis Group at LBL developed a mathematical approximation for foundation heat losses combining the best available empirical data on steady-state foundation U-values with the simulation capabilities of DOE-2.1A.

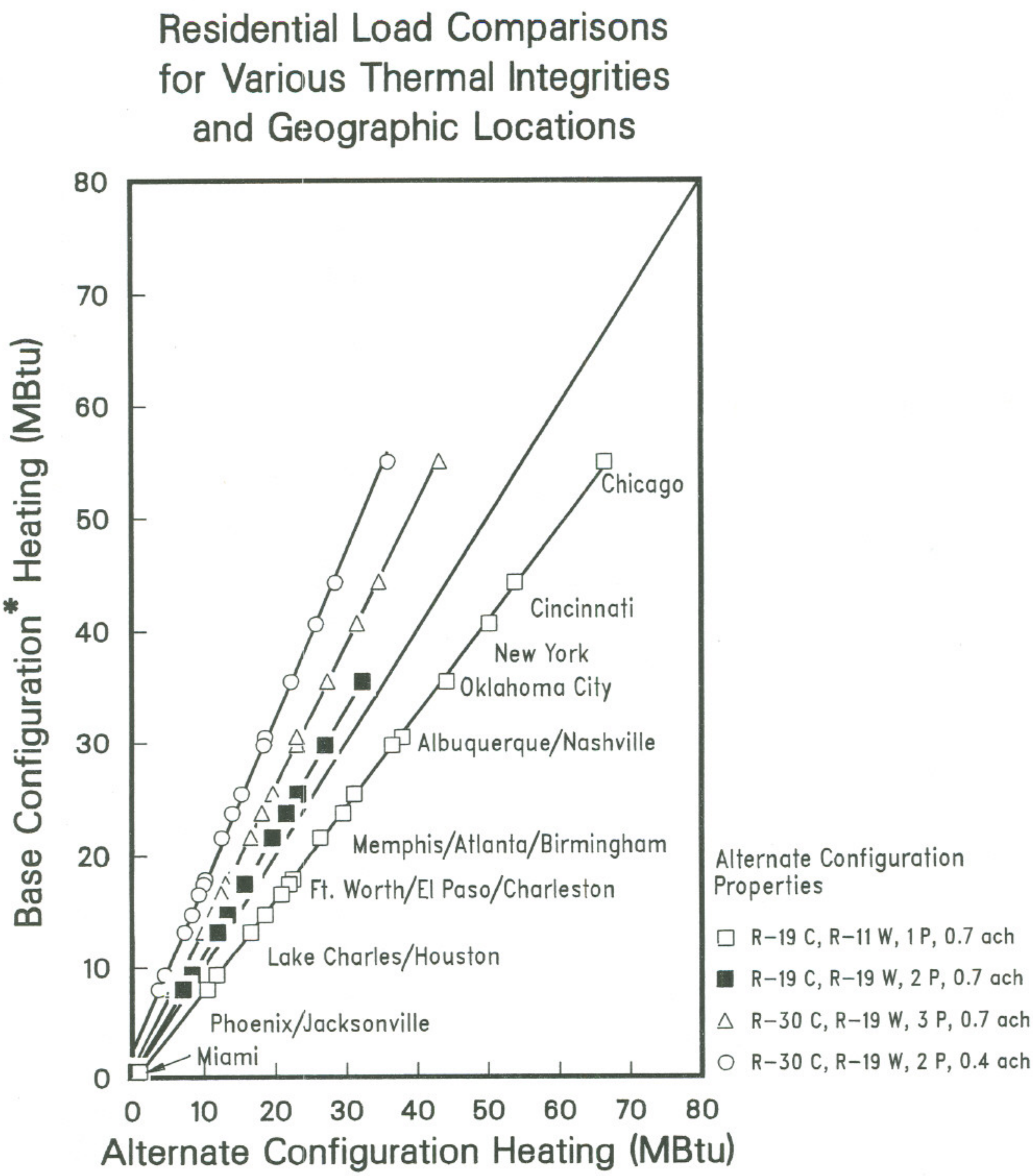
Heat transfer for various slab and basement configurations was first calculated as perimeter length times an effective U-value between indoor and outdoor air temperature using a two-dimensional finite element program. Since these U-values are calculated under steady-state conditions, they cannot be used directly in DOE-2.1A, where outdoor temperatures vary greatly on an hourly basis. To circumvent this problem, we assumed a large amount of thermal mass as the outermost layer of the foundation surface. The effect of this thermal mass is to dampen the daily temperature swing, which corresponds physically to the thermal lag evident in the soil near the foundation. Other properties of this thermal mass were adjusted so that the total heat loss through the foundation corresponded to that previously calculated. We calculated heat transfer for crawl space configurations using the total UA of the raised floor. Table 3.3b gives the effective U-values used as input for the DOE-2 simulations (for more detailed descriptions of the foundation model used in this analysis, see Appendix C).

In 1984, a finite-difference foundation model was developed and incorporated into a developmental version of DOE-2.1B. Resultant calculations using this DOE-2.1B program showed that foundation heat losses varied linearly to the temperature difference between indoor and outdoor air temperatures, thus validating the basic assumption used in this study.[4]

We expanded the database results for alternate foundation types (i.e., not part of the original database) for all 45 weather locations using a very convenient proportional relationship that were shown to exist between configurations. We employed two methodologies:

1. A short set of parametric runs for a particular location, prototype, and floor type was expanded into a full parametric set using a linear least squares fit similar to that expressed in Figure 3.3.11. The thermal load relationship between a base case configuration and four other configurations is shown for 22 locations. Knowing the base parametric load value for an arbitrary location and using such a linear representation, one can determine the load values for the alternate configurations. The alternates correspond to changing glass conductance, wall and roof conductance, and infiltration levels. One should note the proportional nature of the change in load

4. R. Sullivan, et.al., "Description of an Earth Contact Modeling Capability in the DOE-2.1B Energy Analysis Program" (presented at the ASHRAE Semi-Annual Conference, Jan. 1985), Lawrence Berkeley Laboratory Report 17459, Berkeley CA (1984).



*Base configuration is R-19 ceiling, R-11 wall, 2-pane windows, 0.7 ach infiltration

Fig. 3.3.11.

XCG 8511-494

Table 3.3b. Foundation Conductivities

Foundation Measure	Insulation Level	Effective U-value (Btu/hr·F)
Slab-on-grade		
FM0	R-0	1.18 per perimeter ft.
FM1	R-5 Two feet	0.40 " " "
FM2 †	R-10 Two feet	0.32 " " "
FM3	R-5 Four feet	0.28 " " "
FM4 †	R-10 Four feet	0.18 " " "
Heated Basement (R-0 floor)		
FM0	R-0 wall	1.86 per perimeter ft.
FM1	R-5 Four feet	1.05 " " "
FM2 †	R-10 Four feet	0.81 " " "
FM3	R-5 Eight feet	0.766 " " "
FM4	R-10 Eight feet	0.485 " " "
Unheated Basement (R-0 basement wall)		
FM0	R-0 floor	0.221 per sq.ft. of floor
FM5	R-19 floor	0.0425 " " "
Ventilated Crawl Space		
FM0	R-0	0.208 per sq.ft. of floor
FM1	R-11 floor	0.067 " " "
FM2	R-19 floor	0.047 " " "
FM3 †	R-30 floor	0.031 " " "
FM4 †	R-38 floor	0.020 " " "

† measures not used in generating data base

values regardless of geographic location. Essentially, a linear relationship exists between the base case load and alternate configuration loads.

2. For those locations in which a short parametric set did not exist, we did a correlation between floor types so that, for example, non-existent slab data for a particular location could be obtained from existing basement or crawl floor type data. A linear relationship similar to that discussed above was also found in this case.

For some of the geographic locations characterized by climate extremes, such as Miami, FL or Bismarck, ND, additional correction factors were applied to insure proper definition of the thermal load values.

Table 3.3c shows the level of accuracy of the procedure described above. The table shows heating load correlation coefficients resulting from a least squares fit among 17 different configurations of the one-story ranch prototype. The R^2 values are very close to 1.0 for perturbations that do not involve a major configuration change (primarily occurring diagonally). As one proceeds vertically down or horizontally across (right to left), the R^2 decreases. This is because larger variations exist between the configurations being compared. Such tables of coefficients were

Table 3.3c. Heating Load Correlation Coefficients for Parametric Options of the One-Story Slab-on-Grade Configuration

Option	A01	B01	C01	D01	E01	F02	G05	G01	H04	I07
B01	**0.9989**									
C02	0.9973	**0.9995**								
D01	0.9967	0.9994	**0.9999**							
E01	0.9948	0.9984	0.9990	**0.9998**						
F02	0.9920	0.9963	0.9969	0.9984	**0.9994**					
G05	0.9870	0.9922	0.9952	0.9960	0.9980	**0.9998**				
G01	0.9902	0.9951	0.9957	0.9977	0.9989	0.9999	**1.0000**			
H04	0.9873	0.9930	0.9934	0.9963	0.9979	0.9994	0.9998	**0.9998**		
I07	0.9854	0.9915	0.9915	0.9952	0.9970	0.9990	0.9994	0.9995	**0.9999**	
J06	0.9824	0.9887	0.9925	0.9936	0.9963	0.9988	0.9996	0.9996	1.0000	0.9999
J06	0.9794	0.9861	0.9904	0.9915	0.9946	0.9979	0.9991	0.9988	0.9997	1.0000
K03	0.9835	0.9901	0.9895	0.9941	0.9962	0.9984	0.9989	0.9991	0.9997	0.9999
K01	0.9800	0.9867	0.9908	0.9919	0.9952	0.9982	0.9992	0.9990	0.9998	0.9999
L04	0.9763	0.9836	0.9882	0.9895	0.9931	0.9969	0.9984	0.9980	0.9992	0.9997
M03	0.9724	0.9802	0.9854	0.9868	0.9909	0.9953	0.9972	0.9967	0.9984	0.9991
H54	0.9741	0.9828	0.9810	0.9884	0.9910	0.9941	0.9936	0.9954	0.9969	0.9976

Option	I06	J06	K03	L04	M03	H54
J06	**0.9998**					
K03	0.9997	**1.0000**				
K01	0.9999	0.9999	**0.9999**			
L04	0.9995	0.9999	1.0000	**0.9998**		
M03	0.9988	0.9995	0.9996	0.9993	**0.9998**	
H54	0.9958	0.9967	0.9979	0.9963	0.9971	**0.9976**

generated for all prototypes and were used to establish the best least squares fit between configurations. Further substantiation of these results and the theoretical implications are documented elsewhere[5].

It is evident that a large number of computer runs would be required if all combinations of the described insulation parameters were to be simulated for each of the five prototypes in all 45 locations. Consequently, certain criteria were used to select appropriate combinations of insulation measures that would reduce the number of computer runs without critically affecting the information obtained. For example, we did not simulate triple-pane windows on uninsulated houses. Similarly, high R-values were not simulated in locations where they made little sense, such as R-49 ceiling insulation in Miami. In Section 6.1 (Insulation), we describe the various combinations used in more detail.

5. R. Sullivan, et al. "Thermal Analysis of Buildings - Configuration Perturbations and Observed Climate Interface" (to be presented at ASHRAE Semi-Annual Meeting, January 1986) Lawrence Berkeley Laboratory Report No. 19373, Berkeley, CA (1985).

3.3.2 Infiltration

Infiltration is the uncontrolled leakage of air through cracks and other openings in a building's envelope. Infiltration rates are known to depend on wind velocity, outside-inside temperature differences and building characteristics. An equation of the form shown below was used to simulate the effect of wind speed and outside-inside temperature differences on infiltration rate.

$$I = A + BV + C\,\Delta T \qquad (1)$$

where I is the infiltration rate in air changes per hour (ach), V is the wind speed in miles per hour, and ΔT is the difference between indoor and outdoor temperature in F. The coefficients in this equation (known as the Achenbach-Coblenz equation) were derived from a statistical fit to data collected by Coblenz and Achenbach during the winter in 10 residential buildings in Indiana.[6] We used the following general equation in our DOE-2.1A calculations:

$$I = 0.252 + 0.0218V + 0.0084\Delta T \qquad (2)$$

The three coefficients in equation (2) show the relative impact of wind speed and temperature differences on the infiltration rate. For any location, the resultant seasonal infiltration rate will vary depending on the climate. To maintain uniformity in these infiltration rates, we adjusted the coefficients to yield an average winter (November through March) infiltration rate of 0.7 ach for all locations.

Two additional levels of infiltration (1 ach-high) and 0.4 ach-low) were also considered, to cover a wider spectrum of infiltration values. We obtained the high rate through extrapolation (see Section 6.2), while the low infiltration rate was actually modeled. To produce the low rate, we adjusted the coefficients of equation (2) so as to to yield an average winter infiltration rate of 0.4 ach for all locations. We used the general equation:

$$\text{Low (0.4ach) } I = 0.144 + 0.0125V + 0.0048\Delta T \qquad (3)$$

The low infiltration case assumes either of two conditions: (1) the house has a natural infiltration rate of 0.3 ach plus 0.1 ach due to building use (opening of doors and windows), or (2) the house is constructed with an air infiltration rate of 0.2 ach, but a heat exchanger has been added to maintain indoor air quality. We assumed the air-to-air heat exchanger had a heat recovery of 75% and an air flow rate of 0.4 ach.

This assumption insures that the low infiltration house had the same average ventilation rate, and thus similar indoor air quality, as the medium infiltration house (0.7 ach). However, the heat loss will correspond only to that of an air flow rate of 0.4 ach due to the use of a heat

6. Achenbach, P.R. and C.W. Coblenz. "Field Measurements of Air Infiltration in Ten Electrically-heated Houses". *ASHRAE Transactions 69*: 358-365 (1963).

exchanger: 0.1 ach (heat exchanger) plus 0.2 ach (infiltration) plus 0.1 ach (building operations).

Later versions of DOE-2 (2.1B and 2.1C) include an additional method for determining infiltration rates in residential structure when the leakage area, geometry, surrounding terrain, wind speed, and inside-outside temperature differences are known. It was not available, however, at the time of our analysis.

3.4 Window Characteristics

Window area in new construction was found to equal 8% to 10% of the floor area based on the NAHB survey of 1981. This analysis assumed a 10% ratio for one- and two-story prototypes, 11% for the split-level, and 12% for the end and middle unit townhouses. In this study, we also assumed that the window areas given are for gross window area including sash and not for net glass area. For the base case simulations, we modeled the windows as being equally distributed on all exterior walls to remove directional bias in the database and to reflect the statistical randomness of building orientation. It should be noted, however, that the floor plans shown in Figures 3.2.1 though 3.2.6 have unequal window distribution, since they are actual building plans for the closest architectural representations of the five prototypes. To account for the effects of different window distributions and house orientations, we conducted extensive sensitivity studies (see Section 6.4.3).

In this analysis, an ASHRAE window (with no sash) was modeled. The number of window glazings ranged from one to three with a ½ inch air gap assumed between window panes. Extrapolations were done for different sash types such as wood, aluminum and aluminum with thermal breaks, and for ¼ inch air gap spacing (see Section 6.4.1). Table 3.4a shows window conductances reflecting ASHRAE winter U-values with outside film coefficient subtracted.

Table 3.4a. Window Conductances

Number of panes	ASHRAE U-value	Converted ASHRAE U-value with outside air-film subtracted
Single glazing:	1.10	1.350 Btu/ft^2·F·hr
Double glazing:	0.49	0.535 Btu/ft^2·F·hr
Triple glazing:	0.31	0.327 Btu/ft^2·F·hr

We used these values to calculate conductive heat loss or gain through windows. Converted winter values are appropriate for the entire year since the main difference between winter and summer window conductances is the outside air coefficient, which is simulated on a hourly basis by the

7. Sherman, M.H. and D.T. Grimsrud, "Measurement of Infiltration Using Fan Pressurization and Weather Data", Lawrence Berkeley Laboratory Report 10892, Berkeley, CA (1980).

DOE-2.1A code.

Solar heat gain through the windows has both diffuse and direct solar radiation components. For each component, we added the amount of solar radiation transmitted directly through the windows to the amount absorbed in the window and reradiated inward. Standard windows were modeled using Glass-Type-Code = 1 in the DOE-2.1A input. (Sensitivity studies on the impact of reflective and absorptive glass on building loads are covered in Section 6.4.4). We show the transmittance and reflectance values for solar radiation at normal incidence in Table 3.4b for single, double and triple glazing. The DOE-2.1A program uses precalculated transmission and absorption coefficients to determine solar gain as a function of angle of incidence of solar radiation.

Table 3.4b. Transmittance and Reflectance of Glazing

Glazing layers	Transmittance (%)	Reflectance (%)	Shading Coefficient
Single pane	88	7	1.000
Double pane	75	16	0.909
Triple pane	68	18	0.833

In addition to the effect of incident solar radiation on the glass itself, we also assumed that window sash covers 15% of the gross window area and that typical drapes of medium color and semi-open weave with a shading coefficient of 0.54 are drawn over half the windows during all hours of the day throughout the year.[8] These assumptions result in an area-weighted shading coefficient for the overall solar spectrum of 0.63. Thus, the resulting solar gain is the product of 0.63 times the solar gain from both diffuse and direct solar radiation striking the windows. In other words, we assumed that drapes and window sash will reduce the solar gain through typical windows by 27% compared to an ideal window with no obstructions.

3.5 Attached Sunspaces

We modeled the attached sunspace as an extension to the south wall of the building, and covers as much as 44% of the south wall area. The sunspace constituted a separate thermostatic zone, allowing heat transfer to the house to reduce heating loads for the living space. The attached sunspace was only modeled for the one-story ranch house prototype with 1540 ft^2 of floor area plus the additional sunspace area.

8. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, *ASHRAE Handbook of Fundamentals*, Table 38 (1981).

Sunspace configurations modeled were eight ft in width, and either 12 or 24 ft long (see Figure 3.5.1). We simulated single-glazed sunspaces on houses with three levels of thermal integrity. In addition, sensitivity studies were done on double-glazed sunspaces in cold locations (see Section 6.8 for details on results of these sensitivity studies). The side walls of the sunspace and the partition wall between the sunspace and the living space were assumed to have the same level of insulation as the walls of the main building. Thermal mass in the sunspace was provided by a six in concrete floor slab and by a facing brick wall situated on the sunspace side of the partition separating it from the house. The sunspace roof was assumed to be sloped with a 3:12 pitch, and was modeled as either glazed or opaque. We assumed the construction and insulation level of the opaque roof was similar to the roof of the main house.

Sunspace operating conditions were set after consultation with a technical review panel. We assumed the sunspace was a semi-conditioned space representing a compromise between energy efficiency and livability. As modeled, the sunspace can be occupied during the day and is not allowed to freeze at night. Its thermostat settings differ from those of the living space, with temperatures allowed to drop to 45 F, at which point a baseboard heater turns on. When sunspace temperatures exceed 80 F, venting equalizes sunspace temperature with that of the outdoors. This reduces somewhat the energy efficiency of the sunspace, but prevents overheating on sunny winter days. During the heating season, night heat loss was reduced by covering the front glass wall (and roof if glass) of the sunspace with R-5 movable insulation from 10 p.m. to 8 a.m. During the cooling season, movable shading with a shading coefficient of .30 was assumed during those hours when the sun shines on the glass roof and walls.

Heat is transferred from the sunspace to the living space by use of a thermostatically controlled fan to reduce the heating load of the living space. We assumed the fan was activated when the temperature differential between the two areas was greater than 3 F during periods when the living space had a heating load. Forced air was returned to the sunspace through another set of vents. We did not assumed convection occurred between the two zones through either open doors or windows in the partition.

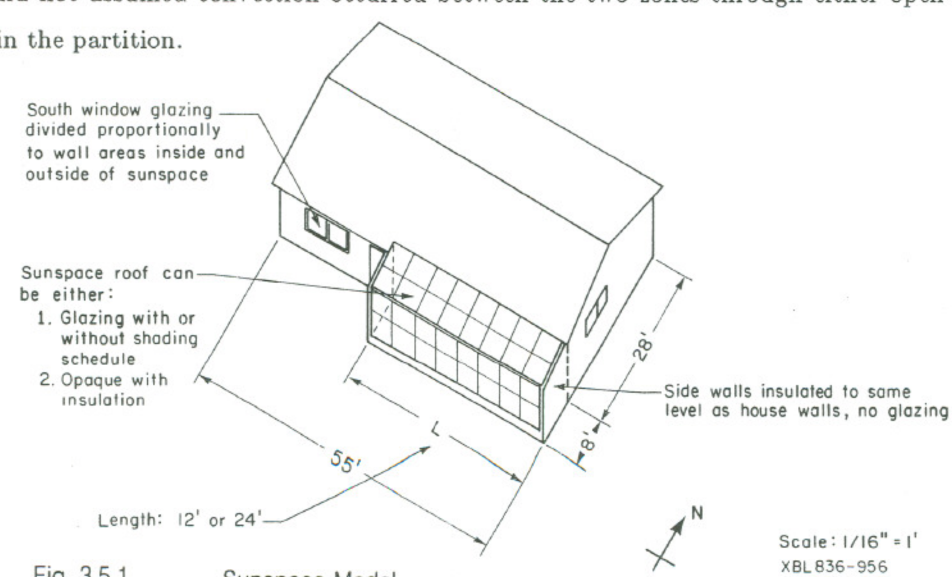


Fig. 3.5.1 Sunspace Model

4.0 STANDARD BUILDING OPERATING CONDITIONS

Standard building operating conditions refer to those operations that are under the control of the homeowner, such as temperature settings, night thermostat setback, window and whole house ventilation, movable night insulation and day shading devices, internal loads due to occupants and appliances, and the type and operation of space conditioning equipment. For this study, the intent was to define the most typical, rather than optimal, operating conditions in U.S. homes based on survey data and other studies. These operating conditions were kept constant to provide a basis for comparing different conservation measures and climatic conditions. However, we also investigated the impacts of changing these assumptions through various sensitivity analyses.

4.1 Thermostat Set Points

The whole building (living space) was assumed to consist of one zone, and the basement area, if there were one, constituted a second zone. We modeled the first zone as a thermostatically controlled one while the second zone had no control and was allowed to have a floating temperature. Thus, only one thermostat was assumed in all cases to control temperatures in the living space. We modeled the thermostat setting as 70 F for heating, and 78 F for cooling.

A night setback to 60 F between midnight and 6 a.m. was assumed during the heating season, except for houses with heat pumps. Recent studies have indicated that from one-half to three-quarters of homeowners turn down their thermostats at night.[9] This suggests that setbacks should be regarded not as an option, but as a typical operating condition. In this study, a short six hour setback period was selected as an average of no setback and setbacks of longer duration.

For houses equipped with heat pumps, we assumed a thermostat setting of 70 F for heating, and 78 F for cooling during all hours. Setbacks were not modeled because they are known to be non-productive for heat pumps.

4.2 Building Venting

We assumed natural window venting when the two following criteria were met: (1) the outdoor temperature in the summer was lower than the indoor temperature, but not higher than 78 F, and (2) the enthalpy of outdoor air was less than that of indoor air. This second requirement is needed so that indoor humidity is not adversely affected by window venting. We assumed a single venting schedule from May 15 through September 30 for all climates. A constant 10 air changes

9. Vine, E., "Savings Energy the Easy Way: An Analysis of Thermostat Management", Lawrence Berkeley Laboratory Report 16322, Berkeley CA (1983).

per hour was assumed when natural venting occurs. The DOE-2.1A program is unable to vary air change rates depending on climate conditions or building characteristics.

4.3 Window Operations

The standard window shading coefficients mentioned in Section 3.4 was based on the assumption that drapes or blinds cover half of the window area at all times. For the sun-tempered sensitivities, however, we assumed that the drapes or blinds on the south windows were always open during the heating season to maximize the solar benefit and closed during the cooling season to prevent overheating.

We describe a complete set of window sensitivities, which addresses other occupant behavior features, such as movable night insulation as well as several sun-tempered designs (e.g. attached sunspaces, and thermal mass options), in later sections.

4.4 Internal Loads

Under normal occupancy, the interior space of a house collects heat, which is termed the internal load, released by people, appliances and lighting. We assumed house occupancy to be 3.2 persons, reflecting an average single-family household in the United States. A recent estimate of the average single-family building occupancy indicated a value of 3.05 persons per household based on 1980-81 census data. The impact of 3.05 persons in comparison to 3.2 persons on heating and cooling loads is less than 1%, which is negligible for analytical purposes. In the analysis we assumes internal loads were due to heat gain from the following appliances: range, refrigerator, freezer, clothes dryer, water heater, and television. Heating equipment was assumed to be located in unconditioned spaces and thus heat losses did not contribute to building internal loads.

Average saturation levels and energy use estimates based on 1981 standards were used to predict internal loads for all appliances of significance, and for heat released by lighting and occupants. The total average annual internal load, both sensible and latent, was derived on an item-by-item basis, and then combined (see Table 4.4a). For the one-story ranch house, we assumed the total daily internal loads were 56,106 Btu of sensible and 12,156 Btu of latent load. Table 4.4b contains the hour-by-hour schedule of the internal loads schedule assumed in the analyses for the one-story ranch house prototype (see Appendix D for detailed breakdown of internal loads assumptions).

Internal loads were taken to be a property of the occupants rather than the house and thus were independent of house size (except for lighting energy, which is assumed to increase in proportion to floor area). We made this assumption because there are no data relating internal loads or number of occupants to house size, and because internal loads are subject to saturation. Therefore,

Table 4.4a. Estimated Average Annual Internal Loads for Prototype Houses

Use	Saturation	Energy per Unit per Year	Percent Indoors	Sensible Heat Load per Year	Latent Heat Load per Year
New Refrigerator	1.00	1125 kWh	100	1125 kWh	0
Old Refrigerator	.15	1600 kWh	15	35 kWh	0
Freezer	.45	950 kWh	50	214 kWh	0
Range (gas)	.19	60 therms	100	805 kWh	415 kWh
(elec)	.78	1200 kWh			
Lighting	1.00	1 kWh/ft^2	90	1386 kWh (Ranch)	0
				2016 kWh (Two Story)	0
				1714 kWh (Split-level)	0
				1080 kWh (Townhouses)	0
Hot Water (standby losses)	1.00	45 therms or 1320 kWh	50	660 kWh	0
(water use)	1.00	95 therms or 2800 kWh	10*	280 kWh	140 kWh
Television	2000 set-hr	100 W	100	200 kWh	0
Clothes Dryer	.70	900 kWh	10	63 kWh	0
Dishwasher	.70	250 kWh		~0	0
Miscellaneous Appliances				300 kWh	0
People	3.2 persons			930 kWh	735 kWh
Totals		Ranch		6000 kWh (56100 Btu/day)	1290 kWh (12150 Btu/day)
		Two Story		6630 kWh	1290 kWh
		Split-level		6328 kWh	1290 kWh
		Townhouses		5694 kWh	1290 kWh

* Internal loads due to water use is about 10% of the energy used for water heating.

except for lighting, the same internal loads were assumed for all building prototypes.

The exact schedule of hour by hour internal loads could be derived, in principle, appliance by appliance. However, the uncertainties associated with such detailed scheduling are often greater than the uncertainty in total daily energy use. Test simulations using internal loads schedules, which differed only in their hourly distributions, resulted in less than 1/20% change in heating loads. Rather than deriving an appliance-by-appliance hourly load schedule, we used schedules from previous studies and scaled them to our daily total.[10] The results are shown in Table 4.4b, with load peaks at breakfast and dinner time, greater loads in the evening than at midday, and the lowest loads during the night. We considered seasonal variations (see Appendix D, Internal Loads), but did not use them because they produce only a small effect.

Table 4.4b. Internal Loads Schedule for One-Story Ranch House (1540 ft^2)

Hour of Day	Sensible Load (Btu)	Latent Load (Btu)	Hour of Day	Sensible Load (Btu)	Latent Load (Btu)
1	1139	247	13	1707	370
2	1139	247	14	1424	308
3	1139	247	15	1480	321
4	1139	247	16	1480	321
5	1139	247	17	2164	469
6	1903	412	18	2334	506
7	2391	518	19	2505	543
8	4782	1036	20	3928	851
9	2790	604	21	3928	851
10	1707	370	22	4101	888
11	1707	370	23	4101	888
12	2277	493	24	3701	802
			Totals	56106	12156

4.5 Heating and Cooling Systems

Most of our analysis is concerned with the effect of various conservation measures on the building's heating and cooling loads. In this study, we focus on the reductions in loads obtained through improvements in the thermal integrity of the building envelope (roof, walls, windows, etc.). In order to convert these changes in building loads into changes in actual space conditioning energy use, it is necessary to determine the performance of the heating and cooling equipment.

We modeled three types of space conditioning systems for all 5 prototypes in all 45 locations:

- Gas or oil furnace (heating) - modeled for all levels of thermal integrity.
- Electric air conditioner (cooling) - modeled for all levels of thermal integrity.
- Electric heat pump (heating & cooling) - modeled for an average level of thermal integrity (R-30 ceiling, R-19 wall, R-5 4-ft foundation, double glazing, and 0.7 ach infiltration).

The relationship of actual equipment energy use to building loads was determined by the equipment efficiency at full load (which may or may not be dependent on outdoor conditions) and the possible degradation of that efficiency under part-load conditions. For computer simulations of

10. B.A. Peavy, F.J. Powell and D.M. Burch, "Comparison of Measured and Computer-Predicted Thermal Performance of a Four-Bedroom Wood-frame Townhouse", Institute of Applied Technology, National Bureau of Standards, NBS Science Series 57, Gaithersburg, MD. (1975).

equipment performance, it was necessary to input both the heating coefficient of performance (COP) and cooling energy efficiency ratio (EER) at full load versus the outdoor drybulb temperature, and the COP or EER at any load versus the partial load ratio. Figures 4.5.1 and 4.5.2 show typical curves that were used for modeling a heat pump. Because the shape of these curves can vary from one manufacturer to another, we performed a sensitivity analysis to determine the effect of differing equipment performance on energy budgets. The results of this analysis are described in Appendix B.

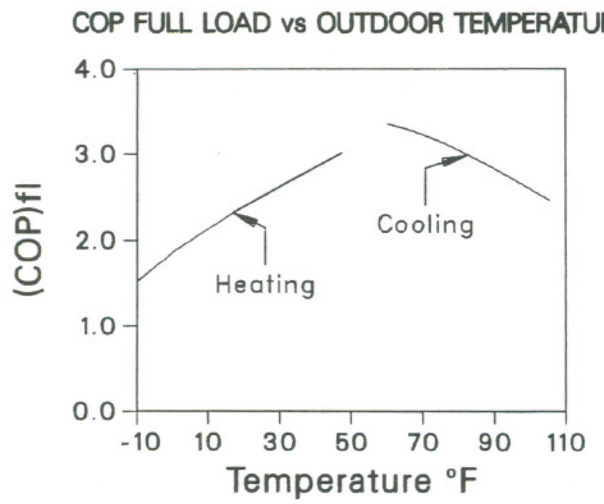


Fig. 4.5.1

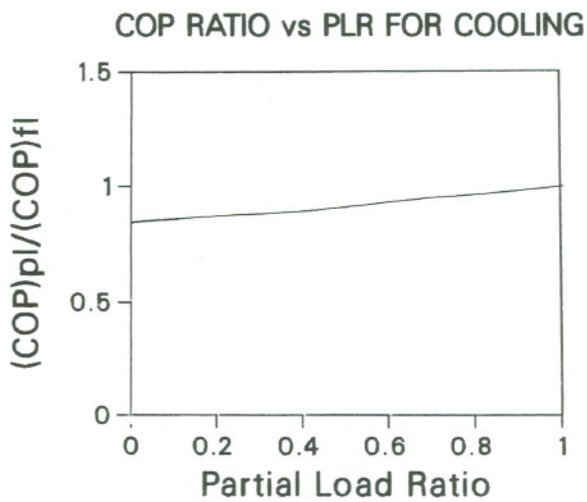


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Fig.4.5.2

We assumed the furnace had a fixed efficiency of 0.70, which corresponds to a gas furnace with an intermittent ignition device and a tight stack damper. The furnace was assumed to be located outside the living space, (i.e. in the basement), so that it had no effect on the building's internal loads. The performance curves for such devices were supplied by the National Bureau of Standards. We assumed that the partial load efficiency was equal to one, meaning that furnace efficiencies are unaffected by sizing. The full-load efficiency was modeled as 0.77, independent of outside temperatures. We also assumed that heat loss through ducts and increased infiltration reduce the net seasonal efficiency of the furnace by 10% in terms of (energy delivered/energy consumed) to 0.70, or 70%. The rated capacity of the furnace was modeled as 50,000 Btu/hr for the one-story and townhouse prototypes, and 100,000 Btu/hr for the two-story and split-level prototypes.

We modeled the air-conditioner with an EER of 9.2 at 95 F drybulb/75 F wetbulb outdoor and 80 F drybulb/67 F wetbulb indoor temperatures. The rated capacity was assumed to be 33,000 Btu/hr for the one-story and townhouse, and 66,000 Btu/hr for the two-story and split-level prototypes. The total and sensible capacities are functions of outdoor wetbulb and drybulb temperatures. A full-load efficiency curve (COP) versus outdoor drybulb (T) and indoor wetbulb (W) was obtained and is expressed as follows:

$$COP_{\text{Full Load Cooling}} = [\, 6.5705575 - 0.16429932W + 0.00120362W^2 - 0.01296T + 0.00008698T^2 + 0.00007554WT \,]^{-1} \times COP\ (95\ F) \qquad (4)$$

We derived the curve for partial load efficiency as a function of the partial load ratio (PLR) of the air-conditioner on the basis of measured data obtained by National Bureau of Standards (NBS) that assumed a one-cycle-per hour frequency of operation.[11] The following curve was obtained by fitting this data:

$$\frac{COP}{COP\ (\text{Full Load})} = \frac{1}{1.197 - .197(PLR)} \qquad (5)$$

If a different steady-state EER is used, we modified the seasonal EER by multiplying the base case seasonal EER as calculated by DOE-2.1A by the ratio of the new to the base case steady-state EERs. Because of the partial load ratio curve, it can be expected that air conditioner sizing will have some impact on the net seasonal EER. However, because insulation levels, window orientation, shading, and climate parameters all play a role in determining the peak cooling loads, the impact of air-conditioner sizing on net seasonal efficiencies was not incorporated into the basic methodology for generating the database. Selected sensitivities done to study these effects show that, given the performance curves described, the changes in seasonal EERs were relatively minor (see Appendix B).

We based the analysis of the heating and cooling energy use of an air-to-air heat pump system on the Coleman 3230-601 model heat pump. However, reports have shown that the heating and cooling COP curves, as a function of outdoor temperature, do not vary very much from one manufacturer to another.

The air-to-air heat pump was modeled with a heating COP of 3.1 (at 47 F outdoor temperature) and a cooling EER of 9.2. We used two different sets of full and partial load curves that took into account part load degradation (cycling) on an hourly basis as well as defrost degradation

11. W.H. Parker, R.W. Beausoliel, and G.E. Kelly, "Factors Affecting the Performance of a Residential Air-To-Air Heat Pump", ASHRAE Transactions, Vol. 83, pp. 839-849, New York NY (1977).

in the heating mode. For the cooling cycle, the relationship of COP and capacity to wetbulb and drybulb temperatures and the part-load ratio (PLR) curves utilize the same equations as described previously for the air conditioner system. For the heating cycle, the following equations were used to adjust the COP for outdoor drybulb temperatures and part-load ratios:

$$\frac{\text{COP (Part Load)}}{\text{COP (Full Load)}} = \frac{1}{1.165-.165(\text{PLR})} \tag{6}$$

$$\text{COP}_{\text{Full Load Heating}} = \left[1.812-0.036\text{T} + 0.00057\text{T}^2-0.0000037\text{T}^3\right]^{-1}$$

The seasonal performance of heat pumps will vary as a function of climate and load. Simulations were done for all 5 prototypes in all 45 locations to calculate location and building specific seasonal efficiencies for a heat pump with the characteristics just described. If a different set of steady-state COP or EER values were used, the corresponding seasonal COP and EER for a particular location were derived by modifying the seasonal values for the base case by the ratio of the new to the base steady-state COP and EER.

The final step in this analysis was to incorporate the equipment efficiencies into a usable format. For furnaces, this task was not difficult since the seasonal efficiencies are constant and independent of climate and part-load conditions. Hence, efficiencies can be regarded as simply a multiplicative scaling factor of the building loads.

For air-conditioners and heat pumps, we assumed that net seasonal efficiencies for a particular equipment type will vary depending on location and prototype, but will remain constant for different levels of thermal integrity. Therefore we reduced the simulation data to lists of seasonal efficiencies for air-conditioners and heat pumps of different COPs and SEERs for the 45 cities (see Table 4.5a). The efficiencies listed in the table were based on DOE-2.1A simulations for a typical thermal integrity of R-30 ceiling, R-19 wall, double-glazing, FMI foundation, and 0.7 ach infiltration. These efficiencies are incorporated into the microcomputer program.

Table 4.5a Approximate Seasonal Cooling Equipment Efficiencies *

(COP, modeled air-conditioner SEER = 9.2)

Location Number	One-Story	Middle Townhouse	End Townhouse	Two-Story	Split-level
1	2.083	2.005	2.033	2.081	2.093
2	2.349	2.315	2.319	2.331	2.338
3	2.405	2.363	2.371	2.374	2.375
4	1.638	1.646	1.677	1.749	1.773
5	1.745	1.720	1.757	1.825	1.844
6	1.698	1.700	1.718	1.801	1.812
7	2.537	2.502	2.509	2.478	2.474
8	1.284	1.365	1.391	1.442	1.478
9	1.314	1.352	1.391	1.455	1.495
10	2.470	2.417	2.425	2.423	2.420
11	1.094	1.177	1.211	1.248	1.310
12	1.800	1.768	1.801	1.890	1.893
13	2.143	2.108	2.128	2.177	2.177
14	1.456	1.445	1.495	1.569	1.597
15	2.296	2.242	2.257	2.268	2.267
16	2.433	2.380	2.393	2.390	2.385
17	2.197	2.125	2.154	2.176	2.181
18	1.078	1.154	1.195	1.234	1.300
19	2.626	2.606	2.610	2.578	2.575
20	2.506	2.464	2.473	2.461	2.456
22	2.271	2.212	2.230	2.273	2.264
23	2.496	2.450	2.460	2.448	2.443
24	2.293	2.221	2.239	2.230	2.228
25	.767	.837	.862	.873	.940
26	1.908	1.737	1.773	1.871	1.876
27	2.407	2.352	2.365	2.373	2.369
28	2.583	2.551	2.558	2.523	2.519
29	1.968	1.939	1.965	2.027	2.035
20	2.327	2.286	2.295	2.310	2.311
31	2.023	2.004	2.020	2.070	2.074
32	2.325	2.268	2.282	2.302	2.299
33	2.128	2.083	2.103	2.159	2.159
34	2.161	2.130	2.140	2.176	2.171
35	2.362	2.290	2.307	2.286	2.281
36	1.891	1.899	1.917	1.965	1.985
37	1.114	1.221	1.262	1.305	1.360
38	1.315	1.159	1.198	1.305	1.334
39	1.617	1.586	1.634	1.697	1.738
40	1.865	1.832	1.863	1.919	1.938
41	2.454	2.409	2.418	2.408	2.404
42	1.167	1.209	1.198	1.216	1.310
43	.256	.324	.327	.289	.356
44	.583	.629	.672	.721	.771
45	2.251	2.196	2.213	2.256	2.249

* Location number 21 (Juneau) not included

5.0. CLIMATE ANALYSIS

The three major goals to the climate analysis done in support of the Residential Guidelines project are to: (1) determine the number of base cities necessary for thermal integrity simulations, (2) devise a simple technique for extrapolating building loads from base city locations to other areas, and (3) select the cities necessary for parametric studies of window sensitivities.

The selection of base cities involved analyzing a preliminary DOE-2 database of residential energy use for nearly 50 locations. The development of the extrapolation procedure included comparing the same DOE-2 database to various climate parameters, and selecting the appropriate ones to be used for extrapolating base city data to other locations. For the climate analysis, we used data from the National Oceanic and Atmospheric Administration (NOAA) for more than 3,320 U.S. locations, as well as hourly weather tapes available at LBL for 300 locations. This extrapolation procedure had to be geographically comprehensive, reliable, and simple enough to be used by the intended non-technical audience.

We selected a smaller number of base cities for analyzing window effects after the first two tasks were completed. For the climate analysis, we used a database that included the effects of selected window configurations in 45 different locations.

5.1. Selection of Base Cities

A preliminary DOE-2.1A database of nearly 1000 computer simulations for a one-story ranch prototype in 47 locations was analyzed for the following energy characteristics: absolute heating and cooling loads, and incremental changes in heating and cooling loads for varying thermal integrities. This data, which was created by LBL in 1981-1982 using the DOE-2.1A computer program is a precursor to the more comprehensive residential database developed for this project. For consistency, all simulations were done using Test Reference Year (TRY) weather tapes. The 47 cities gave a good cross-section of population-weighted U.S. climate differences, and included 23 of the 25 largest Standard Metropolitan Statistical Areas (SMSA) with nearly half of the U.S. population (see Table 5.1a). The objective of the analysis was not to define climate zones but to investigate how many base cities could be eliminated without substantially affecting the comprehensiveness of the database, and to determine what additional locations were needed.

Figures 5.1.1 and 5.1.2, which are taken from this database are plots of the annual heating and cooling loads for the one-story ranch house in various locations against building k-value. Building k-value is the heat loss per unit of time per F through the building shell (heat conductivity and infiltration losses) and has units of Btu/hr·F. The highest loads on the right are for a totally uninsulated house at 0.7 ach infiltration with a total k-value of nearly 1200 Btu/hr·F; the lowest on the left are for a house with a R-60 ceiling, R-27 wall, 8 ft. of R-10 perimeter insulation,

Table 5.1a. Locations in Preliminary DOE-2 Residential Data Base

City	1980 SMSA Population (x 1000)	Rank (out of top 25)	City	1980 SMSA Population (x 1000)	Rank (out of top 25)
Albuquerque NM	420	-	Los Angeles CA	11,498	2
Atlanta GA	2,138	16	Medford OR	132	-
Birmingham AL	884	-	Memphis TN	913	-
Bismarck ND	-	-	Miami FL	2,644	12
Boise ID	173	-	Minneapolis MN	2,137	17
Boston MA	3,972	7	Nashville TN	851	-
Brownsville TX	210	-	New Orleans LA	1,256	-
Buffalo NY	1,243	-	New York NY	17,539	1
Burlington VT	115	-	Oklahoma City OK	861	-
Charleston SC	430	-	Philadelphia PA	5,681	4
Cheyenne WY	-	-	Phoenix AZ	1,509	24
Chicago IL	7,937	3	Pittsburgh PA	2,423	13
Cincinnati OH	1,660	20	Portland ME	194	-
Denver CO	1,618	21	Portland OR	1,100	-
Detroit MI	4,753	6	Raleigh NC	561	-
El Paso TX	480	-	Richmond VA	761	-
Fort Worth TX	2,931	10	St. Louis MO	2,377	14
Fresno CA	515	-	Salt Lake City UT	910	-
Great Falls MO	81	-	San Diego CA	1,862	19
Honolulu HA	763	-	San Francisco CA	5,368	5
Houston TX	3,101	9	Seattle WA	2,093	18
Jacksonville FL	722	-	Tulsa OK	657	-
Kansas City MO	1,433	25	Washington DC	3,251	8
Lake Charles LA	167	-			

3-pane windows, and 0.4 ach infiltration, with a total k-value of only 295 Btu/hr·F.

The figures demonstrate why the changes in loads as well as the total loads must be considered when selecting base cities. In heating (Fig. 5.1.1), the curves are similar, which indicates that in all locations the loads are determined mostly by conductive losses. Thus, the changes were roughly proportional to the total loads, and both were proportional to heating degree-days. However, there were still up to 15% variations in the change in loads for places with similar total loads, such as Cheyenne (C) and Chicago (D). For cooling (Fig. 5.1.2), the relationship between changes in loads and total loads was not as good, with arid locations such as El Paso (D) and Phoenix (J) showing much higher relative slopes than humid locations such as Memphis (G) and Miami (H).

A criterion of 5% or 5 MBtu difference in loads was used in grouping the cities in the database. This criterion was considered as a reasonable level of accuracy, since 5-10% differences in degree-days and, for the worst case, 22% differences in heating requirements were observed between different weather tapes for the same location.[12]

12. Anderson, J. and Madison, D, "Comparison of TMY and TRY Data", Solar Energy Research Institute, Golden CO (1980).

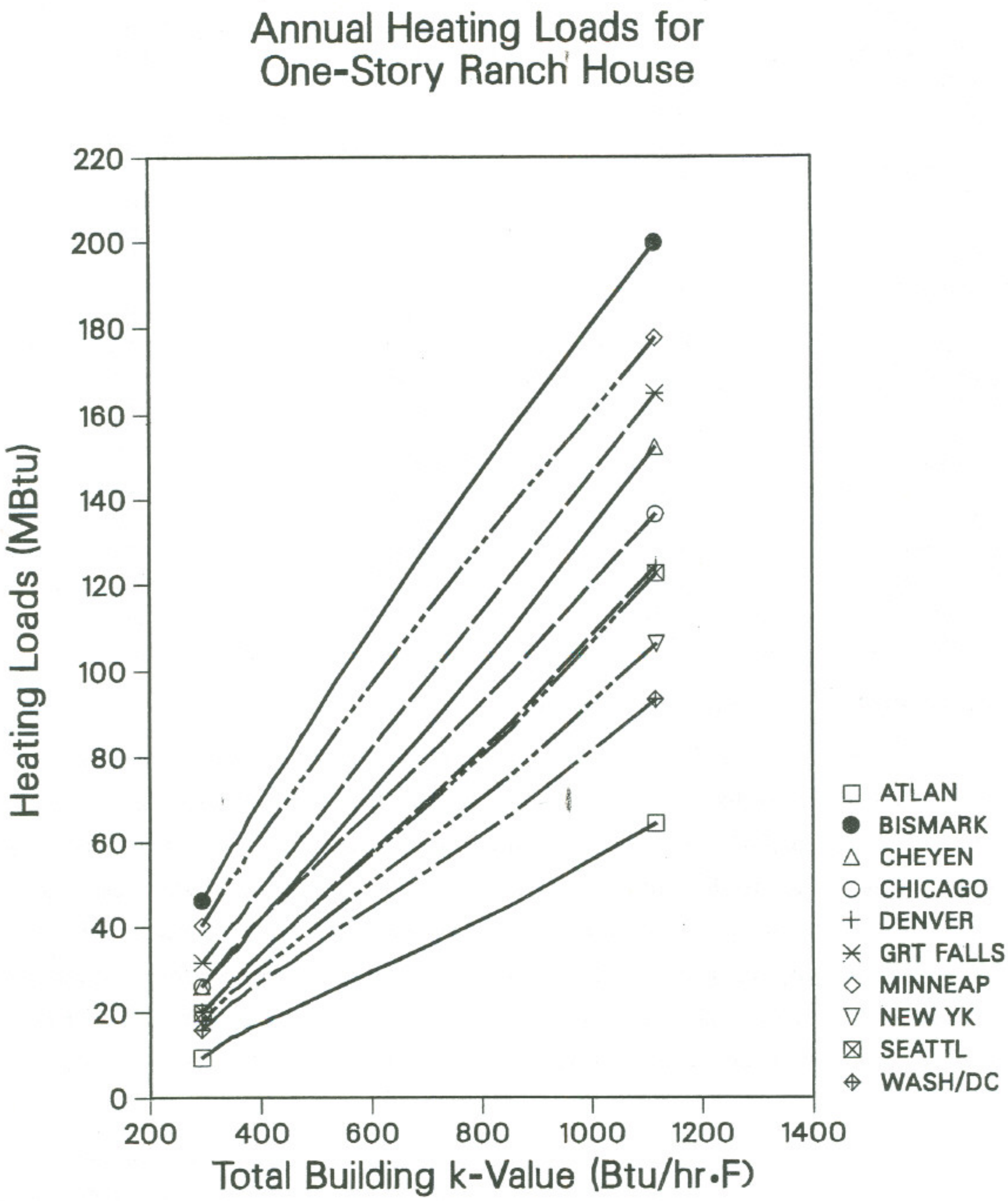

Fig. 5.1.1

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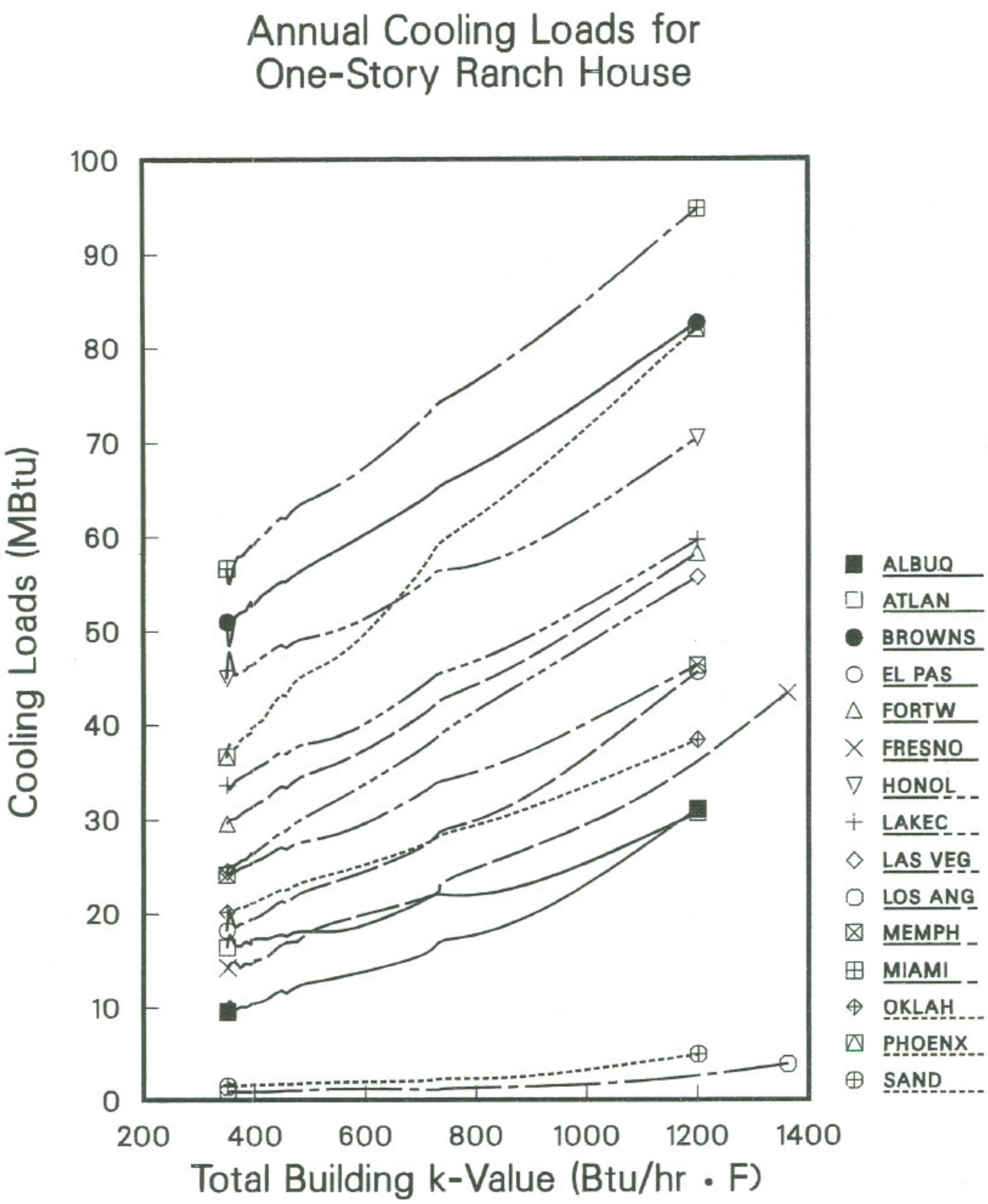

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Fig. 5.1.2

The cities were grouped first by similarity in total loads for an average house with a R-30 ceiling, R-19 wall, FM1 foundation, double glazing, and 0.7 ach infiltration. This resulted in 10 groups for heating and 9 for cooling. The groups were then subdivided if the changes in loads from the average house to uninsulated or to very tight houses differed by more than the same 5% or 5 MBtu. This expanded the number of groups to 18 for both heating and cooling (see Tables 5.1b and 5.1c). When heating and cooling were considered together, the number of groups increased to 40. Despite the increase in base cities, we used the combined groupings because it avoided having two base cities for one location (one for heating, another for cooling), or composite loads not associated with real locations.

In the combined groupings, only six cities out of the 47 were found to have heating and cooling characteristics similar enough to other locations to be eliminated as base cities. After reviewing major climate parameters, we added three additional locations (Las Vegas, Reno and San Antonio) for better differentiation between coastal and inland areas in the west and south. In addition, Omaha was added in the Great Plains area and Juneau to cover the 49th state. This brought the final number of base cities to 45 (see Table 5.1d). These 45 locations, or subsets of them, were used for subsequent simulations for all five building prototypes, differing conservation levels, and the various sensitivity studies described in Chapter 6. The base cities and their metropolitan areas covered about 70% of all new residential construction.

5.2. Development of Extrapolation Procedure

The goal of the extrapolation technique was to permit users of the voluntary guidelines to make simple yet relatively accurate adjustments from the 45 discrete base locations to nearby secondary locations. This technique should not be considered an independent loads calculation procedure, but only as an extrapolation from the DOE-2.1A database for regionalized climatic differences. Instead of attempting to characterize climate regions, "extrapolation zones" were drawn around each base city within which climatic differences can be reduced to a single adjustment factor. We kept the zones relatively compact so that secondary adjustments for insolation, wind speed, humidity, etc. were not necessary.

The characteristics selected as the most crucial are total heating and cooling loads and the incremental changes in those loads due to conservation measures, or Δ loads. Regional variations in total loads were corrected by "location multipliers" based on heating and cooling degree-days. Variations in Δ loads were handled by grouping locations for which the ratios of Δ loads to total loads were similar. For example, zone boundaries in the southern states were drawn along humidity gradients to separate humid from arid locations that had higher relative Δ cooling loads. The climate parameters considered as the most reliable indicators of these loads characters were:

Table 5.1b. Grouping of Original DOE-2 Cities by Similar Absolute Heating Loads and Similar Δ Heating Loads for Changing Thermal Integrities.

Similar Absolute Heating Loads*	Similar Delta Heating Loads*	Cities	
1.	1.	Bismarck	
2.	2.	Burlington	Minneapolis
3.	3A.	Buffalo	Portland, ME
	3B.	Great Falls	
4.	4A.	Boston Chicago	Detroit Salt Lake City
	4B.	Cheyenne	
5.	5A.	Boise Cincinnati Kansas City Philadelphia	Pittsburgh Portland, OR St. Louis Seattle
	5B.	Denver	
6.	6.	Medford New York Oklahoma City	Richmond Tulsa Washington
7.	7A.	Albuquerque	
	7B.	Nashville	Raleigh
8.	8A.	Fresno	San Francisco
	8B.	Atlanta Birmingham	Charleston Memphis
9.	9A.	El Paso	Fort Worth
	9B.	Houston Lake Charles	New Orleans
10.	10A.	Jacksonville Phoenix	San Diego
	10B.	Los Angeles	
	10C.	Brownsville Honolulu	Miami

* For example, Portland Maine, Buffalo, and Great Falls have all been placed in Group 3 because of their similar absolute heating loads. However, Great Falls (3B) has been separated from the other two cities (Portland and Buffalo) because of differences in their delta heating loads.

Table 5.1c. Grouping of Original DOE-2 Cities by Similar Absolute Cooling Loads and Similar Δ Cooling Loads for Changing Thermal Integrities.

Similar Absolute Cooling Loads *	Similar Delta Cooling Loads *	Cities	
1.	1.	Miami	
2.	2.	Brownsville	
3.	3A.	Honolulu	
	3B.	Phoenix	
4.	4A.	Houston Jacksonville	Lake Charles New Orleans
	4B.	Fort Worth	
5.	5A.	Charleston	Memphis
	5B.	Birmingham Oklahoma City	Tulsa
	5C.	El Paso	
6.	6A.	Fresno	
	6B.	Atlanta Kansas City Nashville Raleigh	Richmond St. Louis Washington
7.	7A.	Albuquerque	
	7B.	Cincinnati Minneapolis	New York Philadelphia
8.	8A.	Salt Lake City	
	8B.	Bismarck Chicago	Detroit Pittsburgh
	8C.	Boston	Portland, ME
9.	9A.	Cheyenne	Denver
	9B.	Boise Buffalo Burlington Great Falls Los Angeles	San Francisco San Diego Seattle Portland, OR

* For example, Honolulu and Phoenix were both placed in Group 3 because of their similar absolute cooling loads. However, they have been separated into subgroups 3A and 3B because of differences in their delta cooling loads.

Table 5.1d. Final Base Cities For Voluntary Energy Guidelines Project

City	Location Number	Window Region	City	Location Number	Window Region
Albuquerque NM	1	H*	Las Vegas NV	24	D
Atlanta GA	2	D*	Los Angeles CA	25	J
Birmingham AL	3	D	Medford OR	26	C
Bismarck ND	4	A	Memphis TN	27	D
Boise ID	5	B	Miami FL	28	F*
Boston MA	6	B	Minneapolis MN	29	A*
Brownsville TX	7	F	Nashville TN	30	D
Buffalo NY	8	A	New York NY	31	C*
Burlington VT	9	A	Oklahoma City OK	32	D
Charleston SC	10	D	Omaha NE	33	B
Cheyenne WY	11	G	Philadelphia PA	34	C
Chicago IL	12	B*	Phoenix AZ	35	K*
Cincinnati OH	13	C	Pittsburgh PA	36	B
Denver CO	14	G*	Portland ME	37	B
El Paso TX	15	H	Portland OR	38	I
Fort Worth TX	16	E	Reno NV	39	C
Fresno CA	17	D	Salt Lake City UT	40	B
Great Falls MT	18	A	San Antonio TX	41	E
Honolulu HA	19	F	San Diego CA	42	J
Jacksonville FL	20	E	San Francisco CA	43	J*
Juneau AK	21	A	Seattle WA	44	I*
Kansas City MO	22	C	Washington DC	45	C
Lake Charles LA	23	E*			

Reno, Las Vegas, Omaha, Juneau, and San Antonio were added to complete national coverage. Detroit, Houston, New Orleans, Raleigh, Tulsa, St. Louis, and Richmond were deleted because they have heating and cooling characteristics within 5% of other base cities.

* Regions used for window sensitivity analyses are identified in parenthesis, with reference cities shown by asterisks (see section 5.5).

1. *Heating degree-days at base 60 F for total heating loads.*

The traditional heating degree-days method for estimating building heating requirements was first developed more than 50 years ago using average daily temperatures and a base temperature of 65 F. In recent years, several suggestions have been made to improve the accuracy of this well-known method. For degree-day values to correlate with actual building loads, the base temperature should correspond to the average balance point temperature of the house, which in turn depends on the house thermal integrity, internal and solar gains, and the thermostat setting. One study noted that 65 F may no longer be applicable to new houses due to the improved thermal integrity of current construction and that a lower base temperature be used,[13] Others have

13. E.A. Arens and W. L. Carroll, "Geographical Variation in the Heating and Cooling Requirements of a Typical Single-Family House, and Correlation of These Requirements to Degree-Days", National Bureau of Standards, Washington, D.C. NBS Building Science Series 116 (1978).

proposed a variable base method that would account for differing balance point temperatures.[14] In addition, with the increasing availability of hourly weather data, researchers have begun to use hourly rather than average daily temperatures.

Extensive correlations were done comparing the heating loads in the preliminary DOE-2.1A database to heating degree-days and degree-hours calculated at various base temperatures varying from 53 to 65 F.* In this analysis we showed that the base temperatures giving the highest correlations to heating loads varied with the thermal integrity of the house. These values can be interpreted as nationally-averaged balance point temperatures for houses of those configurations. Figures 5.2.1 and 5.2.2 show the improved correlation from the standard base 65 F to base 60 F heating degree-days for a house of average thermal integrity. In contrast, Figure 5.2.3 shows that base 65 F heating degree-days correlate well for an uninsulated house. The climate analysis also revealed that the base temperatures differed significantly between heating degree-hours and degree-days (see Table 5.2a), but that using heating degree-hours did not result in higher correlation coefficients. The reasons are that the regressions were done using yearly totals and the same base temperatures for all locations and times of the year, whereas the balance point temperature varied in different locations depending on the amount of insolation. Therefore, it should be emphasized that the temperatures given in Table 5.2a are only estimates of national averages. It should also be noted that they are highly dependent on the assumed operating conditions for the house, which in our case includes a night setback. If this setback is removed, these temperatures would probably be higher by 2 to 3 degrees. (For more detailed description of the climate analysis, refer to Huang et al.).[15]

Heating degree-days at base 60 F were selected for extrapolating regional variations in heating loads since it corresponded to the national balance point temperature for a house of average thermal integrity and was available from NOAA in the form of 30-year averages for more than 3,000 weather stations. Figure 5.2.4 is a computer generated map of the U.S. showing heating degree-days at base 60 F. Heating degree-hours at base 57 F were not used because their availability was limited only to locations with hourly weather tapes.

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* The analysis was done using climate parameters calculated from the same weather tapes used for the DOE-2.1A simulations to avoid random weather variations. However, once the relationships between climate and building loads was established, the extrapolations for regional climate variations (i.e., "location multipliers") were done using long-term climate data from the National Oceanic and Atmospheric Administration (NOAA) because of their much wider geographical availability.

14. T. Kusuda, I. Sud and T. Alereza, "Comparison of DOE-2-Generated Residential Design Energy Budgets with Those Calculated by the Degree-Day and Bin Methods", American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Transactions, Vol. 87, Part I (1981).

15. Y. J. Huang et al., "Climate Indicators for Residential Heating and Cooling Loads", Lawrence Berkeley Report 21101, Berkeley CA (1986).

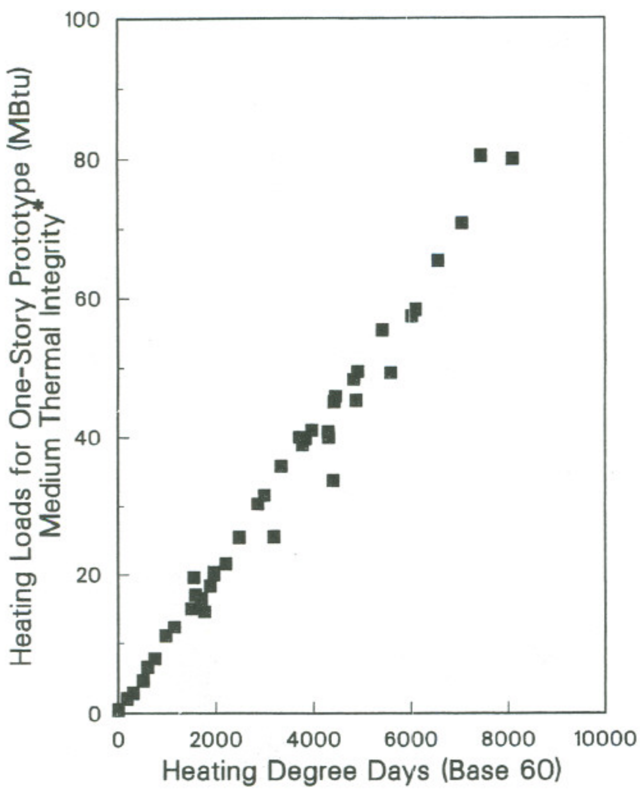

Fig. 5.2.1

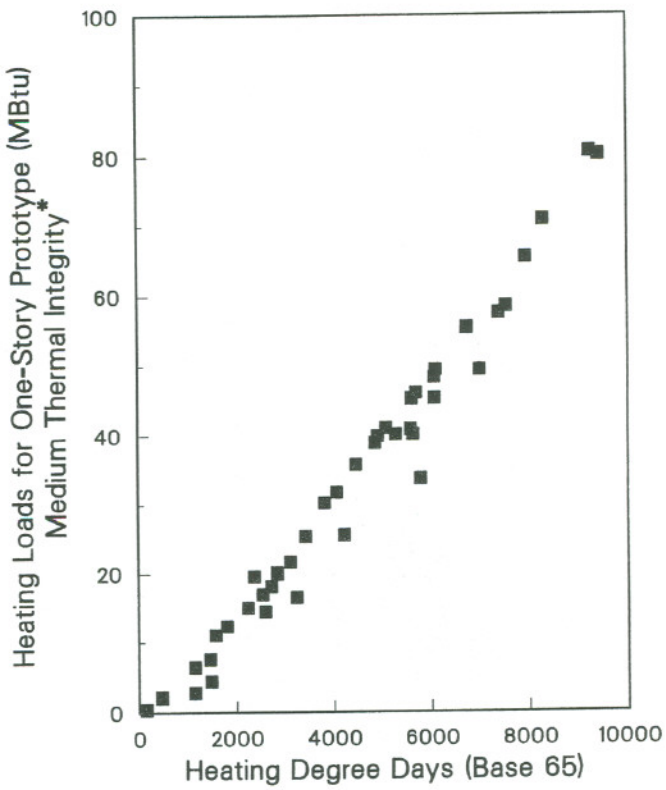

Fig. 5.2.2

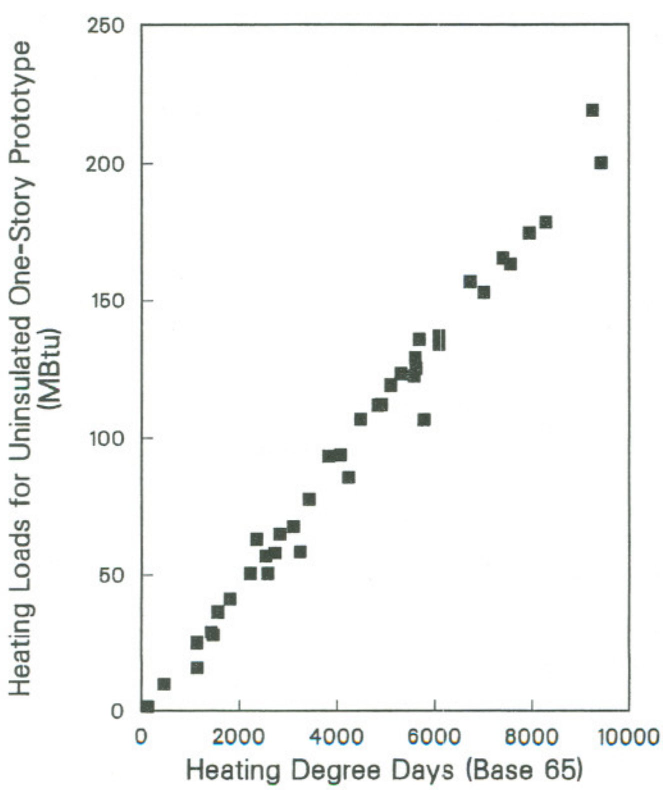

Fig. 5.2.3

Note: Medium thermal integrity prototype is R-30 ceiling, R-19 walls, 2-pane windows, 0.7 ach infiltration

Uninsulated prototype is R-0 ceiling, R-0 walls, 1-pane windows, 0.7 ach infiltration

Table 5.2a. Average Heating Balance Point Temperatures for One Story Ranch House

House Thermal Integrity†	Heating degree days	Heating degree hours
uninsulated	65 F	63 F
loose	62	59
medium	60	57
tight	59	56

† uninsulated = R-0 ceiling, wall, and fdn, 1-pane windows; loose = R-19 ceiling, R-11 wall, FM1 fdn, 1-pane windows; medium = R-30 ceiling, R-19 wall, FM3 fdn, 2-pane windows; tight = R-49 ceiling, R-27 wall, FM4 fdn, 3-pane windows. All have 0.7 ach infiltration.

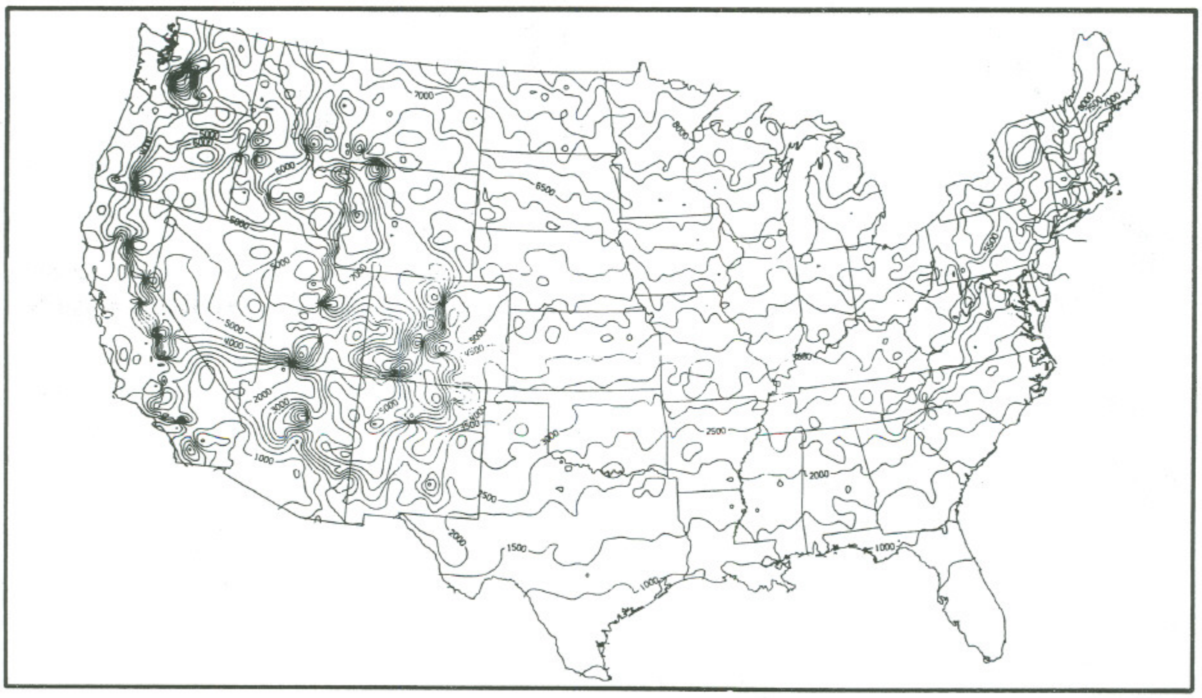

Fig. 5.2.4 Heating Degree Days at 60F Base Temperature 30-year average (1950-1980) for 3200 NOAA stations

XBL 856-2934

2. *The ratio of base 65 F heating degree-days to base 57 F heating degree-days for the relative change in heating loads due to added conservation measures.*

Recent simplified loads calculations have recognized that the balance point temperature of a house will be lower for tighter houses. A tighter house in essence "sees" fewer heating degree-days and has lower heat losses per degree-day. This difference in balance point temperatures appears in the correlations mentioned earlier where the national averages ranged from 65 F for an uninsulated house to 59 F for a tight house.

The reduction in heating degree-days as the base temperature is lowered was location-specific and was dependent on the hourly temperature profiles. In maritime locations with small temperature swings (such as San Francisco), the number of heating degree-days was very sensitive to the base temperature, while in colder locations such as Chicago or Minneapolis the effect was relatively small. A convenient interpretation for this phenomenon is that in milder locations, conservation doubles effectiveness because it shortens the length of the heating season as well as reduces the heat losses.

The relationship of variable base heating degree-days to heating load reductions was analyzed by comparing heating degree-day ratios to heating load ratios from the preliminary DOE-2 database. Heating degree-day ratios are defined as:

$$\text{HDD Ratios} = (\text{HDD}_{65} \,/\, \text{HDD}_{57}) \tag{7}$$

We selected 65 F and 57 F as base temperature because they corresponded to average balance point temperatures for a totally uninsulated and tightly insulated house, respectively. Heating load ratios are defined as:

$$\text{HL Ratios} = (\text{HL}_{\text{uninsulated}} \,/\, \text{HL}_{\text{tight}}) \tag{8}$$

According to the variable degree-day calculations, the two ratios should have a linear relationship, since:

$$\text{HL}_{\text{uninsulated}} = \text{UA}_{\text{uninsulated}} * \text{HDD}_{65} \tag{9}$$

and

$$\text{HL}_{\text{tight}} = \text{UA}_{\text{tight}} * \text{HDD}_{57}$$

or

$$\frac{\text{HL}_{\text{uninsulated}}}{\text{HL}_{\text{tight}}} = \frac{\text{UA}_{\text{uninsulated}}}{\text{UA}_{\text{tight}}} * \frac{\text{HDD}_{65}}{\text{HDD}_{57}} \tag{10}$$

Figure 5.2.5 is a plot of these ratios for more than 40 cities in the preliminary DOE-2 database. Although the correlation is not as good as that in Figure 5.2.2, a linear relationship is apparent.

The similarity between the geographical distribution of heating degree-day ratios to heating load ratios can be seen by comparing Figures 5.2.6 and 5.2.7. In Figure 5.2.6, we map the degree-day ratios ($\text{HDD}_{65}/\text{HDD}_{57}$) using NOAA long-term data for 3,260 weather stations in the lower 48 states. Figure 5.2.7 is a much coarser plot based on the 45 locations covered in the DOE-2 database. The second map is less well defined geographically, but a correlation can be detected between the two, with higher degree-day and loads ratios in the warmer locations and along the west coast.

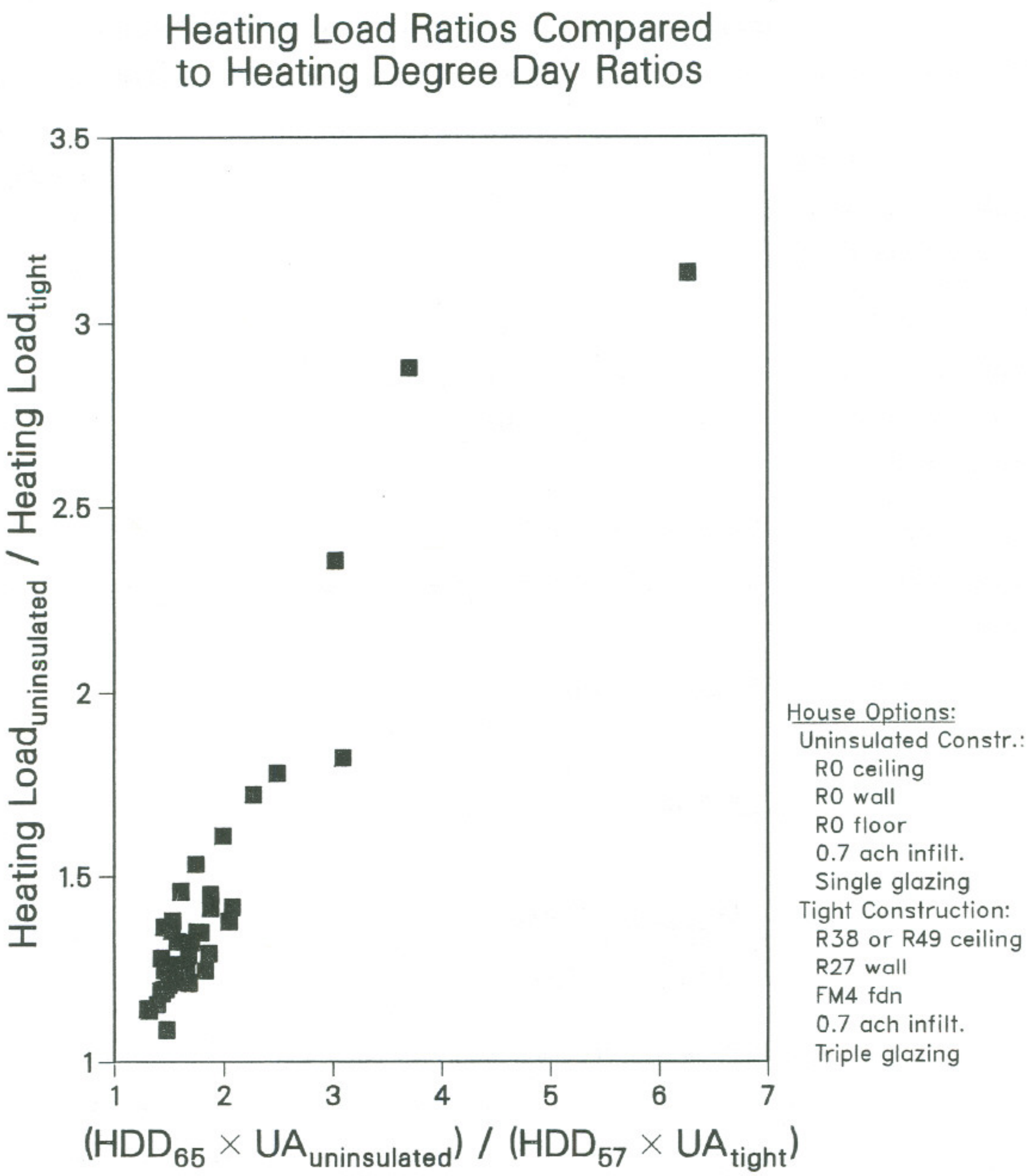

Fig. 5.2.5

XCG 8511–493

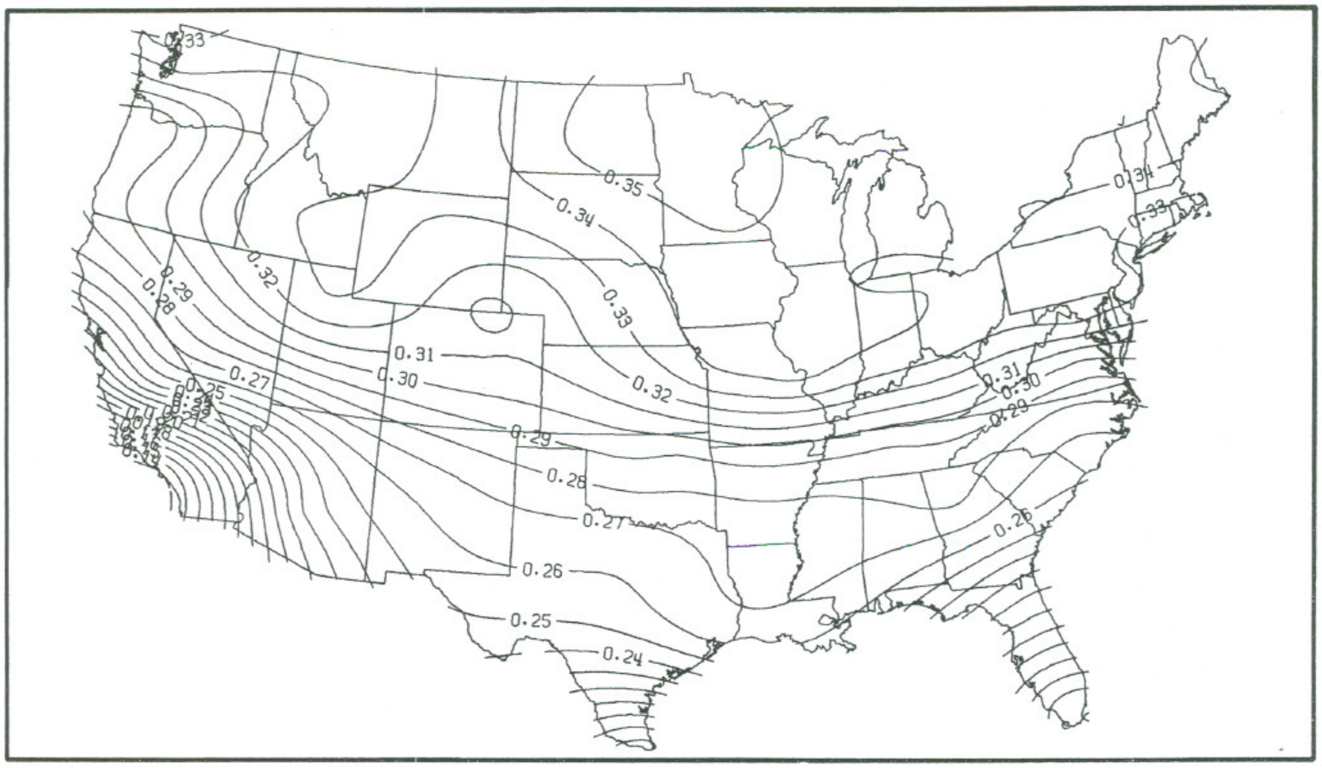

Fig.. 5.2.6 Heating Loads Ratio (Tight/Unins)

XBL 856-2932

Fig.. 5.2.7 Heating Degree Days Ratio (HDD57/HDD65)

XBL 856-2931

3. *Base 65 F cooling degree-days for absolute cooling loads.*

The relationship between building loads and degree days was more problematic for cooling than for heating because of the added effects of latent loads, natural venting, and thermal lag. The first factor will increase, while the second will decrease cooling loads when compared to standard degree-day approximations. The effect of the thermal lag was harder to gauge. When compared to heating, the correlations between the preliminary DOE-2 cooling loads to base 65 F cooling degree-days were not as good for uninsulated and loose houses and worse for tighter houses. They do not improve with changing base temperatures (see Figures 5.2.8, 5.2.9, and 5.2.10). Better correlations were possible using degree-hours rather than degree-days, and subtracting hours when venting was likely to occur (see Fig. 5.2.11). This procedure, however, would require detailed hourly climate data that was not available for most locations. Therefore, standard base 65 F cooling degree-days were selected as the indicator for absolute cooling loads. Figure 5.2.12 is a computer generated map of NOAA 30-year average (1950-1980) cooling degree-days (at base 65 F) for 3,260 weather stations in the lower 48 states.

4. *Ratio of cooling degree-days to cooling enthalpy days for the incremental change in cooling loads due to changing conservation measures.*

Because of the presence of latent loads and natural venting, degree-day ratios were not reliable indicators for relative changes in cooling loads due to added conservation measures. We therefore selected a different climate parameter, cooling enthalpy hours, which measures differences in latent as well as sensible energy from a defined condition, such as the comfort zone.* Since latent loads remain basically constant for changes in thermal integrity (assuming a constant infiltration rate), humid locations with large cooling enthalpy hours relative to degree-days will show smaller percentage reductions in cooling loads for added conservation measures. Conversely, arid locations with smaller cooling enthalpy hours relative to degree-days will benefit more from improved thermal integrity.

* Enthalpy hours (Btu·hour/pound·air) was calculated by summing over the year the energy necessary to lower ambient air conditions to a humidity ratio of 0.0116 and a drybulb temperature of 75 F, conditions corresponding to the upper limit of the ASHRAE comfort zone. Latent enthalpy days is a measure of the change in enthalpy necessary to lower humidity ratios to 0.0116 while keeping drybulb temperatures fixed. Sensible enthalpy days is a measure of the additional change in enthalpy necessary to lower drybulb temperatures to 75 F at the fixed humidity ratio of 0.0116. Total cooling enthalpy hours is the sum of the latent and sensible enthalpy hours, and the difference in enthalpy necessary to meet both comfort criteria. On the psychometric chart, changes in sensible enthalpy correspond to horizontal movement, while changes in latent enthalpy correspond to vertical movement on the chart. Negative enthalpies and those that occur when drybulb temperatures are less than 75 F were not counted, since cooling loads were assumed to be zero.

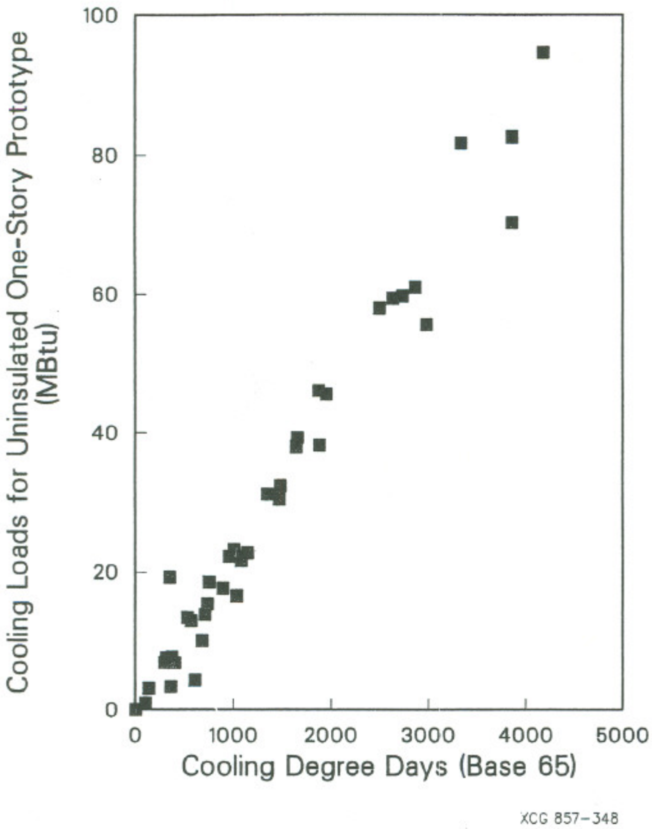

Fig. 5.2.8

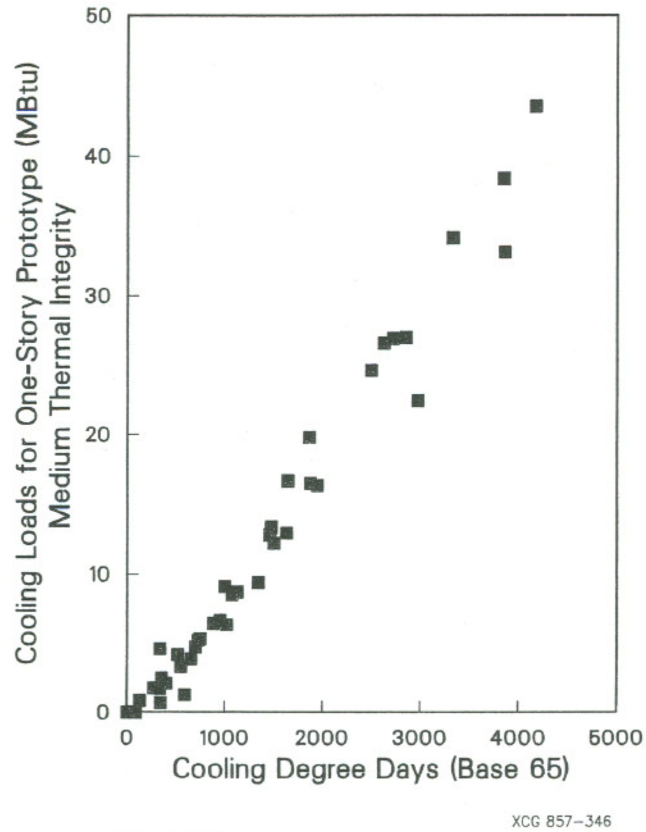

Fig. 5.2.9

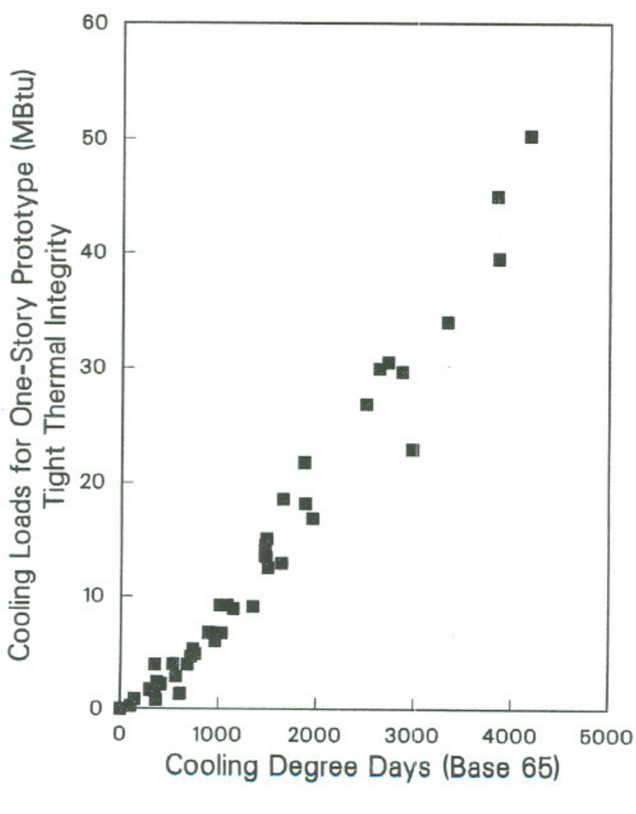

Fig. 5.2.10

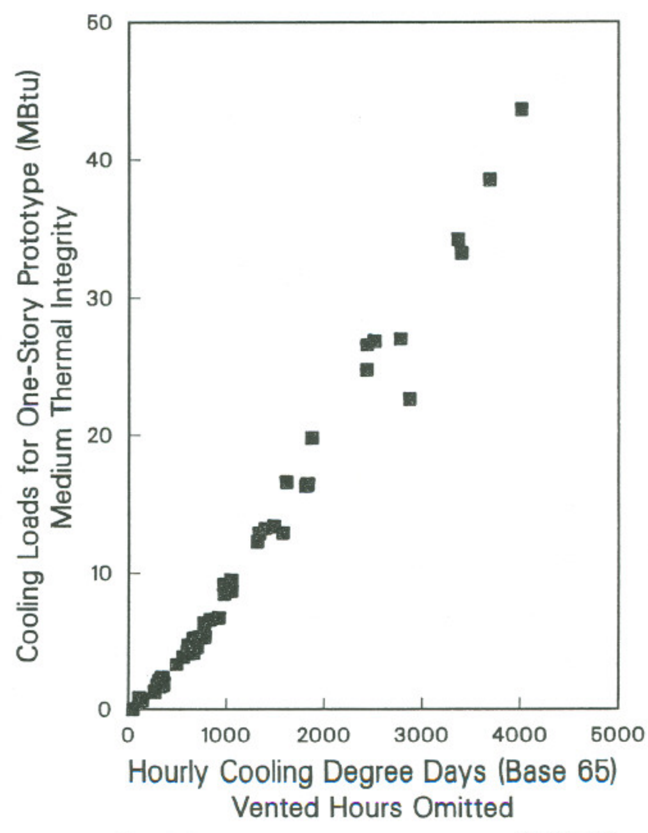

Fig. 5.2.11

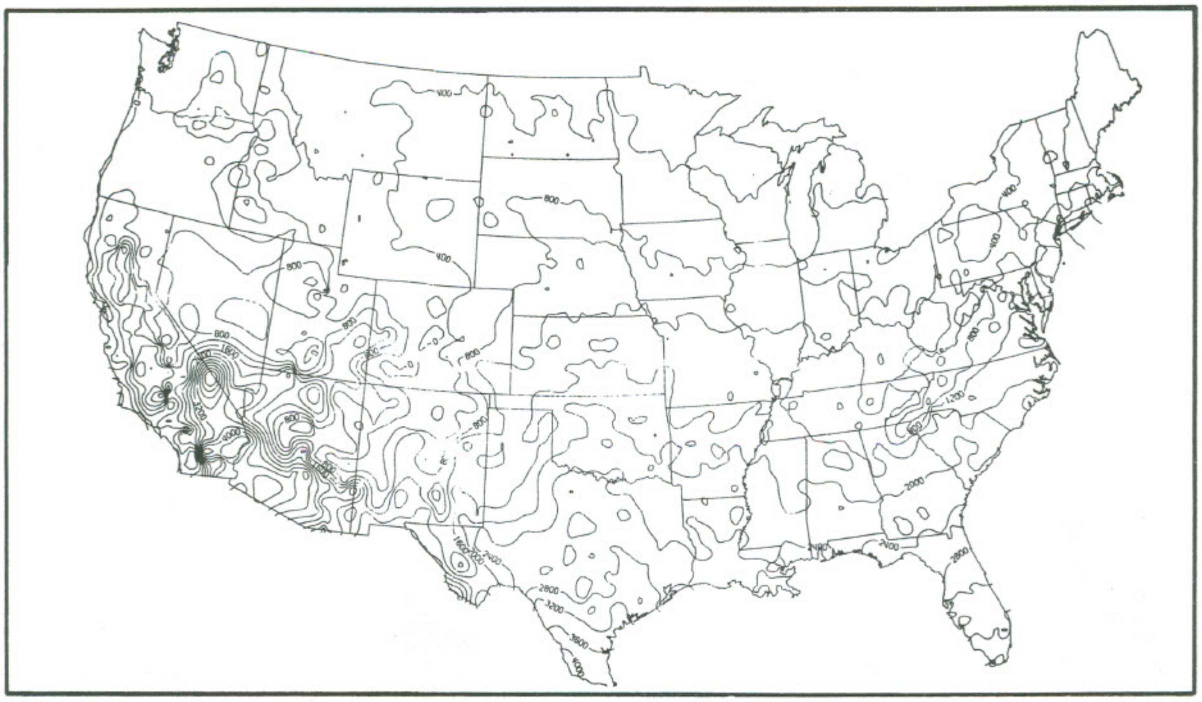

Fig. 5.2.12 Cooling Degree Days at 65 Base Temperature 30-year average (1950-1980) for 3200 NOAA stations

XBL 856-2935

In Figure 5.2.13, cooling load ratios between a "loose" house and a "tight" house are plotted against the ratios of cooling degree-days to cooling enthalpy hours for 20 locations with significant cooling loads. A "loose" house refers to one with no insulation, single glazing, and 0.7 ach infiltration, while a "tight" house refers to one with R-30 ceiling, R-19 walls, 2 ft of R-5 perimeter insulation, double-glazing, and 0.7ach infiltration. A linear relationship is evident with the highest ratios for arid locations such as Albuquerque and El Paso, and the lowest for humid locations such as Brownsville and Miami.

The geographical distribution for these same two values are compared in Figures 5.2.14 and 5.2.15. In Figure 5.2.14, we show a map of ratios (cooling degree-days/cooling enthalphy hours) for TMY locations; Figure 5.2.15 depicts ratios (cooling load "loose"/ cooling load "tight") for the 47 locations in the preliminary DOE-2.1A database. The use of ratios (cooling degree-days/cooling enthalpy hours) made it possible to distinguish between climates such as Phoenix and Houston that had similar cooling loads but very different latent load ratios.

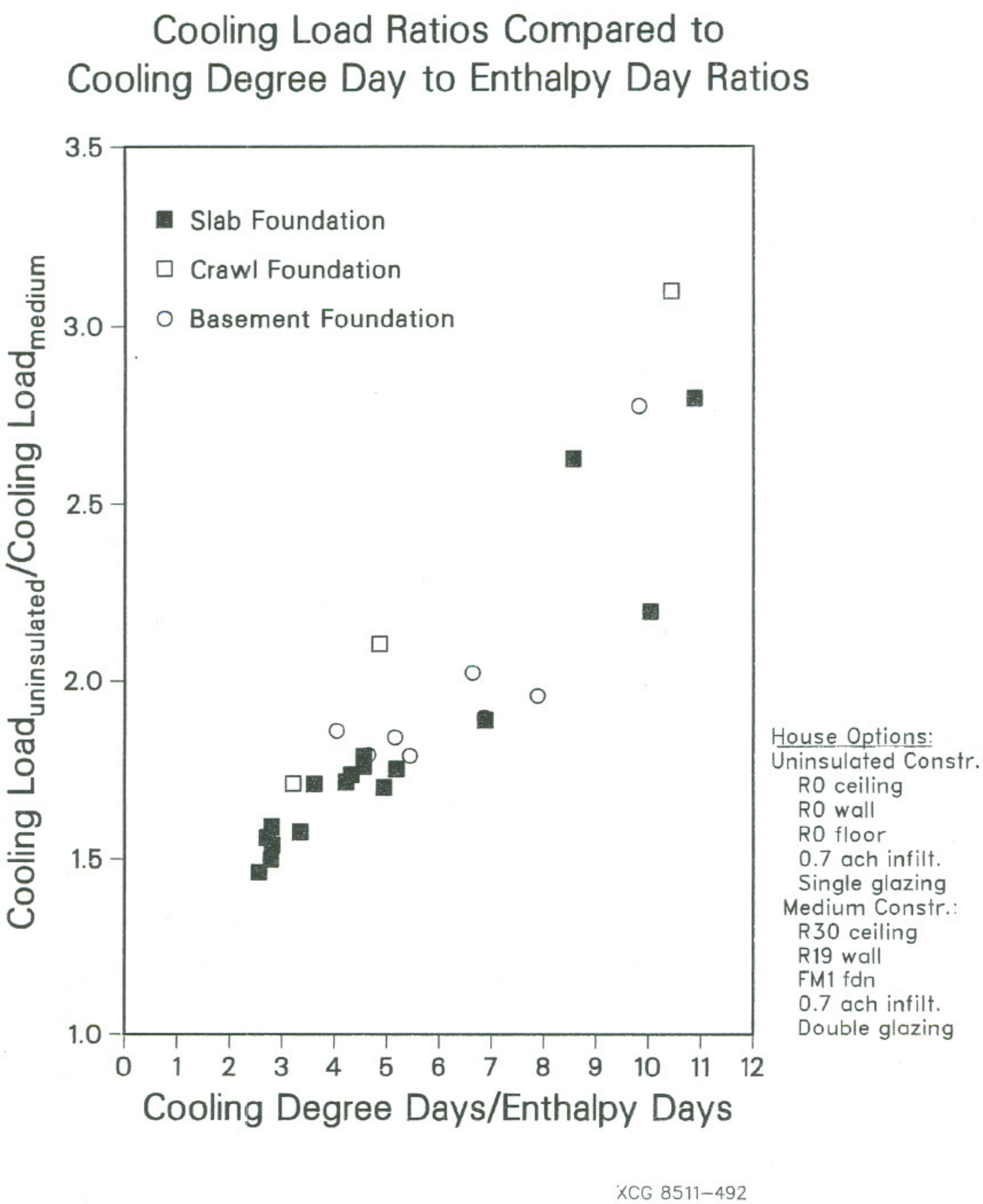
Cooling Load Ratios Compared to
Cooling Degree Day to Enthalpy Day Ratios
Slab Foundation
Crawl Foundation
Basement Foundation
Cooling Load uninsulated/Cooling Load medium
3.5
3.0
2.5
2.0
1.5
1.0
0
1
2
3
4
5
6
7
8
9
10
11
12
Cooling Degree Days/Enthalpy Days
House Options:
Uninsulated Constr.:
R0 ceiling
R0 wall
R0 floor
0.7 ach infilt.
Single glazing
Medium Constr.:
R30 ceiling
R19 wall
FM1 fdn
0.7 ach infilt.
Double glazing
XCG 8511-492

Fig. 5.2.13.

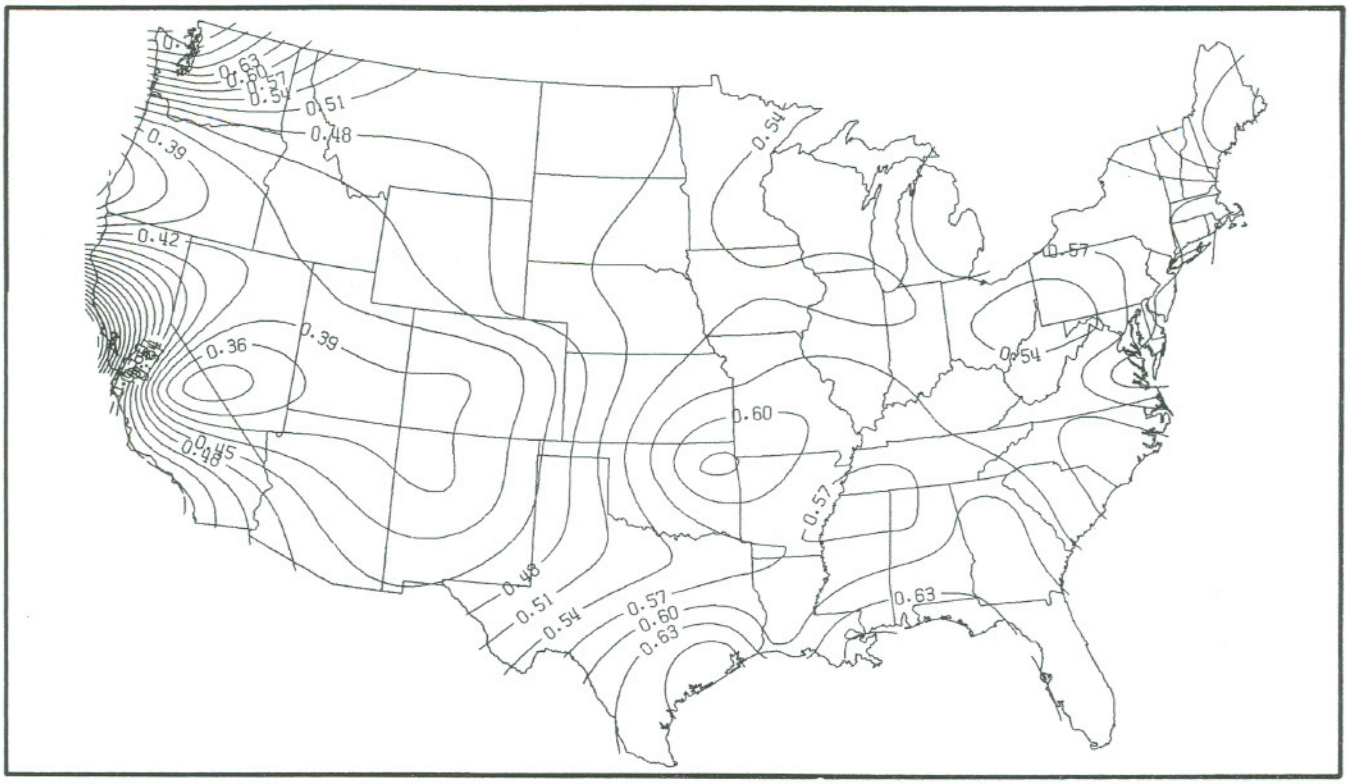

Fig. 5.2.14 Cooling Energy Ratio (Medium/unins)

XBL 856-2930

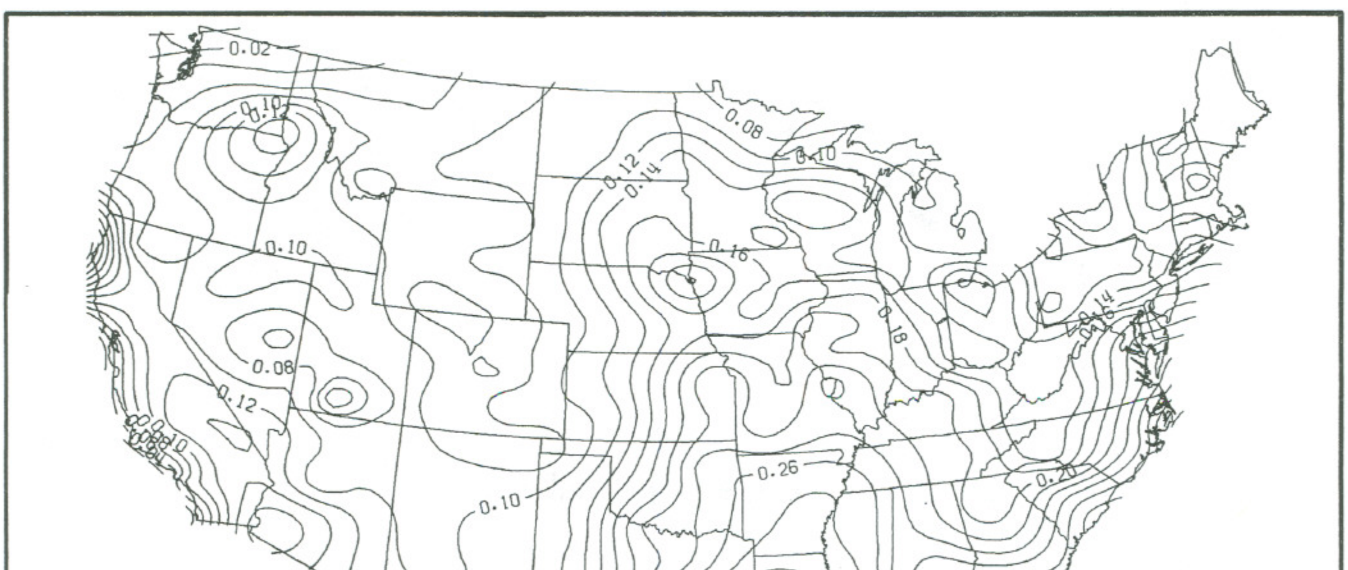

Fig. 5.2.15 Cooling Enthalpy Hours/CDD65

XBL 856-2929

5.3. Definition of Extrapolation Boundaries

Boundaries around each base city were drawn so that reliable extrapolations could be done using a simple one-step operation. Of the climate data described previously as indicators for building loads, heating degree-days at base 60 F, and cooling degree-days at base 65 F, were the most critical. Therefore, the one-step extrapolation corrected for heating and cooling degree-day differences between the base cities and other nearby locations. The correction terms or "location multipliers" are actually the ratios of heating degree-days at base 60 F and cooling degree-days at base 65 F between secondary locations and the base city.

Since the extrapolation corrected explicitly for degree-day differences, emphasis was placed on keeping the other two climate indicators (heating degree-day ratios and cooling degree-day/enthalpy hour ratios) as uniform as possible within any one region. A three-tiered system (in descending order of importance) was used to define boundary lines for heating and cooling (see Table 5.3a). If boundaries could not be distinguished between two base cities based on the first criterion, we used the second one. If neither works, then the third criterion was used.

Table 5.3a. Criteria for Determining Base City Boundaries

Heating Boundaries	Cooling Boundaries
(1) Equal differences in the ratio of heating degree-days base 65 F to heating degree-days base 57 F between base cities.	(1) Equal differences in the ratio of cooling enthalpy hours to cooling degree-days base 65 F between base cities.
(2) Equal differences in heating degree-days (base 60 F)	(2) Equal differences in cooling degree-days. (base 65 F)
(3) Equal geographical distance between base cities	(3) Equal geographical distance between base cities

Figures 5.3.1 and 5.3.2 show separate boundaries for heating and cooling based on the criteria defined above. On the heating map, the first two criteria generally gave identical boundaries, except in the colder areas where degree day ratios were constant. On the cooling map, the first two criteria produced significantly different boundaries in the transitional areas such as Oklahoma and Texas where cooling degree-day gradients were perpendicular to the humidity gradients. For reasons already given, we followed enthalpy ratio lines in such cases, since degree-day differences were accounted for by direct extrapolation.

In the final step, the two sets of boundaries were merged, depending on whether heating or cooling loads predominated in a given base city, producing the map shown in Figure 5.3.3.

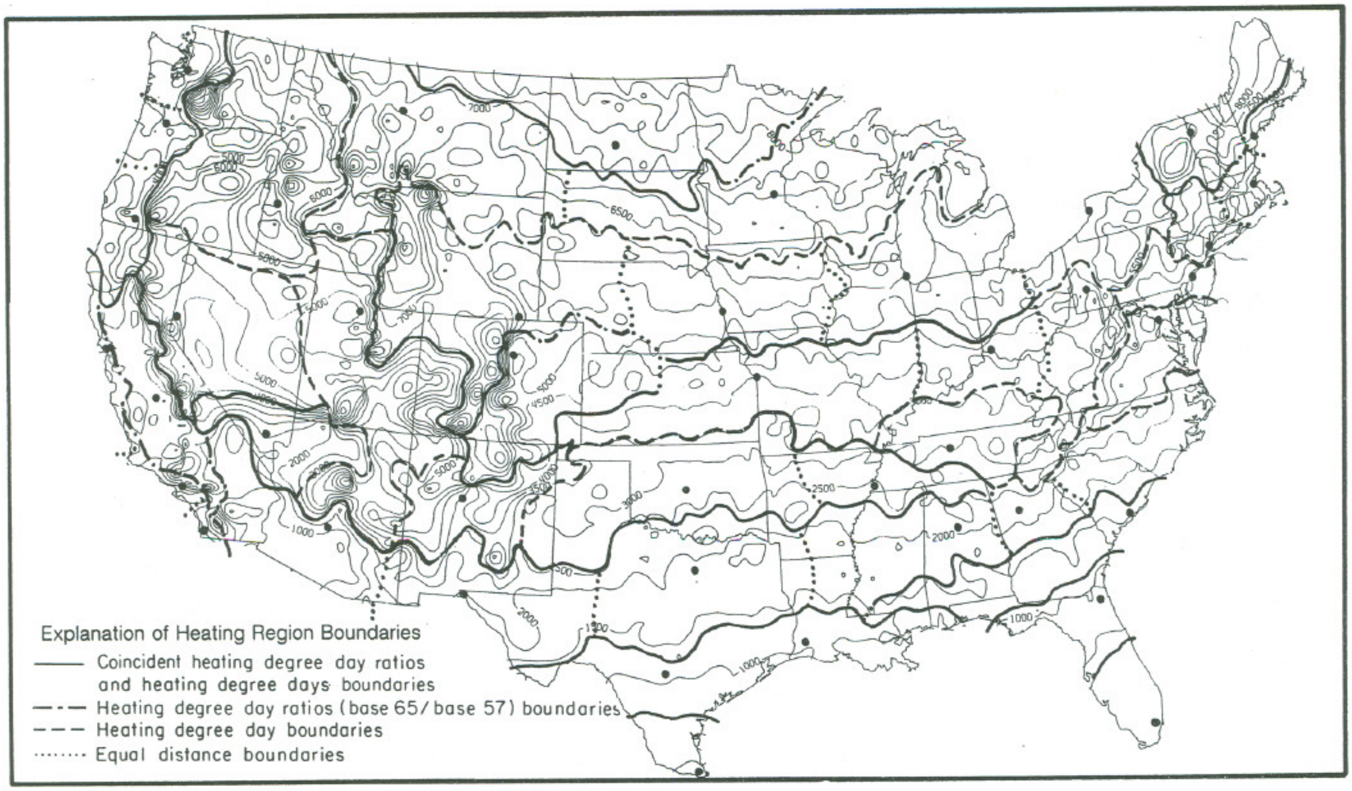

Fig. 5.3.1 Extrapolation Boundaries for Heating Loads

XBL 8312-2460

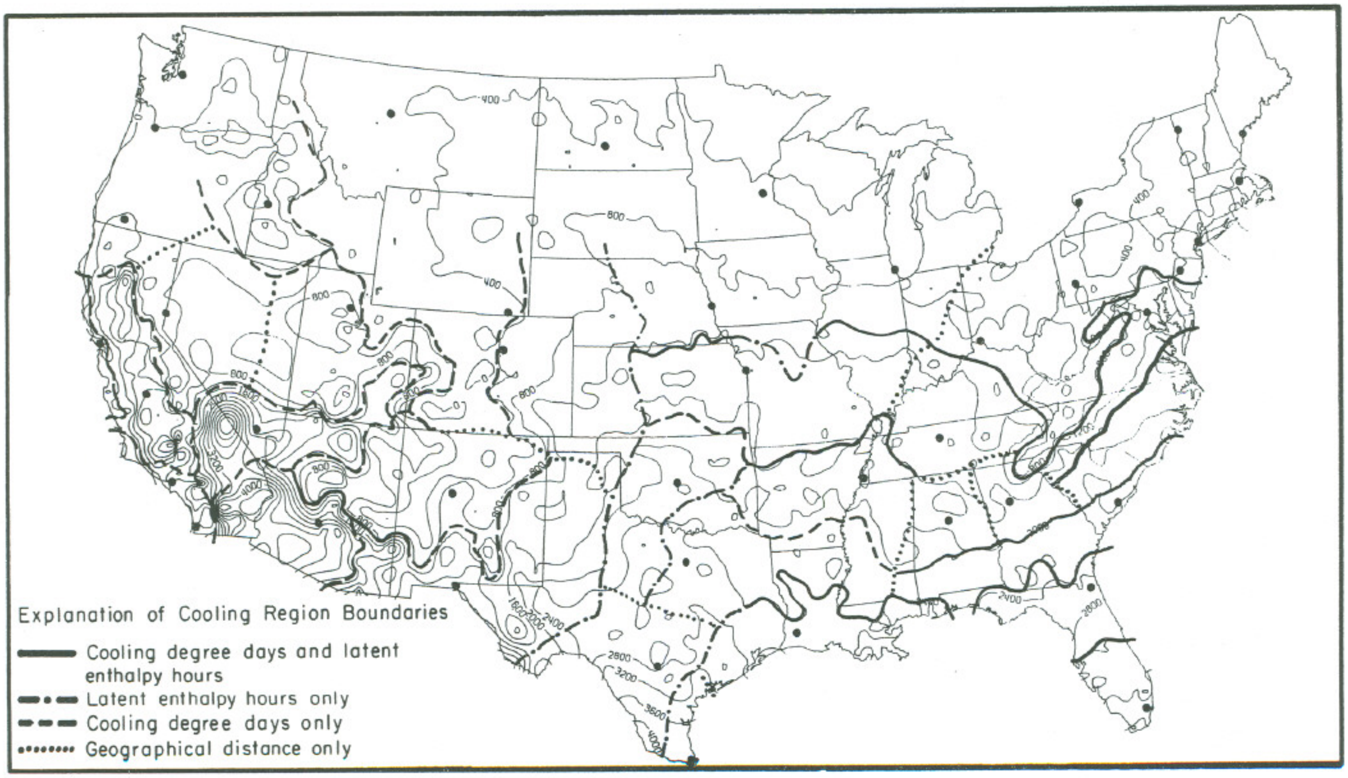

Fig. 5.3.2 Extrapolation Boundaries for Cooling Loads

XBL 836-970

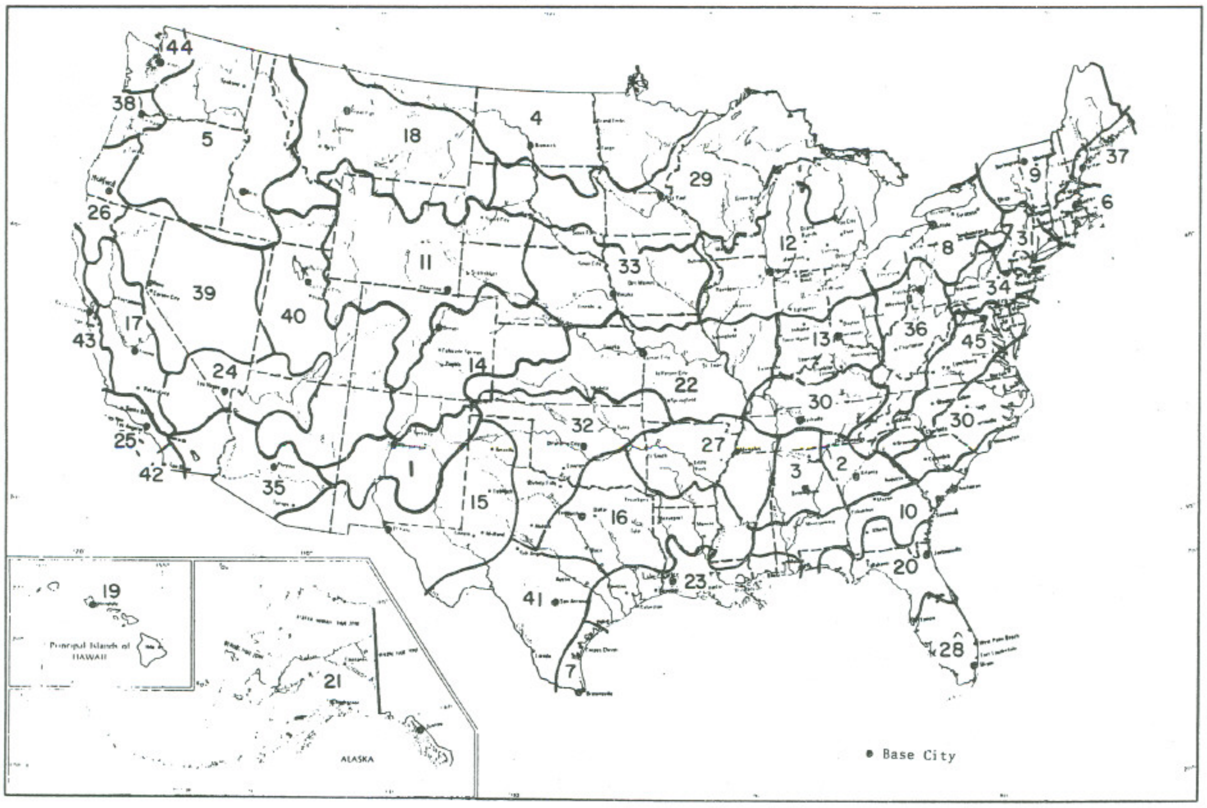

Fig. 5.3.3 Final Extrapolation Boundaries for 45 Locations

XBL 831-1083A

These boundaries determined which base city was used in calculating "location multipliers" for the secondary locations. The 45 "regions" defined do not imply specific climatic conditions, but are only areas within which reliable extrapolations are expected from a particular base city. Appendix A.1 contains the location multipliers used in PEAR.

5.4. Analysis of Extrapolation Boundaries

We made spot checks to determine the reliability of the final extrapolation boundaries. DOE-2 runs were done at three levels of thermal integrity for two cold locations (Cleveland OH, and Charleston WV) and two warm locations (Lubbock TX, and Jackson MS) not in the database. The calculated heating and cooling loads for these cities were then compared to extrapolated values based on the designated base city as well as neighboring base cities. To avoid errors due to differences in weather data, degree-day values were calculated from the same TRY weather tapes used in the DOE-2 analyses.

Table 5.4a. DOE-2 and Extrapolated Heating and Cooling Loads for Four Test Cities

		Heating loads†				Cooling loads†			
Test city	Data	unins	loose	med	tight	unins	loose	med	tight
Lubbock TX	**DOE-2**	**80.7**	**41.5**	**21.1**	**15.9**	**33.2**	**20.7**	**16.4**	**15.2**
Extrapolated from:	El Paso *	73.3	36.9	18.8	14.1	36.5	21.8	16.2	14.5
	Oklahoma City	83.5	45.6	24.4	18.9	31.8	22.7	18.1	16.7
	Albuquerque	69.2	36.3	18.6	14.0	36.1	18.2	12.7	11.0
Jackson MS	**DOE-2**	**52.8**	**27.3**	**14.5**	**11.1**	**52.8**	**38.5**	**30.9**	**28.6**
Extrapolated from:	Fort Worth *	54.3	27.8	14.5	11.0	55.0	38.9	30.5	27.9
	Memphis	49.2	26.2	14.1	11.0	58.4	41.6	33.0	30.4
	Birmingham	49.5	25.8	13.9	10.8	56.3	39.6	32.0	30.0
	Charleston SC	54.7	27.6	14.3	10.8	49.9	37.1	31.3	29.5
Cleveland OH	**DOE-2**	**146.6**	**75.1**	**51.6**	**39.3**	**12.7**	**7.0**	**6.0**	**5.4**
Extrapolated from:	Buffalo *	149.9	76.7	52.6	39.9	10.9	5.5	4.6	3.9
	Chicago	146.9	74.8	51.4	39.0	12.8	6.8	5.7	4.9
	Pittsburgh	150.5	76.1	52.1	39.4	13.9	7.3	6.2	5.5
Charleston WV	**DOE-2**	**100.9**	**50.2**	**34.7**	**26.3**	**20.8**	**11.4**	**9.9**	**8.7**
Extrapolated from:	Pittsburgh *	101.6	51.4	35.2	26.6	19.8	10.4	8.8	7.8
	Nashville	109.2	53.4	35.9	26.6	20.3	12.8	11.7	10.6
	Cincinnati	103.3	52.0	35.5	26.8	18.5	11.1	9.5	8.4

Table 5.4b Differences between DOE-2 and Extrapolated Heating and Cooling Loads for Four Test Cities

Test city	Heating load differences (%)				Average	Cooling load differences (%)				Average
and base cities	unins	loose	med	tight	(%)	unins	loose	med	tight	(%)
Lubbock TX										
El Paso *	-9.1	-10.9	-10.8	-11.0	10.5	9.9	5.2	-1.4	-4.2	5.2
Oklahoma City	3.5	9.9	15.7	19.2	12.1	-4.2	9.6	10.3	9.9	8.5
Albuquerque	-14.3	-12.5	-11.7	-11.6	12.5	8.7	-12.1	-22.7	-27.3	17.7
Jackson MS										
Fort Worth *	2.8	1.6	-.4	-1.1	1.4	4.1	.9	-1.4	-2.5	2.2
Memphis	-6.8	-4.2	-2.7	-1.2	3.7	10.5	8.0	6.7	6.3	7.9
Birmingham	-6.4	-5.6	-4.0	-2.8	4.7	6.5	2.8	3.3	4.9	4.4
Charleston SC	3.4	.8	1.4	2.8	2.1	-5.6	-2.8	1.4	2.9	3.2
Cleveland OH										
Buffalo *	2.2	2.2	1.8	1.6	1.9	-14.3	-21.2	-24.0	-26.8	21.6
Chicago	.2	-.5	-.3	-.6	.4	.9	-2.3	-5.8	-9.1	4.5
Pittsburgh	2.6	1.3	1.0	.4	1.3	9.3	4.6	3.3	1.8	4.7
Charleston WV										
Pittsburgh *	.7	2.3	1.5	1.3	1.5	-5.0	-9.0	-10.9	-10.2	8.8
Cincinnati	2.3	3.7	2.5	2.0	2.6	-11.1	-2.8	-4.2	-3.2	5.3
Nashville	8.2	6.4	3.7	1.4	4.9	-2.4	12.2	18.2	21.4	13.6

*Base cities chosen in climate analysis.

†unins = R0 ceil, wall and fdn, 1-glazing, 0.7 ach;
loose = R-19 ceil, R-11 wall, FM0 slab or FM1 basement, 1-glazing, 0.7 ach;
med = R-30 ceil, R-19 wall, FM1 slab or FM3 basement, 2-glazing, 0.7 ach;
tight = R-38 or R-49 ceil, R-27 wall, FM3 slab or FM4 basement, 3-glazing, 0.7 ach.

The results show that for three of the four test cities, the designated base cities produced the closest extrapolated values, on average, as compared to the actual DOE-2 runs (see Tables 5.4a and 5.4b). For the fourth city (Cleveland), the extrapolated loads were not as good as using other potential cities, but were still within 2% for heating (cooling loads being negligible). Although these spot checks were not definitive, they did tend to indicate that the extrapolation procedure was good for heating loads in cold climates, but may be off by 10% for heating loads in warmer locations. For cooling, the extrapolated values were within 6% for locations with significant loads.

The largest difference among the 16 test cases was cooling energy for an uninsulated house in Lubbock, where the extrapolated heating load was high by 9% (7.4 MBtu). For combined heating and cooling loads, differences in all four locations were within 8% or 4.1 MBtu. In the two cold locations, the combined differences were well within 2% or 2 MBtu. These deviations can be attributed to climatic differences not accounted for by the one-step degree day extrapolations.

5.5. Determination of Base Cities for Window Sensitivity Studies

A significant part of the technical effort in this project was to provide parametric analyses on the energy impact of window size, orientation, and control strategies in various U.S. locations. The intent of this aspect of the climate analysis was to determine the number and location of base cities to be used for the window sensitivity studies. Because of the number of parametric variations involved, we developed a strategy to simulate the most critical window effects in all 45 locations, but to extrapolate the less significant effects from a smaller number of locations.

DOE-2.1A was run in all 45 base cities to determine the energy impact of the following variations in window conditions from a standard 154 ft^2 of equally-distributed glazing (10% of floor area)

(a) 231 ft^2 glazing (15%) single-glazed, equally distributed, loose thermal integrity*

(b) 231 ft^2 glazing (15%) triple-glazed, equally distributed, tight thermal integrity*

(c) 231 ft^2 glazing (15%) single-glazed, 12.5% south & 2.5% north, loose thermal integrity*

(d) 231 ft^2 glazing (15%) triple-glazed, 12.5% south & 2.5% north, tight thermal integrity*

The equally-distributed window sensitivities show the combined effects of solar gains and conduction losses for increases in window size; south-oriented window sensitivities demonstrate the energy effects of strategies that attempt to maximize solar gain. We modeled single and triple pane glass to cover the range of glass conductivities.

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* Loose thermal integrity = R-19 ceiling, R-11 wall, FM1 foundation, 0.7 ach infiltration; tight thermal integrity = R-30 ceiling, R-19 wall, FM3 foundation, 0.7 ach infiltration.

The Δ heating and cooling loads for each window sensitivity were then mapped by computer to distinguish regional trends. Figure 5.5.1 is a typical map for the Δ heating loads in a house with single-glazed windows with changes in the window orientation from the base case of 10% equally-distributed to 15% predominantly south-oriented. It indicates that for single-glazed windows, increasing the amount of south windows lowered heating loads only in areas with large amounts of insolation (such as Denver or Albuquerque), but was counterproductive in most other climates. In the warmer locations, reductions in heating loads were considered in conjunction with increases in cooling loads, as shown in Figure 5.5.2 (for more information on the energy impact due to window size and orientation, see Section 6.4 and Turiel[16]).

The eight maps (4 for heating, 4 for cooling) resulting from the sensitivity studies described made it possible to group the 45 cities into a smaller number of regions for more detailed parametric studies of window strategies. A difference of 3 MBtu in heating energy or the equivalent resource fuel in cooling energy was used as the criterion for distinguishing window regions, with equal importance given to either space conditioning mode. For example, San Francisco and Fresno were grouped together based on the heating impact of windows alone, but were separated due to the great disparity in their Δ cooling loads because of increased window sizes.

The resultant grouping of cities into 11 "window regions" is indicated on Table 5.1d. The "window base city" selected for each window region was the one used for the more detailed window studies described in Sections 6.4.3 through 6.4.5. There are six zones in the eastern half of the country running basically east-west (Zones A,B,C,D,E,F) reflecting increasing conductive losses for increases in window size. Zones G and H were separated because of the large solar heat gains in the Rockies and the Southwest, while Zones I and J were distinguished by the low solar heat gains along the Pacific Coast. Finally, Zone K in the southwest was separated because of the extreme increases in cooling loads for increased window size.

16. I. Turiel et.al., "Parametric Analysis of Impact of Windows on Heating and Cooling Loads in Residential Buildings", Lawrence Berkeley Report 16758, Berkeley CA (1985).

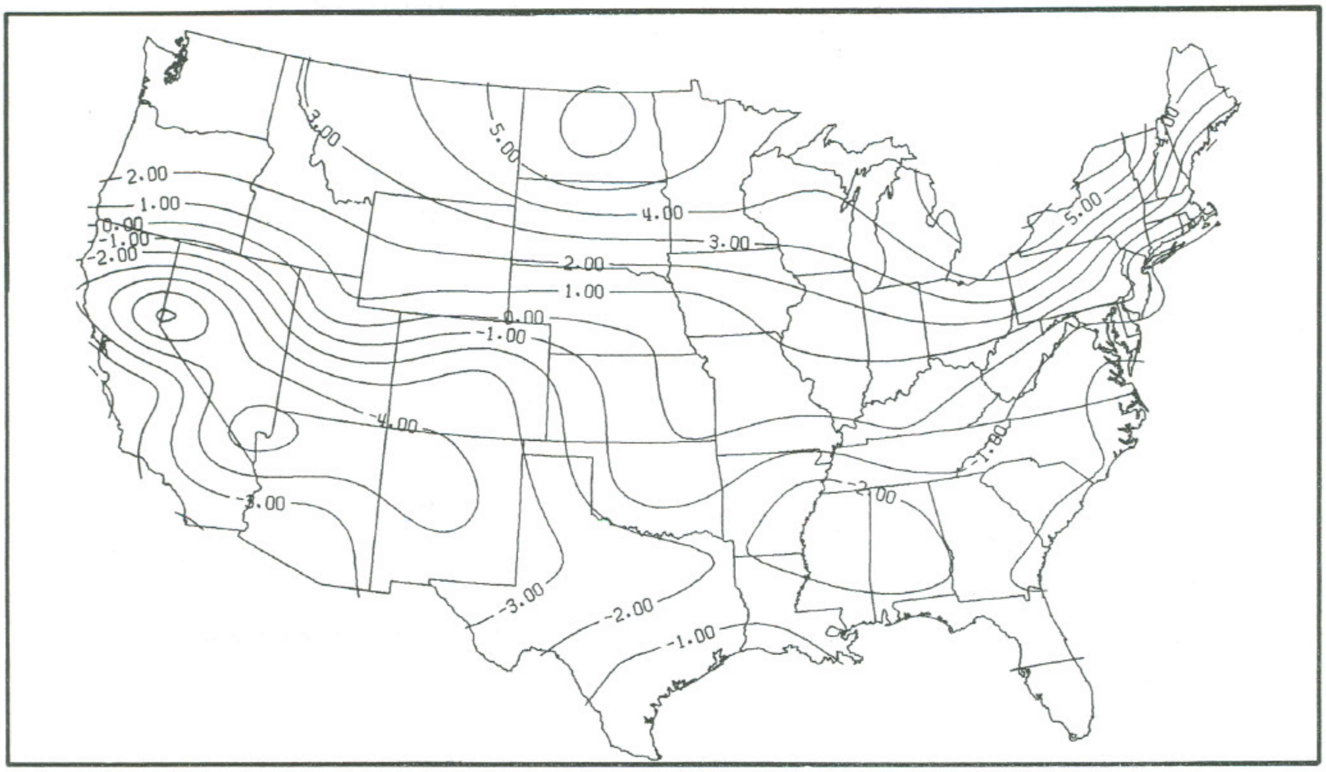


Fig. 5.5.1 Delta Heating Energy 12.5 S-10 Base Case, 1-P

XBL 856-2933

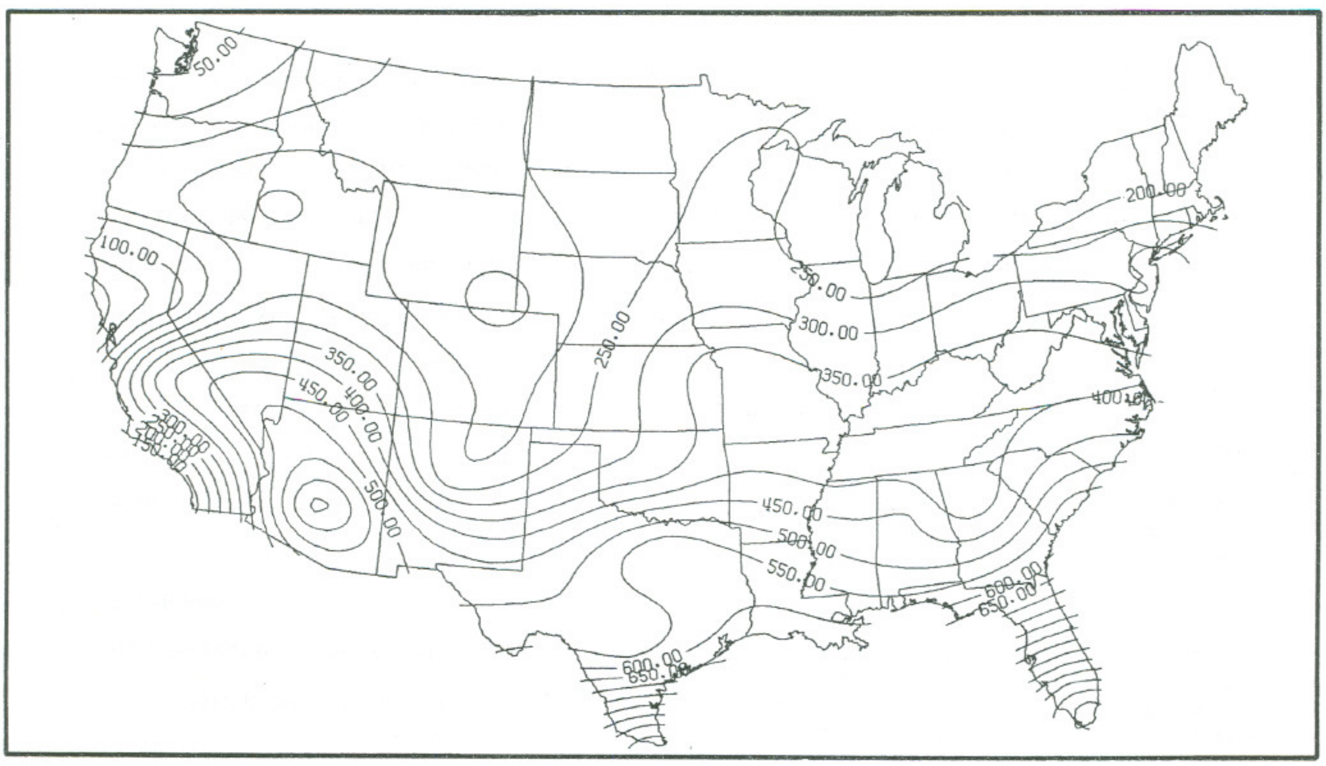


Fig. 5.5.2 Delta Cooling Energy 12.5 S-10 Base case, 1-P

XBL 856-2928

6.0. ANALYSIS OF SPACE CONDITIONING CONSERVATION OPTIONS

This section describes various options for which sensitivity analyses have been performed. It includes descriptions of the methodological approaches, the results for each sensitivity, and how these results have been incorporated into the data base tables and PEAR microcomputer program. The section is organized into eight topic areas covering the following major space conditioning conservation options:

- Insulation
- Thermal mass in exterior walls
- Infiltration
- Windows
- Night temperature setback
- Building floor area
- Exterior building color
- Attached sunspaces

In addition, the window discussion is separated into several subcategories: sash type and air gap interpolations, window area, window orientation, movable night insulation, and reflective and absorptive glazings.

6.1. Insulation

Because of the importance of insulation in reducing building loads, more than 70% of the database are simulations done for different combinations of ceiling, wall, and foundation insulation.

Energy savings due to increased insulation for any one building component (e.g., ceiling, wall, or foundation) are calculated as the difference in annual heating and cooling loads between two successive DOE-2.1A simulations while keeping all other house components constant and at comparable levels of thermal integrity to the measure being simulated. This insures maximum accuracy for most reasonable construction situations. Sensitivity studies for the one story prototype have shown that the interactions in energy savings between different building components are negligible except in extreme conditions such as when a R-38 ceiling is combined with R-0 walls and floors. In these cases the poor overall thermal integrity of the house may reduce energy savings in one component by as much as 10%.* The unlikelihood of such building constructions and the complexity needed to present these second-order interactions justify the assumption that the energy impacts of individual component measures are independent and additive.

In warm locations, five ceiling, four wall, and three foundation levels have been modeled for all five building prototypes. In cold locations, seven ceiling, four wall, and five foundation levels

* See Appendix E for analysis of interactions between ceiling, wall, and foundation insulation measures in the one-story ranch house prototype.

have been modeled. This requires in total from 12 to 14 different simulations for each prototype, foundation type, and location. Since the simulations assume similar thermal integrities for all building components, there is no base case option embedded in the data base, but rather a sliding series of base cases.

Tables 6.1a, 6.1b, and 6.1c list the individual insulation measures simulated along with the thermal integrity levels assumed for the rest of the building. Construction details corresponding to the measures and the simulation methodology are described in Section 3.3.

The energy impacts for intermediate insulation measures not covered in the data base have been interpolated by correlating the energy savings for simulated measures to their difference in conductance, and then scaling the savings to the conductance differences for the intermediate measures. Ceiling, wall, and ventilated crawl space floor conductances used for this UA interpolation are based on the actual R-values of the sections on Figures 3.3.1 through 3.3.9, and not on their nominal R-values.

Interpolations for intermediate unheated basement measures require a more complex calculation taking into account heat transfer from the living space to the basement (Q_1) as well as from the basement to the ground (Q_2). The following steady-state approximations are made:

$$Q_1 = (K_{flr} \times A)\,(T_{room} - T_{bsmt})$$

$$Q_2 = (K_{bsmt} \times L)\,(T_{bsmt} - T_{outside})$$

$$Q_1 = Q_2$$

A is the floor area; L is the perimeter length; K_{flr} is the conductance per ft^2 of the floor over the basement, and K_{bsmt} is the conductance per perimeter foot of the basement wall as given in Appendix C. Q_1 can then be expressed as:

$$Q_1 = \frac{(K_{flr}A)\,(K_{bsmt}L)}{(K_{flr}A + K_{bsmt}L)} \left(T_{room} - T_{outside}\right) \qquad (11)$$

This equation is used to compute different values for Q_1 and the $\Delta\ Q_1$ from the uninsulated R-0 case, depending on differences in K_{flr}. Interpolations for intermediate unheated basement floor measures are then done by scaling the load differences between the two simulated cases (R-0 and R-19 floors) by their respective $\Delta\ Q_1$.

Table 6.1d gives steady-state conductances for both intermediate and simulated conservation measures, and expresses the Δ conductances for the intermediate measures as a ratio of Δ conductances for the simulated cases. These ratios are used for interpolating Δ loads for these intermediate conservation measures based on the Δ loads from the appropriate DOE-2.1A simulations.

To assess the accuracy of interpolations for ceiling and wall Δ loads, test DOE-2.1A runs have been done for R-7, R-11, and R-13 walls and ceilings in four representative cities: Minneapolis

Table 6.1a. Insulation Measures Calculated For Slab Foundation Buildings

Ceiling Insulation	Wall	Foundation	Glazing	Infiltration
R-0	R-0	R-0	1-pane	0.7 ach
R-0, R-11	R-0	R-0	1-pane	0.7 ach
R-11, R-19	R-11	R-0	1-pane	0.7 ach
R-19, R-30	R-11	R-5 2 ft	2-pane	0.7 ach
R-30, R-38	R-19	R-5 2 ft	3-pane	0.7 ach

Wall Insulation	Ceiling	Foundation	Glazing	Infiltration
R-0	R-0	R-0	1-pane	0.7 ach
R-0, R-11	R-11	R-0	1-pane	0.7 ach
R-11, R-19	R-30	R-5 2 ft	2-pane	0.7 ach
R-19, R-27	R-38	R-5 4 ft	3-pane	0.7 ach

Slab Insulation	Ceiling	Wall	Glazing	Infiltration
R-0	R-0	R-0	1-pane	0.7 ach
R-0, R-5 2 ft	R-19	R-11	1-pane	0.7 ach
R-5 2 ft, R-10 2 ft	R-30	R-19	3-pane	0.7 ach

(Construction of Rest of Building)

Table 6.1b. Insulation Measures Calculated For Crawl Foundation Buildings

Ceiling Insulation	Wall	Foundation	Glazing	Infiltration
R-0	R-0	R-0	1-pane	0.7 ach
R-0, R-11	R-0	R-0	1-pane	0.7 ach
R-11, R-19	R-11	R-0	1-pane	0.7 ach
R-19, R-30	R-11	R-11	2-pane	0.7 ach
R-30, R-38	R-19	R-19	3-pane	0.7 ach
R-38, R-49	R-27	R-19	3-pane	0.7 ach

Wall Insulation	Ceiling	Foundation	Glazing	Infiltration
R-0	R-0	R-0	1-pane	0.7 ach
R-0, R-11	R-11	R-0	1-pane	0.7 ach
R-11, R-19	R-30	R-11	2-pane	0.7 ach
R-19, R-27	R-38	R-19	3-pane	0.7 ach

Crawl Space Insulation	Ceiling	Wall	Glazing	Infiltration
R-0 floor	R-0	R-0	1-pane	0.7 ach
R-0, R-11 floor	R-19	R-11	1-pane	0.7 ach
R-11, R-19 floor	R-30	R-19	2-pane	0.7 ach

(Construction of Rest of Building)

Table 6.1c. Insulation Measures Simulated For Basement Foundation Buildings

Ceiling Insulation	Construction of Rest of Building: Wall	Foundation	Glazing	Infiltration
R-0	R-0	R-0	1-pane	0.7 ach
R-0, R-11	R-0	R-0	1-pane	0.7 ach
R-11, R-19	R-11	R-0	1-pane	0.7 ach
R-19, R-30	R-11	R-5 8 ft	2-pane	0.7 ach
R-30, R-38	R-19	R-5 8 ft	3-pane	0.7 ach
R-38, R-49	R-27	R-10 8 ft	3-pane	0.7 ach
R-49, R-60	R-27	R-10 8 ft	3-pane	0.7 ach

Wall Insulation	Construction of Rest of Building: Ceiling	Foundation	Glazing	Infiltration
R-0	R-0	R-0	1-pane	0.7 ach
R-0, R-11	R-11	R-0	1-pane	0.7 ach
R-11, R-19	R-30	R-5 8 ft	2-pane	0.7 ach
R-19, R-27	R-38	R-10 8 ft	3-pane	0.7 ach

Basement Insulation	Construction of Rest of Building: Ceiling	Wall	Glazing	Infiltration
R-0	R-0	R-0	1-pane	0.7 ach
R-0, R-5 4 ft	R-19	R-11	1-pane	0.7 ach
R-5 4 ft, R-5 8 ft	R-19	R-19	2-pane	0.7 ach
R-5 8 ft, R-10 8 ft	R-38	R-19	3-pane	0.7 ach
R-10 8 ft, R-19 floor	R-49	R-27	3-pane	0.7 ach

(cool), New York (temperate), Phoenix (hot-arid), and Lake Charles (hot-humid). Because interactions between different building components have been observed at low thermal integrity levels (see Appendix E), different combinations of the lightly insulated ceilings and walls have been modeled. Comparisons of the test results to interpolated values show differences smaller than the observed variations due to interactions between different building components (see Tables 6.1e and 6.1f.)

To test the accuracy of interpolations for intermediate unheated basement Δ loads, DOE-2.1A runs have been done for R-4, R-7, and R-11 unheated basement floors in Minneapolis and New York (see Table 6.1g). For both cities, the differences between the test results and interpolated values are less than 0.15 MBtu.

The Δ loads for insulation measures for the five prototype buildings are listed in tabular format in the accompanying data base document, and are stored in modified format in the PEAR microcomputer program. See Chapter 7 for the methodology used to convert Δ loads to component loads.

Table 6.1d. Conductances for Simulated and Intermediate R-values

Nominal R-value	Actual R-value	Steady-State Conductance (Btu/hr·ft^2·F)	Ratio of load differences
Ceiling Measures			
R-0	4.17	0.2396	
R-7	10.89	0.0918	0.870 of ΔLoad from R-0 to R-11
R-11*	14.36	0.0696	1.000 of ΔLoad from R-0 to R-11
R-13	15.99	0.0625	0.338 of ΔLoad from R-11 to R-19
R-19*	20.59	0.0486	1.000 of ΔLoad from R-11 to R-19
R-22	22.02	0.0454	0.183 of ΔLoad from R-19 to R-30
R-30*	31.88	0.0314	1.000 of ΔLoad from R-19 to R-30
R-38*	40.02	0.0250	1.000 of ΔLoad from R-30 to R-38
R-49*	51.13	0.0196	1.000 of ΔLoad from R-38 to R-49
R-60*	62.19	0.0161	1.000 of ΔLoad from R-49 to R-60
Wall Measures for Standard Walls			
R-0*	4.56	0.2191	
R-7	9.31	0.1074	0.842 of ΔLoad from R-0 to R-11
R-11*	11.57	0.0864	1.000 of ΔLoad from R-0 to R-11
R-13	12.53	0.0798	0.231 of ΔLoad from R-11 to R-19
R-19*	17.28	0.0579	1.000 of ΔLoad from R-11 to R-19
R-24	22.28	0.0449	0.751 of ΔLoad from R-19 to R-27
R-27*	24.64	0.0406	1.000 of ΔLoad from R-19 to R-27
Wall Measures for Stucco Walls:			
R-0*	2.78	0.3594	
R-7	7.60	0.1316	0.889 of ΔLoad from R-0 to R-11
R-11*	9.70	0.1031	1.000 of ΔLoad from R-0 to R-11
R-13	10.55	0.0948	0.218 of ΔLoad from R-11 to R-19
R-19*	15.36	0.0651	1.000 of ΔLoad from R-11 to R-19
R-24	20.89	0.0479	0.731 of ΔLoad from R-19 to R-27
R-27*	24.10	0.0415	1.000 of ΔLoad from R-19 to R-27
Floor Measures for Ventilated Crawl Space Foundations:			
R-0*	4.81	0.2080	
R-7	10.56	0.0947	0.801 of ΔLoad from R-0 to R-11
R-11*	14.99	0.0667	1.000 of ΔLoad from R-0 to R-11
R-19*	21.22	0.0471	1.000 of ΔLoad from R-11 to R-19
R-22	23.34	0.0428	1.219 of ΔLoad from R-11 to R-19

*insulation measures simulated in data base

Table 6.1d. Conductance for Simulated and Intermediate R-Values (Continued)

Perimeter Insulation Measures for Slab Foundations		
Measure	K per perimeter ft. (Btu/hr·ft·F)	Ratio of load differences
R-0*	1.180	
R-5 2 ft. *	0.395	1.000 of ΔLoad from R-0 to R-5 2 ft
R-10 2 ft	0.320	0.652 of ΔLoad from R-5 2 ft to R-5 4 ft
R-5 4 ft. *	0.280	1.000 of ΔLoad from R-5 2 ft to R-5 4 ft
R-10 4 ft	0.180	1.870 of ΔLoad from R-5 2 ft to R-5 4 ft

Floor Measures for Basement Foundations		
Measure	K total (Btu/hr·F)	Ratio of load differences
1-Story Ranch Prototype:		
R-0*	157.2	
R-7	91.7	0.631 of ΔLoad from R-0 to R-19
R-11	74.1	0.801 of ΔLoad from R-0 to R-19
R-19*	53.4	1.000 of ΔLoad from R-0 to R-19
R-22	48.4	1.048 of ΔLoad from R-0 to R-19
2-Story Prototype:		
R-0*	121.6	
R-7	69.1	0.641 of ΔLoad from R-0 to R-19
R-11	55.4	0.808 of ΔLoad from R-0 to R-19
R-19*	39.7	1.000 of ΔLoad from R-0 to R-19
R-22	35.9	1.046 of ΔLoad from R-0 to R-19
Split-level Prototype:		
R-0*	64.3	
R-7	35.7	0.649 of ΔLoad from R-0 to R-19
R-11	28.4	0.814 of ΔLoad from R-0 to R-19
R-19*	20.2	1.000 of ΔLoad from R-0 to R-19
R-22	18.3	1.043 of ΔLoad from R-0 to R-19
Townhouse Prototypes:		
R-0*	75.6	
R-7	40.2	0.664 of ΔLoad from R-0 to R-19
R-11	31.7	0.824 of ΔLoad from R-0 to R-19
R-19*	22.3	1.000 of ΔLoad from R-0 to R-19
R-22	20.0	1.043 of ΔLoad from R-0 to R-19

*insulation measures simulated in data base

Table 6.1e. Comparison of DOE-2 and Interpolated Δ Loads for Low Ceiling Conservation Measures in Four Locations

	Δ Heating Load (MBtu/yr)			Δ Cooling Load (MBtu/yr)		
Ceiling conditions and Locations	DOE-2 R-0 Wall	DOE-2 R-11 Wall	Inter-polated	DOE-2 R-0 Wall	DOE-2 R-11 Wall	Inter-polated
R-0 to R-7 Ceilings						
Minneapolis	-33.89	-39.85	-34.32	-4.28	-4.26	-4.36
New York	-26.61	-27.16	-26.41	-4.07	-3.83	-3.97
Phoenix	-9.30	-9.15	-9.21	-13.39	-15.20	-13.55
Lake Charles	-10.39	-10.34	-10.29	-8.90	-9.36	-8.87
R-7 to R-11 Ceilings						
Minneapolis	-5.57	-6.26	-5.13	-0.62	-0.58	-0.64
New York	-3.75	-3.56	-3.95	-0.50	-0.53	-0.59
Phoenix	-1.29	-1.25	-1.38	-2.01	-2.54	-2.03
Lake Charles	-1.44	-1.41	-1.54	-1.30	-1.41	-1.33
R-11 to R-13 Ceilings						
Minneapolis	-1.82	-2.03	-2.02	-0.20	-0.22	-0.18
New York	-1.19	-1.40	-1.19	-0.17	-0.15	-0.16
Phoenix	-0.41	-0.39	-0.39	-0.94	-0.86	-0.87
Lake Charles	-0.46	-0.50	-0.45	-0.45	-0.46	-0.43

Table 6.1f. Comparison of DOE-2 and Interpolated Δ Loads for Low Wall Conservation Measures in Four Locations

	Δ Heating Load (MBtu/yr)			Δ Cooling Load (MBtu/yr)		
Wall conditions and Locations	DOE-2 R-0 Ceiling	DOE-2 R-11 Ceiling	Inter-polated	DOE-2 R-0 Ceiling	DOE-2 R-11 Ceiling	Inter-polated
R-0 to R-7 Walls						
Minneapolis	-14.78	-20.46	-20.64	-1.20	-1.13	-1.14
New York	-12.35	-12.94	-12.95	-1.00	-0.81	-0.83
Phoenix	-3.80	-3.65	-3.66	-3.76	-5.50	-5.58
Lake Charles	-4.80	-4.75	-4.74	-2.63	-3.09	-3.13
R-7 to R-11 Walls						
Minneapolis	-3.08	-4.06	-3.87	-0.23	-0.23	-0.22
New York	-2.46	-2.43	-2.43	-0.19	-0.18	-0.16
Phoenix	-0.73	-0.70	-0.69	-0.72	-1.13	-1.05
Lake Charles	-0.91	-0.89	-0.89	-0.53	-0.63	-0.59
R-11 to R-13 Walls						
Minneapolis	-0.99	-1.29	-1.43	-0.07	-0.07	-0.05
New York	-0.74	-0.76	-0.79	-0.06	-0.06	-0.04
Phoenix	-0.23	-0.22	-0.22	-0.25	-0.36	-0.44
Lake Charles	-0.29	-0.28	-0.30	-0.17	-0.17	-0.16

Table 6.1g. Comparison of DOE-2 and Interpolated Δ Loads for Intermediate Underfloor Conservation Measures in Unheated Basements

Underfloor Insulation	Δ Heating Loads (MBtu/yr) DOE-2	Δ Heating Loads (MBtu/yr) Interpolated	Δ Cooling Loads (MBtu/yr) DOE-2	Δ Cooling Loads (MBtu/yr) Interpolated
R0 to R4				
Minneapolis	-7.65	-7.87	-0.03	-0.09
New York	-4.49	-4.52	-0.03	-0.17
R0 to R7				
Minneapolis	-11.14	-11.29	-0.04	-0.13
New York	-6.37	-6.49	-0.12	-0.25
R0 to R11				
Minneapolis	-14.23	-14.36	-0.17	-0.16
New York	-8.24	-8.23	-0.17	-0.31

6.2 Thermal Mass in Exterior Walls

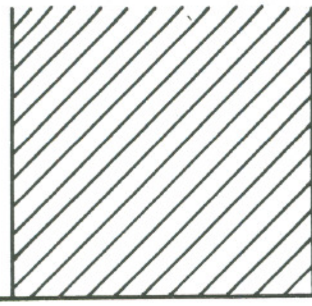
The use of massive materials in exterior wall construction can be an effective means of reducing both heating and cooling loads in residential buildings. The magnitude of the savings depends on a complex interaction of parameters including the climate, the amount of mass, the physical properties of the mass, and other building design parameters, such as the area and orientation of windows, the type of window glass, the thermal integrity of the building and the building operating conditions. For the current version of the PEAR program, we have chosen to quantify the thermal mass effect for a typical residence and deal qualitatively with other cases.

Three wall constructions (Figures 6.2.1 - 6.2.2) are simulated in a parametric series with DOE-2.1C using custom weighting factors to account for the thermal storage characteristics of the mass. Shown in Figure 6.2.1, the wall with integral insulation represents a log wall and approximates a brick or concrete masonry unit with the cores filled with insulation. Figures 6.2.2 and 6.2.3 represent brick or concrete masonry with a layer of insulation either inside or outside of the mass. Table 6.2a shows the range of the characteristics modeled for each wall type. In addition, sensitivity runs are done to quantify the effect of changes in specific parameters.

Table 6.2a. Mass Wall Characteristics

Insulation Location	Mass Conductivity (Btu/hr·ft·F)	Mass Thickness (in.)	Heat Capacity (Btu/ft^2·F)	Wall R-value (hr·ft^2·F/Btu)
Outside	0.5	4 - 8	3.3 - 13.3	5 - 20
Inside	0.5	4 - 8	3.3 - 13.3	5 - 20
Integral	0.07 - 0.33	4 - 8	3.3 - 13.3	5 - 10

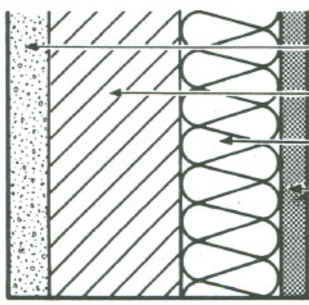
Mass Wall
Integral Insulation



Note:
Mass thickness, conductivity, density and specific-heat vary

Fig. 6.2.1

Mass Wall
Insulation Inside

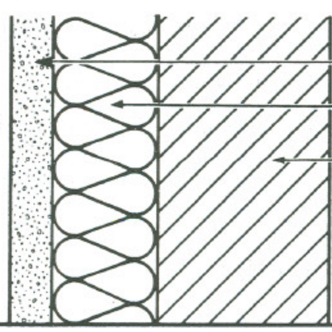


	R-Value
1″ Stucco	0.2
Mass	Varies
Insulation	Varies
1/2″ Drywall	0.45

Note:
Mass Conductivity = 0.5
Mass thickness, density and specific-heat vary

Fig. 6.2.2

Mass Wall
Insulation Outside



	R-Value
1″ Stucco	0.2
Insulation	Varies
Mass	Varies

Note:
Mass Conductivity = 0.5
Mass thickness, density and specific-heat vary

XBL 849-10793

Fig. 6.2.3

Throughout this section, reference will be made to ***thermal mass savings*** and ***delta load***. For the purpose of this discussion, these terms are equivalent and are defined as follows:

$$\Delta\text{Load} = \text{Load}_{\text{frame wall}} - \text{Load}_{\text{mass wall}} \qquad (12)$$

where:
Load = total building annual heating or cooling load (MBtu/yr) where the R-value of the frame wall equals that of the mass wall.

Additionally, wall ***heat capacity*** is defined here as:

$$\text{Heat capacity} = \text{Wall mass} \cdot \text{Specific heat} \qquad (13)$$

where:
Wall mass = weight of wall per ft^2 of wall area (lb/ft^2)
Specific heat = specific heat of wall mass (Btu/lb·F)

The following modeling assumptions apply to the base case thermal mass simulations. A full description of the prototype is included in Section 3.

Interior Mass
Furniture:
3.30 lb. per ft^2 of floor area
0.30 Btu/lb
2.00 in. thick
Interior Walls:
3.57 lb per ft^2 of floor area
0.26 Btu/lb
0.50 in thick

Natural Ventilation Temperature
78 F Winter
72 F Summer
Spring and Autumn dates adjusted by climate

Floor
Carpet covered 4 inch concrete slab with perimeter insulation

Ceiling
R-30 Insulation

Window Glass Type
Single pane clear glass
Transmittance = 0.88
Reflectance = 0.07
Drapery shading coefficient = 0.63

Window Area
15% of floor area equally distributed in four orientations

6.2.1 Interaction with Building Design Parameters

The ability of thermal mass to reduce heating and cooling loads depends not only on the climate and the wall type, but also on the design of the building itself. In particular, any design feature that affects solar gain is likely to affect the load savings due to thermal mass. As solar gain in a building increases, the effectiveness of thermal mass also increases, due to the ability of mass to store excess heat gains.

The results of DOE-2.1C simulations exploring this phenomenon are shown in Figure 6.2.4. Window orientation, window glass type, window area and drapery schedule are modified for the ranch prototype with either wood frame walls or masonry walls with insulation outside (total wall R-value = 5 hr·ft^2·F/Btu). For each case, the difference between the frame wall and the masonry wall is plotted. Case 1 is similar to the base case used for analyzing other conservation measures, while in cases 2-8 a single design parameter has been changed. Case 9 represents a simultaneous change in four parameters.

Other design parameters that can affect the thermal mass savings include natural ventilation rate, amount of internal mass (furniture, walls, appliances, etc.) and the thermal integrity of the building. Occupant behavior and operating conditions, such as thermostat settings and night setback also have an impact. In developing the PEAR data base, we have attempted to analyze typical building designs and operating conditions to quantify the thermal mass effect in average cases. However, the user should be aware that the effect in an actual building may vary.

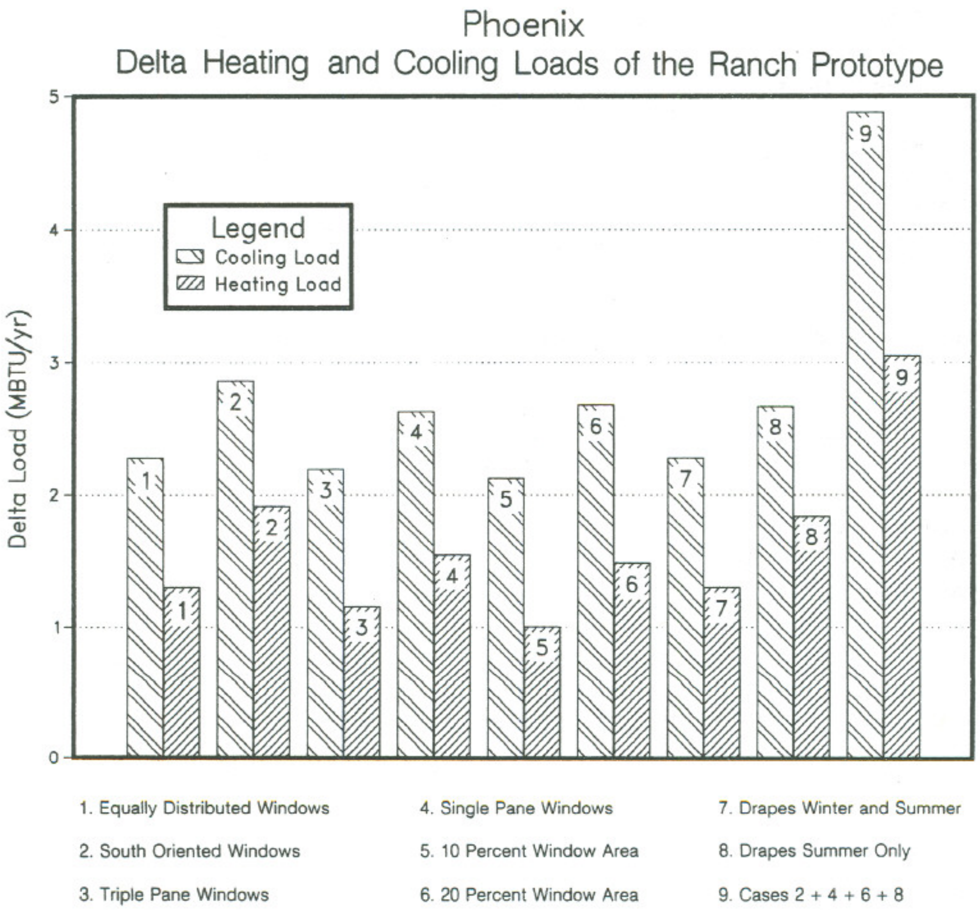


Fig. 6.2.4

6.2.2 The Effect of Mass Conductivity

The effectiveness of thermal mass in reducing heating and cooling loads depends on its ability to dampen interior temperature swings by storing excess heat gains during the day that, at night, can offset heating loads during the winter or be vented to the outside during the summer. The more quickly the mass can respond to surface temperature fluctuations, the more effective it will be in reducing heating and cooling loads. The conductivity of the mass has a direct impact on this response time and consequently on the load reduction.

For the current version of PEAR, we have chosen to not handle multiple interactions, but to simulate massive walls with either interior or exterior insulation (Figures 6.2.2 and 6.2.3), while keeping the mass conductivity constant at 0.5 Btu/hr·ft·F, which is typical of uninsulated concrete. In the simulations of walls with the insulation and the mass well mixed (Figure 6.2.1), the conductivity is allowed to vary within the range typical of solid wood and insulated concrete (Table 6.2a). This approach allows the results for all three wall types to be represented by regression equations in which the only independent variables are mass heat capacity and total wall R-value (Section 6.2.5).

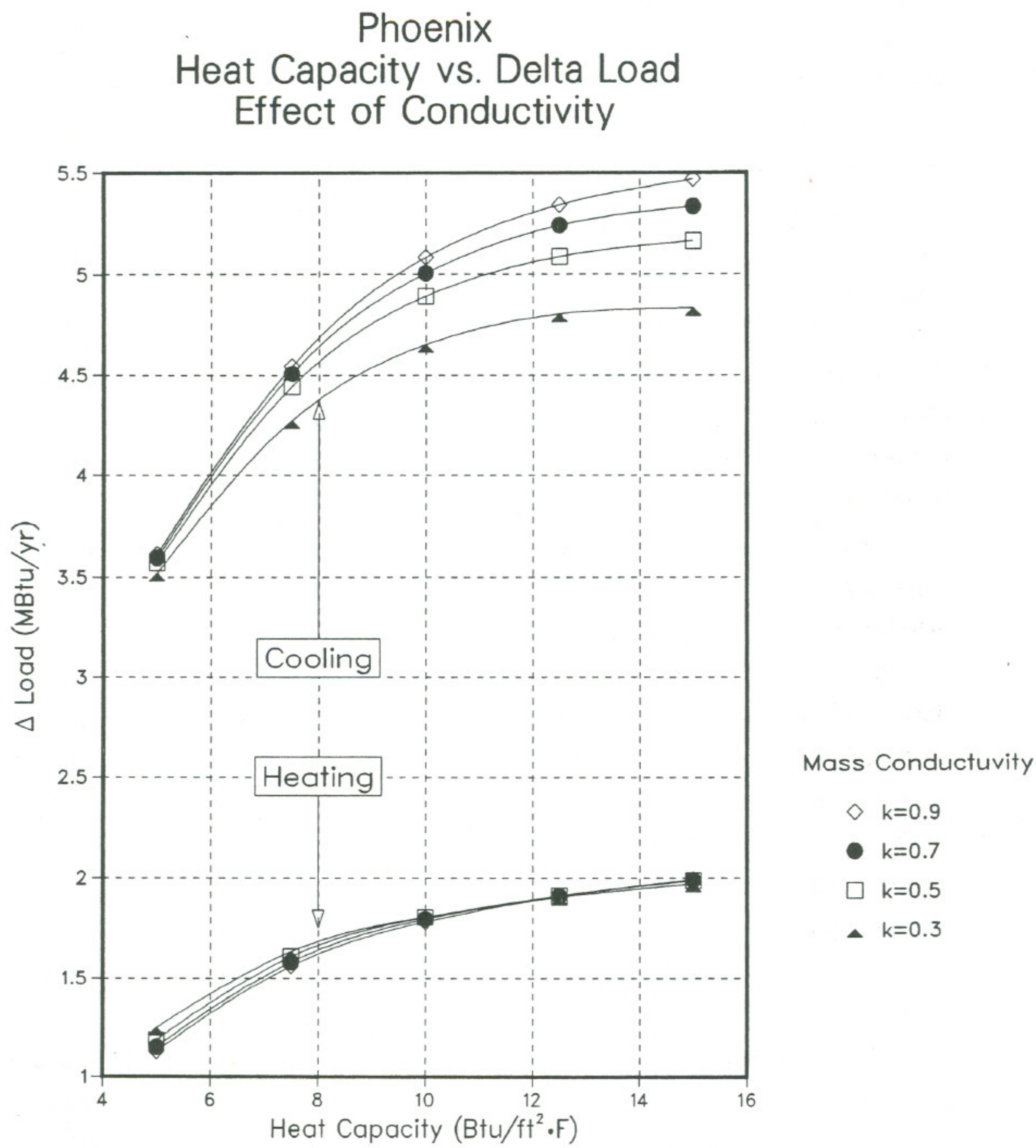
Sensitivity runs are done to quantify the effect of changes in mass conductivity. Shown in Figure 6.2.5 are typical results, in this case for an R-5 wall of 8 inch masonry with insulation outside of the mass.

As the mass conductivity increases, the difference in load between a massive and a lightweight wall also increases. The higher the conductivity of the mass, the more effective it is in reducing loads compared to a lightweight wall with the same total wall R-value. This effect is more pronounced in cooling than heating. Although the results shown here are climate and building specific, the trends are representative of any location and building design.

6.2.3. The Effect of Wall U-value

A sensitivity analysis is done for several wall configurations in which the mass layer is held constant while the U-value of the insulation layer was varied. A representative case (8 inch medium weight masonry) is shown in Figure 6.2.6.

In the case of both heating and cooling, the thermal mass effect is seen to diminish as the U-value of the wall decreases. Further, the effect of thermal mass is nearly linear with the wall U-value. It should be noted that total heating load is more sensitive to changes in wall U-value (or R-value) than to changes in the amount of thermal mass. However, total cooling load is influenced more by the addition of thermal mass than by wall insulation. Although the magnitude of these results will change with building design (see Section 6.2.1), the importance of thermal mass in cooling dominated climates is clearly shown.



Phoenix
Heat Capacity vs. Delta Load
Effect of Conductivity
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
Δ Load (MBtu/yr)
4
6
8
10
12
14
16
Heat Capacity (Btu/ft²•F)
Cooling
Heating
Mass Conductuvity
k=0.9
k=0.7
k=0.5
k=0.3

Fig. 6.2.5.

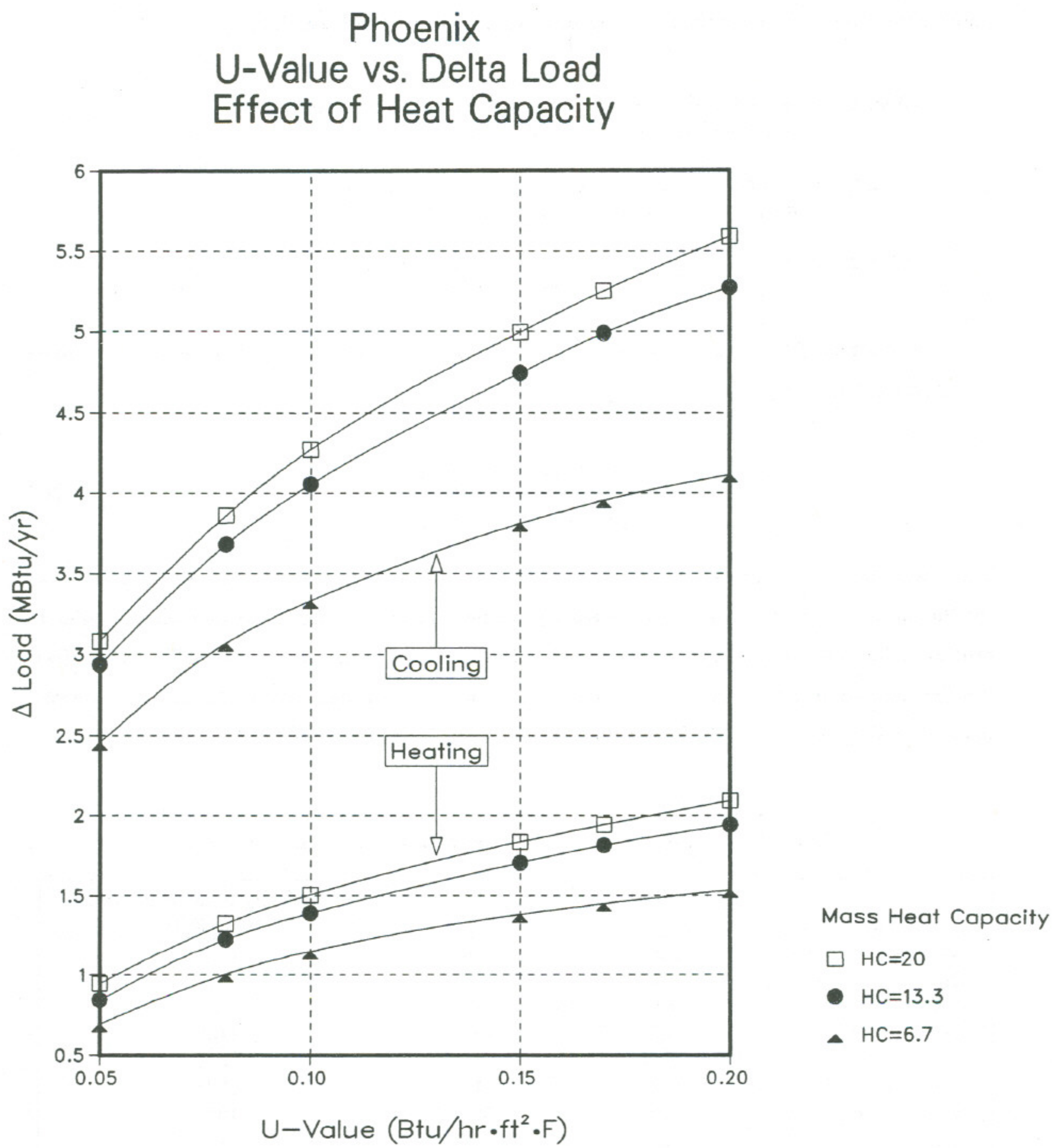

Phoenix
U-Value vs. Delta Load
Effect of Heat Capacity
Δ Load (MBtu/yr)
U-Value (Btu/hr•ft²•F)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0.05
0.10
0.15
0.20
Cooling
Heating
Mass Heat Capacity
HC=20
HC=13.3
HC=6.7

Fig. 6.2.6.

6.2.4. Selection of Heating and Cooling Zones

Because of the many types of commonly built masonry and log walls, it is impractical to simulate with DOE-2.1C all possible configurations in all 45 base cities. Consequently, detailed simulations are run for only the following three wall types in all 45 locations.

Wall 1 = 4 inch medium weight block with insulation outside
total wall R-value = 5 $hr \cdot ft^2 \cdot F/Btu$

Wall 2 = 8 inch medium weight block with insulation outside
total wall R-value = 5 $hr \cdot ft^2 \cdot F/Btu$

Wall 3 = 8 inch medium weight block with insulation outside
total wall R-value = 20 $hr \cdot ft^2 \cdot F/Btu$

An analysis of the results indicated that the 45 base cities could be grouped into twelve zones based on the following ratio:

$$\frac{Load_{wall\ 1} - Load_{wall\ 2}}{Load_{wall\ 1} - Load_{wall\ 3}} \qquad (14)$$

This ratio separates the effects of thermal mass from the effects due to steady state wall conductance. Calculating this ratio separately for heating and cooling loads and then sorting the results yields the twelve cities indicated in Table 6.2b. The heating and cooling loads from detailed simulations in these twelve cities can be used to estimate the performance of various massive wall types in each of the 45 base locations as indicated in Table 6.2c.

Table 6.2b. Locations of Thermal Mass Parametric Runs

Location	HDD Base 65 F	CDD Base 65 F	Mean Daily Solar Radiation (Btu/ft^2)
Atlanta GA	3095	1589	1345
Brownsville TX	650	3874	1548
Buffalo NY	6927	437	1034
Cincinnati OH	5070	1080	1159
Denver CO	6016	625	1585
Los Angeles CA	1819	615	1594
Medford OR	4930	562	1353
Miami FL	206	4038	1473
Phoenix AZ	1552	3508	1869
San Diego CA	1507	722	1598
San Francisco CA	3042	108	1553
Seattle WA	5185	129	1053

Source: *Input Data for Solar Systems,* V. Cinquemani, et. al., U.S. Dept. of Energy, 1978.

Table 6.2c. Mass Wall Performance Index Zones For Each of 45 Base Locations

Location Number	Location Name	MWPI Cooling Zone	MWPI Heating Zone
1	Albuquerque, NM	2	3
2	Atlanta, GA	1	1
3	Birmingham, AL	8	7
4	Bismarck, ND	5	3
5	Boise, ID	5	1
6	Boston, MA	4	4
7	Brownsville, TX	2	2
8	Buffalo, NY	3	3
9	Burlington, VT	5	4
10	Charleston, SC	4	11
11	Cheyenne, WY	6	5
12	Chicago, IL	4	3
13	Cincinnati, OH	4	4
14	Denver, CO	5	5
15	El Paso, TX	2	11
16	Fort Worth, TX	1	11
17	Fresno, CA	2	11
18	Great Falls, MO	3	5
19	Honolulu, HI	2	-
20	Jacksonville, FL	2	6
21	Juneau, AK	-	3
22	Kansas City, MO	2	7
23	Lake Charles, LA	1	11
24	Las Vegas, NV	1	11
25	Los Angeles, CA	6	6
26	Medford, OR	7	7
27	Memphis, TN	9	1
28	Miami, FL	8	8
29	Minneapolis, MN	2	3
30	Nashville, TN	2	7
31	New York, NY	4	4
32	Oklahoma City, OK	2	12
33	Omaha, NB	4	12
34	Philadelphia, PA	9	4
35	Phoenix, AZ	9	9
36	Pittsburgh, PA	4	3
37	Portland, ME	6	4
38	Portland, OR	7	12
39	Reno, NV	12	1
40	Salt Lake City, UT	5	12
41	San Antonio, TX	8	11
42	San Diego, CA	10	10
43	San Francisco, CA	11	11
44	Seattle, WA	12	12
45	Washington, DC	2	3

6.2.5. Mass Wall Data Base

A data base of DOE-2.1C simulations has been generated for various massive walls in the twelve U.S. cities listed in Table 6.2b. This data was then analyzed using the *Statistical Analysis System* software package to produce a set of regression equations that can be used to calculate the Δ heating and cooling loads for massive walls of any U-value and heat capacity. The following linear model is used to predict the annual building heating and cooling loads for the base case with wood frame walls:

$$\text{Load} = \beta_0 + \beta_1 U_T \tag{15}$$

Where:

β_{0-1} = regression coefficients

U_T = total wall U-value (Btu/hr·ft^2·F)

The following nonlinear model is used to predict the Δ load between a wood frame wall and a massive wall of the same U-value:

$$\phi = e^{\beta_0 * HC} \tag{16}$$

$$\Delta\text{Load} = \beta_1 + \beta_2\phi + \beta_3 U_T + \beta_4 \phi U_T \tag{17}$$

Where:

β_{0-4} = regression coefficients

HC = wall heat capacity (Btu/ft^2·F)

U_T = total wall U-value (Btu/hr·ft^2·F)

This model accounts for the exponential decay effect of wall heat capacity, the linear effect of wall U-value and the interaction between these two effects. As shown in Figures 6.2.7 - 6.2.10, the regression equations accurately predict the thermal mass effect of heavyweight exterior walls. The regression equation coefficients are given in Table 6.2d, and stored in the PEAR microcomputer program for calculating the effect of thermal mass in exterior walls. Based on user inputs for the insulation R-value, location (outside, inside, or integral), and wall heat-capacity, the PEAR program calculates the actual R-value of the wall, the component heating and cooling loads for a wood-frame wall of that R-value, and finally the Δ loads from the wood-frame case based on the described regression equations.

PHOENIX
Heat Capacity vs. Delta Heating Load
For Various Massive Walls

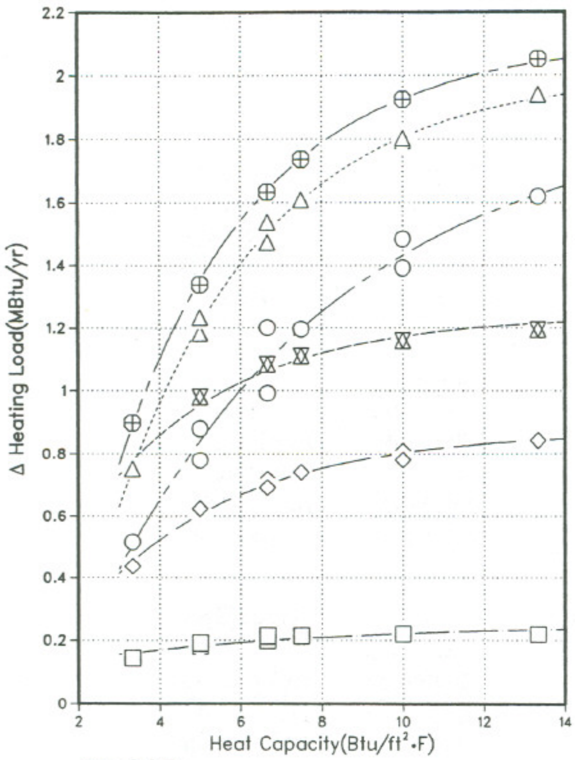


Fig. 6.2.7

PHOENIX
Heat Capacity vs. Delta Cooling Load
For Various Massive Walls

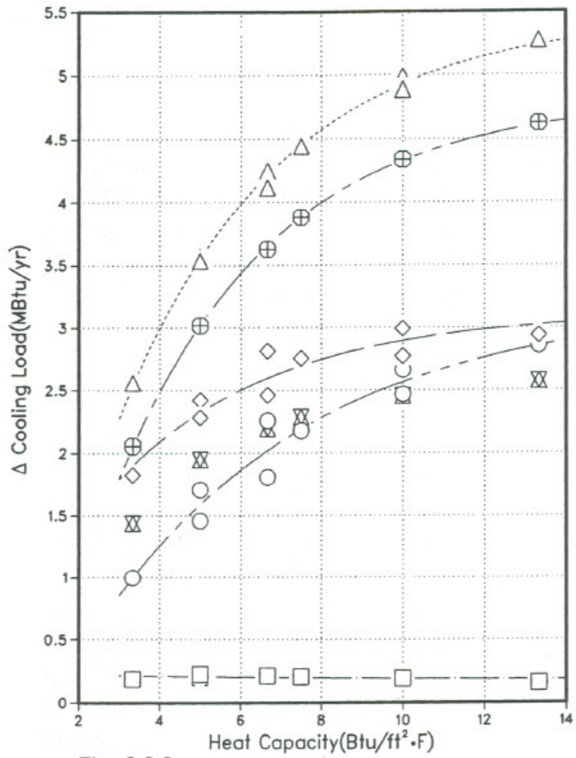


Fig. 6.2.8

Legend △ R5 OUTSIDE ◇ R20 OUTSIDE ○ R5 INSIDE □ R20 INSIDE ⌛ R10 INTEGRAL ⊕ R5 INTEGRAL

ATLANTA
Heat Capacity vs. Delta Heating Load
For Various Massive Walls

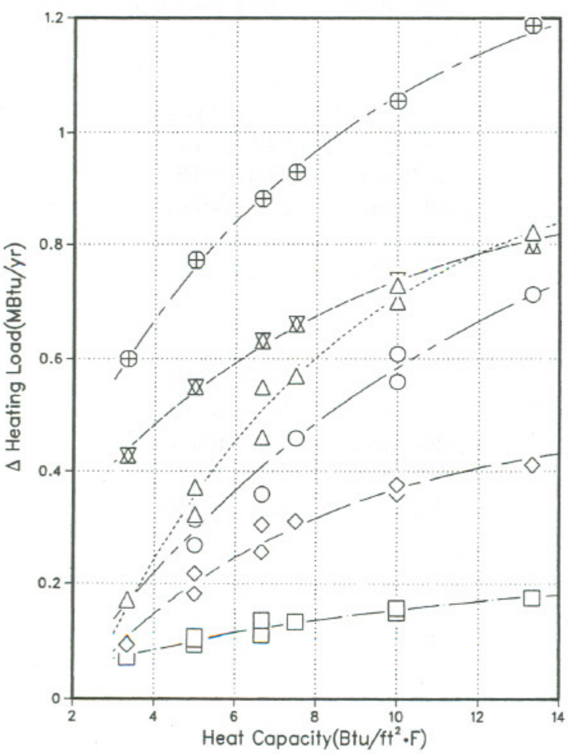


Fig. 6.2.9

ATLANTA
Heat Capacity vs. Delta Cooling Load
For Various Massive Walls

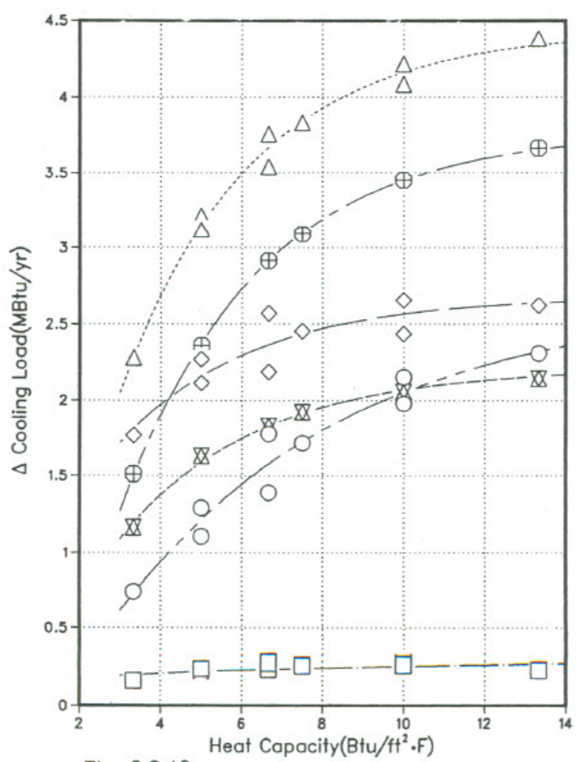


Fig. 6.2.10

Table 6.2d.
Delta Load Regression Coefficients

		β_0	β_1	β_2	β_3	β_4
Atlanta, GA						
O	Cooling	-0.31033170	1.98560154	-1.01026225	14.41404343	-29.63875771
O	Heating	-0.16856453	0.30816579	-0.39358902	3.92055178	-6.12171364
I	Cooling	-0.17361312	-0.64337611	1.14777040	19.47826958	-27.13255310
I	Heating	-0.09658411	-0.07908358	0.16546948	6.64464235	-8.16489750
M	Cooling	-0.29143831	0.37657726	1.20341718	20.03146362	-42.51749039
M	Heating	-0.14415453	0.41500840	-0.27052307	5.52224779	-5.57048845
Brownsville, TX						
O	Cooling	-0.19282086	2.72659254	-2.50365162	5.50640869	-10.54868698
O	Heating	-0.10684901	0.66877317	-0.72056955	4.29262972	-5.60885334
I	Cooling	-0.03986632	-0.43693703	0.55389285	15.08236599	-15.57272148
I	Heating	-0.06646303	-0.10134790	0.13894524	7.48766804	-8.51593676
M	Cooling	-0.12518367	1.01473081	-1.05398750	13.88278484	-16.63009834
M	Heating	-0.11157196	0.51145381	-0.44548643	4.08825159	-5.18963957
Buffalo, NY						
O	Cooling	-0.25319937	0.86564881	-0.60677916	5.22092962	-9.22351837
O	Heating	-0.15597723	0.39356562	-0.47796059	5.72248459	-10.63172245
I	Cooling	-0.13625047	-0.27593467	0.47430557	8.10883713	-10.71153069
I	Heating	-0.04361864	-0.17218265	0.22908160	10.41266823	-11.59384827
M	Cooling	-0.24513686	0.20182616	0.27681655	7.46171236	-14.34758854
M	Heating	-0.05786215	0.47754827	-0.53525257	13.34937859	-9.65328598
Cincinnati, OH						
O	Cooling	-0.26564309	1.81593859	-1.16619873	11.63267326	-21.93136406
O	Heating	-0.15218517	0.25163874	-0.41165686	4.20144129	-7.22594023
I	Cooling	-0.16505212	-0.60325122	1.08083475	16.61412621	-23.72812843
I	Heating	-0.07695776	-0.08061322	0.12568545	5.68816757	-6.56403930
M	Cooling	-0.24102692	0.33290505	0.78830659	17.20302963	-32.29616165
M	Heating	-0.07325753	0.24936835	-0.25168762	9.06789398	-6.58984613
Denver, CO						
O	Cooling	-0.27836037	1.28018177	-0.54463863	11.74938583	-21.45341682
O	Heating	-0.19521606	0.36457345	-0.51844519	6.68187475	-10.50294495
I	Cooling	-0.18208922	-0.57391769	1.02465951	15.80735016	-22.47966194
I	Heating	-0.11020503	-0.19842374	0.29190937	9.46208477	-11.84701840
M	Cooling	-0.27426261	0.16989145	1.09394729	15.86125374	-31.86371040
M	Heating	-0.13803351	0.40041184	-0.23829436	10.68175793	-9.58891487
Los Angeles, CA						
O	Cooling	-0.25018331	0.32478523	-0.20692101	3.02613902	-3.87581301
O	Heating	-0.27050284	0.44646174	-0.20042038	6.94669437	-13.84564686
I	Cooling	-0.18214102	-0.15266848	0.24329290	4.01516628	-5.12441778
I	Heating	-0.14563049	-0.30322817	0.51252455	11.28443623	-15.35463559
M	Cooling	-0.26927316	0.01161079	0.15529487	4.12260962	-6.46043015
M	Heating	-0.26194468	0.24154402	0.55916643	8.92164707	-17.64890862

Wall Type O = Mass Wall With Insulation Outside of Mass
Wall Type I = Mass Wall With Insulation Inside of Mass
Wall Type M = Mass Wall With Insulation and Mass Well Mixed

Table 6.2d.
Delta Load Regression Coefficients (continued)

		β_0	β_1	β_2	β_3	β_4
Medford, OR						
O	Cooling	-0.31235337	1.46315753	-0.56911618	15.26815414	-30.02867317
O	Heating	-0.21427679	0.46151346	-0.40688482	11.75613976	-19.70692825
I	Cooling	-0.19997521	-0.78522438	1.50964141	20.27443886	-30.47970963
I	Heating	-0.14285178	-0.39751139	0.75037092	16.02144623	-22.23238683
M	Cooling	-0.32368144	0.11819975	2.25913572	20.25464249	-49.27121353
M	Heating	-0.20958303	0.35532618	0.77464628	14.87691975	-24.67847252
Miami, FL						
O	Cooling	-0.19166204	2.47168994	-2.33949280	6.97748756	-9.40568352
O	Heating	-0.14687890	0.17821832	-0.19399278	1.43998659	-2.14092708
I	Cooling	-0.23285460	-0.55313832	0.63219172	9.25009346	-13.34974670
I	Heating	-0.06767942	-0.05504773	0.07704289	2.89916515	-3.35923093
M	Cooling	-0.09437819	0.61620796	-0.42350870	17.67057419	-18.78199005
M	Heating	-0.13109516	0.15303041	-0.11791853	1.53641510	-2.20868325
Phoenix, AZ						
O	Cooling	-0.25548711	2.19324684	-1.26547158	19.27495384	-32.99242401
O	Heating	-0.27271420	0.42256454	-0.21221262	9.36290169	-17.20839119
I	Cooling	-0.18983062	-0.99315703	1.69976151	24.59542656	-34.26731873
I	Heating	-0.16557455	-0.39192408	0.72540897	13.44741058	-18.43807586
M	Cooling	-0.25948146	0.16380972	1.51999617	27.44420624	-47.78850555
M	Heating	-0.28524593	0.21967442	1.10688996	11.14248753	-25.16121483
San Diego, CA						
O	Cooling	-0.30582818	0.38934463	-0.29491019	3.60768294	-4.99154472
O	Heating	-0.26192224	0.43905640	-0.31630176	6.69234324	-11.64267540
I	Cooling	-0.19655822	-0.20018288	0.38021469	4.96283960	-7.60612059
I	Heating	-0.16391607	-0.26856500	0.47820309	10.03506947	-14.06073881
M	Cooling	-0.33723348	0.15623753	0.26372176	4.21565342	-10.72881985
M	Heating	-0.26403114	0.21705136	0.41533273	8.26024914	-15.58840752
San Francisco, CA						
O	Cooling	-0.30864921	0.16552071	0.00405509	2.57778955	-4.38464928
O	Heating	-0.19099370	0.33358997	-0.27059460	4.17903709	-9.14344406
I	Cooling	-0.18991084	-0.11967507	0.17740139	3.20604539	-4.14381075
I	Heating	-0.12139977	-0.19788454	0.36545214	8.85691643	-12.02775264
M	Cooling	-0.28150588	0.05569848	0.13027377	2.91186881	-5.24989605
M	Heating	-0.22089767	0.42664668	0.23063689	5.74322939	-9.85311604
Seattle, WA						
O	Cooling	-0.24266867	0.44669309	-0.26091349	3.12594604	-5.02568722
O	Heating	-0.15296170	0.14933537	-0.36994049	5.51922226	-9.64529324
I	Cooling	-0.15875621	-0.13945979	0.28538117	4.63341427	-6.70571375
I	Heating	-0.08287608	-0.12169401	0.21666963	7.26270151	-8.90933749
M	Cooling	-0.26355827	0.15049157	0.19835152	4.17797518	-9.07191372
M	Heating	-0.06911375	0.17817804	0.07409954	11.23699665	-9.81671524

Wall Type O = Mass Wall With Insulation Outside of Mass
Wall Type I = Mass Wall With Insulation Inside of Mass
Wall Type M = Mass Wall With Insulation and Mass Well Mixed

6.3. Infiltration

The base case infiltration rate chosen for the residential analysis is 0.7 ach. We have also studied the effects on the heating and cooling loads of a house of good thermal integrity due to a lower infiltration rate of 0.4 ach.* It is assumed that the savings thus calculated using DOE-2.1A can be extended to the range of thermal integrities covered in the data base. For example,the changes in heating and cooling loads due to infiltration rate changes shown in Table 6.3a are used for all one-story houses for any combination of glazing and insulation. Similar tables can also be constructed for the other four prototypes. For different house sizes, the effects of infiltration changes on heating and cooling loads can be scaled by the ratio of house volumes to that of the base prototypes. For the one-story ranch house, scaling would be done by multiplying Table 6.3a values by the ratio of actual house volume to the base case house volume of 12,320 ft^3.

Table 6.3a shows the changes in heating and cooling loads for both low (0.4 ach) and medium (0.7 ach) infiltration rates relative to the loads at a higher rate of 1.0 ach. For most cities, the heating load changes are much larger than the cooling load changes. Moreover, constructing a tighter house will always reduce the heating load, but not necessarily the cooling load. In several cities, cooling loads are greater at lower infiltration rates.

The difference in heating and cooling loads for houses with low and medium infiltration rates are obtained from actual DOE-2.1A simulations. To reduce the number of computer simulations, the assumption is made that changes in heating and cooling loads are constant per change in infiltration rate; e.g., the load change from 0.7ach to 0.4 ach is the same as that from 1.0 to 0.7 ach. This hypothesis has been tested in four cities by performing DOE-2.1A simulations at 1.0 ach. Table 6.3b lists the results of this analysis. With regard to heating load changes, the differences between the test DOE-2.1A runs and the extrapolated values are 4.3%, 2.5%, and 7.0% for Albuquerque, Cheyenne, and Minneapolis, respectively. With regard to cooling load changes, there are much larger percentage differences between the two approaches in the same three cities. However, these cooling load Δ's are of little consequence, since they are all less than 0.3 MBtu. For Miami, there is a 7.4% difference (0.38 MBtu) in cooling loads between the test run and the extrapolated result.

The DOE-2.1A data base includes simulations at 0.7 and 0.4 ach infiltration rates for all five prototype houses in the 45 base locations. The Δ heating and cooling loads due to a 0.3 ach reduction in infiltration are presented in the data base tables. The same data is normalized by house volume and used in the PEAR microcomputer program for calculating infiltration loads.

* The following thermal integrities have been assumed for the infiltration studies: R-30 ceiling, R-19 wall, FM1 slab, and double glazing for warmer locations; R-49 ceiling, R-27 wall, FM4 basement, and triple glazing for colder locations.

Table 6.3a. Heating and Cooling Load Changes Resulting From Infiltration Rate Changes in 1540 ft^2 One-story Prototype House †
(MBtu)

City	Heating Med (.7 ach)	Heating Low (.4 ach)	Cooling Med (.7 ach)	Cooling Low (.4 ach)
Albuquerque	-6.22	-12.45	-0.17	-0.34
Atlanta	-5.49	-10.97	+0.44	+0.87
Birmingham	-5.18	-10.37	-0.52	-1.04
Bismark	-14.81	-29.61	-0.07	-0.15
Boise	-8.69	-17.39	-0.19	-0.37
Boston	-9.56	-19.13	+0.14	+0.29
Brownsville	-1.00	-1.99	-5.76	-11.53
Buffalo	-11.11	-22.22	0.0	0.0
Burlington	-13.08	-26.16	+0.04	+0.08
Charleston	-4.12	-8.24	-1.10	-2.20
Cheyenne	-9.26	-18.52	-0.04	-0.08
Chicago	-10.09	-20.18	+0.06	+0.13
Cincinnati	-8.48	-16.96	-0.05	-0.09
Denver	-8.41	-16.82	-0.10	-0.21
El Paso	-4.12	-8.24	-0.21	-0.43
Fort Worth	-4.36	-8.72	-2.30	-4.61
Fresno	-4.90	-9.80	-0.92	-1.84
Great Falls	-10.40	-20.79	-0.05	-0.11
Honolulu	0.0	0.0	+0.11	+0.42
Jacksonville	-2.55	-5.11	-2.55	-5.11
Juneau	-14.97	-29.95	0.0	0.0
Kansas City	-8.44	-16.87	-1.05	-2.09
Lake Charles	-3.44	-6.89	-2.90	-5.79
Las Vegas	-4.71	-9.42	-2.33	-4.67
Los Angeles	-2.35	-4.70	+0.06	+0.13
Medford	-8.41	-16.82	-0.20	-0.39
Memphis	-5.73	-11.45	-1.96	-3.91
Miami	-0.25	-0.49	-5.55	-11.10
Minneapolis	-13.55	-27.10	-0.22	-0.45
Nashville	-6.31	-12.62	-0.58	-1.16
New York	-7.98	-15.96	-0.12	-0.23
Oklahoma City	-7.15	-14.29	-1.49	-2.99
Omaha	-10.55	-21.09	-0.38	-0.76
Philadelphia	-8.68	-17.36	-0.20	-0.40
Phoenix	-2.84	-5.67	-3.18	-6.35
Pittsburgh	-9.36	-18.72	-0.02	-0.04
Portland ME	-12.06	-24.12	+0.02	+0.03
Portland OR	-8.18	-16.35	-0.06	-0.12
Reno	-8.32	-16.64	-0.16	-0.32
Salt Lake City	-9.25	-18.51	-0.28	-0.57
San Antonio	-3.69	-7.38	-2.64	-5.29
San Diego	-1.50	-3.01	+0.34	+0.68
San Francisco	-6.13	-12.26	+0.03	+0.06
Seattle	-9.13	-18.26	-0.06	-0.11
Washington	-7.50	-15.00	-0.54	-1.08

† Base case infiltration rate equals 1.0 ach for this table.

Table 6.3b. Comparison of DOE-2.1A and Extrapolated Δ Loads for Infiltration Reduction from 1.0 to 0.7 ach

City	Δ Heating Loads (MBtu)		Δ Cooling Loads (MBtu)	
	DOE-2	Estimated	DOE-2	Estimated
Albuquerque	-6.50	-6.22	-0.22	-0.17
Cheyenne	-9.49	-9.26	-0.05	-0.04
Minneapolis	-12.66	-13.55	-0.34	-0.22
Miami	-0.34	-0.25	-5.17	-5.55

6.4. Windows

Sensitivity analyses have been performed for several window-related topics, including interpolations for different window sash types and air gap spacings, different window areas and orientations, and control strategies such as movable insulation and the use of reflective and absorptive glazing. Each of these issues is covered in this section.

6.4.1. Window Sash and Gap Interpolation

Different window sash types and air gap spacings affect building loads by changing the conductivity of the window. The window conductivities used throughout the DOE-2.1A modeling are based on ASHRAE values for plain windows without any sash corrections (see Section 3.4), and with ½ inch air gap spacings in the case of double and triple pane glazings. The energy impact due to different types of window sash and air spacings has been analyzed for the one-story prototype in nine locations using test simulations where the window conductivities have been modified using ASHRAE correction values for differing sash and gap conditions (see Table 6.4.1a). * A relationship was established linking this impact to the Δ loads due to varying wall insulation measures. This relationship was then used to interpolate window sash and gap effects for all locations and house prototypes.

Three sash types (wood, aluminum, aluminum with thermal breaks) and two gap spacings (½ inch and ¼ inch) have been considered. Instead of making DOE-2.1A simulations for every sash and gap condition, correlations have been developed based on changes in conductance between the energy effects of sash and gap variations and the much larger effects due to different wall insulation measures.

* A more rigorous methodology could conceivably simulate the actual sash area as a separate wall layer, and adjust the net glass area accordingly. In view of large variations in window construction details, this level of detailed simulation has been judged inappropriate and unnecessary for this study.

Table 6.4.1a. ASHRAE Correction Values for Window Sash and Gap

Window Type	Window Conductance ($Btu/hr \cdot ft^2 \cdot F$)	Sash Correction Values			
		Plain	Wood	Alum	Alum with Thermal Breaks
Single glazing	1.10*	1.00	0.90	1.05	0.95
Double glazing with ¼ inch gap	0.58	1.00	0.95	1.25	1.05
Double glazing with ½ inch gap	0.49*	1.00	0.95	1.25	1.05
Triple glazing with ¼ inch gap	0.39	1.00	0.975	1.40	1.125
Triple glazing with ½ inch gap	0.31*	1.00	0.975	1.40	1.125

*Simulated window configurations.
Source: *Handbook of Fundamentals,* pp. 27.10-11, ASHRAE (1981).

This interpolation eliminates a large number of repetitive simulations but retains the precision of the DOE-2.1A data base in performing hourly calculations and computing sol-air effects on exterior wall surfaces. An extensive number of test runs in nine locations confirm the accuracy of this interpolation procedure. For heating, the average difference between the test data and the interpolated values is only 0.09 MBtu, with an extreme error of 0.73 MBtu (out of a 13 MBtu variation in Minneapolis). For cooling, a modified interpolation technique combining the above UA correction with degree-day modifiers results in average errors of 0.10 MBtu, with an extreme error of 0.51 MBtu.

The residential DOE-2.1A data base for 45 cities is used to calculate slopes for the change in building loads as a function of changes in wall conductance:

$$\text{Slope} = (\Delta\text{Load}/\Delta\text{UA})_{\text{wall}} \tag{18}$$

This slope is basically location specific, although it does vary slightly within one location depending on the thermal integrity of the house. For example, heating slopes for Minneapolis and Lake Charles are:

	Minneapolis	Lake Charles	Wall Measure
$(\Delta\ \text{Load}/\Delta\ \text{UA})_{\text{wall}} =$	0.1602	0.0368	R-0 → R-11 walls
	0.1789	0.0366	R-11 → R-19 walls
	0.2208	0.0430	R-19 → R-27 walls

units are in (MBtu/year)/(Btu/hr-F) or 10^6 degree-hours/yr.

For warmer locations (those simulated with slab and crawl foundations), a single slope based on the Δ load from R-0 to R-11 walls is used for interpolating all window variations. For cold locations (those simulated with basements), the slope based on the Δ load from R-0 to R-11 walls is used for single glazed windows, and another based on the Δ load from R-11 to R-19 walls is used for double and triple pane windows.

The interpolated value is derived by multiplying this slope by the differences in conductance between the plain (no sash) ASHRAE windows modeled and the other sash and gap configurations as shown in Table 6.4.1b. The ASHRAE conductances are assumed to be constant throughout the year.

$$\Delta Load_{sash\ and\ gap} = \Delta UA_{sash\ and\ gap} \cdot (\Delta Load/\Delta UA)_{wall} \quad (19)$$

For heating, comparisons between test runs done for extreme sash and gap conditions in five locations show that, for all practical purposes, the interpolated Δ loads are identical to the actual DOE-2.1A simulated values (see Table 6.4.1c).

Table 6.4.1b. Differences in Window Conductance for Various Sash Types and Air Gaps in 1540 ft² 1-Story Prototype House

values are Δ conductances (Btu/hr·ft²·F) due to sash and gap differences from base case plain window with no sash and ½ inch gap.

	Sash Type			
Glazing and air gap	Plain	Wood	Alum	Alum with thermal breaks
10% windows (154 ft²)				
1-pane	0.0	-16.9	+ 8.5	- 8.5
2-pane with ¼ in. gap	+13.9	+ 9.4	+36.2	+18.3
2-pane with ½ in. gap	0.0	- 3.8	+19.9	+ 3.8
3-pane with ¼ in. gap	+12.3	+10.8	+36.3	+29.1
3-pane with ½ in. gap	0.0	- 1.2	+19.1	+ 6.0
15% windows (231 ft²)				
1-pane	0.0	-25.4	+12.8	-12.8
2-pane with ¼ in. gap	+20.9	+14.1	+54.3	+27.4
2-pane with ½ in. gap	0.0	- 5.7	+29.9	+ 5.7
3-pane with ¼ in. gap	+18.4	+16.2	+54.4	+38.0
3-pane with ½ in. gap	0.0	- 1.8	+28.6	+ 9.0
20% windows (308 ft²)				
1-pane	0.0	-33.8	+17.0	-17.0
2-pane with ¼ in. gap	+27.8	+18.8	+72.4	+36.6
2-pane with ½ in. gap	0.0	- 7.6	+39.8	+ 7.6
3-pane with ¼ in. gap	+24.6	+21.6	+72.6	+58.2
3-pane with ½ in. gap	0.0	- 2.4	+38.2	+12.0

Table 6.4.1c. Comparison of DOE-2.1A and Interpolated Δ Heating Loads in 1-Story Prototype due to Different Window Sash Types and Air Gaps *

(values are Δ loads (MBtu) from base case with no sash and ½ in. air gaps for 2- and 3-pane windows)

Window Area and Type	Lake Charles DOE-2	Lake Charles Est.	Phoenix DOE-2	Phoenix Est.	Seattle DOE-2	Seattle Est.	New York DOE-2	New York Est.	Minneapolis DOE-2	Minneapolis Est.
10 Pct. Windows (154 ft^2)										
1-pane Wood	-0.61	-0.62	-0.46	-0.48	-1.86	-2.00	-1.73	-1.70	-2.70	-2.71
1-pane Alum	0.27	0.31	0.17	0.24	0.94	1.01	0.86	0.85	1.34	1.36
2-pane Wood ½ in.	-0.17	-0.14	-0.15	-0.11	-0.48	-0.45	-0.43	-0.38	-0.71	-0.68
2-pane Alum ¼ in.	1.33	1.33	1.02	1.06	4.28	4.30	3.78	3.61	6.22	6.48
3-pane Wood ½ in.	-0.06	-0.04	-0.06	-0.03	-0.15	-0.14	-0.14	-0.12	-0.24	-0.22
3-pane Alum ¼ in.	1.36	1.34	1.07	1.03	4.40	4.31	3.82	3.62	6.51	6.49
15 Pct. Windows (231 ft^2)										
1-pane Wood	-0.87	-0.93	-0.64	-0.72	-2.72	-3.00	-2.55	-2.55	-3.89	-4.06
1-pane Alum	0.43	0.47	0.29	0.36	1.42	1.51	1.31	1.28	1.98	2.04
2-pane Wood ½ in.	-0.22	-0.21	-0.19	-0.16	-0.68	-0.68	-0.62	-0.57	-1.02	-1.02
2-pane Alum ¼ in.	1.97	2.00	1.50	1.54	6.31	6.45	5.62	5.41	9.28	9.71
3-pane Wood ½ in.	-0.07	-0.07	-0.06	-0.05	-0.21	-0.21	-0.19	-0.18	-0.33	-0.32
3-pane Alum ¼ in.	2.00	2.00	1.55	1.55	6.44	6.46	5.63	5.43	9.69	9.74
20 Pct. Windows (308 ft^2)										
1-pane Wood	-1.14	-1.24	-0.82	-0.96	-3.56	-4.00	-3.32	-3.39	-4.96	-5.42
1-pane Alum	0.58	0.63	0.40	0.48	1.88	2.01	1.76	1.71	2.56	2.72
2-pane Wood ½ in.	-0.29	-0.28	-0.23	-0.22	-0.88	-0.90	-0.78	-0.76	-1.32	-1.36
2-pane Alum ¼ in.	2.58	2.66	1.94	2.06	8.29	8.59	7.43	7.22	12.22	12.95
3-pane Wood ½ in.	-0.09	-0.09	-0.07	-0.07	-0.26	-0.29	-0.23	-0.24	-0.40	-0.43
3-pane Alum ¼ in.	2.59	2.67	1.98	2.06	8.42	8.62	7.38	7.24	12.82	12.99

* in the interest of space, data for Brownsville, El Paso, Fresno, and San Antonio have not been shown.

For cooling, test runs showed that the above method overestimated the change in loads due to sash and gap. For the three cool locations (Minneapolis, New York, and Seattle) as well as the hot-humid location (Lake Charles), the test runs show no perceptible differences in cooling loads due to sash and gap variations because of the small magnitude of conductive cooling loads. Only in locations where summer temperatures rise appreciably above the comfort zone (Phoenix, Brownsville, San Antonio, El Paso, Fresno) are there definite correlations between Δ window conductances and Δ cooling loads due to the tested sash and gap variations. Even in these locations, however, the correlation is nonlinear, e.g., Δ cooling loads for 20% windows are not double those for 10% windows (see Figure 6.4.1.1).

Two observations were made based on the test runs: (1) correlations between predicted and actual cooling load differences are best for locations with a high proportion of sensible loads and

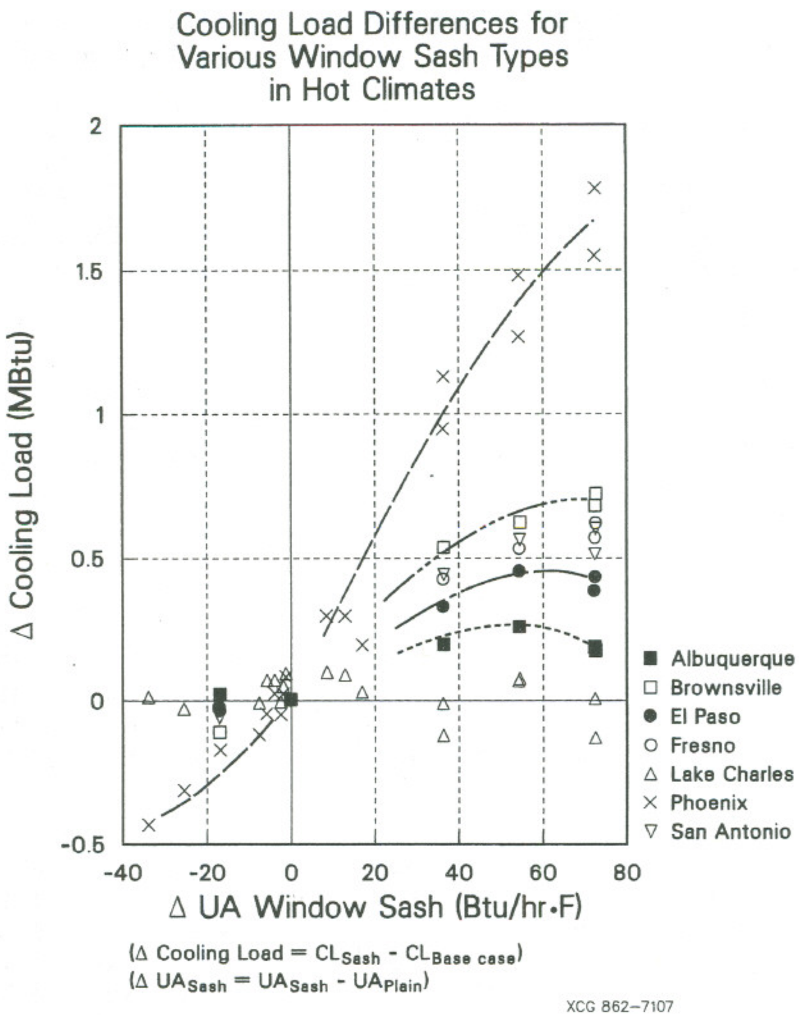


Fig. 6.4.1.1

worst for locations with a high proportion of latent loads. (2) daily temperature swings mask hourly effects so that the total annual change in cooling loads is significantly lower than that predicted using differences in wall conductances.

The best sash and gap interpolations for cooling were found when the basic methodology has been modified by scaling down the interpolated cooling delta by the following cooling degree day ratios at base 78 F.

Window size	Modified Interpolation
10%	Δ Load = $\Delta UA_{window} \cdot (\Delta L/\Delta UA)_{wall} \cdot (CDD/2130)$
15%	Δ Load = $\Delta UA_{window} \cdot (\Delta L/\Delta UA)_{wall} \cdot (CDD/2530)$
20%	Δ Load = $\Delta UA_{window} \cdot (\Delta L/\Delta UA)_{wall} \cdot (CDD/2800)$

units are (MBtu/yr); CDD = Cooling degree days base 78 F.

Since the air conditioner thermostat setting is assumed at 78 F, cooling degree-days calculated using this base temperature are indicative of the total annual cooling load due to conduction. No attempt has been made to give a physical explanation for this empirically derived interpolation, although the results correlate within 0.20 MBtu for all nine cities for which test DOE-2.1A simulations have been done (see Table 6.4.1d). Subsequent climate analysis at LBL using the same data base revealed that cooling degree-days at a high base temperature correlate very well to the sensible cooling loads due to conduction through the walls and ceiling.[17]

Table 6.4.1d. Comparison of DOE-2.1A and Interpolated Δ Cooling Loads for 1-Story Prototype due to Different Window Sash Types and Air Gaps*

values are Δ loads (MBtu) from base case with no sash; base case air gap for 2- and 3-pane is ½ inch

	Location											
Window Area	Lake Charles		Phoenix		Brownsville		El Paso		Fresno		San Antonio	
and Type	DOE-2	Est.	DOE-2	Est.	DOE-2	Est.	DOE-2	Est.	DOE-2	Est.	DOE-2	Est.
10% Windows (154 ft^2)												
1-Pane Wood	-.03	-.10	-.17	-.55	-.12	-.22	-.02	-.12	-.03	-.13	-.06	-.15
1-Pane Alum	.10	.05	.30	.28		.11		.06		.06		.08
2-Pane Wood ½ in	.07	-.02	.03	-.12		-.05		-.03		-.03		-.03
2-Pane Alum ¼ in	-.01	.21	.96	1.18		.47		.25		.27		.33
3-Pane Wood ½ in	.05	-.01	.09	-.04		-.02		-.01		-.01		-.01
3-Pane Alum ¼ in	-.12	.21	1.14	1.18	.54	.47	.33	.25	.44	.27	.45	.33
15% Windows (231 ft^2)												
1-Pane Wood	-.03	-.13	-.31	-.69		-.28		-.15		-.16		-.19
1-Pane Alum	.09	.06	.30	.35		.14		.07		.08		.10
2-Pane Wood ½ in	.07	-.03	-.04	-.16		-.06		-.03		-.04		-.04
2-Pane Alum ¼ in	.07	.27	1.28	1.48		.59		.31		.34		.41
3-Pane Wood ½ in	.05	-.01	.03	-.05		-.02		-.01		-.01		-.01
3-Pane Alum ¼ in	.08	.27	1.49	1.49	.63	.59	.47	.31	.54	.34	.57	.41
20% Windows (308 ft^2)												
1-Pane Wood	.01	-.15	-.43	-.83		-.33		-.17		-.19		-.23
1-Pane Alum	.03	.08	.20	.42		.17		.09		.10		.12
2-Pane Wood ½ in	-.01	-.03	-.11	-.19		-.08		-.04		-.04		-.05
2-Pane Alum ¼ in	.01	.32	1.56	1.79	.69	.72	.39	.37	.58	.41	.52	.50
3-Pane Wood ½ in	.01	-.01	-.04	-.06		-.02		-.01		-.01		-.02
3-Pane Alum ¼ in	-.13	.33	1.79	1.79	.73	.71	.44	.38	.63	.41	.61	.50

* Only extreme window sash and gap configurations were done for Brownsville, El Paso, Fresno, and San Antonio. In the interest of space, tests for Minneapolis, New York, and Seattle have not been shown.

The accuracy of these interpolation methods for sash and gap corrections is shown by Table 6.4.1e, which gives the differences between interpolated and simulated values for the nine test

17. Y. J. Huang, R. Ritschard and J. Bull, "Climatic Indicators for Heating and Cooling Loads", Lawrence Berkeley Laboratory Report 21101, Berkeley, CA. (1986).

locations. The average errors are approximately 0.1 MBtu, a level that can be regarded as insignificant when compared with the general accuracy of the data base itself.

Table 6.4.1e Differences between DOE-2.1A and Interpolated Δ Loads for Different Window Sash Types and Air Gaps

(Interpolated Δ load - DOE-2.1A Δ load, in MBtus)

	Heating					Cooling *					
Window area and sash type	Lake Charles	Phoenix	Seattle	New York	Minneap-olis	Lake Charles	Phoenix	Browns-ville	El Paso	Fresno	San Antonio
10% Windows (154 ft^2)											
1-Pane Wood	-.01	-.02	-.14	-.03	-.01	-.07	-.38	-.11	-.10	-.10	-.09
1-Pane Alum	+.04	+.07	+.07	-.01	+.02	-.05	-.02				
2-Pane Wood ½	+.03	+.04	+.03	+.05	+.03	-.09	-.15				
2-Pane Alum ¼	<.01	+.01	+.02	-.17	+.26	+.22	+.22				
3-Pane Wood ½	+.02	-.28	+.01	+.02	+.03	-.06	-.13				
3-Pane Alum ¼	-.02	-.04	-.09	-.20	-.02	+.33	+.04	-.07	-.09	-.16	+.12
15% Windows (231 ft^2)											
1-Pane Wood	-.06	-.08	-.28	+.01	-.17	-.10	-.38				
1-Pane Alum	+.04	+.07	+.09	-.03	+.06	-.03	+.05				
2-Pane Wood ½	+.01	+.03	+.01	+.05	.00	-.10	-.12				
2-Pane Alum ¼	+.03	+.04	+.14	-.21	+.43	+.20	+.20				
3-Pane Wood ½	<.01	+.01	<.01	+.01	<.01	-.10	-.08				
3-Pane Alum ¼	<.01	<.01	+.02	-.20	+.05	+.19	-.01	-.03	-.15	-.20	-.16
20% Windows (308 ft^2)											
1-Pane Wood	-.10	-.14	-.44	-.07	-.46	-.16	-.40				
1-Pane Alum	+.05	+.08	+.13	-.06	+.16	+.05	+.22				
2-Pane Wood ½	+.01	+.01	-.02	+.02	-.04	-.02	-.08				
2-Pane Alum ¼	+.08	+.12	+.30	-.21	+.73	+.31	+.23	+.02	-.02	-.17	-.02
3-Pane Wood ½	<.01	<.01	-.03	-.01	-.03	-.01	-.02				
3-Pane Alum ¼	+.08	+.08	+.20	-.14	+.17	+.46	<.01	-.02	-.07	-.21	-.11

* Test runs for extreme window sash and gap configurations only were done for Brownsville, El Paso, Fresno, and San Antonio. To save space, cooling results for Minneapolis, New York, and Seattle have not been shown.

6.4.2. Window Area

The LBL residential data base includes a complete set of parametric DOE-2.1A simulations for the one story prototype where the window area has been increased from the base case 10% to 15% and 20% of total floor area. A total of 270 simulations were done to cover single, double, and triple pane windows in the 45 base cities. Table 6.4.2a and 6.4.2b give the resultant changes in heating and cooling loads. To produce equivalent data sets for various window areas in the other four prototypes would have required more than 1,000 additional simulations. An alternative

Table 6.4.2a Δ Heating Loads for Increased Window Area in 1-Story Prototype

(values are Δ loads in MBtu's from windows at 10% of floor area or 154 ft^2)

Location	Window Region	Single Glazing 15%	Single Glazing 20%	Double Glazing 15%	Double Glazing 20%	Triple Glazing 15%	Triple Glazing 20%
Albuquerque	H*	2.641	5.426	-0.719	-1.224	-1.402	-2.548
Atlanta	D*	2.287	4.673	-0.297	-0.444	-0.802	-1.436
Birmingham	D	1.657	3.409	-0.427	-0.723	-0.850	-1.557
Bismarck	A	10.351	20.345	2.598	5.282	0.706	1.540
Boise	B	5.516	11.089	0.868	1.878	-0.204	-0.257
Boston	B	6.064	12.164	0.542	1.232	-0.563	-0.951
Brownsville	F	0.328	0.703	-0.138	-0.215	-0.180	-0.292
Buffalo	A	7.728	15.441	1.453	2.986	0.043	0.195
Burlington	A	8.543	17.007	1.762	3.603	0.187	0.451
Charleston	D	1.501	3.103	-0.411	-0.664	-0.779	-1.403
Cheyenne	G	6.754	13.570	0.393	0.968	-0.886	-1.596
Chicago	B*	6.078	12.198	0.835	1.787	-0.326	-0.492
Cincinnati	C	4.854	9.735	0.483	1.028	-0.501	-0.897
Denver	G*	4.743	9.578	-0.235	-0.266	-1.248	-2.256
El Paso	H	1.363	2.851	-0.587	-0.995	-0.955	-1.717
Fort Worth	E	1.471	3.054	-0.542	-0.907	-0.904	-1.616
Fresno	D	1.663	3.453	-0.402	-0.634	-0.776	-1.356
Great Falls	A	8.694	17.274	1.580	3.258	0.028	0.172
Honolulu	F	0.000	0.000	0.000	0.000	0.000	0.000
Jacksonville	E	0.517	1.134	-0.485	-0.824	-0.624	-1.095
Juneau	A	12.109	24.134	4.006	8.069	2.023	4.133
Kansas City	C	4.944	9.902	0.625	1.358	-0.296	-0.474
Lake Charles	E*	1.214	2.500	-0.238	-0.367	-0.503	-0.890
Las Vegas	D	2.675	5.366	0.434	0.920	-0.064	-0.065
Los Angeles	J	0.122	0.456	-0.874	-1.466	-0.830	-1.370
Medford	C	3.709	7.494	0.322	0.789	-0.506	-0.837
Memphis	D	2.280	4.614	-0.282	-0.436	-0.820	-1.494
Miami	F*	0.067	0.150	-0.032	-0.047	-0.044	-0.064
Minneapolis	A*	9.113	17.887	2.085	4.247	0.409	0.928
Nashville	D	3.176	6.380	0.113	0.322	-0.545	-0.983
New York	C*	4.410	8.846	0.072	0.262	-0.785	-1.433
Oklahoma City	D	3.937	7.938	-0.029	0.074	-0.843	-1.511
Omaha	B	5.919	11.815	0.659	1.462	-0.491	-0.816
Philadelphia	C	5.163	10.344	0.490	1.064	-0.495	-0.904
Phoenix	K*	0.569	1.308	-0.462	-0.735	-0.661	-1.116
Pittsburgh	B	5.919	11.841	0.871	1.815	-0.261	-0.449
Portland ME	B	6.915	13.825	0.891	1.879	-0.461	-0.802
Portland OR	I	4.891	9.862	0.735	1.619	-0.190	-0.212
Reno	C	2.838	5.793	-1.013	-1.787	-1.819	-3.334
Salt Lake City	B	5.664	11.390	0.553	1.258	-0.577	-0.998
San Antonio	E	1.353	2.794	-0.314	-0.503	-0.640	-1.129
San Diego	J	0.071	0.310	-0.529	-0.832	-0.495	-0.784
San Francisco	J*	1.402	3.022	-1.237	-2.105	-1.579	-2.733
Seattle	I*	5.236	10.598	0.488	1.185	-0.470	-0.716
Washington	C	3.485	7.029	-0.095	-0.057	-0.836	-1.530

* base city for window sensitivity parametric simulations.

Table 6.4.2b Δ Cooling Loads for Increased Window Area in 1-Story Prototype

(values are Δ loads in MBtu's from windows at 10% of floor area or 154 ft^2)

Location	Window Region	Single Glazing 15%	Single Glazing 20%	Double Glazing 15%	Double Glazing 20%	Triple Glazing 15%	Triple Glazing 20%
Albuquerque	H*	4.094	8.490	3.508	7.378	3.250	6.773
Atlanta	D*	4.454	8.957	4.249	8.459	4.165	8.217
Birmingham	D	5.256	10.416	4.797	9.714	4.531	9.298
Bismarck	A	2.449	5.051	2.099	4.379	1.950	4.064
Boise	B	3.024	6.237	2.598	5.377	2.420	4.972
Boston	B	2.119	4.122	1.946	3.794	1.775	3.618
Brownsville	F	10.119	20.038	8.684	17.299	8.198	16.295
Buffalo	A	1.618	3.563	1.474	3.261	1.443	2.922
Burlington	A	1.585	3.281	1.427	2.947	1.431	2.876
Charleston	D	6.238	12.497	5.714	11.514	5.474	10.912
Cheyenne	G	1.717	3.625	1.514	3.231	1.363	2.928
Chicago	B*	2.522	4.889	2.131	4.464	2.088	4.129
Cincinnati	C	3.736	7.554	3.394	6.910	3.290	6.567
Denver	G*	2.143	4.481	1.866	3.901	1.685	3.576
El Paso	H	6.143	12.372	5.201	10.612	4.898	9.866
Fort Worth	E	6.746	13.430	5.750	11.427	5.278	10.593
Fresno	D	5.112	10.357	4.321	8.780	3.962	8.129
Great Falls	A	1.565	3.228	1.334	2.787	1.155	2.537
Honolulu	F	11.548	22.925	10.768	21.496	10.210	20.413
Jacksonville	E	7.235	14.418	6.432	12.943	6.123	12.307
Juneau	A	0.001	0.004	0.000	0.004	0.000	0.003
Kansas City	C	4.271	8.430	3.622	7.222	3.361	6.856
Lake Charles	E*	6.953	13.873	6.104	12.305	5.874	11.738
Las Vegas	D	5.707	11.401	4.256	8.716	3.765	7.751
Los Angeles	J	0.880	1.841	0.777	1.741	0.732	1.626
Medford	C	2.758	5.567	2.408	4.869	2.253	4.529
Memphis	D	5.334	10.688	4.700	9.437	4.344	8.829
Miami	F*	10.742	21.343	9.407	18.829	9.056	17.945
Minneapolis	A*	3.044	5.953	2.667	5.368	2.474	5.052
Nashville	D	4.838	9.655	4.360	8.813	4.105	8.415
New York	C*	3.082	6.099	2.812	5.612	2.609	5.347
Oklahoma City	D	4.846	9.813	4.191	8.504	3.947	7.976
Omaha	B	3.591	7.294	3.156	6.522	3.029	6.126
Philadelphia	C	3.272	6.543	2.901	5.921	2.880	5.812
Phoenix	K*	7.807	15.391	6.355	12.732	5.884	11.869
Pittsburgh	B	3.070	6.191	2.888	5.821	2.677	5.657
Portland ME	B	1.746	3.607	1.605	3.274	1.454	3.122
Portland OR	I	1.205	2.575	1.045	2.294	0.986	2.077
Reno	C	2.651	5.551	2.314	4.861	2.084	4.433
Salt Lake City	B	3.583	7.388	3.024	6.264	2.745	5.716
San Antonio	E	6.720	13.517	5.850	11.792	5.440	10.982
San Diego	J	1.117	2.526	1.118	2.429	0.899	2.101
San Francisco	J*	0.330	0.695	0.304	0.636	0.284	0.598
Seattle	I*	0.598	1.261	0.506	1.080	0.433	0.953
Washington	C	4.221	8.310	3.630	7.261	3.446	6.811

* base city for window sensitivity parametric simulations.

approach was taken whereby the energy impacts of varying window areas in these prototypes were extrapolated from the data for the one-story prototype based on basic principles, and then checked and modified where necessary based on test runs done for up to 15 locations.

Extrapolation to other prototypes from the 1-story prototype data is done by scaling the Δ loads by the square footage of glass. This procedure is based on the assumption that in typical residential construction (i.e. excluding passive solar designs, where window areas can be as much as 30% of the floor area), the energy impact of window glazing on building loads does not interact with other components, and varies linearly with the square footage of window glass. Extensive DOE-2.1A test runs showed that while this assumption is basically valid, minor modifications to the extrapolation procedure based on the test runs can make the results more accurate.

This basic extrapolation assumes that the Δ loads due to windows are identical per square foot for all five prototypes. Hence, the ratio (Δload/ft^2 windows) between the 1-story and other prototypes should be equal to 1. Test runs, however, show that in some cases this ratio may vary slightly, causing the extrapolations to under or over predict by small amounts. These minor but consistent perturbations are probably due to interactions between house size and window area ignored in the basic extrapolation. To improve the extrapolation procedure, window area ratio multipliers for each prototype have been added (see Table 6.4.2c). These multipliers are based on test simulations done for up to 16 cities (see Tables 6.4.2d and 6.4.2e).

Table 6.4.2c. Window Area Ratio Multipliers

	Heating multipliers			Cooling multipliers		
	1-pane	2-pane	3-pane	1-pane	2-pane	3-pane
One Story	1.00	1.00	1.00	1.00	1.00	1.00
Two Story	1.07	1.00	1.00	0.99	0.99	0.98
Split Level	1.00	1.00	1.00	1.00	1.00	1.00
Middle Unit Townhouse	1.04	1.00	1.00	1.08	1.08	1.07
End Unit Townhouse	1.02	1.00	1.00	1.09	1.02	1.04

With these ratio multipliers, the extrapolated values for the two story prototype show an average deviation of 0.17 MBtu in heating and 0.14 MBtu in cooling, with maximum deviations at 0.67 MBtu for either mode (see Table 6.4.2f).

For the two townhouse prototypes, the extrapolated values show slightly higher maximum deviations, but the average deviations are still moderate (see Table 6.4.2g). For the middle-unit townhouse, the deviations are 0.81 MBtu maximum and 0.20 MBtu average for heating, and 0.97 MBtu maximum and 0.20 MBtu for cooling; for the end-unit townhouse, they are 0.69 MBtu maximum and 0.24 MBtu for heating, and 0.91 MBtu maximum and 0.18 MBtu average for cooling.

Table 6.4.2d. Heating Ratios for Different Window Areas

$(\Delta\text{Heating load/ft}^2)_{prototype}/(\Delta\text{Heating load/ft}^2)_{1-story}$

City	Two Story 15%	Two Story 20%	Middle-unit Townhouse 15%	Middle-unit Townhouse 20%	End-unit Townhouse 20%
Single Pane					
Albuquerque			1.03	1.01	0.90
Atlanta	1.06	1.06	1.04	1.03	1.05
Birmingham	1.07	1.07	1.04	1.04	
Brownsville	1.09	1.09			
Chicago			1.03	1.03	1.01
Denver			1.04	1.04	1.08
El Paso	1.12	1.10			
Lake Charles	1.08	1.07	1.05	1.04	0.85
Memphis	1.06	1.07			
Miami	1.08	1.15	1.01	1.03	0.98
Minneapolis	1.07	1.09	1.05	1.08	1.04
Nashville	1.03	1.04			
New York	1.05	1.05	1.03	1.03	0.98
Phoenix			1.17	1.13	0.95
San Francisco					1.11
Seattle					1.01
Average	1.07		1.04		1.02
Double Pane					
Albuquerque			0.65	0.56	0.55
Atlanta	0.62	0.50	0.22	0.06	0.17
Birmingham	0.78	0.74	0.55	0.45	
Brownsville	0.98	0.95			
Chicago			1.27	1.26	1.42
Denver			0.49	1.67	0.31
El Paso	0.80	0.78			
Lake Charles	0.72	0.67	0.32	0.14	0.36
Memphis	0.61	0.50			
Miami	0.86	0.96	0.17	0.05	0.33
Minneapolis	0.41	1.11	1.59	1.49	1.00
Nashville	1.62	1.55			
New York	3.44	2.20	0.60	0.49	2.08
Phoenix			0.60	0.49	0.54
San Francisco					0.78
Seattle					1.14
Average	1.00 *		1.00 *		1.00*
Triple Pane					
Albuquerque			0.76	0.71	0.63
Atlanta	0.87	0.86	0.69	0.65	0.68
Birmingham	0.91	0.89	0.69	0.68	
Brownsville	0.96	0.97			
Chicago			0.05	0.47	0.10
Denver			0.63	0.60	0.90
El Paso	0.89	0.89			
Lake Charles	0.90	0.90	0.60	0.58	0.38
Memphis	0.87	0.85			
Miami	1.20	1.15	0.26	0.22	0.26
Minneapolis	1.48	1.43	1.57	2.18	0.86
Nashville	0.87	0.84			
New York	0.69	0.74	0.62	0.58	0.55
Phoenix			0.63	0.59	0.48
San Francisco					0.53
Seattle					0.01
Average	1.00 *		1.00 *		1.00 *

*Load differences for double and triple pane are too small for calculating consistent ratios; 1.00 is assumed.

Table 6.4.2e. Cooling Ratios for Different Window Areas

$(\Delta\text{Cooling load/ft}^2)_{prototype}/(\Delta\text{Cooling load/ft}^2)_{1-story}$

City	Two Story 15%	Two Story 20%	Middle-unit Townhouse 15%	Middle-unit Townhouse 20%	End-unit Townhouse 20%
Single Pane					
Albuquerque			1.09	1.10	0.97
Atlanta	1.00	1.00	1.03	1.04	0.97
Birmingham	1.00	1.02	1.04	1.04	
Brownsville	0.99	0.99			
Chicago					1.11
Denver			1.03	1.10	
El Paso	0.97	0.98	1.14	1.15	
Lake Charles	0.98	0.99	1.01	1.03	
Memphis	0.99	0.99			
Miami	0.99	1.00	1.05	1.04	1.01
Minneapolis	0.96	1.00	1.09	1.14	1.05
Nashville	0.98	0.98			
New York	0.98	0.99	1.07	1.09	1.03
Phoenix			1.14	1.15	
San Francisco					0.92
Seattle					1.69
Average	0.99		1.08		1.09
Double Pane					
Albuquerque			1.10	1.12	1.02
Atlanta	0.99	0.99	1.01	1.05	0.96
Birmingham	1.00	0.99	1.03	1.04	
Brownsville	0.98	0.98			
Chicago			1.08	1.03	
Denver			1.14	1.17	
El Paso	0.96	0.96			
Lake Charles	0.99	1.00	1.05	1.10	1.02
Memphis	0.97	0.97			
Miami	0.99	0.98	1.05	1.04	1.03
Minneapolis	1.15	1.07	1.13	1.13	1.09
Nashville	0.99	0.96			
New York	0.98	0.99	1.09	1.09	0.93
Phoenix			1.10	1.13	
San Francisco					1.07
Seattle					1.07
Average	0.99		1.08		1.02
Triple Pane					
Albuquerque			1.10	1.12	1.18
Atlanta	0.96	0.96	1.05	1.07	1.04
Birmingham	1.00	0.97	1.09	1.07	
Brownsville	0.98	0.98			
Chicago			1.00	1.05	1.03
Denver			1.14	1.17	1.13
El Paso	0.94	0.96			
Lake Charles	0.98	0.98	1.04	1.04	1.02
Memphis	0.98	0.97			
Miami	0.98	1.00	1.01	1.03	0.97
Minneapolis	1.00	0.98	1.12	1.12	1.09
Nashville	0.96	0.96			
New York	1.00	0.96			1.06
Phoenix			1.09	1.09	1.01
San Francisco			1.09	1.09	1.01
Seattle					1.30
Average	0.98		1.07		1.04

Table 6.4.2f Comparison of Extrapolated to DOE-2 Δ Loads for Window Area Variations in the Two-Story Prototype

(Extrapolated Δ Load - DOE-2.1A Δ Load, in MBtu)

City	No. of Panes	Heating		Cooling	
		15%	20%	15%	20%
Atlanta	1	.04	.07	-.06	-.07
	2	-.16	-.32	0.00	.02
	3	-.15	-.28	.14	.23
Birmingham	1	.01	-.02	-.13	-.40
	2	-.14	-.27	-.02	.02
	3	-.11	-.25	-.10	.12
Brownsville	1	-.01	-.02	-.01	-.02
	2	0.00	-.02	.04	.23
	3	-.01	-.01	-.01	.13
El Paso	1	-.09	-.13	.17	.
	2	-.17	-.31	.22	.49
	3	-.14	-.28	.27	.32
Lake Charles	1	0.00	-.01	.09	-.02
	2	-.10	-.19	-.01	-.08
	3	-.06	-.12	.01	-.03
Memphis	1	.03	.02	-.01	.01
	2	-.16	-.32	.16	.26
	3	-.16	-.33	-.02	.11
Miami	1	-.01	-.02	-.01	-.12
	2	0.00	0.00	.02	.17
	3	.01	.01	.04	.14
Minneapolis	1	-.04	-.64	.16	-.12
	2	-.32	-.67	-.62	-.67
	3	-.28	-.58	-.07	-.03
Nashville	1	.19	.28	.09	.15
	2	-.09	-.25	.14	.36
	3	-.12	-.23	.13	.24
New York	1	.16	.27	.04	-.02
	2	-.20	-.42	.05	.25
	3	-.34	-.58	-.08	.12
Average Deviation		0.17		0.14	
Maximum Deviation		0.67		0.67	

Table 6.4.2g. Comparison of Extrapolated to DOE-2 Δ Loads for Window Area Variations in Townhouse Prototypes

(Extrapolated Δ Load - DOE-2.1A Δ Load, in MBtu)

City	No. of Panes	Mid-Unit Townhouse Heating 15%	Mid-Unit Townhouse Heating 20%	Mid-Unit Townhouse Cooling 15%	Mid-Unit Townhouse Cooling 20%	End-Unit Townhouse Heating 15%	End-Unit Townhouse Cooling 20%
Albuquerque	1	.04	.11	-.05	-.18	-.01	.20
	2	-.19	-.41	-.07	-.19	-.23	-.22
	3	-.26	-.57	-.08	-.23	-.34	-.15
Atlanta	1	.01	.03	.20	.27	-.05	.51
	2	-.18	-.32	.14	.20	-.23	-.14
	3	-.19	-.39	.06	0.00	-.25	.02
Birmingham	1	-.01	.00	.20	.33		
	2	-.15	-.31	.06	.20		
	3	-.20	-.39	-.09	.01		
Chicago	1	.07	.13	.11	-.08	-.06	.12
	2	-.18	-.37	0.00	.04	-.26	.10
	3	-.26	-.51	.08	-.02	-.34	.10
Denver	1	.02	.00	-.10	-.28	-.15	-.07
	2	-.27	-.56	-.10	-.28	-.37	-.25
	3	-.42	-.81	-.11	-.30	-.54	-.18
Lake Charles	1	-.01	.00	.36	.54	-.06	.62
	2	-.13	-.25	.13	.30	-.16	.02
	3	-.15	-.29	.12	.27	-.20	.19
Miami	1	.00	.00	.27	.59	.00	.91
	2	-.03	-.04	.23	.62	-.02	.07
	3	-.03	-.04	.38	.67	-.03	.48
Minneapolis	1	-.11	-.48	-.02	-.27	-.61	.04
	2	-.16	-.33	-.10	-.19	-.23	-.25
	3	-.19	-.35	-.08	-.20	-.25	-.17
New York	1	.05	.09	.04	-.04	-.04	.18
	2	-.20	-.39	-.01	-.06	-.23	-.03
	3	-.27	-.54	-.06	-.11	-.36	-.09
Phoenix	1	-.06	-.08	-.34	-.97	-.08	-.12
	2	-.15	-.30	-.18	-.50	-.20	-.42
	3	-.17	-.35	-.09	-.22	-.24	-.04
San Francisco	1					-.21	.03
	2					-.56	.00
	3					-.69	.00
Seattle	1					-.07	-.06
	2					-.35	-.12
	3					-.45	-.13
Average Deviation		0.20		0.20		0.24	0.18
Maximum Deviation		0.81		0.97		0.69	0.91

6.4.3. Window Orientation

Extensive computer simulations have been done in eleven representative locations to quantify the effects of various window configurations in different U.S. locations. These configurations include both conventional window orientations as well as moderate sun-tempered designs such as increased amounts of south-facing glass, reflective and absorptive glass coatings, and the use of night insulation. Custom passive solar designs, however, have not been modeled because of the difficulty in quantifying their thermal performance on generic basis.

For each of the eleven locations, DOE-2.1A simulations have been done for single, double, and triple glazed windows in 17 different orientations with total window areas ranging from 10% to 20% of floor area (see Table 6.4.3a).

Table 6.4.3a. Summary of Window Orientations

		Amount of Windows (% of Floor Area)				
Case Number	Building.* Orientation	North	South	East	West	Total
1	0	2.5	2.5	2.5	2.5	10
2	0	5	5	0	0	10
3	1	0	0	5	5	10
4	0	2.5	7.5	0	0	10
6	0	3.75	3.75	3.75	3.75	15
7	0	7.5	7.5	0	0	15
8	1	0	0	7.5	7.5	15
9	0	5	10	0	0	15
10	1	0	0	5	10	15
11	0	10	5	0	0	15
12	1	0	0	10	5	15
13	0	2.5	12.5	0	0	15
14	0	0	10	2.5	2.5	15
15	0	5	5	5	5	20
16	0	5	15	0	0	20
19	0	0	15	2.5	2.5	20
20	0	10	10	0	0	20

* 0 = long axis east-west, 1 = long axis north-south

These windows orientations are not energy efficient designs, but rather those frequently found in typical residential houses. For example, Cases 3, 8, 10 and 12 with predominantly east and west facing windows represent typical window orientations in houses built along streets that run north to south. For the three equally distributed window orientations (Cases 1,6, and 15), additional parametric studies have been done on the effects of reflective glass, absorptive glass, and night insulation. Analysis of these conservation strategies are covered in Sections 6.4.4 and 6.4.5.

The energy impact of the various window orientations is first calculated by comparing their annual heating and cooling loads to that for a house with the same window area equally distributed on four sides. The Δ loads for the 17 window orientations for each glazing type are then analyzed by multi-linear regressions, using building orientation and window area differences in each direction as the five independent variables. The regressions result in five coefficients for Δ loads due to building orientation and the amount of windows facing north, south, east, or west.

Figure 6.4.3.1 shows sample regression results of Δ heating and cooling loads for different single-pane window orientations in Albuquerque. The regression coefficients for each orientation give the Δ load in MBtu's per 100 ft^2 of window compared to windows of average orientation. For example, 100 ft^2 of south-facing single-pane windows yields a 3.94 MBtu reduction in heating loads compared to windows of average orientation. The coefficient for building orientation takes into account shading differences due to the locations of eave overhangs and neighboring houses.

This analytical approach utilizes building loads derived from whole-house simulations, but then "filters" them through multi-linear regressions to deduce the individual effects of specific window orientations. On average, the heating regressions show a R^2 of 0.979 and a standard error of 0.26 MBtu. For cooling, they are 0.984, and 0.18 MBtu, respectively. These accuracies are judged sufficient for the purpose of this work. Table 6.4.3b gives the calculated regression coefficients for single, double, and triple glazed windows in the eleven locations. The reliability of the regressions can be seen in Figures 6.4.3.2 and 6.4.3.3, which are plots of predicted versus actual Δ loads for different single-pane window orientations in Albuquerque.

These coefficients are used in the PEAR program to calculate the changes in Δ loads for differing window orientations. Orientation coefficients for the other 34 locations are taken from those for the eleven base window cities using the groupings developed in the climate analysis (See Section 5.5). Since the window area sensitivity analysis (see Section 6.4.2) is used for calculating Δ loads due to total changes in window area, the orientation coefficients described here is used only to estimate the variations in those Δ loads for specific orientations due to differences in solar gain. The assumption is made that locations in the same window groupings share similar insolation patterns and that:

$$\Delta\text{Load}_{\text{average orientation}} - \Delta\text{Load}_{\text{N,S,E, or W}} = \text{constant for cities in same window grouping} \quad (20)$$

This methodology requires two calculations for estimating the energy impact of windows, one to derive the Δ loads for total window area (assuming equal orientation on all sides), and another to modify the Δ loads for specific window orientations. Since this procedure is somewhat tedious

ALBUQUERQUE COOLING SINGLE-PANE WINDOWS

TOTAL WINDOW AREA	BLDG ORIENT	DELTA WINDOW AREA FROM EQUAL DISTRIB (SQ FT) NORTH	SOUTH	EAST	WEST	DELTA LOAD (MBTU)	PREDICTED LOAD (MBTU)
154.0	0.0	0.0	0.0	0.0	0.0	.000	.000
154.0	0.0	38.5	38.5	-38.5	-38.5	-2.147	-2.130
154.0	1.0	-38.5	-38.5	38.5	38.5	1.156	.487
154.0	0.0	0.0	77.0	-38.5	-38.5	-1.698	-1.505
231.0	0.0	0.0	0.0	0.0	0.0	.000	.000
231.0	0.0	57.8	57.8	-57.8	-57.8	-3.256	-3.194
231.0	1.0	-57.8	-57.8	57.8	57.8	1.077	1.552
231.0	0.0	19.3	96.3	-57.8	-57.8	-2.479	-2.570
231.0	1.0	-57.8	-57.8	19.3	96.3	2.626	2.723
231.0	0.0	96.3	19.3	-57.8	-57.8	-3.688	-3.818
231.0	1.0	-57.8	-57.8	96.3	19.3	.283	.380
231.0	0.0	-19.3	134.7	-57.8	-57.8	-2.166	-1.946
308.0	0.0	0.0	0.0	0.0	0.0	.000	.000
308.0	0.0	0.0	154.0	-77.0	-77.0	-2.948	-3.011
231.0	0.0	-57.8	96.3	-19.3	-19.3	.233	.184
308.0	0.0	-77.0	154.0	-38.5	-38.5	-.108	-.257
308.0	0.0	77.0	77.0	-77.0	-77.0	-4.426	-4.259

COEFF -1.642619 -2.193398 -.572240 -.138610 2.904247

R2 = .986141 R2MOD = .979841 STANDARD ERROR = .257697 MBTU

ALBUQUERQUE HEATING SINGLE-PANE WINDOWS

TOTAL WINDOW AREA	BLDG ORIENT	DELTA WINDOW AREA FROM EQUAL DISTRIB (SQ FT) NORTH	SOUTH	EAST	WEST	DELTA LOAD (MBTU)	PREDICTED LOAD (MBTU)
154.0	0.0	0.0	0.0	0.0	0.0	.000	.000
154.0	0.0	38.5	38.5	-38.5	-38.5	-.880	-.746
154.0	1.0	-38.5	-38.5	38.5	38.5	1.295	2.095
154.0	0.0	0.0	77.0	-38.5	-38.5	-4.128	-3.408
231.0	0.0	0.0	0.0	0.0	0.0	.000	.000
231.0	0.0	57.8	57.8	-57.8	-57.8	-1.250	-1.119
231.0	1.0	-57.8	-57.8	57.8	57.8	3.006	2.469
231.0	0.0	19.3	96.3	-57.8	-57.8	-4.364	-3.781
231.0	1.0	-57.8	-57.8	19.3	96.3	1.777	1.646
231.0	0.0	96.3	19.3	-57.8	-57.8	2.003	1.542
231.0	1.0	-57.8	-57.8	96.3	19.3	3.423	3.292
231.0	0.0	-19.3	134.7	-57.8	-57.8	-6.178	-6.442
308.0	0.0	0.0	0.0	0.0	0.0	.000	.000
308.0	0.0	0.0	154.0	-77.0	-77.0	-6.213	-6.815
231.0	0.0	-57.8	96.3	-19.3	-19.3	-6.508	-5.696
308.0	0.0	-77.0	154.0	-38.5	-38.5	-8.178	-8.730
308.0	0.0	77.0	77.0	-77.0	-77.0	-1.548	-1.492

COEFF 1.349333 2.971866 -3.940855 1.553325 -.584337

R2 = .983580 R2MOD = .976117 STANDARD ERROR = .516713 MBTU

Fig. 6.4.3.1

Table 6.4.3b Window Orientation Coefficients

City	Glazing	Heating Coefficients (MBtu/100ft^2 Glass) Bldg Orient	Windows North	Windows South	Windows East	Windows West	Cooling Coefficients (MBtu/100ft^2 Glass) Bldg Orient	Windows North	Windows South	Windows East	Windows West
Albuquerque	1	1.35	2.97	-3.94	1.55	-0.58	-1.64	-2.19	-0.57	-0.14	2.90
	2	1.17	2.41	-3.29	1.36	-0.48	-1.44	-2.01	-0.52	-0.16	2.69
	3	0.99	1.85	-2.65	1.17	-0.37	-1.24	-1.83	-0.47	-0.18	2.48
Atlanta	1	0.65	1.73	-2.25	0.78	-0.26	-0.74	-1.93	-0.24	0.07	2.10
	2	0.56	1.41	-1.87	0.67	-0.22	-0.67	-1.89	-0.20	-0.01	2.09
	3	0.46	1.09	-1.49	0.56	-0.17	-0.59	-1.84	-0.15	-0.09	2.08
Chicago	1	0.72	2.25	-2.81	0.83	-0.26	-0.64	-1.16	0.04	-0.05	1.17
	2	0.58	1.93	-2.50	0.77	-0.20	-0.56	-1.08	0.01	-0.02	1.09
	3	0.44	1.60	-2.19	0.71	-0.13	-0.49	-0.99	-0.01	0.00	1.01
Denver	1	1.21	3.15	-4.16	1.46	-0.45	-0.75	-1.12	-0.08	-0.07	1.27
	2	1.02	2.68	-3.67	1.34	-0.36	-0.66	-1.01	-0.08	-0.09	1.18
	3	0.83	2.21	-3.18	1.23	-0.26	-0.58	-0.90	-0.08	-0.12	1.10
Lake Charles	1	0.42	0.98	-1.21	0.42	-0.18	-0.97	-2.58	-0.08	0.12	2.54
	2	0.34	0.78	-0.99	0.36	-0.15	-0.91	-2.47	-0.05	0.05	2.47
	3	0.25	0.58	-0.76	0.30	-0.12	-0.84	-2.36	-0.02	-0.01	2.39
Miami	1	0.05	0.08	-0.08	0.01	-0.01	-1.57	-3.79	1.11	-0.07	2.76
	2	0.04	0.06	-0.06	0.01	-0.01	-1.45	-3.54	0.99	-0.04	2.60
	3	0.02	0.04	-0.04	0.01	-0.01	-1.34	-3.29	0.87	-0.01	2.43
Minneapolis	1	0.67	2.58	-3.52	1.20	-0.26	-0.55	-1.61	0.15	-0.21	1.68
	2	0.55	2.29	-3.21	1.11	-0.19	-0.48	-1.48	0.12	-0.23	1.59
	3	0.43	1.99	-2.90	1.03	-0.12	-0.41	-1.35	0.10	-0.24	1.50
New York	1	0.63	2.36	-3.14	1.09	-0.31	-0.51	-1.43	0.11	-0.21	1.53
	2	0.51	2.01	-2.77	0.99	-0.23	-0.43	-1.33	0.10	-0.19	1.42
	3	0.39	1.65	-2.41	0.89	-0.14	-0.36	-1.22	0.08	-0.17	1.31
Phoenix	1	0.78	1.07	-1.61	0.67	-0.13	-2.11	-3.58	-0.08	0.02	3.64
	2	0.64	0.81	-1.25	0.57	-0.13	-1.92	-3.43	-0.11	-0.11	3.66
	3	0.51	0.54	-0.89	0.47	-0.12	-1.74	-3.29	-0.15	-0.24	3.68
San Francisco	1	1.49	2.85	-2.23	0.68	-1.31	-0.11	-0.23	0.12	-0.09	0.20
	2	1.19	2.17	-1.81	0.61	-0.98	-0.11	-0.23	0.12	-0.08	0.19
	3	0.88	1.49	-1.38	0.54	-0.66	-0.10	-0.22	0.11	-0.07	0.18
Seattle	1	0.46	2.02	-2.32	0.50	-0.20	-0.14	-0.40	-0.02	-0.20	0.62
	2	0.33	1.69	-2.06	0.50	-0.12	-0.11	-0.36	-0.02	-0.19	0.57
	3	0.21	1.36	-1.79	0.49	-0.05	-0.08	-0.31	-0.01	-0.18	0.51

when done by hand, we combined the calculations in Appendix A.2 into a simplified format that shows quickly whether changing the amounts of north or south windows are viable conservation measures.

Appendix A.2 shows the net impact on heating and cooling loads for increased south or decreased north window areas. The Δ loads shown are the sums of the window area coefficients

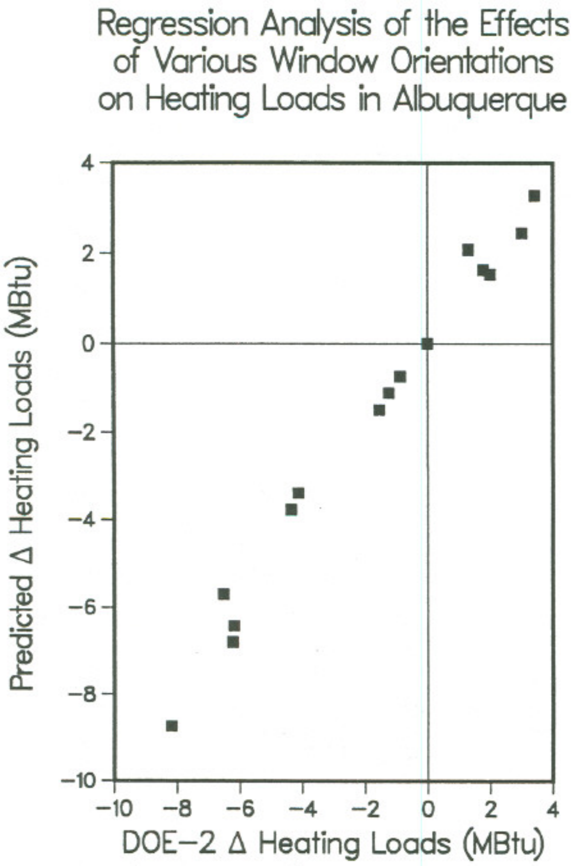


Fig. 6.4.3.2

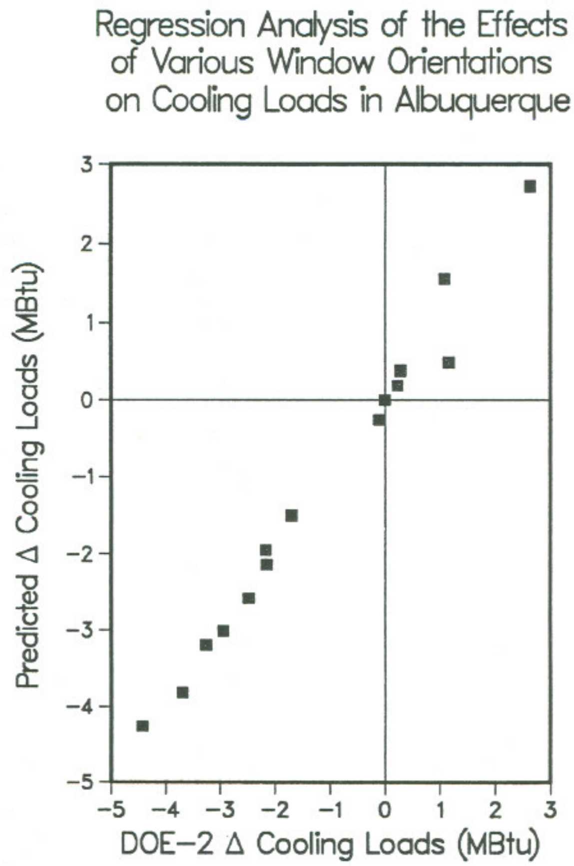


Fig. 6.4.3.3

from Section 6.4.2 and the window orientation coefficients for north and south windows shown in Table 6.4.3b. To simplify the table, we have assumed that the walls have R-11 insulation in the case of single- and double-pane windows, and R-19 insulation in the case of triple-pane windows. For the other 34 cities, Appendix A.2 combines the window area coefficient for that city with the north and south orientation coefficient from the base window location to which the city has been grouped.

6.4.4. Reflective and Absorptive Glazings

Sensitivity analyses have been performed for the one story prototype on the impact on cooling loads due to the use of reflective and absorptive glazings on windows. The optical properties of these glazings are shown on Table 6.4.4a.

The influence of the solar transmittance of glass on cooling loads can be quite significant. For example, DOE-2.1A runs for Miami indicate that the decrease in cooling load due to installation of heat absorbing glass can be as high as 15% of total cooling load for a 1-story house with 231 ft^2 of

Table 6.4.4a. Transmittance and Reflectance of Glazing for Reflective and Absorptive Glass

	Reflective Glass			Absorptive Glass		
	Transmittance (%)	Reflectance (%)	Shading Coeff	Transmittance (%)	Reflectance (%)	Shading Coeff
Single pane	20	45	.356	50	6	.700
Double pane	19	45	.276	43	9	.587
Triple pane	17	45	.252	39	7	.522

single glazed windows. As in the other window analyses, all results are based on DOE-2.1A simulations for 11 cities, and then extrapolated to all 45 locations based on climate correlations. Table 6.4.4b specifies the DOE-2.1A simulations done:

Table 6.4.4b. Reflective and Absorptive Glazing Runs

	single glazing			double glazing			triple glazing		
Glazing Type	10%	15%	20%	10%	15%	20%	10%	15%	20%
Reflective Glass		X						X	
Heat Absorbing Glass			X	X	X				X

The results for other cases have been produced either by interpolation or extrapolation from the computer simulation results. For example, the regression equations for double-pane reflective glass are obtained by interpolation. Installation of reflective or heat absorbing glass results in a decrease in cooling load and an increase in heating load. The effects on heating and cooling loads have been studied separately.

1. Cooling Loads

The first attempt to find a relationship between cooling load savings and climate parameters such as solar radiation is presented in Figure 6.4.4.1. Cooling energy savings (MBtu) on the vertical axis are plotted against summer horizontal insolation ($KBtu/ft^2$). A comparatively weak correlation exists with a correlation coefficient of 0.889. The deviation of cooling load savings from a linear regression line is almost 2 MBtu for Miami. The problem with this approach is that it considers total summer horizontal insolation, while the more appropriate variable would be insolation during the cooling period only. Table 6.4.4c lists the average vertical insolation during hours that the outdoor dry-bulb temperature is greater than 65 F. Hours when venting is possible are not

Table 6.4.4c. Winter and Summer Insolation for 45 Base Locations

Location	Average winter vertical insolation (KBtu/ft^2)	Average summer vertical insolation (KBtu/ft^2)
Albuquerque	175	91
Atlanta	105	140
Birmingham	98	154
Bismarck	157	67
Boise	154	69
Boston	164	69
Brownsville	28	248
Buffalo	145	44
Burlington	156	41
Charleston	76	177
Cheyenne	196	44
Chicago	151	66
Cincinnati	121	106
Denver	180	54
El Paso	112	132
Fort Worth	99	167
Fresno	114	116
Great Falls	163	38
Honolulu	0	323
Jacksonville	62	196
Juneau	175	0
Kansas City	127	107
Lake Charles	65	182
Las Vegas	107	164
Los Angeles	134	26
Medford	115	60
Memphis	108	141
Miami	12	269
Minneapolis	150	81
Nashville	104	136
New York	144	82
Oklahoma City	126	128
Omaha	147	92
Philadelphia	133	97
Phoenix	73	189
Pittsburgh	132	79
Portland ME	179	44
Portland OR	157	24
Reno	149	64
Salt Lake	155	92
San Antonio	72	187
San Diego	119	35
San Francisco	215	8
Seattle	171	12
Washington	125	105

included. These are hours when the dry-bulb temperature in less than 78 F and the humidity ratio is less than 0.0116.

By using this variable, a more strongly correlated linear relationship is obtained (see Figure 6.4.4.2). The correlation coefficient was 0.99 for both the single and triple pane regressions.

2. Heating Loads

In analyzing the heating load, the general approach remains the same, to correlate the increase in heating loads to the amount of vertical insolation for the heating period only.

Table 6.4.4c shows the average vertical insolation during the hours heating is required. The best correlations were obtained for a base temperature of 65 F. Figure 6.4.4.3 illustrates the dependence of heating load increases on vertical insolation during heating hours.

The correlation between heating loads increase and insolation during heating hours was not as strong as for the cooling load correlations described above. For single and triple-pane regressions the coefficient greater than 0.96. Previous analyses showed that the Δ heating and cooling loads per ft^2 of window change little as the Δ window area changes when the number of panes remains constant. For simplicity in presentation, we did not incorporate this interaction in the PEAR calculations.

3. Incorporation of results into data base tables and the PEAR microcomputer program

The regression equations resulting from the described analysis are listed in equations 21 through 26. For the eleven base cities, PEAR uses results from the DOE-2 simulations. For the other 34 locations, PEAR uses the regression coefficients and stored insolation data to calculate cooling load decreases and heating load increases due to reflective or heat absorbing glass. The same information is presented in Appendix A.3 in terms of MBtu change in loads per 100 ft^2 of glazing.

1. Reflective Glass.

a. single glazing:

$$C = 0.875 \times 10^{-4} + 2.887\times10^{-4} \cdot S \qquad (21)$$
$$H = 13.8 \times 10^{-4} + 2.208\times10^{-4} \cdot W$$

b. double glazing:

$$C = -4.380 \times 10^{-4} + 2.855\times10^{-4} \cdot S \qquad (22)$$
$$H = 11.5 \times 10^{-4} + 1.948\times10^{-4} \cdot W$$

c. triple glazing:

$$C = -9.636 \times 10^{-4} + 2.823\times10^{-4} \cdot S \qquad (23)$$
$$H = 9.221 \times 10^{-4} + 1.688\times10^{-4} \cdot W$$

Effect of Reflective Glass on Cooling Loads
15% Window Size
Single Pane

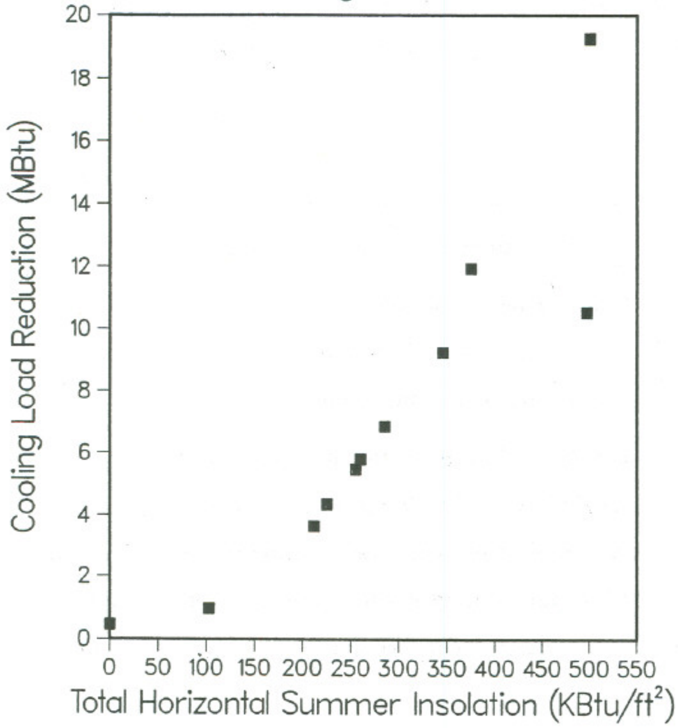


Fig 6.4.4.1

Effect of Reflective Glass on Cooling Loads
15% Window Size
Single Pane

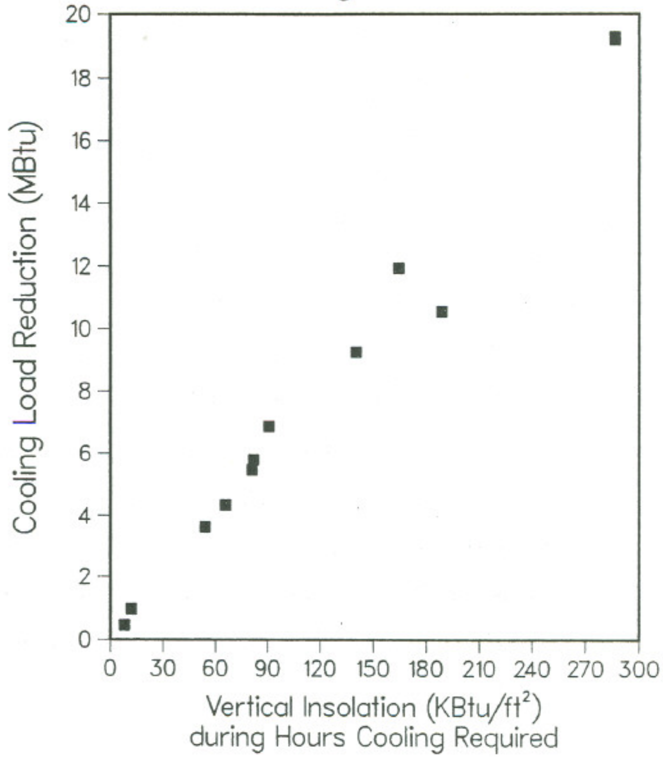


Fig. 6.4.4.2

Effect of Reflective Glass on Heating Loads
15% Window Size
Single Pane

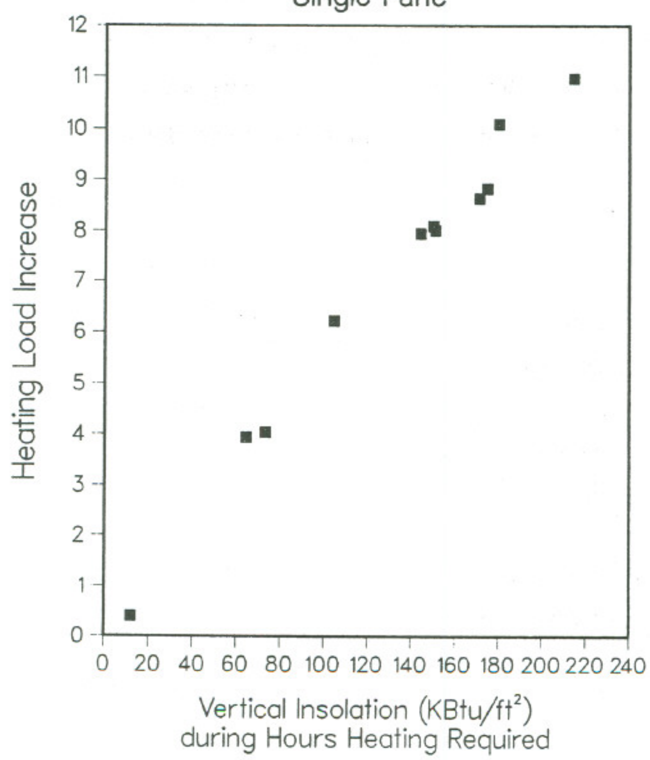


Fig. 6.4.4.3

2. Heat Absorbing Glass.

a. single glazing:

$$C = 0.215 \times 10^{-4} + 1.360 \times 10^{-4} \cdot S \tag{24}$$

$$H = 7.50 \times 10^{-4} + 1.026 \times 10^{-4} \cdot W$$

b. double glazing:

$$C = 9.383 \times 10^{-4} + 1.760 \times 10^{-4} \cdot S \tag{25}$$

$$H = 7.273 \times 10^{-4} + 1.169 \times 10^{-4} \cdot W$$

c. triple glazing:

$$C = 5.123 \times 10^{-4} + 1.740 \times 10^{-4} \cdot S \tag{26}$$

$$H = 1.330 \times 10^{-3} + 8.766 \times 10^{-5} \cdot W$$

where:

S = average vertical insolation (kBtu/ft^2) during hours of cooling is required.
W = average hourly vertical insolation (kBtu/ft^2) during hours heating is required.
C = cooling load savings (MBtu/ft^2)
H = heating load increase (MBtu/ft^2)

6.4.5 Movable Window Insulation

Products that are moved into place over the windows in the evening hours to reduce winter time heat losses are classified as movable insulation. In this study, we simulated one R-value for a standard off-the-shelf product with a material R-value of 2 (ft^2·hr·F/Btu). We assumed that the total component R-value for this product is R-3, the additional R-1 being attributed to the air space between the product and glazing. In order to achieve that additional resistance, the window covering must be tightly fit and sealed around all edges of the window. Although movable insulation may reduce infiltration somewhat, we did not attempt to model this effect in our simulations. A previous study considered the effect on heating load of such a reduction in infiltration.[18]

We assume that the movable insulation is in place between the hours of 10 p.m. and 8 a.m. during the heating season, which we vary depending upon the local climate. Thus, the assumed heating season is from October 1 through April 30 for cities typified by cool climates; from November 1 through March 31 in cities in temperate climate zones, and, from December 1 through

18. S. Selkowitz and V. Bazjanac, "Thermal Performance of Managed Window Systems", Lawrence Berkeley Laboratory Report 9933, Berkeley, CA. (1979).

February 28 for cities with hot climates.

We selected 11 cities representing the range of characteristic climates in the United States to examine the impact of movable insulation on the annual heating load. Table 6.4.5a summarizes the results of DOE 2.1A simulations carried out for the three glazing types in the ranch house prototype.

Table 6.4.5a. Heating Load Reduction with Movable Insulation for 1540 ft² One-Story Prototype House (MBtu)

	15% (231 ft^2)		
City	1-pane	2-pane	3-pane
Albuquerque NM	-6.20	-2.29	-1.17
Atlanta GA	-3.01	-1.08	-0.54
Chicago IL	-7.47	-2.72	-1.41
Denver CO	-7.67	-2.76	-1.42
Lake Charles LA	-2.24	-0.83	-0.43
Miami FL	-0.27	-0.09	-0.05
Minneapolis MN	-12.15	-4.52	-2.37
New York NY	-6.60	-2.29	-1.18
Phoenix AZ	-2.65	-0.97	-0.50
San Francisco CA	-2.57	-0.97	-0.49
Seattle WA	-5.34	-2.00	-0.96

To extend the results from Table 6.4.5a to other locations, we compared the predicted savings for the cities to climate variables. We found a good correlation between the heating load reduction and nighttime heating degree-days. Nighttime heating degree-days are summed from 10 p.m. to 8 a.m., the hours during which the insulation covered all windows. Figure 6.4.5.1 shows heating load reduction plotted as a function of nighttime heating degree-days (NHDD) at base 63 F for the one-story prototype with single-pane windows in 11 cities. The windows are evenly distributed among all four wall orientations with a 15% window to floor area ratio. Miami was excluded because of its extremely small heating load.

Similar fits were obtained for double and triple-pane simulations. The correlation coefficient was 0.99 for all three regressions. Using test runs we showed that the ratio of heating load reduction to window area was not constant for the three window areas studied, but decreased as the window area increased. For example, for double-glazed windows, the average heating load reduction for 15% window area was 1.42 times the average reduction for 10% window area. For 20% window area, the average heating load reduction was 1.78 times the average reduction for 10% window area. Therefore, when using 15% window area simulation results to compute regression equations for prediction of heating load reductions in other locations, we must note that they are not strictly extendable without a correction factor to other window areas. Because of this nonlinearity, the decision has been made to use the middle (15%) window area DOE-2.1A simulations

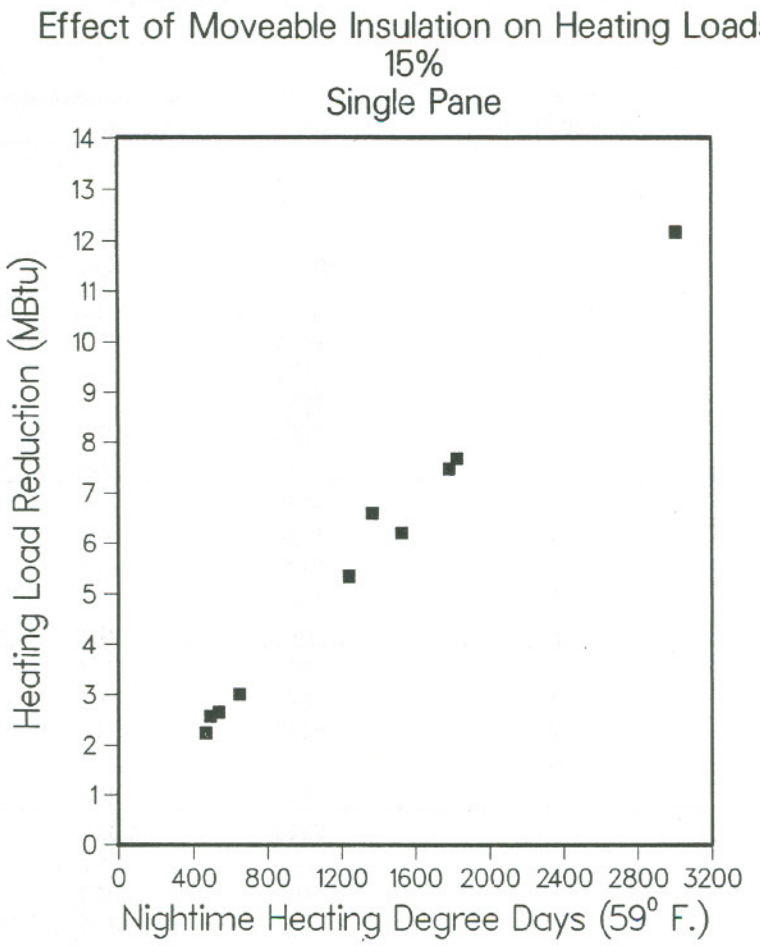


Fig. 6.4.5.1

in 11 cities to compute regression equations for predicting heating load reductions in the other 34 locations. The equations shown below are most accurate for values of NHDD above 200 degree days. The units are in (MBtu/ft^2 of window area).

$$\text{Single pane} = .00202 + 1.706\text{x}10^{-5}\ \text{NHDD} \quad (27)$$

$$\text{Double pane} = .00113 + 0.794\text{x}10^{-5}\ \text{NHDD} \quad (28)$$

$$\text{Triple pane} = .00034 + 0.422\text{x}10^{-5}\ \text{NHDD} \quad (29)$$

where: NHDD = nighttime heating degree-days (F·days).
ΔL = change in heating load (MBtu)
A = window area (ft^2)

We tabulated nighttime heating degree-days (NHDD) for 45 cities in Table 6.4.5b for three different balance point temperatures. These values can be inserted in the regression equations to obtain predictions of heating load reductions per ft^2 for 1-, 2- and 3-pane windows. We found that

Table 6.4.5b. Nighttime Heating Degree Days

City	Number of Winter Months	Base Temperature 59 F	61 F	63 F
Albuquerque	5	1525	1650	1776
Atlanta	3	649	722	797
Birmingham	3	705	775	846
Bismarck	7	3447	3624	3799
Boise	5	1622	1748	1875
Boston	5	1658	1784	1911
Brownsville	3	135	172	216
Buffalo	7	2255	2426	2599
Burlington	7	2703	2877	3051
Charleston	3	582	651	723
Cheyenne	7	2565	2741	2919
Chicago	5	1783	1906	2031
Cincinnati	5	1482	1606	1733
Denver	5	1825	1950	2076
El Paso	3	824	898	973
Fort Worth	3	604	673	743
Fresno	3	677	751	827
Great Falls	7	2537	2714	2890
Honolulu	3	0	0	0
Jacksonville	3	345	407	471
Juneau	7	2440	2615	2792
Kansas City	5	1660	1781	1904
Lake Charles	5	465	529	597
Las Vegas	3	427	495	566
Los Angeles	3	242	315	389
Medford	5	1442	1569	1695
Memphis	5	1097	1211	1327
Miami	3	46	62	81
Minneapolis	7	3010	3183	3358
Nashville	5	1144	1262	1385
New York	5	1368	1492	1618
Oklahoma City	5	1374	1494	1616
Omaha	7	2401	2572	2745
Philadelphia	5	1639	1764	1891
Phoenix	3	535	610	685
Pittsburgh	5	1661	1786	1911
Portland, ME	7	2658	2834	3011
Portland, OR	5	1250	1376	1501
Reno	5	1856	1982	2109
Salt Lake City	5	1914	2040	2167
San Antonio	3	528	595	663
San Diego	3	251	323	397
San Francisco	3	490	565	639
Seattle	5	1241	1367	1492
Washington	5	1259	1383	1508

the goodness of fit was weakly dependent on the balance point temperature chosen.

The balance point temperature of 63 F for single pane windows is estimated as follows. There are ten hours (10 p.m. to 8 a.m.) during which insulation covers the windows. From 12 p.m. to 6 a.m., the thermostat setpoint is 60 F and from both 10 p.m. to 12 p.m., and 6 a.m. to 8 a.m. the thermostat setting is 70 F. During the hours from 10 p.m. to 8 a.m., the balance point temperature is slightly less than the thermostat setpoint since the only thermal additions to the house are from internal gains, which are lower at night than during the day. Assuming a one degree reduction in balance point temperature for houses with single pane windows, the estimated average balance point temperature would be 0.4 (69) + 0.6 (59) = 63 F. Although a better estimate of nighttime degree days could conceivably be obtained by calculating them for three separate time periods (e.g., 10 p.m. to 12 p.m., 12 p.m. to 6 a.m., and 6 a.m. to 8 a.m.) at three separate balance points, we considered such complexity to be unnecessary. Consequently, we used a single average balance point temperature as derived above.

The DOE-2.1A simulations used to generate the load reductions (see Table 6.4.5a) were all done for R-3 insulation and no window sash. In order to predict heating load reductions for various window sash types and for various movable insulation R-values, we calculated sash and R-value correction factors shown in Tables 6.4.5c and 6.4.5d respectively. We derived sash correction factors by calculating U-values for the various combinations of sash type and insulation using ASHRAE adjustment factors to obtain U-values for 1-, 2-, and 3-pane windows with various sash types. R-value correction factors were obtained in a similar manner.

Table 6.4.5c. Sash Correction Factors †

	Sash Type		
	Wood	Aluminum	Aluminum with Thermal Break
Single Glazed	.945	1.12	.994
Double Glazed with ½ in. air gap	1.03	1.48	1.18
Triple Glazed with ½ in. air gap	1.09	1.83	1.35

† These factors are multiplied by the heating load reductions for windows without sash (Table 6.4.5a) to obtain the load reductions for windows with sash types such as wood, aluminum, and aluminum with a thermal break.

To calculate loads reduction due to movable insulation, PEAR uses regression equations 27 through 29 together with a data base of nighttime heating degree-days. For the eleven base cities, PEAR uses directly results from the DOE-2 simulations. The same information is presented in Appendix A.4, which lists the estimated heating load reductions from the use of movable insulation. Modifiers are given for 45 cities for three sash types and three glazing types. In order to

Table 6.4.5d. R-Value Correction Factors†

	R-1	R-3	R-5
Single pane	.68	1.00	1.10
Double pane	.55	1.00	1.19
Triple pane	.49	1.00	1.26

† These factors are multiplied by the heating load reductions for R-3 insulation (Table 6.4.5a) to obtain the heating load reductions for windows with either R-1 or R-5 insulation.

obtain the heating load reduction in MBtu, the modifiers should be multiplied by window area (in ft^2) and divided by 100.

$$\Delta \text{ Heating load (MBtu)} = \text{Modifier x Window area } (ft^2)/100 \qquad (30)$$

6.5. Exterior Building Color

For the base case simulations, both the roof and wall absorptance are assumed to be 0.7 corresponding to dark-colored paint or shingles. In certain areas of the country using a light or white-color roof or wall rather than a dark one can reduce the cooling energy requirements. The light color reflects much of the sunlight striking it, thus reducing the heat gain through either the roof or wall of the house.

A series of sensitivity analyses have been conducted in selected locations where cooling requirements predominate, in order to provide homebuilders with a means for estimating these savings. Table 6.5a lists the 16 cities in which sensitivity runs are performed.

Table 6.5a. Exterior Building Color Test Cities

Albuquerque NM	Charleston SC	Honolulu HI	Miami FL
Atlanta GA	El Paso TX	Jacksonville FL	Oklahoma City OK
Birmingham AL	Fort Worth TX	Lake Charles LA	Phoenix AZ
Brownsville TX	Fresno CA	Memphis TN	San Antonio TX

Several absorptivity options are simulated for each location, including: 0.3 roof and 0.7 wall, 0.7 roof and 0.3 wall, and 0.3 wall and roof. 0.3 corresponds to the absorptivity of white semi-gloss paint. In each case, three thermal integrities have been simulated: loose (uninsulated, single-pane, 0.7ach), medium (R-19 Ceiling, R-11 Walls, R-0 Slab, 1-pane, 0.7 ach) and tight (R-30 Ceiling, R-19 Walls, 2' R-5 Slab, 2-pane, 0.7 ach). Changes in the estimated cooling loads are shown in

Table 6.5b. As seen in this table, the use of lower absorptance in the roof or wall results in a decrease in the cooling load in all cases. The option with the lowest absorptance value (0.3 for both roof and wall) shows the greatest savings, followed by the low absorptance roof (with darker walls) and low absorptance walls (with darker roof), respectively. Test simulations have been performed in several locations on the other building prototypes (two-story, split-level and middle-unit townhouse). Since the impact on cooling loads due to the sun hitting roofs and walls of different absorptance values relates closely to their surface areas, it has been found possible to scale the the impact of color on the one-story prototype to the other prototypes by using the appropriate ratios of wall or roof areas. This linear scaling has been to found to give answers within 0.2 MBtus or 15% of the test runs in the worst case (scaling from the one-story to a townhouse prototype).

For ease in presentation, the impact on cooling loads of light wall and roof colors have been calculated per 1,000 square feet of roof or wall area, based on test data for the one-story prototype (see Appendix A.5). Values are given for the 16 locations and three levels of wall and roof thermal integrity described earlier. Appendix A.5 can be used to derive approximate cooling load reductions for various house sizes by multiplying the values shown by the appropriate ceiling and wall areas divided by 1000.

$$\Delta \text{ Cooling load}_{\text{ceiling}} \text{ (MBtu)} = \text{Ceiling modifier x Ceiling area } (\text{ft}^2)/1000 \quad (31)$$

$$\Delta \text{ Cooling load}_{\text{wall}} \text{ (MBtu)} = \text{Wall modifier x Wall area } (\text{ft}^2)/1000 \quad (32)$$

The same procedure is used in the PEAR microcomputer program for estimating the cooling load reductions due to light-colored ceilings and walls. For ceiling and wall R-values different from those modeled (R-0, R-11, R-38 ceilings, R-0, R-11, and R-19 walls), PEAR interpolates the estimated cooling load reductions using component U-values.

6.6. Night Temperature Setback

The standard operating conditions used for the base case simulations assume a six hour night setback from 70 F to 60 F between the hours of 12 and 6 a.m. (see Sec. 4.1). The energy impact for no night setback was investigated with DOE-2.1A simulations for a number of climates and house conditions with the thermostat set at 70 F all day. The increases in heating loads were then compared to different climate parameters and a correlation procedure developed for estimating setback impacts for all locations and house configurations in the data base. It has been found that the percent increase in heating loads for any particular house correlates linearly to the percent increase in heating degree-days due to the higher nighttime indoor temperatures.

Table 6.5b. Cooling Load Reductions for Different Roof and Wall Absorptivities

Location	Option†	Total Cooling Load (MBtu)	ΔCooling Load 0.3 Roof (MBtu)	ΔCooling Load 0.3 Wall (MBtu)	ΔCooling Load 0.3 Roof/Wall (MBtu)
Albuquerque	Uninsulated	31.164	-9.46	-2.06	-11.52
	Loose	15.739	-1.80	-0.84	-2.64
	Tight	10.979	-1.16	-0.53	-1.69
Atlanta	Uninsulated	30.668	-8.26	-2.42	-10.59
	Loose	21.509	-1.74	-0.77	-2.96
	Tight	17.256	-1.18	-0.84	-2.02
Birmingham	Uninsulated	39.430	-9.41	-2.77	-12.18
	Loose	27.771	-2.07	-1.34	-3.26
	Tight	22.398	-1.32	-0.98	-2.30
Brownsville	Uninsulated	82.763	-9.00	-2.84	-11.84
	Loose	64.214	-1.95	-1.29	-3.20
	Tight	54.259	-1.36	-0.91	-2.27
Charleston	Uninsulated	41.888	-7.90	-2.53	-10.43
	Loose	31.145	-1.61	-1.07	-2.72
	Tight	26.335	-1.16	-0.78	-1.94
El Paso	Uninsulated	45.693	-10.19	-2.53	-12.73
	Loose	27.335	-1.91	-1.08	-2.96
	Tight	20.318	-1.26	-0.66	-1.92
Fort Worth	Uninsulated	58.256	-8.51	-2.50	-11.01
	Loose	41.213	-1.87	-1.13	-2.98
	Tight	32.309	-1.28	-0.79	-2.07
Fresno	Uninsulated	43.331	-9.76	-3.52	-13.28
	Loose	22.215	-1.99	-1.15	-3.15
	Tight	15.848	-1.33	-0.72	-2.05
Honolulu	Uninsulated	70.515	-15.13	-4.50	-19.62
	Loose	55.280	-2.96	-1.75	-4.79
	Tight	47.627	-1.87	-1.26	-3.13
Jacksonville	Uninsulated	60.019	-9.80	-2.97	-12.77
	Loose	44.930	-2.00	-1.28	-3.27
	Tight	36.741	-1.37	-0.88	-2.25
Lake Charles	Uninsulated	59.624	-9.61	-2.94	-12.53
	Loose	44.324	-2.09	-1.31	-3.40
	Tight	36.073	-1.47	-1.17	-2.64
Memphis	Uninsulated	46.320	-8.00	-2.30	-10.30
	Loose	33.027	-1.77	-1.00	-2.83
	Tight	26.173	-1.24	-0.74	-1.24
Miami	Uninsulated	94.764	-12.44	-3.98	-16.73
	Loose	72.711	-2.68	-1.87	-4.60
	Tight	60.606	-1.84	-1.30	-3.14
Oklahoma City	Uninsulated	38.410	-5.35	-1.44	-6.80
	Loose	27.459	-1.11	-0.65	-1.76
	Tight	21.917	-0.76	-0.47	-1.23
Phoenix	Uninsulated	81.977	-11.19	-2.77	-14.03
	Loose	56.987	-2.85	-0.10	-3.30
	Tight	41.128	-1.92	-0.18	-2.10
San Antonio	Uninsulated	61.196	-8.60	-2.45	-11.05
	Loose	45.047	-1.85	-1.12	-3.03
	Tight	35.797	-1.23	-0.78	-2.01

† Uninsulated = R-0 Ceil, R-0 Wall, FM0 Fdn, 1-glaze, 0.7ach infil; Loose = R-19 Ceil, R-11 Walls, FM0 Fdn, 1-glaze, 0.7ach infil; Tight = R-38 Ceil, R-19 Wall, R-5 2' Fdn, 2-glaze, 0.7ach infil.

Test DOE-2.1A simulations with no night setback were done for three building prototypes in up to 20 different locations with thermal integrities ranging from totally uninsulated to very tight houses with R-49 ceiling insulation, R-27 wall insulation, 3-pane windows, and 0.4 ach infiltration (see Table 6.6a). The resulting Δ loads were then correlated to the Δ nighttime heating degree-days and the percent Δ heating degree-days due to the absence of a night setback. The Δ nighttime heating degree-days are derived by calculating heating degree-days (actually degree-hours divided by 24) for the six setback hours (12 to 6 a.m.) using two base temperatures separated by 10 F. These base temperatures correspond to house balance point temperatures at night with and without the thermostat setback. The percent Δ heating degree-days is the Δ nighttime heating degree-days divided by the total heating degree-days for the house with a setback, i.e.

$$\frac{(\text{NHDD}_{\text{no setback}} - \text{NHDD}_{\text{setback}})}{(\text{DHDD} + \text{NHDD}_{\text{setback}})} \tag{33}$$

where:

NHDD = Nighttime heating degree-days from Hours 1 to 6

DHDD = Daytime heating degree-days from Hours 7 to 24

Table 6.6a Sensitivity Runs with No Night Temperature Setback

	Prototype and Thermal Integrity †								
	One-story					Two-story		Townhouse	
Location	Unins	Loose	Med	Tight	V. Tight	Loose	Tight	Loose	Tight
Albuquerque		X	X	X					
Atlanta	X	X	X	X	X	X	X	X	X
Birmingham		X	X	X					
Chicago		X		X	X	X	X	X	X
Denver			X	X		X	X	X	X
Fresno		X	X	X					
Houston	X	X	X	X		X	X	X	X
Kansas City		X		X					
Miami		X	X	X					
Minneapolis		X	X	X	X	X	X	X	X
Nashville		X	X	X					
New York		X	X	X	X	X	X	X	X
Phoenix	X	X	X	X		X	X	X	X
Salt Lake City		X		X					
San Francisco			X			X	X	X	X
Washington				X	X				

† Unins = uninsulated; Loose = R-19 ceil, R-11 wall, 1-pane, 0.7ach infil; Med = R-30 ceil, R-19 wall, 2-pane, 0.7ach infil; Tight = R-49 ceil, R-27 wall, 3-pane, 0.7ach infil; V. Tight = same as Tight but with 0.4ach infil.

The nighttime balance point temperatures for a house are location-independent (assuming constant infiltration rates) and vary only with the house thermal integrity and internal loads. For a given house, the same base temperature can be used to calculate nighttime heating degree for all locations. The daytime balance point temperatures, however, are location-specific and vary with the amount of solar gain. Table 6.6b gives the balance-point temperatures for variations of the one-story prototype in the 45 base case locations. These are used as base temperatures in calculating the daytime heating degree-days. Balance point temperatures for the other prototypes also have been calculated, but are not shown here for the sake of brevity. Nighttime values are the same for the two-story and split-level, and 1-2 F higher for the townhouses; daytime values are the same for the two-story, 1-2 F higher for the split-level , 3-7 F higher for the middle-unit townhouse, and 3-5 F higher for the end-unit townhouse.

Correlations between the Δ loads due to no setback and the degree-day data showed better results using percent Δ heating degree-days rather than Δ nighttime heating degree-days. Figure 6.6.1 shows the relatively large scatter in a typical data set plotting Δ loads for no setback against Δ nighttime heating degree-days. Figure 6.6.2 shows the improved fit when the same data is plotted using percent Δ loads against percent Δ heating degree-days. The improvement is because the percent values incorporate the geographical variations in the loads-to-degree-day relationship previously mentioned in Chapter 5.

The correlation is further improved when the location-specific balance point temperatures in Table 6.6b are used in calculating the daytime heating degree-days. In Figure 6.6.2 an average daytime balance point temperature of 57 F was used for all locations, producing a correlation coefficient of 0.9684. In Figure 6.6.3, different daytime balance point temperatures from Table 6.6a were used depending on location ranging from 56 F for sunny Albuquerque to 59 F for cloudy Chicago.† This produced an improved correlation coefficient of 0.9865.

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† Balance points temperatures (BPT) have been calculated as follows:

$$BPT = T_{indoor} - (1/n \cdot UA) * \left(\sum_{j=1}^{n} SG_j + \sum_{j=1}^{n} IL_j \right)$$

For the stated operating conditions of 70 F thermostat setting for 18 hours and 60 F night thermostat setback for 6 hours, the two balance point temperatures are:

$$\text{Non-setback period } BPT = 70 - (1/18 \cdot UA) * \left(\sum_{7}^{24} SG_j + \sum_{7}^{24} IL_j \right)$$

$$\text{Setback period } BPT = 60 - (1/6 \cdot UA) * \sum_{1}^{6} IL_j$$

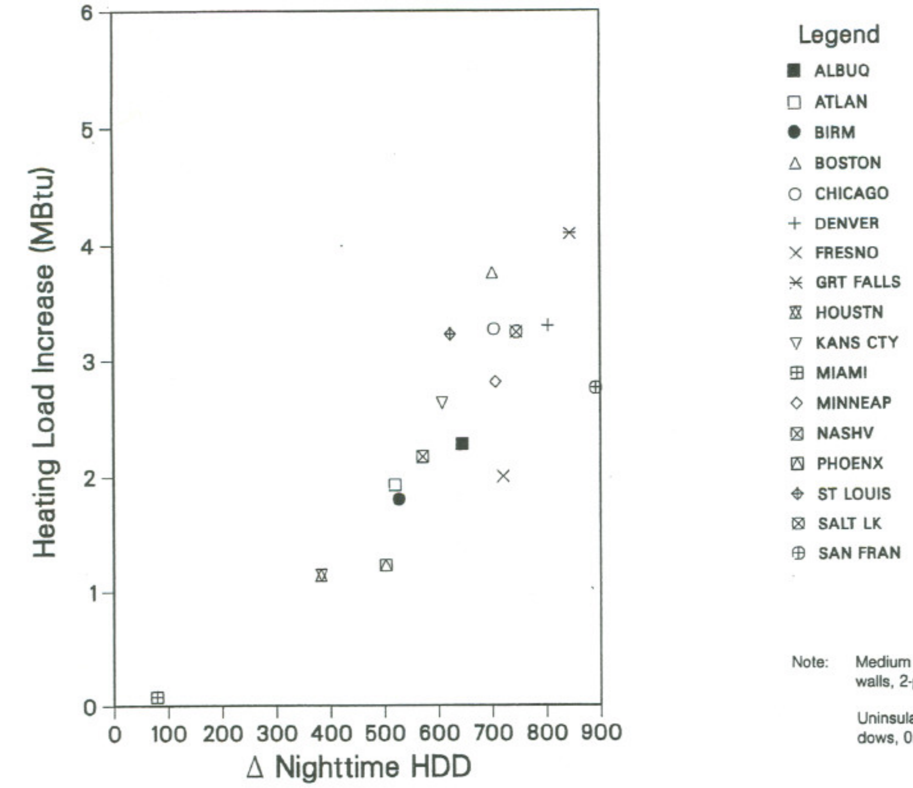
Table 6.6b. Balance Point Temperatures for the One Story Prototype with Different Thermal Integrities in 45 U.S. Locations

(Thermostat set at 70 °F, 60 °F setback)

City	Loose House*	Medium House*	Tight House*	Very Tight House*
Nighttime :				
without setback	68	67	66	66
with setback	58	57	56	56
Daytime :				
Albuquerque	59	56	54	
Atlanta	60	58	56	
Birmingham	60	58	56	
Bismarck	61	59	56	53
Boise	61	59	57	54
Boston	61	59	57	54
Brownsville	60	58	56	
Buffalo	62	59	57	54
Burlington	62	59	57	54
Charleston	61	59	55	
Cheyenne	60	57	55	51
Chicago	62	59	57	
Cincinnati	61	59	57	54
Denver	60	58	55	52
El Paso	59	57	54	
Fort Worth	60	57	55	
Fresno	61	58	56	
Great Falls	61	59	56	53
Honolulu	59	56	53	
Jacksonville	60	57	55	
Juneau	63	61	59	57
Kansas City	62	59	57	54
Lake Charles	61	59	57	
Las Vegas	60	57	55	
Los Angeles	60	58	55	
Medford	62	60	56	
Memphis	60	58	56	
Miami	61	58	56	
Minneapolis	62	59	57	54
Nashville	61	59	56	
New York	61	59	56	53
Oklahoma City	60	58	55	
Omaha	61	58	56	53
Philadelphia	61	59	57	54
Phoenix	60	57	55	
Pittsburgh	62	59	57	54
Portland ME	61	59	56	53
Portland OR	62	60	56	
Reno	61	58	56	53
Salt Lake City	61	58	56	53
San Antonio	60	58	55	
San Diego	60	57	55	
San Francisco	60	58	56	
Seattle	62	60	58	55
Washington	62	59	57	54

*Note: Loose = R-19 ceil, R-11 wall, 1-glazing, and 0.7ach infil; Medium = R-30 ceil, R-19 wall, 2-glazing, and 0.7ach infil; Tight = R-38 ceil, R-19 wall, 2-glazing, and 0.4ach infil(warm locations), or R-49 ceil, R-27 wall, 3-glazing, and 0.7ach infil(cold locations); Very tight = R-49 ceil, R-27 wall, 3-glazing, and 0.4ach infil(cold locations only).

Effect of No Night Setback on Heating Loads
(One-Story Prototype of Medium Thermal Integrity)

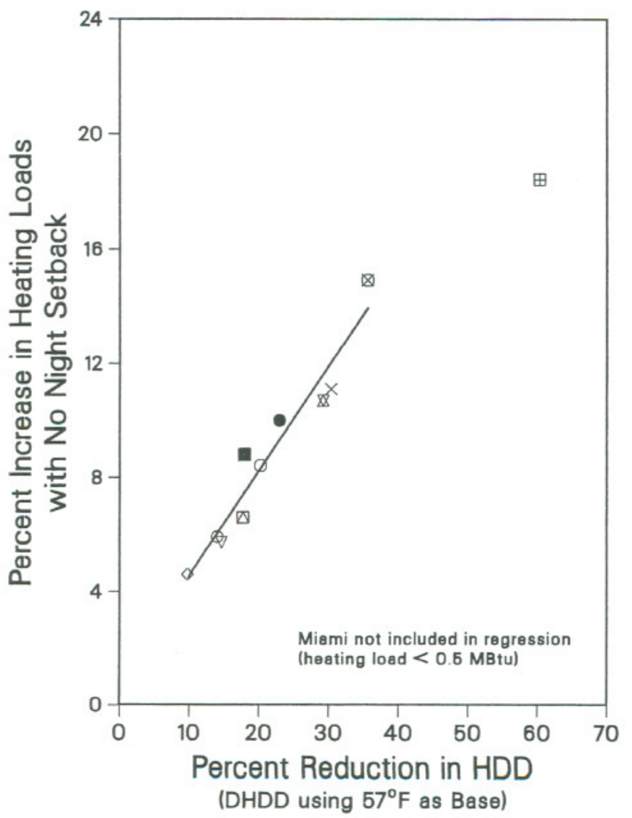


Note: Medium thermal integrity prototype is R-30 ceiling, R-19 walls, 2-pane windows, 0.7 ach infiltration

Uninsulated prototype is R-0 ceiling, R-0 walls, 1-pane windows, 0.7 ach infiltration

Fig. 6.6.1

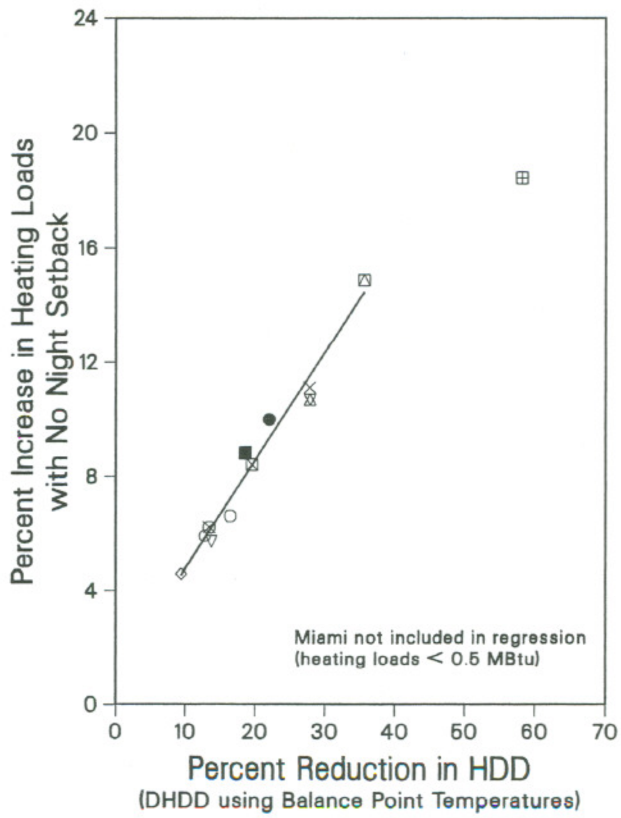
XCG 8511-486



CORRELATION COEFFICIENT 0.96845

XCG 8511-487

Fig. 6.6.2



CORRELATION COEFFICIENT 0.98520

Fig. 6.6.3

XCG 8511-488

The no setback sensitivity runs show that a linear relationship exists between the percent change in heating loads and the percent change in heating degree-days for all prototypes and configurations tested, with correlation coefficients above 0.9816 (see Table 6.6c). The Δ load can be expressed as:

$$\text{Setback savings} = \text{Slope x } \frac{(NHDD_{base\ 67} - NHDD_{base\ 57})}{(DHDD_{BPT} + NHDD_{base\ 67})} + k \qquad (34)$$

where:

$DHDD_{BPT}$ = Daytime heating degree-days using balance-point temperatures from Table 6.6b
$NHDD_{base\ 67}$ = Nighttime heating degree-days at base 67 F
$NHDD_{base\ 57}$ = Nighttime heating degree-days at base 57 F
Slope = slope from Table 6.6c
k = intercept from Table 6.6c

Table 6.6c. Linear Regressions for Different House Prototypes and Thermal Integrities

House prototype	House thermal integrity	Number of cities	Slope	Intercept	Correlation coefficient
One Story	loose	17	.47100	1.6313	.98160
	medium	19	.34963	1.8679	.98655
	tight	14	.31248	1.4986	.98254
Two Story	loose	8	.44326	1.3163	.99013
	medium	8	.34231	1.4392	.98632
Townhouse	loose	8	.48781	-0.2603	.99140
	medium	8	.42175	-1.1851	.98924

The slopes for the one story and two story prototypes are essentially identical, but those for the townhouses are significantly different owing to their lower balance point temperatures.

Although the relationship between the percent reductions in heating loads and degree-days seems linear for all levels of thermal integrity tested, the slope is always less than one, indicating that the percent reduction in loads is less than that in heating degree-days. This is not surprising since degree day differences do not take into account the energy needed to reheat the building mass and air once the setback is removed. For tighter houses, the "penalty" for this thermal lag is more pronounced and produces a lower slope (see Figure 6.6.4).

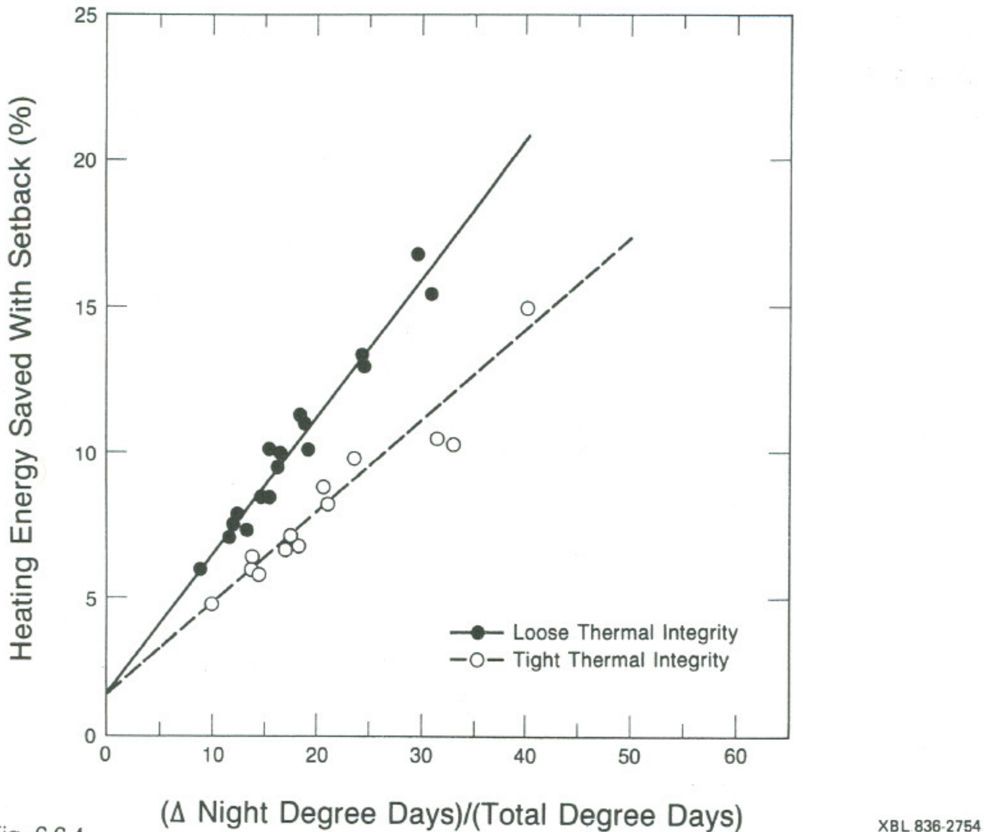


Fig. 6.6.4

The regression equations in Table 6.6c can be used to estimate the percent heating energy savings for a 6-hour night setback from 70 F to 60 F with good accuracy. Maximum errors between the correlations and the no setback DOE-2.1A data base are about 0.3% in the colder climates and 1.0% in the warmer climates (Miami values have been ignored because the total heating loads were less than 0.5 MBtu). Additional test runs done in four locations (Jacksonville, Great Falls, and Boston) all showed errors of less than 1%. The general applicability of this interpolation to typical wood-frame housing is further witnessed by referring to a more extensive DOE-2.1B database for setback savings compiled for manufactured houses in 44 cities (see Figure 6.6.5).[19] The average errors of this data set is less than 0.5%.

The regression equations in Table 6.6c and the balance point temperatures in Table 6.6b are used in the PEAR microcomputer program for calculating Δ loads due to night setback. Appendix A.6 gives approximate percent loads reduction for a house of average thermal integrity for all 45 locations. For locations covered in the sensitivity analysis, test DOE-2 results are used instead of the regression equations. Because the one-story and two-story equations are practically identical,

19. Data from Steven Winter Associates, Technical Support Document for Affordable Manufactured Housing through Energy Conservation, U.S. Department of Energy, Washington (1984).

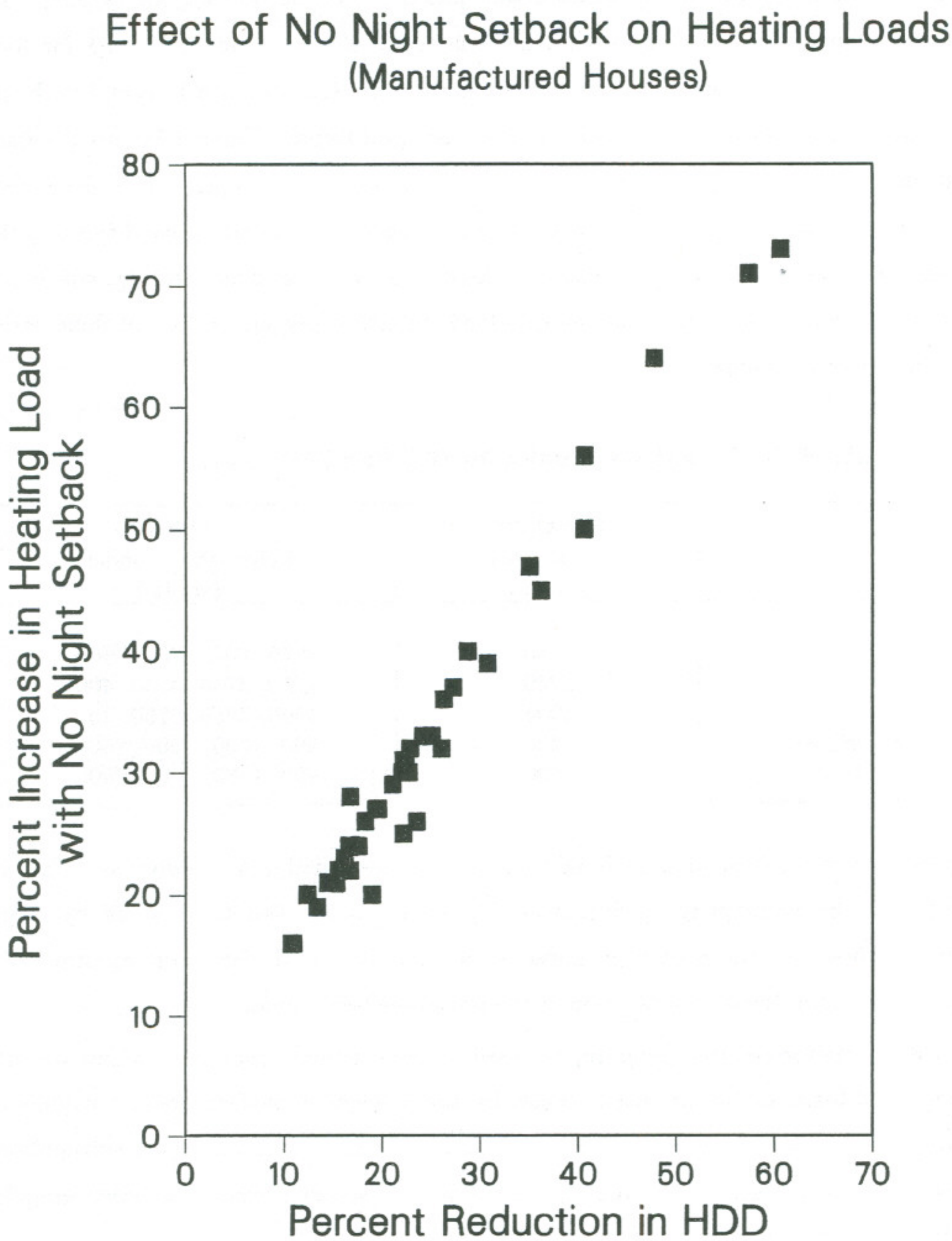


Fig.6.6.5

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one setback value is used to cover all three detached housing prototypes.

6.7. Building Floor Area

The LBL residential data base has been generated using five prototypical residential buildings with dimensions reflecting typical current construction practices (see Section 3.2 for details). To analyze the energy impact of house size variations, sensitivity studies have been done for four representative locations (Minneapolis, New York, Lake Charles or Houston, and Phoenix) with the building floor areas changed from 65% to 200% of the basic prototypes. Table 6.7a lists the floor areas modeled in this sensitivity analysis for the five building prototypes. The floor area sensitivity runs have the same aspect ratios, window percentages, and operating conditions as the base case houses. The internal loads have also been kept constant except for lighting, which has been scaled by floor area. Consequently, the internal loads intensity per square foot of floor varies inversely with the size of the house.

Table 6.7a. Sensitivity Studies for Building Floor Area

Building Prototype	Prototype Floor Area (sq. ft.)	Other Floor Areas Modeled (sq. ft.)
One Story	1540	1176, 2000, 2500, 3000
Two Story	2240	1750, 2750, 3250, 4000
Split-level	1904	1500, 2250, 2750, 3250
Middle Unit Townhouse	1200	900, 1600, 2000, 2500
End Unit Townhouse	1200	900, 1600, 2000, 2500

The impact of varying floor area on building loads has been analyzed in two ways. For the data base tables in the accompanying document [20], we compared the total loads from the sensitivity runs to those for the prototype house sizes, and developed regression equations for varying house sizes for total loads as a function of the prototype house load.

For the PEAR microcomputer program, we used a more detailed procedure where we first scaled the component loads of the prototype house by the changes in surface area or volume to derive an extrapolated total load for the sensitivity cases. We then compared these extrapolated loads to the results from the sensitivity analysis to developed regression equations accounting for the second-order interactions between loads and building size.

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20. Y. J. Huang, et.al., *Affordable Housing Through Energy Conservation, Data Base For Simplified Energy Analysis*, Lawrence Berkeley Laboratory Report 16343, Berkeley (1985).

The following discussion covers only the first simpler procedure. The procedure incorporated into the PEAR microcomputer program is covered in Section 7.

For the data base tables, we first analyzed total loads per ft^2 of floor to avoid the obvious scaling due to increasing house size. The results show that, for all five prototypes, variations in building loads per square foot can be expressed as a linear function of the total load of the base case house. Figures 6.7.1 and 6.7.2 are plots of the heating and cooling loads per ft^2 for floor area variations in three house prototypes.

COOLING LOAD PER SQUARE FOOT FOR
RESIDENTIAL BUILDINGS OF DIFFERENT FLOOR AREA

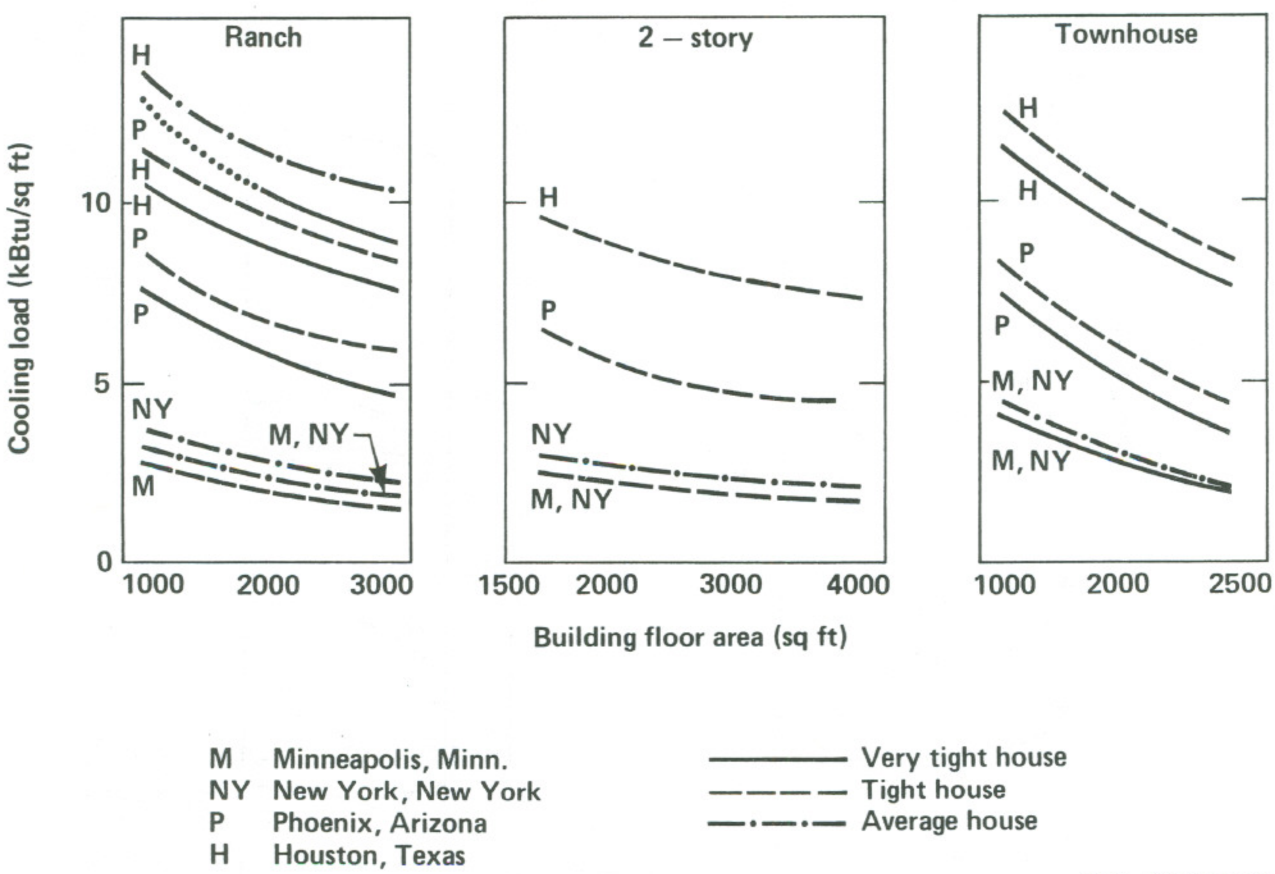

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Fig. 6.7.2

The curves show that the changes in loads per ft^2 are well-behaved across differing combinations of location and thermal integrity. For heating (Figure 6.7.1), larger floor areas are generally more efficient on a ft^2 basis for detached houses due to reduction in the surface-to-volume ratio. However, for attached houses (townhouses) and detached houses with negligible heating loads (less than 12 MBtus for the 1-story ranch house), smaller floor areas can be more efficient on a square foot basis because of the relatively larger internal loads. For cooling (Figure 6.7.2), larger floor

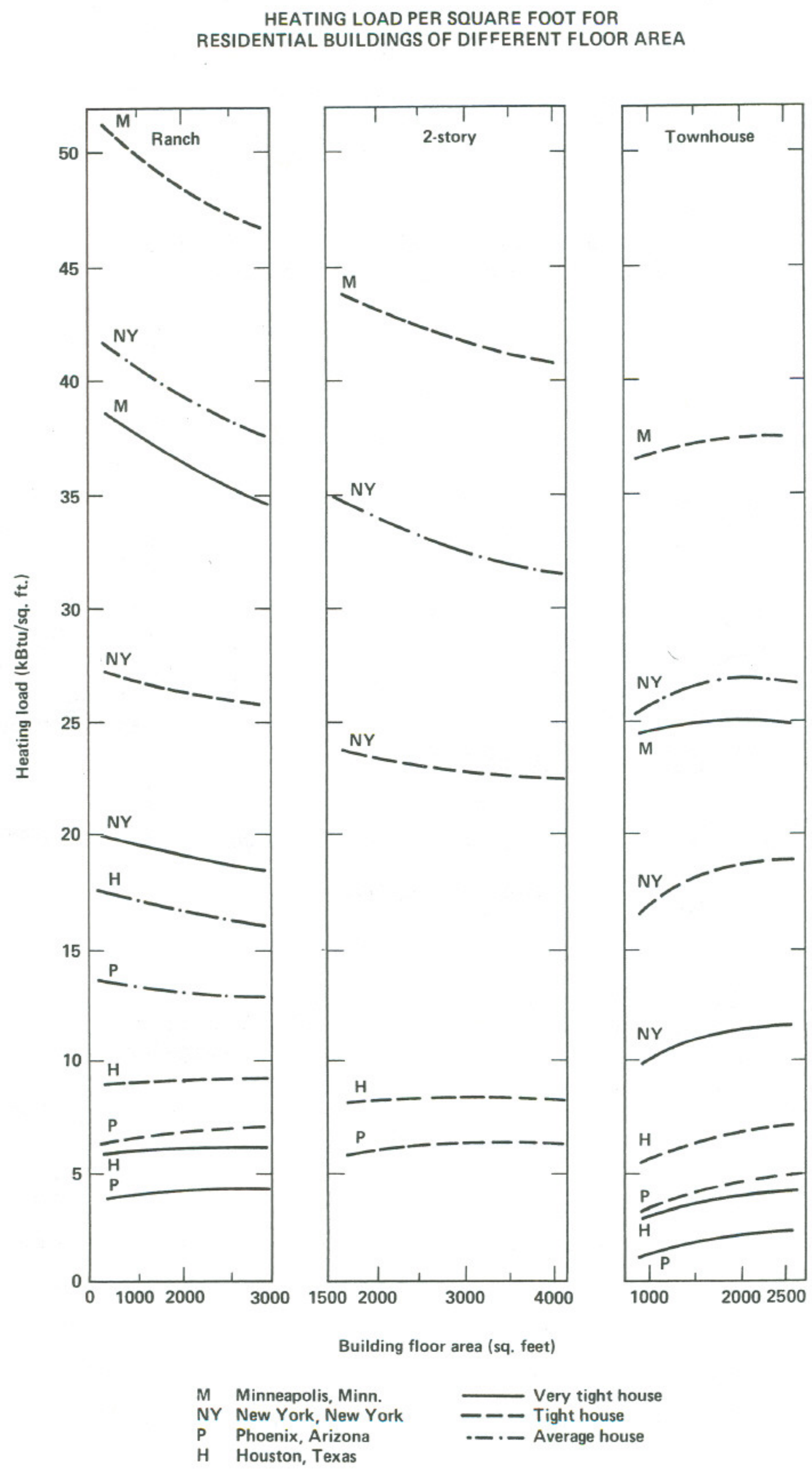

Fig. 6.7.1 Heating Loads per ft² for Residential Buildings of Different Floor Area

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areas are always more efficient on a square foot basis for both detached and attached houses because of their lower internal loads intensity.

For a given floor area variation, the Δ loads per ft^2 from the base case house has been found to vary linearly from the total base case loads , as illustrated by Figures 6.7.3 and 6.7.4. This linear relationship between Δ ft^2 loads and total base case loads irrespective of location and thermal integrity makes it possible to accurately extrapolate the effects of house size for all locations using regression equations based on the parametric studies done for three levels of thermal integrity in only four locations. Since the relationship of Δ loads per ft^2 to Δ floor area is clearly nonlinear, as shown in Figures 6.7.1 and 6.7.2, separate regression equations have been developed for each house size variation for all five building prototypes. For the data base tables, the regressions were done in the following form for total loads rather than loads per ft^2 :

$$TL_a = A \times TL_o + B \tag{35}$$

where: TL_a = estimated total load for house size a

TL_o = total load for base case house

Table 6.7b lists the coefficients developed for these equations. Since the total loads regressions also incorporate the obvious scaling due to increased house size, the correlation coefficients are all extremely high. For illustration, the same data used in Figure 6.7.3 for delta loads per square foot is shown in Figure 6.7.5 for total loads. The ft^2 variation mentioned before results in the small intercept and deviation from the dotted line representing the ratio of floor areas.

The "floor area multipliers" given in the data base matrices are the ratios of the extrapolated loads to the base case house loads:

$$\text{Floor area multiplier} = TL_a/TL_o \quad \text{, or} \quad = A + (B/TL_o) \tag{36}$$

Although the equation indicates that the "floor area multipliers" vary slightly depending on TL_o, for simplicity the data base tables show a single "floor area multiplier" calculated with an average base case load TL_o for each location and house prototype. In the cold locations, the average base case used was a house with R-30 ceiling, R-11 walls, FM3 foundation, 2-pane windows, and 0.7 ach infiltration. In the warm locations, the average base case used was a house with R-19 ceiling, R-11 walls, FM1 foundation, 2-pane windows, and 0.7 ach infiltration. These "floor area multipliers" are location and prototype specific, but do not include the interactive effects of varying thermal integrity.

The Effect of Floor Area on Heating Loads per sq.ft.
(1176 ft² Test House Compared to 1540 ft² Prototype House)

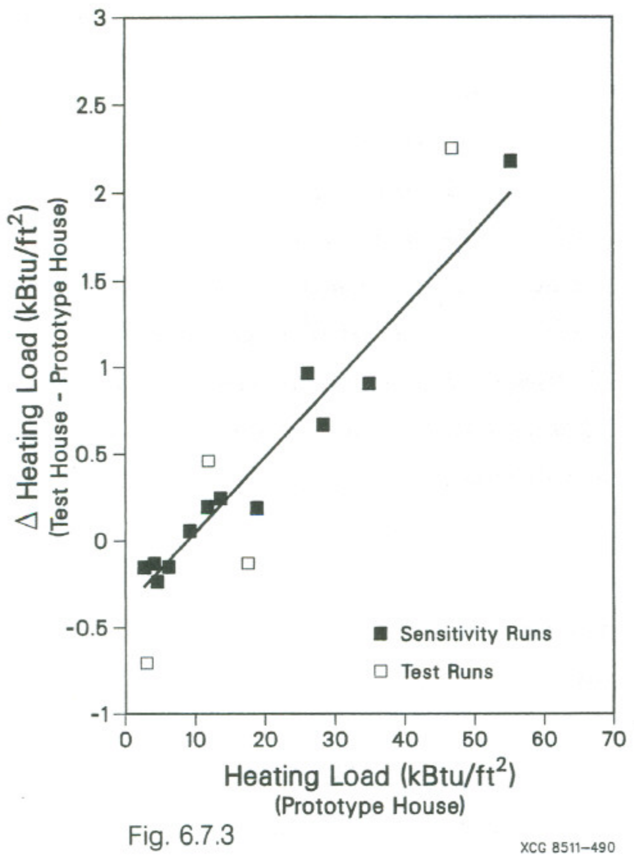

Fig. 6.7.3

The Effect of Floor Area on Cooling Loads per sq.ft.
(1176 ft² Test House Compared to 1540 ft² Prototype House)

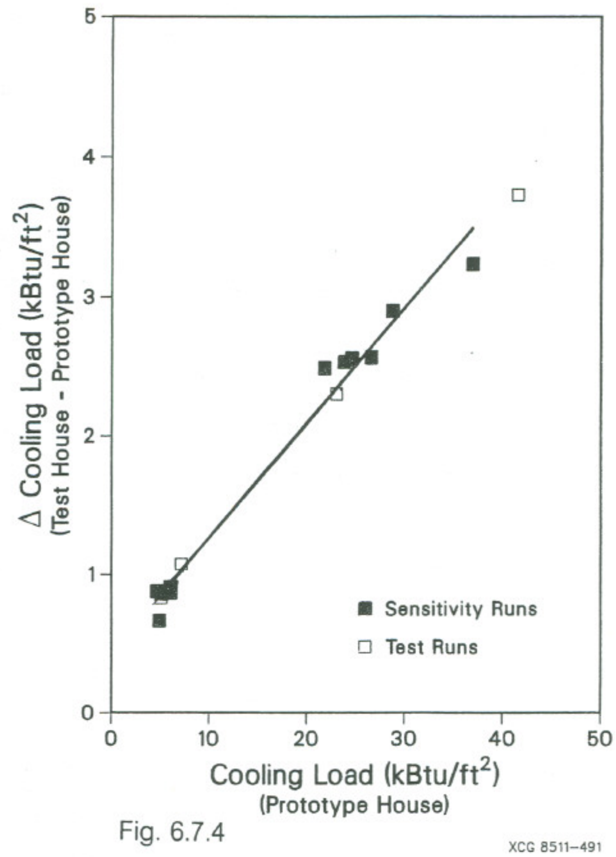

Fig. 6.7.4

The Effect of Floor Area on Heating Load
(1176 ft² Test House Compared to 1540 ft² Prototype House)

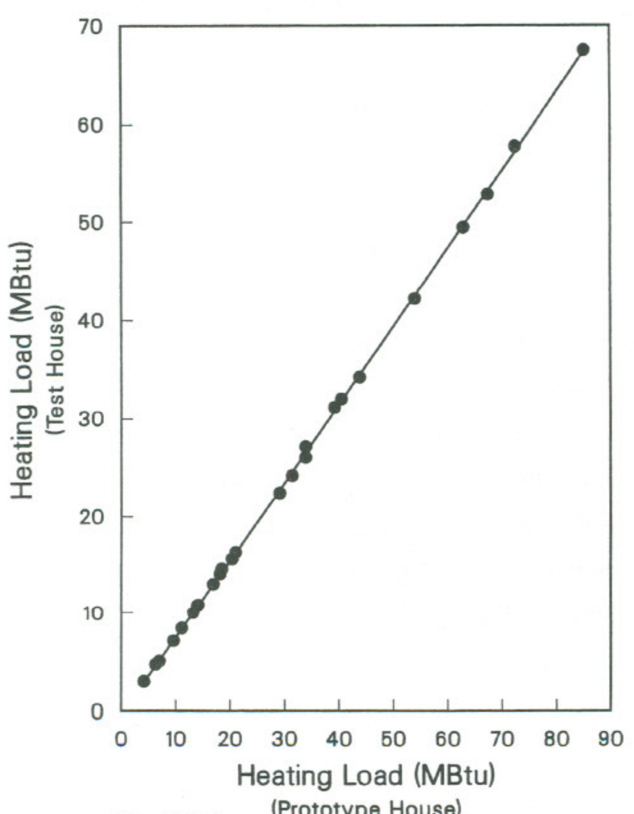

Fig. 6.7.5

The Effect of Floor Area on Cooling Load
(1176 ft² Test House Compared to 1540 ft² Prototype House)

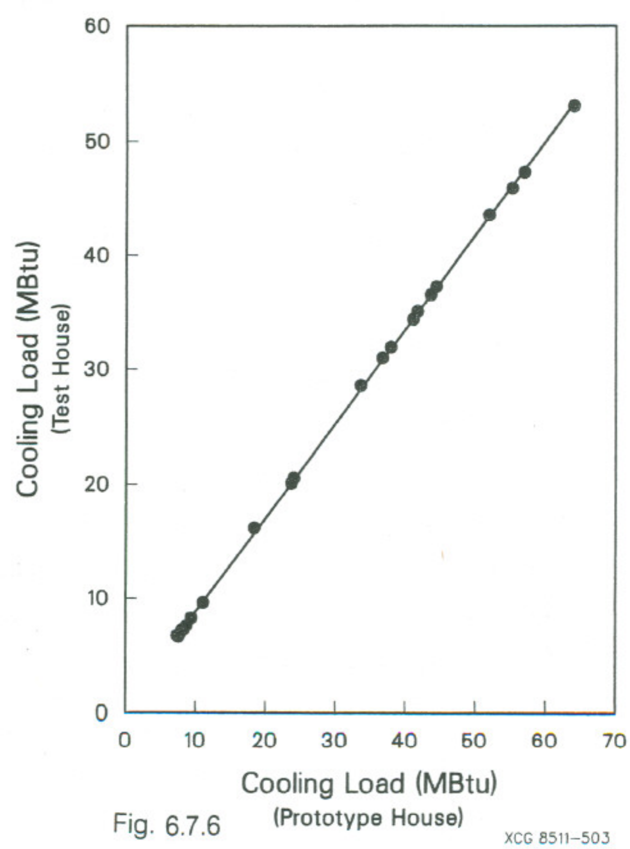

Fig. 6.7.6

Table 6.7b. Floor Area Regression Equations

House size (ft^2)	Heating Slope (A)	Heating Intercept (B)	Cooling Slope (A)	Cooling Intercept (B)
One-story Ranch				
1000	.7005	-.7274	.7400	.7597
2000	1.2457	.5033	1.2125	-.7034
2500	1.5021	1.1379	1.4393	-1.4522
3000	1.7632	1.5927	1.6639	-2.2661
Two-story				
1750	.8042	-.4107	.8309	.4851
2750	1.1975	.4413	1.1723	-.3974
3250	1.3870	.8651	1.3402	-.8304
4000	1.6655	1.4670	1.5909	-1.6250
Split-level				
1500	.8134	-.5802	.8405	.3474
2250	1.1557	.5118	1.1349	-.3643
2500	1.3755	1.2588	1.3259	-.7453
2750	1.5901	2.0172	1.5116	-1.0868
Middle-unit Townhouse				
900	.7564	-.4309	.8397	.1967
1600	1.3141	.6214	1.2200	-.5641
2000	1.6198	1.2634	1.4344	-1.1404
2500	1.9932	2.0727	1.6955	-1.7903
End-unit Townhouse				
900	.7733	-.5331	.8271	.3093
1600	1.2899	.7599	1.2241	-.4857
2000	1.5700	1.5424	1.4453	-1.0438
2500	1.9104	2.5351	1.7168	-1.7889

Tables 6.7c and 6.7d compare the differences between DOE-2.1A test runs for a range of house sizes in two locations (New York and Phoenix) and floor area corrections based on the regression equations in Table 6.7b using both exact and average values for TL_o.

As expected, the largest discrepancies occur at extreme house sizes (1000 and 2250 ft^2). In heating, floor area corrections using an exact load show average deviations of 0.45 MBtu, while those using average loads show average deviations of 0.89 MBtu. In cooling, using either exact or average loads produce comparable deviations of less than 0.30 MBtu.

For a discussion of how floor area corrections are done in the PEAR microcomputer program, refer to Section 7.

6.8. Attached Sunspaces

A sunspace option attached as an extension to the south side of a one-story ranch house can reduce heating loads in some areas of the country. Sensitivity analyses have been performed to

Table 6.7c. Floor Area Sensitivity Test DOE-2.1A Runs for New York Heating

	Loose (R19 Ceil, R0 Wall, R0 Flr, 1-pane windows, 0.7 ach)				Tight (R38 Ceil, R27 Wall, R-10 Flr, 3-pane windows, 0.7 ach)			
	Floor Area Multiplier	Total Heating Load (MBtu)	Δ Heating Load (MBtu)	Pct Δ Heating Load (%)	Floor Area Multiplier	Total Heating Load (MBtu)	Δ Heating Load (MBtu)	Pct Δ Heating Load (%)
1000 sq.ft. house								
DOE-2 test run	0.698	50.502	-	-	0.646	17.578	-	-
exact T_o	0.690	49.947	-0.555	-1.1	0.674	18.322	0.744	4.2
average T_o	0.682	49.315	-1.187	-2.3	0.682	18.538	0.960	5.5
1250 sq.ft. house								
DOE-2 test run	0.841	60.855	-	-	0.813	22.097	-	-
exact T_o	0.834	60.303	-0.552	-0.9	0.826	22.450	0.354	1.6
average T_o	0.829	60.000	-0.855	-1.4	0.829	22.555	0.458	2.1
1540 sq.ft. house (Base case)								
DOE-2 base run	1.000	72.341	-	-	1.000	27.194	-	-
1750 sq.ft. house								
DOE-2 test run	1.111	80.402	-	-	1.133	30.833	-	-
exact T_o	1.115	80.687	0.285	0.3	1.121	30.474	0.358	-1.1
average T_o	1.118	80.886	0.484	0.6	1.118	30.406	-0.427	-1.4
2250 sq.ft. house								
DOE-2 test run	1.367	98.911	-	-	1.446	39.315	-	-
exact T_o	1.385	100.210	1.299	1.3	1.404	38.182	-1.133	-2.9
average T_o.	1.395	101.921	2.010	2.0	1.395	37.938	-1.377	-3.6

Table 6.7d. Floor Area Sensitivity Test DOE-2.1A Runs for Phoenix Cooling

	Loose (R19 Ceil, R0 Wall, FM0 Fdn, 1-pane Windows, 0.7 ach)				Tight (R38 Ceil, R27 Wall, FM3 Fdn, 3-pane Windows, 0.7 ach)			
	Floor Area Multiplier	Total Cooling Load (MBtu)	Δ Cooling Load (MBtu)	Pct Δ Cooling Load (%)	Floor Area Multiplier	Total Cooling Load (MBtu)	Δ Cooling Load (MBtu)	Pct Δ Cooling Load (%)
1000 sq.ft. house								
DOE-2 test run	0.744	47.590	-	-	0.756	26.830	-	-
exact T_o	0.752	48.096	0.506	1.0	0.761	27.030	0.203	0.7
average T_o	0.757	48.413	0.823	1.7	0.757	26.871	0.041	0.2
1250 sq.ft. house								
DOE-2 test run	0.866	55.348	-	-	0.871	30.915	-	-
exact T_o	0.868	55.500	0.152	0.3	0.873	30.992	0.077	0.2
average T_o	0.870	55.675	0.327	0.6	0.870	30.902	-0.013	0.0
1540 sq.ft. house (Base case)								
DOE-2 base run	1.000	63.968	-	-	1.000	35.505	-	-
1750 sq.ft. house								
DOE-2 test run	1.094	69.969	-	-	1.092	38.790	-	-
exact T_o	1.092	69.852	-0.116	-0.2	1.088	38.628	-0.162	-0.4
average T_o	1.089	69.718	-0.250	-0.3	1.089	38.661	-0.129	-0.3
2250 sq.ft. house								
DOE-2 test run	1.309	83.712	-	-	1.312	46.576	-	-
exact T_o	1.309	83.737	0.025	0.0	1.296	45.998	-0.578	-1.2
average T_o	1.302	83.288	-0.424	-0.5	1.302	46.229	-0.347	-0.7

model four sunspace configurations that are 8 feet in width and either 12 or 24 feet long with either opaque or glass roof. The simulations have been run in 11 representative locations with different climatic conditions for three thermal integrities (loose, medium and tight options). Table 6.8a shows the cities and foundation types that have been modeled, while Table 6.8b lists the various thermal integrities by foundation type.

Table 6.8a. Cities and Foundation Conditions for which Attached Sunspaces were Modeled

Albuquerque	slab	Minneapolis	basement
Atlanta	slab	New York	basement
Chicago	basement	Phoenix	slab
Denver	basement	San Francisco	slab
Lake Charles	slab	Seattle	basement
Miami	slab		

Table 6.8b. Thermal Integrities and Foundation Types

Slab Foundation Cases		
Loose	Medium	Tight
R-19 ceiling	R-19 ceiling	R-30 ceiling
R-11 wall	R-11 wall	R-19 wall
No slab edge insulation	R-5 2' perimeter (FM1)	R-5 2' perimeter (FM1)
0.7 ach infiltration	0.7 ach infiltration	0.7 ach infiltration
Single glazing	Double glazing	Double glazing
Basement Foundation Cases		
Loose	Medium	Tight
R-19 ceiling	R-30 ceiling	R-38 ceiling
R-11 wall	R-11 wall	R-19 wall
R-5 4' basement wall (FM1)	R-5 8' basement wall (FM3)	R-10 8' basement wall (FM4)
0.7 ach infiltration	0.7 ach infiltration	0.7 ach infiltration
Single glazing	Double glazing	Triple glazing

It was assumed that the sunspaces did not have glazing properties better than that of the house itself, i.e., single-glazed sunspaces were simulated for all three house types, but double-glazed sunspaces were simulated only on the medium and tight houses. The sunspace results have been compared to a base case house (without a sunspace) with the same thermal properties. For more details on the characteristics of the sunspace and the operating conditions that were modeled see Section 3.5.

Tables 6.8c and 6.8d show the results for each location and for each configuration. Since the cooling loads are increased in some climates with the use of an attached sunspace (especially those with glass roofs), the results are reported as net changes (in MBtu) in the total space conditioning loads of the house. In addition, a Glass Foot factor (GF factor) has been calculated by dividing the delta values by either 12 or 24, corresponding to the width of the sunspace. A modifier is then calculated for each location and each option by multiplying the average glass foot factor (GF factor) by 1000. The resultant modifiers presented in Appendix A.7 can be used to estimate the reductions in heating loads for any of the 45 locations:

$$\text{Heating Load Savings (MBtu)} = \frac{\text{Modifier x Length of sunspace (ft.)}}{1000} \qquad (37)$$

To better incorporate the sunspace results into the PEAR microcomputer program, we regressed the heating load savings due to the sunspace against various climate and building parameters. We found good correlations (coefficients > 0.90) using heating degree-days base 65F to account for temperature differences, and south heating insolation-days at either base 57F or 60F to account for the useful solar gain.† To combine the data for loose, medium and tight houses, we used the base house heating load as an indicator for the house heating demand. Lastly, we added sunspace length as a fourth parameter for changes in the ratio of opaque end walls to glazed surfaces. The final form of the sunspace regression equation is :

$$SS = A + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 \qquad (38)$$

where
- SS = estimated solar savings (in KBtu per ft of sunspace length)
- A = constant (predicted value of SS when X = 0)
- B_1 = heating degree-days at base 65F.
- B_2 = south heating insolation-days at base 57F for sunspaces with opaque roofs, and at base 60F for sunspaces with glazed roofs.
- B_3 = base house heating load in MBtu.
- B_4 = sunspace length in ft.
- $X_{1,2,3,4}$ = regression coefficients.

Figure 6.8.1 shows a sample plot for the single-pane sunspace with a glazed roof. Table 6.8e gives the regression coefficients used in PEAR for estimating the heating load reductions for attached sunspaces, while Table 6.8f gives the heating degree-days and heating insolation-days variables for the 45 cities in the PEAR data base.

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† Heating insolation-days is defined as the amount of insolation in $\text{KBtu}\cdot\text{day/ft}^2$ on a vertical surface when air temperatures are less than the defined base temperature. For this analysis, we used base temperatures of 57F or 60 F on a south-facing wall because that is the orientation of the attached sunspace.

Table 6.8c Opaque Roof Sunspace Sensitivity Results

(Heating Load Savings in MBtu)

Location	Option†	OP12(1) (ΔMBtu)	GF Factor	OP24(1) (ΔMBtu)	GF Factor	Modifier*	OP24(2) (ΔMBtu)	Modifier*
Albuquerque	Loose	-3.76	.313	-6.63	.276	30		
	Medium	-2.57	.214	-4.56	.190	20	-6.10	25
	Tight	-1.98	.165	-3.38	.141	15	-4.71	20
Atlanta	Loose	-1.81	.151	-3.30	.138	15		
	Medium	-1.01	.084	-1.93	.080	8	-2.86	12
Chicago	Loose	-1.26	.105	-2.68	.112	11		
	Medium	-0.56	.047	-1.32	.055	5	-2.86	12
	Tight	-0.07	.006	-0.27	.011	1	-1.62	7
Denver	Loose	-2.28	.190	-4.51	.188	19		
	Medium	-1.52	.127	-3.05	.127	13	-4.90	20
	Tight	-0.99	.083	-1.89	.079	8	-3.66	15
Lake Charles	Loose	-1.40	.117	-2.42	.101	11		
	Medium	-0.83	.069	-1.47	.061	7	-2.08	9
Miami	Loose	-0.10	.008	-0.17	.007	1		
	Medium	-0.06	.005	-0.09	.004	1	-0.13	1
Minneapolis	Loose	-0.77	.064	-2.02	.084	7		
	Medium	-0.03	.003	-0.44	.018	1	-2.97	12
	Tight	+0.58	-.048	+0.85	-.035	-5	-1.59	7
New York	Loose	-1.47	.123	-3.03	.126	13		
	Medium	-0.85	.071	-1.83	.076	7	-3.18	13
	Tight	-0.44	.037	-0.93	.039	4	-2.24	9
Phoenix	Loose	-1.55	.129	-2.66	.111	12		
	Medium	-0.92	.077	-1.62	.068	7	-1.98	8
San Francisco	Loose	-2.67	.223	-4.72	.197	21		
	Medium	-1.56	.133	-2.86	.119	13	-4.02	17
Seattle	Loose	-1.22	.102	-2.55	.106	10		
	Medium	-0.57	.048	-1.29	.054	5	-2.46	10
	Tight	-0.11	.009	-0.34	.014	1	-1.44	6

Notes: * Modifier = Average GF factor x 100
† Loose, medium and tight options are defined in Table 6.8b

OP 12(1) = 12 ft. long sunspace with opaque roof,single-glazed
OP 24(1) = 24 ft. long sunspace with opaque roof,single-glazed
OP 24(2) = 24 ft sunspace with opaque roof, double-glazed+1

Table 6.8d Glass Roof Sunspace Sensitivity Results

(Heating Load Savings in MBtu)

Location	Option†	OP12(1) (ΔMBtu)	GF Factor	OP24(1) (ΔMBtu)	GF Factor	Modifier*	OP24(2) (ΔMBtu)	Modifier*
Albuquerque	Loose	-5.70	.475	-9.41	.392	43		
	Medium	-3.97	.331	-6.45	.269	30	-8.41	35
	Tight	-2.81	.234	-4.34	.181	21	-6.01	25
Atlanta	Loose	-3.00	.250	-4.62	.193	22		
	Medium	-1.65	.138	-2.51	.105	12	-3.91	16
Chicago	Loose	-2.53	.211	-4.44	.185	20		
	Medium	-1.50	.125	-2.51	.105	12	-5.75	24
	Tight	-0.67	.056	-0.97	.040	5	-3.96	17
Denver	Loose	-4.57	.381	-7.90	.329	36		
	Medium	-3.31	.276	-5.67	.236	26	-9.11	38
	Tight	-2.38	.198	-3.87	.161	10	-7.01	29
Lake Charles	Loose	-2.16	.180	-2.81	.117	15		
	Medium	-0.91	.076	-1.21	.050	6	-2.13	9
Miami	Loose	+0.27	-.023	+0.77	-.032	+3		
	Medium	+0.31	-.026	+0.81	-.034	+3	+0.81	+3
Minneapolis	Loose	-1.25	.107	-2.29	.095	10		
	Medium	-0.11	.009	-0.05	.002	1	-5.78	24
	Tight	+0.29	-.024	+1.68	-.070	+5	-3.83	16
New York	Loose	-3.04	.253	-5.19	.216	24		
	Medium	-2.04	.170	-3.48	.145	16	-6.04	25
	Tight	-1.16	.097	-1.98	.083	9	-4.46	19
Phoenix	Loose	-2.27	.189	-3.26	.136	16		
	Medium	-1.14	.095	-1.66	.069	7	-2.14	9
San Francisco	Loose	-5.62	.468	-8.94	.373	42		
	Medium	-3.54	.295	-5.60	.233	26	-7.85	33
Seattle	Loose	-2.67	.233	-4.78	.199	22		
	Medium	-1.67	.139	-3.01	.125	13	-5.59	23
	Tight	-0.96	.080	-1.60	.067	7	-3.92	16

Notes: * Modifier = Average GF factor x 100
† Loose, medium and tight options are defined in Table 6.8b

GL 12(1) = 12 ft. long sunspace with glass roof, single-glazed
GL 24(1) = 24 ft. long sunspace with glass roof, single-glazed
GL 24(2) = 24 ft. sunspace with glass roof, double-glazed

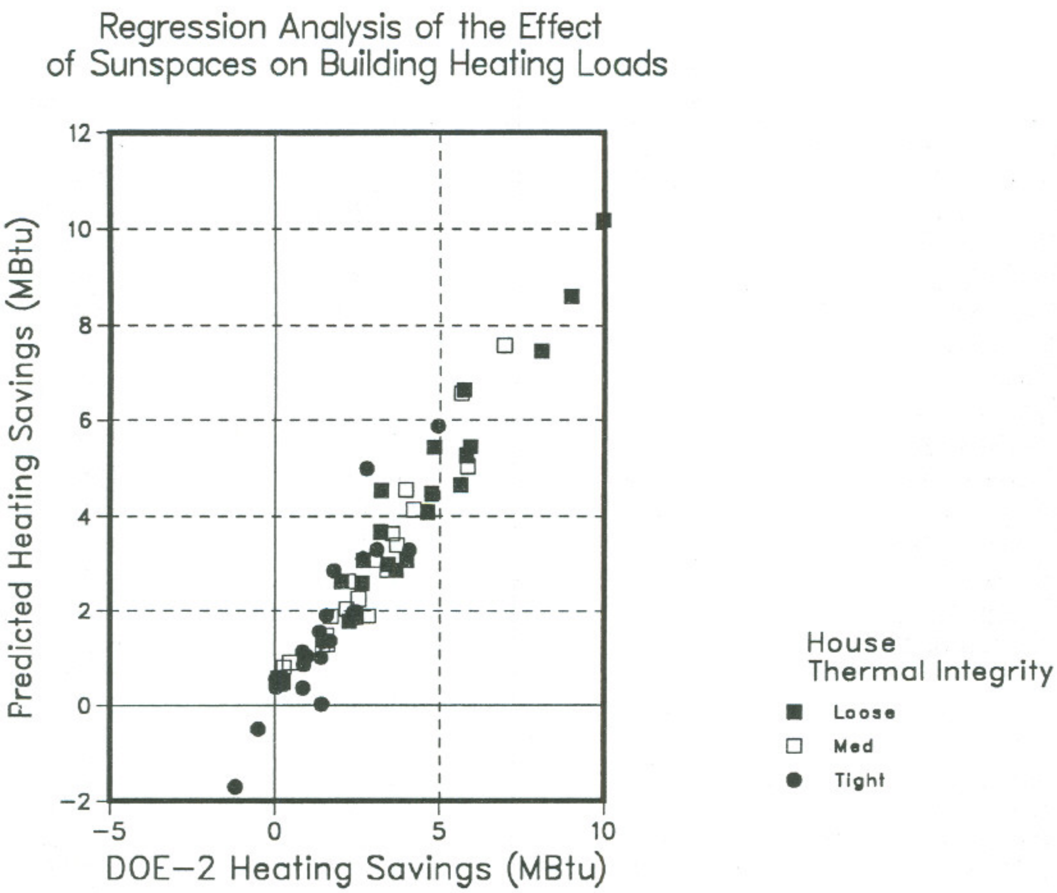


Fig 6.8.1

Table 6.8e Regression Coefficients for Heating Load Reductions for Different Attached Sunspace Configurations

(KBtu per foot of sunspace length)

	Intercept	Slopes			
Sunspace configuration	A (KBtu)	B_1 (HDD 65F)	B_2 (South HID 60F)	B_3 (HL, MBtu)	B_4 (Length, ft.)
Glass roof 1-pane	69.8	-0.1210	2.543	6.2558	-2.4369
Glass roof 2-pane	196.4	-0.0859	2.039	7.3204	-7.5658
Sunspace configuration	A (KBtu)	B_1 (HDD 65F)	B_2 (South HID 57F)	B_3 (HL, MBtu)	B_4 (Length, ft.)
Opaque roof 1-pane	38.0	-0.0833	1.833	3.9250	-.3670
Opaque roof 2-pane	85.0	-0.0666	1.757	3.8162	-2.6296

Table 6.8f Heating degree-days and insolation-days for 45 cities

Location	Heating degree-days 65F	Heating insolation-days (south) base 57F	base 60F
Albuquerque NM	4220	227.0	249.6
Atlanta GA	2828	113.0	130.4
Birmingham AL	2724	104.2	124.6
Bismarck ND	9411	202.7	214.4
Boise ID	5577	168.4	186.5
Boston MA	5690	194.0	215.3
Brownsville TX	464	5.7	22.4
Buffalo NY	6731	158.5	172.9
Burlington VT	7943	181.1	196.9
Charleston SC	2115	85.0	100.0
Cheyenne WY	6988	241.9	262.1
Chicago IL	6065	170.1	186.5
Cincinnati OH	4843	149.6	163.3
Denver CO	5612	211.9	237.2
El Paso TX	2587	127.9	147.2
Fort Worth TX	2229	112.0	129.8
Fresno CA	2535	101.9	122.9
Great Falls MT	7392	201.9	218.6
Honolulu HA	0	.0	.0
Jacksonville	1138	51.8	70.1
Juneau AK	9245	194.6	217.6
Kansas City MO	4904	150.4	165.2
Lake Charles	1570	56.6	71.0
Las Vegas NV	2370	115.6	145.5
Los Angeles CA	1459	41.7	88.1
Medford OR	4864	121.9	137.9
Memphis TN	3106	128.7	145.6
Miami FL	142	5.1	8.3
Minneapolis MN	8282	202.8	216.8
Nashville TN	3425	113.9	130.8
New York NY	4461	164.7	187.1
Oklahoma City	3829	144.5	164.7
Omaha NE	6092	182.2	200.9
Philadelphia	5085	166.9	179.4
Phoenix AZ	1436	58.1	79.1
Pittsburgh PA	5598	156.4	170.1
Portland ME	7537	224.6	244.4
Portland OR	4789	135.5	162.8
Reno NV	5781	166.8	186.9
Salt Lake City	6070	193.8	210.7
San Antonio TX	1800	67.7	81.0
San Diego CA	1132	31.5	67.6
San Francisco	3239	146.5	208.2
Seattle WA	5291	159.7	190.2
Washington DC	4061	150.8	167.3

7.0 DEVELOPMENT OF THE PEAR MICROCOMPUTER PROGRAM

7.1 Component Loads Approach

We designed a software package called PEAR (Program for Energy Analysis of Residences) to serve as the simplified calculation method for estimating the cost and energy effectiveness of different conservation options. The program, which uses the comprehensive DOE-2 database described earlier, covers five residential building prototypes in over 800 locations. PEAR can be used to estimate energy and cost savings resulting from typical conservation measures such as ceiling, wall and floor insulation, window type and glazing layers, infiltration reduction, and equipment efficiency. It also allows the user to adjust for optional measures including roof or wall color, movable insulation, night temperature setback, reflective or heat absorbing glass, thermal mass in exterior walls, and two attached sunspace options.

The methodology used to analyze and quantify the Δ heating and cooling loads* for all these conservation measures was described in detail in the preceding chapters of this report. The Δ loads tables presented in the accompanying document [21] are accurate representations of the data base (see Fig. 7.1.1), but not flexible for extending that data to building geometries, component characteristics, and geographic locations different from those assumed in the DOE-2.1A simulations.

To increase the flexibility of the database to handle different conservation measures and prototypes, we developed the concept of *component loads*. We define component loads as the net annual contribution of each building component to the heating or cooling loads of the building. We have calculated them from regressions correlating the Δ loads to steady-state parameters for the various building components. For insulation measures, we regressed Δ loads against either ceiling and wall conductivity or foundation conductance. For infiltration, we regressed Δ loads against air changes per hour; and for windows, against window area. In Figures 7.1.2 to 7.1.9 we show typical regression plots of Δ heating and cooling loads for the one-story prototype house in Washington, D.C.

We assume that component loads are zero at the y-intercept, i.e., at zero conductance for ceiling, walls, and floors; zero air changes for infiltration; and zero area for windows. † We base the component loads for the simulated measures on their Δ loads from the y-intercept, which is

21. Y.J. Huang, et.al., *Affordable Housing Through Energy Conservation, Data Base For Simplified Energy Analysis,* Lawrence Berkeley Laboratory Report 16343, Berkeley (1985).

*We define Δ loads as the change in loads due to the addition of conservation measures. We calculated them by comparing simulation results in the database that differ by only a single measure.

† We use this extrapolation only for computing the component loads and not for extending the range of the database. Significant interactions between the Δ loads can be expected in super-insulated houses with extremely high insulation levels beyond those covered in the database.

WASHINGTON 1 STORY RANCH HOUSE BASEMENT

HEATING

Base Load = 110.709 MBtu/Yr

Ceiling		Wall		Foundation	
R-0	0.	R-0	0.	R-0	0.
R-11	-28.03	R-11	-13.41	R-5 4ft	-3.76
R-19	-31.15	R-13	-14.12	R-5 8ft	-5.78
R-30	-33.67	R-19	-16.34	R-10 8ft	-8.21
R-38	-34.60	R-24	-17.67	R-11 Flr	-7.25
R-49	-35.39	R-27	-18.11	R-19 Flr	-9.06
R-60	-35.89				

Infiltration	
Hi (1.0 ach)	0.
Med (.7 ach)	-7.50
Low (.4 ach)	-15.00

Window	Sash	10% area	15% area	20% area
1 pane	Alum	-7.77	-3.92	0.
	Alum+TB	-9.26	-6.15	-2.98
	Wood	-10.00	-7.25	-4.45
2 pane 1/2"	Alum	-14.05	-13.26	-12.34
	Alum+TB	-15.48	-15.41	-15.20
	Wood	-16.16	-16.42	-16.55
3 pane 1/2"	Alum	-16.26	-16.25	-16.09
	Alum+TB	-17.43	-17.99	-18.42
	Wood	-18.07	-18.96	-19.70

Area Multipliers

1000	.679	1700	1.091	2400	1.480
1100	.739	1800	1.147	2500	1.535
1200	.798	1900	1.204	2600	1.590
1300	.857	2000	1.260	2700	1.645
1400	.917	2100	1.315	2800	1.700
1500	.976	2200	1.370	2900	1.755
1600	1.034	2300	1.425	3000	1.809

COOLING

Base Load = 39.302 MBtu/Yr

Ceiling		Wall		Foundation	
R-0	0.	R-0	0.	R-0	0.
R-11	-7.82	R-11	-2.24	R-5 4ft	-.70
R-19	-8.74	R-13	-2.37	R-5 8ft	-1.04
R-30	-9.43	R-19	-2.76	R-10 8ft	-1.45
R-38	-9.69	R-24	-2.96	R-11 Flr	-.81
R-49	-9.94	R-27	-3.03	R-19 Flr	-1.01
R-60	-10.08				

Infiltration	
Hi (1.0 ach)	.0
Med (.7 ach)	-.54
Low (.4 ach)	-1.08

Window	Sash	10% area	15% area	20% area
1 pane	Alum	-8.32	-4.09	0.
	Alum+TB	-8.35	-4.13	-.05
	Wood	-8.36	-4.15	-.07
2 pane 1/2"	Alum	-9.39	-5.75	-2.11
	Alum+TB	-9.42	-5.79	-2.16
	Wood	-9.44	-5.81	-2.18
3 pane 1/2"	Alum	-10.03	-6.57	-3.20
	Alum+TB	-10.05	-6.60	-3.23
	Wood	-10.06	-6.62	-3.25

Area Multipliers

1000	.786	1700	1.059	2400	1.315
1100	.825	1800	1.096	2500	1.352
1200	.865	1900	1.133	2600	1.387
1300	.905	2000	1.170	2700	1.422
1400	.944	2100	1.206	2800	1.457
1500	.984	2200	1.243	2900	1.492
1600	1.022	2300	1.279	3000	1.527

Fig. 7.1.1 Sample Data Base Matrix

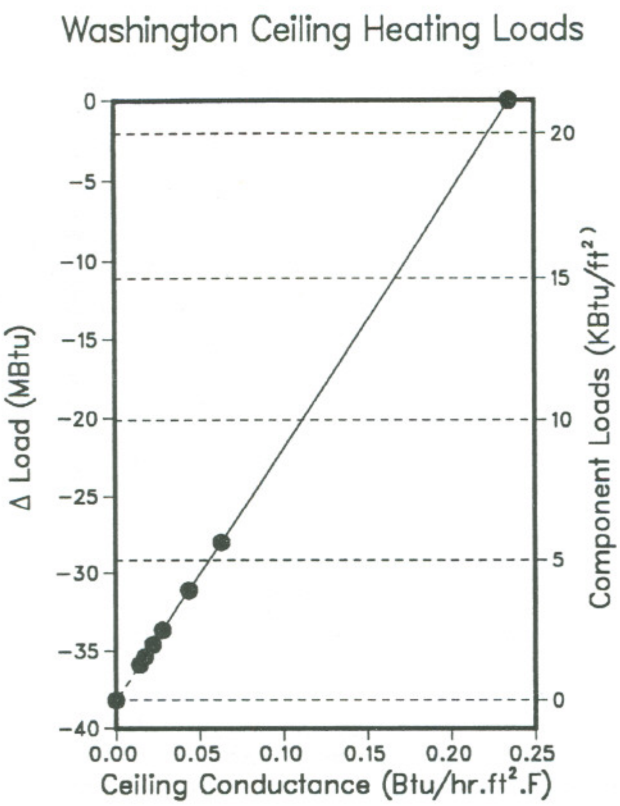


Fig. 7.1.2

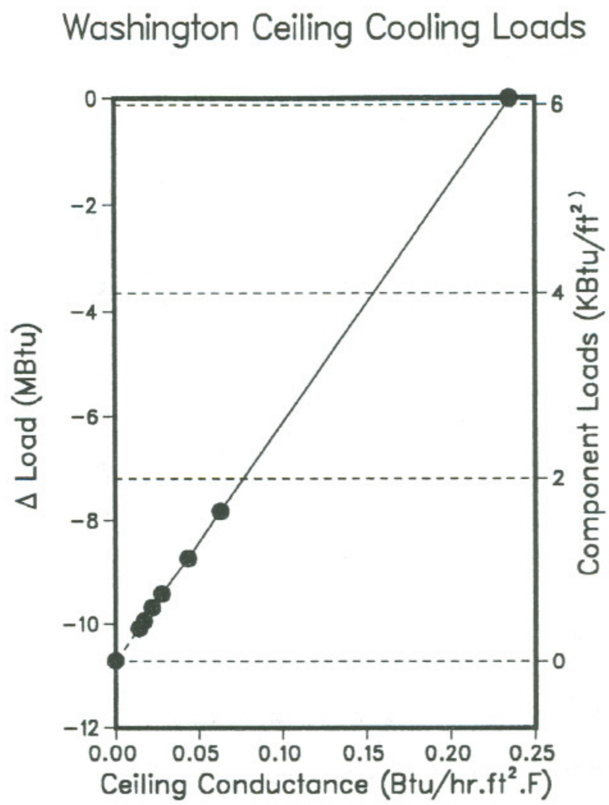


Fig. 7.1.3

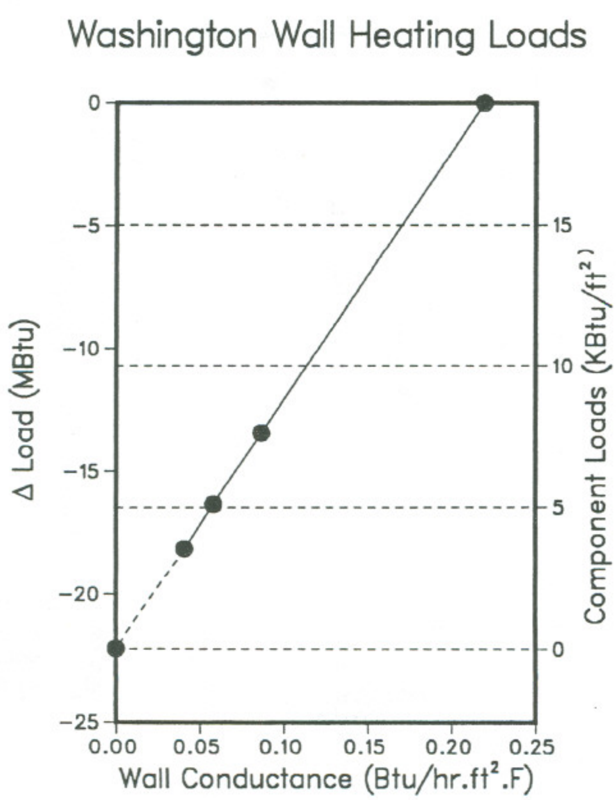


Fig. 7.1.4

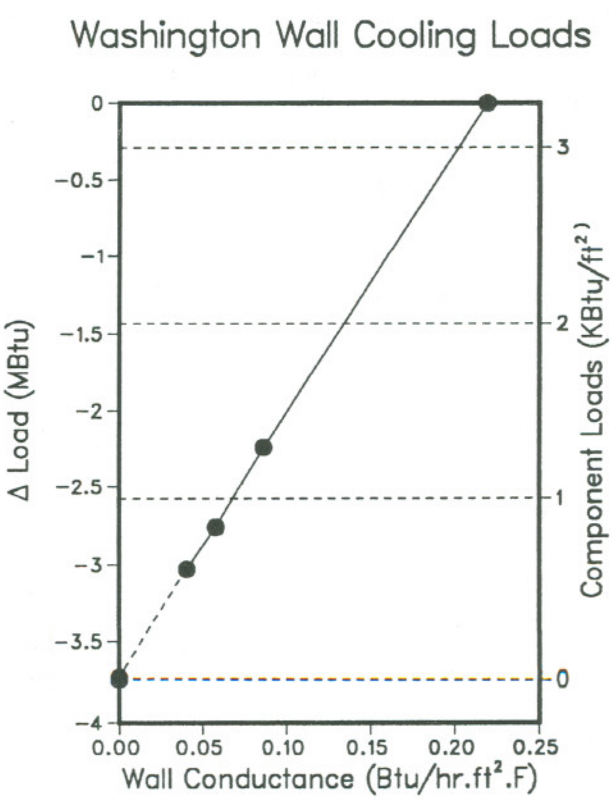


Fig. 7.1.5

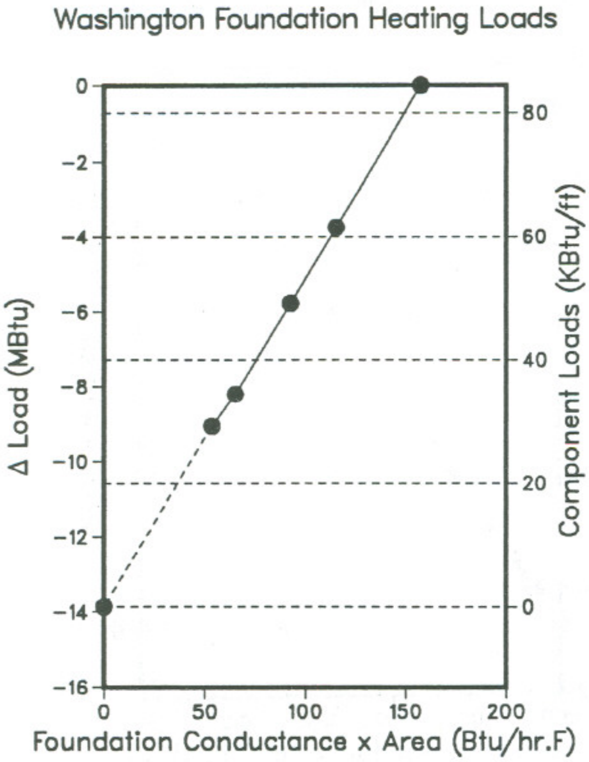


Fig. 7.1.6

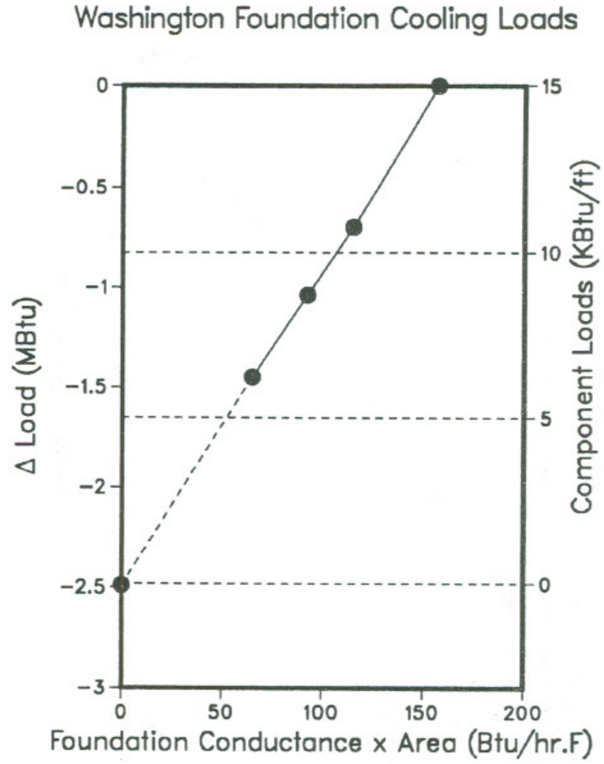


Fig. 7.1.7

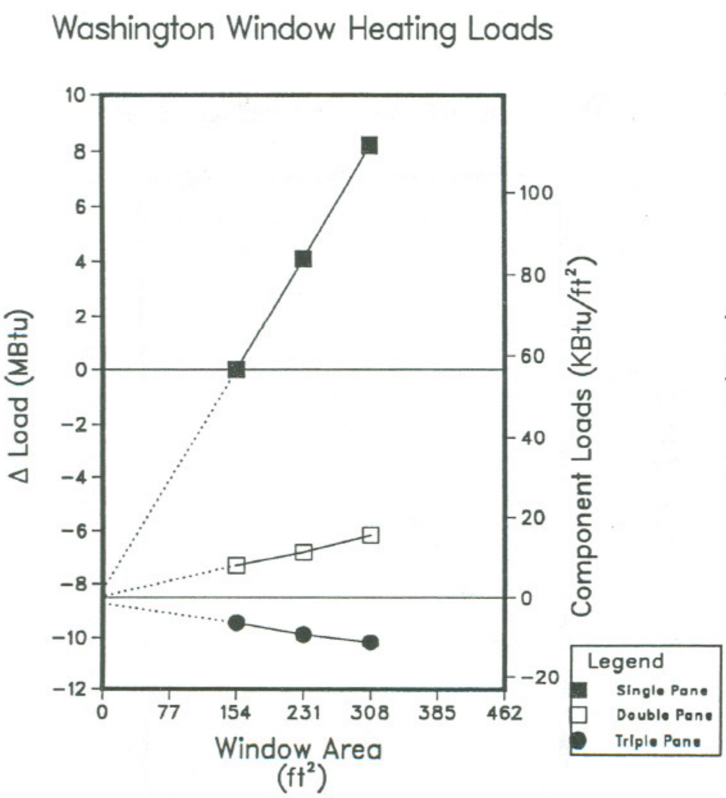


Fig. 7.1.8

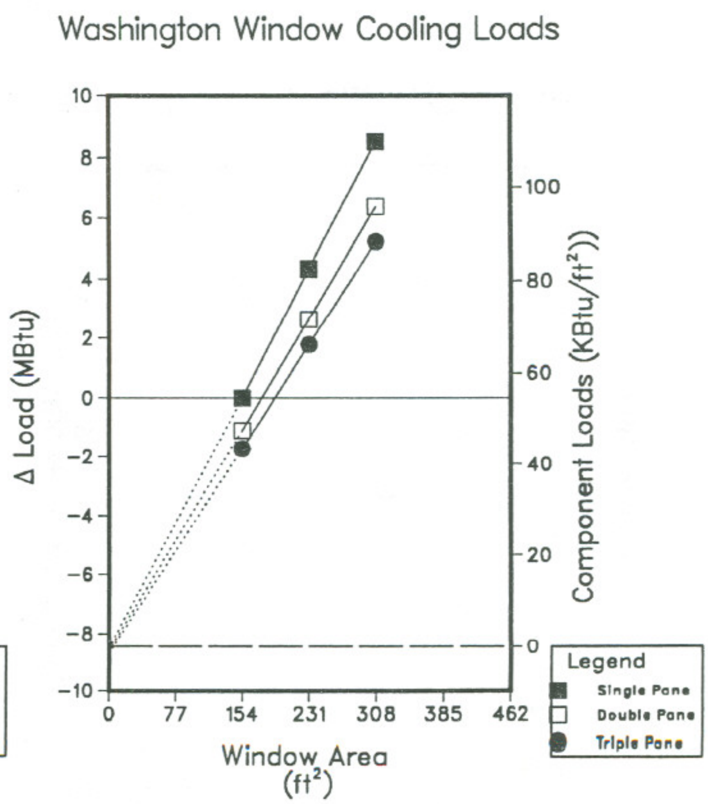


Fig. 7.1.9

indicated on the right-hand scales of Figures 7.1.2 through 7.1.9. To facilitate scaling, we normalized the component loads either by square foot (for ceilings, walls, and windows), per perimeter foot (for foundations), or per cubic foot (for infiltration).

Since component loads correspond to the net loads effect for each component, one can scale them by the actual dimensions of the ceiling, walls, foundation, and windows to make the database relatively nonprototype-specific. The functional form of the regression equations allow one to easily interpolate component loads for intermediate conditions using either adjacent component loads or general equations to describe the entire range. The component loads calculation procedure is summarized as:

$$\text{Bldg Load} = [(\text{Component Load}_{\text{ceiling}} * \text{Area}_{\text{ceiling}}) + (\text{Component Load}_{\text{wall}} * \text{Area}_{\text{wall}}) + (\text{Component Load}_{\text{foundation}} * \text{Length}_{\text{foundation}}) + (\text{Component Load}_{\text{windows}} * \text{Area}_{\text{windows}}) + (\text{Component Load}_{\text{infiltration}} * \text{Volume}_{\text{ach}}) + (\text{Residual Load})] * \text{Floor Area Adjustment} \quad (39)$$

The residual load in the equation is the difference between the sum of the component loads and the total loads from the actual DOE-2 database, and represents the net effect of internal loads and interactions not covered by the component-by-component regression analysis.‡

The *floor area adjustment* is a correction based on the same DOE-2.1A simulations described in Section 6.7 in which the floor areas of each prototype building have been varied, but keeping aspect ratios and ceiling heights constant. This correction differs from the *floor area multiplier* described in Section 6.7 in that differences in surface areas have already been accounted for in the component loads calculations. The *floor area adjustment*, therefore, relates to second-order pertubations in the building loads due to changing internal load densities for different house sizes. Analysis has shown that, for a certain house size change, this correction can be expressed as a linear function of the building load. The slopes are typically positive for houses smaller than the prototype and negative for larger house sizes. Table 7.1a shows the regression equations developed for the floor area adjustments for the five prototype houses.

The component loads calculation procedure in PEAR allows the program to adjust for different roof areas, wall areas and heights, perimeter lengths, and window areas to the point where the sizes of the original prototypes are of only incidental concern.

‡ We did not do regressions for internal loads because they were not treated as a variable. We held them constant for all database simulations.

Table 7.1a Floor Area Adjustment Coefficients for Five Prototype Houses

	Heating		Cooling	
Size (ft^2)	Slope	Intercept	Slope	Intercept
One Story Prototype				
1176	.99803	.40528	.97878	.86336
2000	.99861	-.44484	1.01880	-1.02926
2500	1.00161	-.91838	1.03440	-2.18222
3000	1.00246	-1.41127	1.04775	-3.39810
Two Story Prototype				
1750	1.00196	.44899	.97758	.95810
2750	.99747	-.32825	1.01325	-.73041
3250	.99288	-.69167	1.02312	-1.55846
4000	.99428	-1.24857	1.04322	-3.12625
Middle-unit Townhouse Prototype				
900	1.00224	.24164	1.00766	.49877
1600	.99073	-.07016	.97356	-1.21350
2000	.98714	-.16141	.96276	-2.31791
2500	.98384	-.24321	.95091	-3.62510
End-unit Townhouse Prototype				
900	1.00224	.24164	1.00766	.49877
1600	.99073	-.07016	.97356	-1.21350
2000	.98714	-.16141	.96276	-2.31791
2500	.98384	-.24321	.95091	-3.62510
Split-level Prototype				
1500	.99943	.30797	.98243	.90943
2250	.99714	-.21469	1.00816	-.70523
2750	.99628	-.52408	1.02006	-1.75439
3250	.99516	-.81850	1.02740	-2.79771

7.2 Accuracy of Component Loads Calculations

To assess the accuracy of the component loads approach, we did parametric DOE-2 simulations for houses with floor areas 35% smaller (1000 ft^2) and 95% larger (3000 ft^2) than the 1540 ft^2 prototype type house in four locations (Atlanta, New York, Phoenix, and Washington, D.C.). Since we did not change the building aspect ratio, the test runs were conservative regarding the sensitivity of the calculation procedures to changes in building geometry. We then compared the DOE-2 results for total and incremental building loads to values extrapolated from the database using the component loads procedure. As an example, we show the results for New York in Tables 7.2a and 7.2b. The results are similar for all four cities.

Table 7.2a Comparison of DOE-2 Results to Component Loads for 1000 ft² New York Test House

	Heating (MBtu)		Cooling (MBtu)	
	DOE-2 (load)	Component (difference)	DOE-2 (load)	Component (difference)
Total Loads				
RC00-RW00-FM0-I0.7-1G	72.22	-0.05	12.05	-0.07
RC11-RW00-FM0-I0.7-1G	52.91	+0.04	9.24	-0.07
RC19-RW00-FM0-I0.7-1G	50.50	+0.04	8.92	-0.06
RC00-RW11-FM0-I0.7-1G	38.01	+0.07	8.34	-0.19
RC19-RW11-FM0-I0.7-1G	35.15	+0.10	7.76	-0.18
RC19-RW11-FM1-I0.7-1G	29.42	+0.13	7.46	-0.10
RC30-RW19-FM3-I0.7-2G	23.26	-0.29	6.92	+0.25
Δ Loads				
R0→R19 Ceiling	21.72	+0.09	3.31	+0.01
R0→R11 Wall	12.48	+0.03	0.90	-0.04
R0→R5 (4ft) Fdn	2.86	-0.04	0.24	-0.03
1 Pane→2 Pane	5.73	-0.03	0.03	-0.08
2 Pane→3 Pane	1.57	-0.09	0.10	+0.05

RC = ceiling insulation, RW = wall insulation, FM0 = uninsulated foundation, FM1 = R-5 4 ft bsmt wall, FM3 = R-5 8 ft bsmt wall, I = infiltration rate (ach), and G = number of window glazings.

Table 7.2b Comparison of DOE-2 Results to Component Loads for 3000 ft² New York Test House

	Heating (MBtu)		Cooling (MBtu)	
	DOE-2 (load)	Component (difference)	DOE-2 (load)	Component (difference)
Total Loads				
RC00-RW00-FM0-I0.7-1G	192.87	-1.81	26.81	+0.22
RC11-RW00-FM0-I0.7-1G	132.71	-1.45	17.61	+0.06
RC19-RW00-FM0-I.07-1G	125.30	+1.34	16.76	-0.31
RC00-RW11-FM1-I0.7-1G	111.96	-0.51	16.08	+0.20
RC19-RW11-FM0-I0.7-1G	104.56	-0.14	15.24	-0.19
RC19-RW11-FM1-I0.7-1G	96.99	-0.21	14.50	-0.07
RC30-RW19-FM3-I0.7-2G	65.52	+0.78	12.43	+0.12
RC30-RW19-FM3-I0.7-3G	60.62	+0.76	11.71	+0.32
Δ Loads				
R0→R19 Ceiling	67.57	+0.47	10.05	+0.53
R0→R11 Wall	20.75	+0.06	1.52	-0.12
R0→R5 (4) Fdn	7.57	+0.07	0.74	-0.12
2 Pane→3 Pane	4.90	+0.02	0.72	-0.20

RC = ceiling insulation, RW = wall insulation, FM0 = uninsulated foundation, FM1 = R-5 4ft. bsmt wall, FM3 = R-5 8 ft. bsmt wall, I = infiltration rate (ach), and G= number of window glazings.

For both total and Δ heating loads, the component loads procedure provides results that are within 1% of the actual DOE-2 simulations for both test prototypes. For Δ cooling loads, the differences are within 10%, but the absolute errors are similar to those for heating because of their smaller magnitude. It should be noted that the level of accuracy reflected in Tables 7.2a and 7.2b apply to the house types and range of conservation measures covered in the DOE-2 database, i.e., typical wood-frame houses with up to R-60 ceilings, R-27 walls, R-10 basement wall insulation, and triple-pane windows. We expect more variations in the interactions between building components for super-insulated houses with insulation levels and infiltration rates beyond those covered in the database for houses with significant amounts of thermal mass. Therefore, we have limited PEAR to the range of measures covered in the database.

7.3 Description of the PEAR Microcomputer Program

PEAR is written with user-friendly input and output, and runs on the IBM personal computer with either color or monochromatic monitors. PEAR provides an easy-to-use and very fast compilation of the extensive DOE-2 database. The user interface of the program includes six modes. INPUT consists of four screens that allow users to calculate the energy use of a typical residential building. The BAR CHART option gives a more detailed analysis of any building configuration by plotting the component loads to show the contribution to the total building load from the ceiling, walls, floor, infiltration, and windows. ECONOMICS does economic calculations based on the data used in the INPUT mode. SAVE, READ, and CHANGE FILE are bookkeeping options that show the status of the calculated files, create new files as needed, and allow the user to manipulate existing files.

The INPUT mode is organized on four screens. The left side of *Input Screen 1* contains the location (by state and city for about 800 locations) and the general house description: building prototype, foundation type, floor area, gross wall area, wall height or perimeter length, window orientation, and window area (see Fig. 7.3.1 as an example). This general input appears on the left side of all input screens for reference purposes. The right side of *Input Screen 1* contains the following basic conservation measures: ceiling insulation, roof color, wall insulation, wall color, wall heat capacity, foundation (basement or slab-on-grade), floor insulation (basement or ventilated crawl space), window sash type (plain, wood, aluminum, or aluminum with thermal breaks), glass type (regular, reflective, or absorptive), movable insulation, and level of infiltration (0.4 ach to 1.0 ach). As the various inputs are changed, the heating energy (in therms or kWh) and cooling energy (in kWh) are calculated immediately at the bottom of the screen, allowing users to assess quickly the effectiveness of different basic measures.

On-line help is available for any option on any input screen by typing "?" instead of the usual numeric or code word input. Figure 7.3.1, as an example, shows the keywords for the item

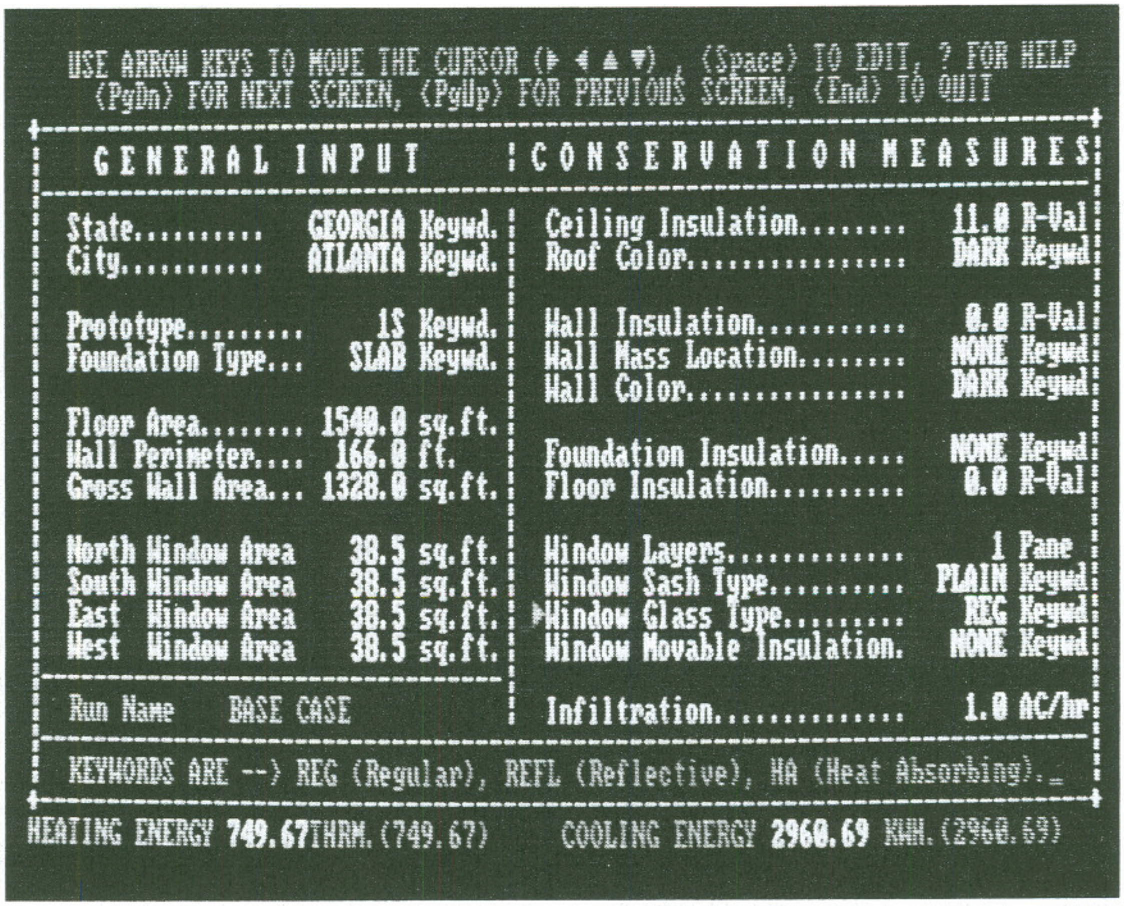


Fig. 7.3.1 CBB 871-587A

"Window Glass Type", which is provided to a user who seeks help.

The right side of *Input Screen 2* offers a selection of optional conservation measures, such as attached sunspaces as well as several space conditioning equipment options. These options include heating (oil and gas furnaces, electric resistance heaters, or heat pumps), and heating efficiency as AFUE (Annual Fuel Utilization Efficiency) or HSPF (Heating Seasonal Performance Factor), night temperature setback, and cooling equipment (central air-conditioners or heat pumps) and cooling efficiency as SEER (Seasonal Energy Efficiency Ratio).

The right side of *Input Screen 3* contains the appliances: domestic hot water, refrigerator, dishwasher, and clothes washer. For each appliance type, the user will input the "annual energy cost" from the FTC Energy Guide labels for the selected appliances; for dishwasher and clothes washer the number of loads per week; and the reference electric and gas price. On this screen only, the appliance electric and gas costs are shown on the bottom of the screen for reference purposes.

Input Screen 4 lists the economic parameters (see Fig. 7.3.2). The various economic input parameters are used to calculate simple payback (in years) and the savings-to-investment ratio (SIR). On this screen, the user can input information on the capital cost of the measures selected, lifetime of the measure, tax credit (where available), initial electric, gas, and oil prices, real fuel price escalation rates, real discount rate, interest rate for the loan, and the loan period. We describe the economic parameters in more detail in Section 7.4.

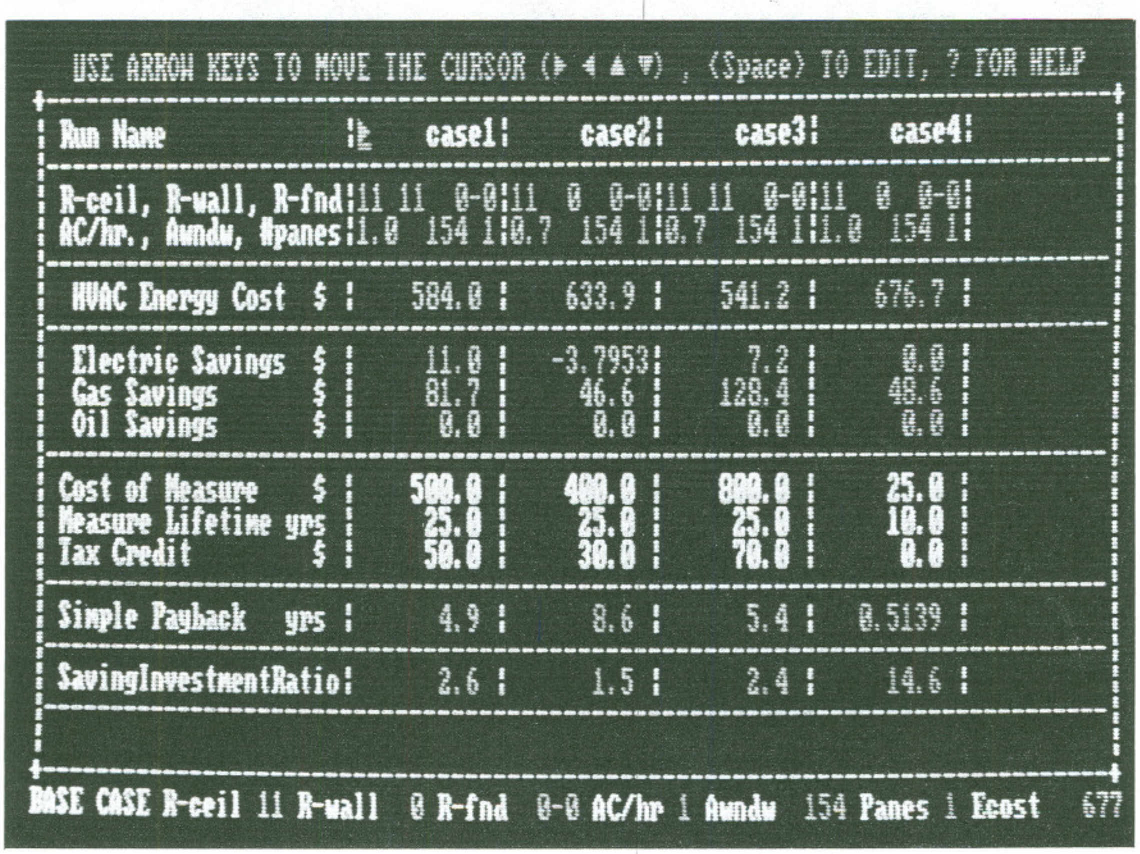


Fig. 7.3.2

CBB 871-585

After completing each of the input screens, the user moves to the SAVE option and names the file in which this combination of conservation options will be stored. The first set of measures constitutes the "base case" run (combination of conservation options selected) upon which all other runs will be compared. The user names each subsequent run after completing all of the input screens and saving the input data.

For users wishing a more detailed diagnosis of any particular set of options or runs, the BAR CHART option, plots the estimated contribution to heating and cooling due to the major building components: ceiling, walls, floor, windows, and infiltration (see Fig. 7.3.3). These graphs allows users to determine quickly which envelope components contribute most to the building loads and should be improved. Heating and cooling contributions are plotted in dollars to provide the proper weighting of heating and cooling energies.

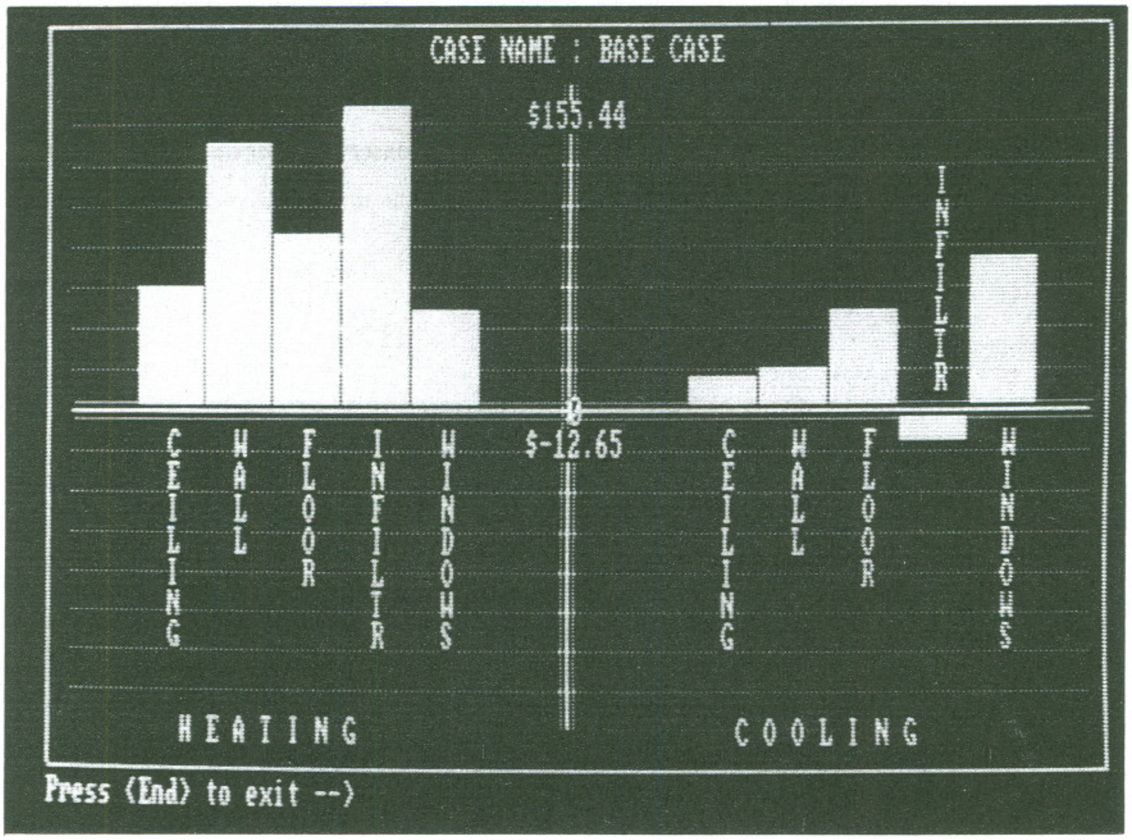


Fig. 7.3.3

CBB 871-589

Once two or more runs been completed (base case or first conservation package and any other combination of conservation measures), the user can enter the ECONOMICS mode to perform an economic analysis using the data from *Input Screen 4*. The ECONOMICS output screen allows the user to compare five runs (combinations of conservation options) against a base case. Additional runs may be viewed by scrolling horizontally. The output on the ECONOMICS screen includes: yearly energy cost (in dollars), electric, gas, and oil savings (in dollars), a summary of economic input parameters (cost of measure, lifetime, and tax credit), and the two economic indicators: payback time and savings-to-investment ratio (SIR). One can change the economic input parameters shown on the ECONOMICS screen to recalculate payback time and SIR using different economic input.

7.4 Economics of PEAR

Two economic indicators are calculated in PEAR: Simple Payback Period (SPP) and Savings-to-Investment Ratio (SIR). The SPP is the amount of time required for the home buyer to recover his or her additional investment in a more energy-efficient home. It offers an approximate way of calculating the actual payback period. For this calculation, we assumed that the additional cost of the conservation measure is paid out in the first year although this cost may be reduced by a tax credit. The difference between the additional capital cost and the tax credit is then divided by the annual energy cost savings. Therefore, simple payback period does not consider escalating fuel costs or the time value of money over the lifetime of the conservation measure. Furthermore, the additional cost of the conservation measure is not added to the mortgage.

$$\mathrm{SPP} = \frac{\mathrm{I} - \alpha}{\Delta \mathrm{E} * \mathrm{P}} \qquad (40)$$

where:
- I = cost of conservation measure ($)
- α = tax credit ($)
- ΔE = annual energy savings (MBtu or kWh)
- P = initial fuel price

A more sophisticated cost-effectiveness indicator is the savings-to-investment ratio (SIR). This approach takes into account escalating fuel costs, the time value of money, lifetime of the conservation option, and loan terms. SIR is equal to the benefit (energy savings) over the measure lifetime divided by the cost of the conservation measures (investment) over the measure lifetime.

$$\mathrm{SIR} = \frac{\alpha + \sum_{j=1}^{2}\sum_{k=1}^{N} \Delta \mathrm{E}(j) * \mathrm{P}(j) * \dfrac{(1+\mathrm{EF}(j))^{k}}{(1+d)^{k}}}{0.2 * \mathrm{I} + \sum_{i=1}^{n} \dfrac{m * 12}{(1+d)^{i}}} \qquad (41)$$

where:
- α = tax credit ($)
- ΔE = annual energy savings (MBtu)
- P = initial fuel price ($)
- EF = fuel escalation rate in real terms
- d = real discount rate (yrs.)
- I = cost of conservation measure ($)
- i = interest rate for loan-annual (%)
- j = heating or cooling
- N = lifetime of measure (yrs.)
- n = loan period (yrs.)
- m = monthly mortgage payment

$$\left[\, 0.8 * \mathrm{I} * (i/100*12) * \frac{(1 + i/100*12)^{n*12}}{(1 + i/100*12)^{n*12} - 1} \,\right]$$

The fuel price escalation rates for heating and cooling fuels should be in nominal terms and represent an annual percentage increase in fuel price. Both the escalation and discount rates should include inflation. In PEAR, the default discount rate is 14%. The discounting of future energy cost savings is done in order to bring all benefits occurring in later years to a present value for the first year. The loan rate is also input in nominal terms as an annual percentage rate with the loan amortized over the loan period. The tax credit is input in dollars and should include both state and federal credits (where available).

Although PEAR is currently limited to these two economic indicators, we plan to include a more comprehensive economic analysis procedure, i.e., life cycle costing or internal rate of return in future versions. We provide a complete description of the subroutines used in PEAR in Appendix F. The list of subroutines contains programs run on main-frame computers as well as programs for a personal computer. In all cases, the main-frame programs were written in FORTRAN and the PC programs in TURBO Pascal. *

* TURBO Pascal is a registered trademark of BORLAND INTERNATIONAL, Inc.

8.0 DEVELOPMENT OF DOMESTIC HOT WATER MULTIPLIERS

Water heating is the second largest use of energy in a house after space heating. In many areas of the U.S., new buildings constructed with energy conservation options will actually use more energy for heating water than for space heating. Therefore, a key strategy in reducing overall household energy consumption is to reduce the amount of energy used to heat domestic water.

In this section, we provide an explanation of the procedures and assumptions used to calculate the domestic hot water (DHW) multipliers. Before the energy savings can be estimated, the annual DHW heating costs must be established. These costs are taken directly from the FTC "Energy Guide labels". Standard water heaters are sold with these labels, which provide estimated yearly energy costs *without* conservation measures, such as flow reducers or solar hot water systems. These labels were developed to allow comparisons with any make or model of water heater manufactured in the United States since May 19, 1980. The algorithm used to calculate the energy consumption for the FTC label is the following:

$$E = \frac{W \times C_p \times \Delta t \times 365 \text{ days}}{EF} \qquad (42)$$

where:

E	=	annual energy use for domestic hot water
W	=	daily domestic hot water consumption (64.3 gal/day)
C_p	=	8.33 Btu/gal·F
Δt	=	(140 F outlet temperature - 50 F inlet temperature)
EF	=	Energy Factor (incorporates recovery efficiency and standby loss)

We provide a sample Energy Guide label (see Fig. 8.1) for illustrative purposes. The label shown, which is for a gas water heater, has an estimated annual operating cost of $198, based on an average cost of gas of 62.7 cents per therm. According to this model's position on the estimated yearly energy costs scale, it is closer to to the low end of the scale (i.e., $183 for the most efficent unit). All of the competing models being compared in this cost range have 48-55 gallon first hour ratings. From the "yearly cost" table shown on the label one can adjust the estimated annual operating cost according to the local cost of gas between 30 and 80 cents per therm. The same information is provided on water heaters that use fuel oil or electricity as an energy source. Energy Guide labels, however do not apply to heat pump water heaters. These domestic water heaters operate on the same principles as do the heat pumps that are used for space heating and cooling.

The DHW multipliers used in PEAR are designed to be used in conjunction with the Energy Guide labels. The user inputs the water heating type, estimated energy savings (in dollars), and

FTC "ENERGY GUIDE" LABEL

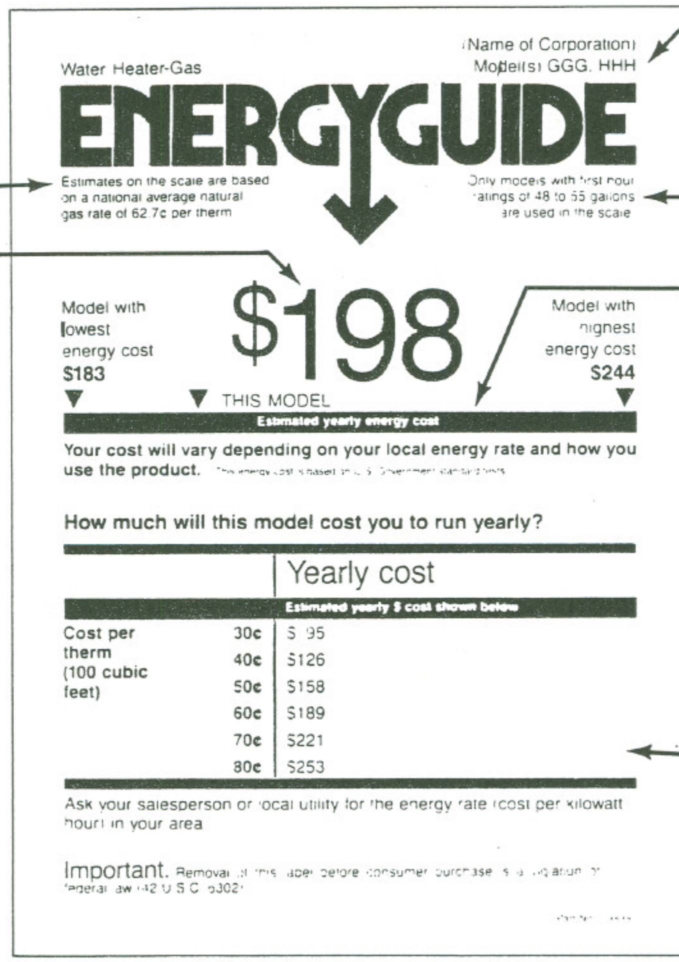
The model numbers for all models to which the label applies are listed. The model number is given in the first column of the Directory listing.

National average unit cost of fuel

Range of first hour ratings.

This is the estimated annual operating cost for this model using the national average unit cost of fuel as shown on the upper left. This estimate is determined by using the energy factor (EF) shown in the third column of the Directory listing and employing the formula as described in the "definitions and calculations" section.

This bar graph shows how this model compares to all other similar models which have first hour rating within the range noted in the upper right. The directory allows for the comparison of the energy factor, and consequently, estimated annual operating costs for each model within a narrower range of first hour ratings based on the consumer's particular hot water needs



This grid shows the different estimated operating costs for this model at different fuel costs. Tables 1 through 6 are a generalized expansion of this grid showing the direct correlation between the energy factor (EF) and the estimated cost of operation for varying fuel costs.

Fig. 8.1

selects a number of different conservation strategies. These strategies, both individually and in combination, were selected because they are judged reasonable, practical and within the control of home builders. The conservation options selected and presented include flow reduction and the use of active solar systems. We have not included additional insulation around hot water heaters because most DHW heater models currently on the market have increased insulation.

Reductions in energy usage can be achieved through the installation of a variety of water-saving devices that enable the user to obtain the same amount of convenience while using less hot water. There are two different approaches to reducing water use in the shower: water-saving shower heads and shower flow-control washers. The low-flow shower heads come as a complete set designed to reduce the flow rate to 2.5-3.0 gallons per minute (gpm), while the shower flow-control system is a flow control washer that is simply a new orifice. The latter device limits the water flow to about 3 to 5 gpm. Both of these systems are fairly inexpensive.

The potential savings from flow restrictors are in the range of 19 to 43% for the two different types of systems (2.5 to 5 gpm versus the normal rate of 7 gpm). The benefit from installing flow restrictors was assumed to reduce overall water consumption by 20%. We chose the conservative end of the scale to avoid overestimation.

$$E_{fr} = E \times 0.80 \tag{43}$$

The conservation benefit of an active solar system was calculated using the F-chart procedure, which was developed to avoid elaborate computer simulations for designing typical active solar systems. The method is based on correlating two important dimensionless variables, x and y. X is the ratio of heating load to a reference collector loss, and y is the ratio of heating load to absorbed solar energy (see Figure 8.2). The solar fraction f is the portion of the total load that is contributed by the solar system.

$$E_{solar} = E - f \tag{44}$$

Normal use of the F-chart method for the design of specific solar systems would require average monthly meteorological data and major system design parameters in order to estimate the long-term performance (i.e., 12 monthly f values to produce the annual solar fraction). However, since only general values are needed for the calculation, the F-chart method can be used in a somewhat different way. The monthly relationships were calculated using the procedure outlined in Table 8a and applied to a month of annual average weather and insolation conditions. The solar fraction (f) for the average month was then calculated for the annual average solar contribution.

The 45 climate zones used in the analysis and presented in the multiplier table are identified in Appendix A.1. The annual water temperatures for the zones were interpolated from monthly data from the National Bureau of Standards (see Figure 8.3).

F-CHART FOR LIQUID SYSTEMS

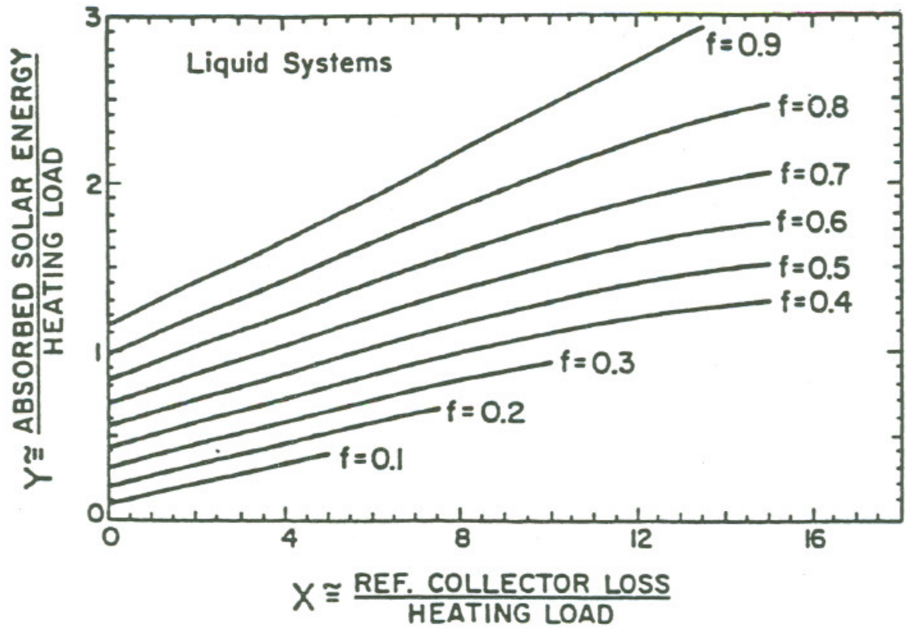


Fig. 8.2

ANNUAL WATER TEMPERATURE MAP

Isotherms = degrees fahrenheit inlet water temperature

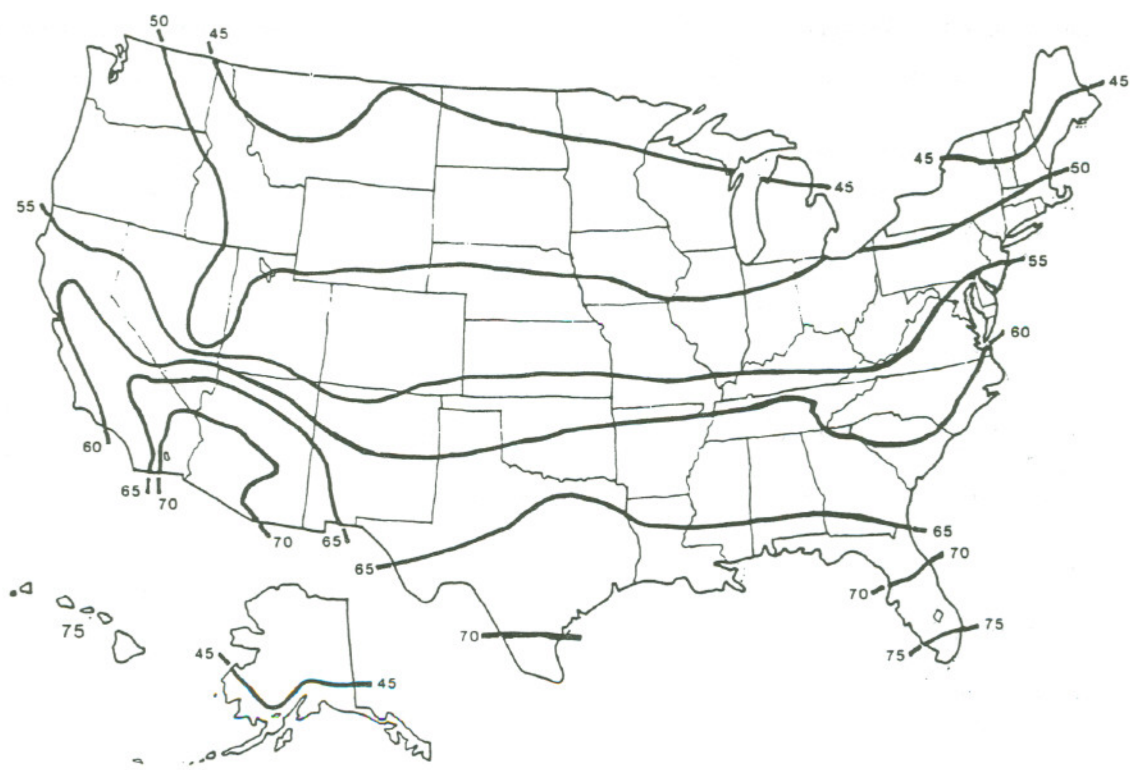


Fig. 8.3

Table 8a. F-Chart Calculation Method [21]

STEP 1: Calculate x:

$$x/A_c = F_R U_L * F'_R/F_R * (T_{ref} T_a) * \Delta\tau * (1/L) \quad (45)$$

STEP 2: Calculate y:

$$y/A_c = F_R \tau\alpha_n * F'_R/F_R * \tau\alpha/\tau\alpha_n * H_\tau * (1/L) * N \quad (46)$$

STEP 3: Calculate (x'/A_c) given (x/A_c): †

$$(x'/A_c) = (x/A_c) * \frac{11.6 + 1.18T_w + 3.86T_m - 2.32T_a}{100 - T_a} \quad (47)$$

STEP 4: Calculate F given A_c:

$$f = 1.029y - 0.065x' - 0.245y^2 + 0.0018x'^2 + 0.0215y^3 \quad (48)$$

INPUT DATA (all units SI):

T_w = outlet water temperature (C) = 60	$F_R U_L$	= 3.75 (double glazed) = 6.50 (single glazed) w/C^2
T_m = inlet water temperature (C)	F'_R/F_R	= 0.94 (dimensionless)
T_{ref} = 100 C	$T\alpha_n$	= monthly transmittance absorptance product at normal
T_a = ambient outside air temperature (C)	$F_R \tau\alpha_n$	= 0.68 (double glazed) = 0.78 (single glazed)
Δt = time in seconds (for month) 2.59×10^6	N	= number of days in the month = 30
H_t = incident solar radiation (J/m^2)	$\tau\alpha_n$	= monthly average transmittance absorptance product.
L = load in Joules·liters·(Kg/Liter) (J/kg·C) * (Δt C)	$\tau\alpha/\tau\alpha_n$	= 0.94 (double glazed) 0.96 (single glazed)
A_c = collector area 1 panel - 2.2 m^2 (24 ft^2), 2 panels - 4.4 m^2 (48 ft^2), 3 panels - 6.6 m^2 (72 ft^2)		

† x' is the domestic water heating correction factor. It is necessary to calculate it because x and y in Steps 1 and 2 were created to correlate a combination space heating and DHW system.

21. W.Beckman, et.al. *Solar Heating Design by the F-CHART Method.* Wiley Interscience, New York (1977).

The location factor on the multiplier table is the ratio between the temperature difference (Δt) of the outlet temperature assumed for the FTC label (140 F) and that taken from the annual water temperature map (Figure 8.3) and 90 F, which is the Δt assumed for the FTC label. This is termed the Δt ratio.

Table 8b presents the algorithms used to calculate the various multipliers. Table 8c is a list of the multipliers that are to be used to calculate the energy savings resulting from the utilization of flow reduction, solar panels or a combination of these strategies for each of the climate regions.

Table 8b. Algorithms Used to Compute Multipliers

Location Factor:	Δt ratio = 140-T_m (F) ÷ 90 (F)
Flow Reduction:	20% ÷ Δt ratio
1 Solar Panel:	SF ÷ Δt ratio
2 Solar Panels:	SF ÷ Δt ratio
Flow Reduction + 1 Solar Panel:	SF_{fr} ÷ Δt ratio
Flow Reduction + 2 Solar Panels:	SF_{fr} ÷ Δt ratio

SF = Solar fraction

SF_{fr} = Solar fraction is calculated separately to reflect a reduced quantity of water input and therefore a reduced load due to the flow restrictor.

Table 8c. Multipliers for Domestic Hot Water Heaters†
(for Site Built Single Family Houses)

Location	Location Factor	Conservation Strategies: Flow Reduction	1 Solar Panel	2 Solar Panels	Flow Reduction + Solar: 1 Panel	2 Panel
1	.93	.22	.53	.88	.63	.95
2	.90	.23	.44	.75	.52	.86
3	.90	.23	.43	.74	.52	.86
4	1.00	.19	.34	.59	.41	.69
5	1.02	.20	.38	.66	.46	.76
6	1.02	.20	.26	.47	.32	.56
7*	.80	.26	.56	.90	.67	.95
8	1.07	.19	.23	.41	.28	.49
9	1.11	.19	.24	.43	.29	.51
10	.90	.23	.39	.68	.47	.79
11	1.03	.20	.36	.62	.43	.73
12	1.06	.20	.30	.52	.36	.62
13	1.00	.21	.29	.52	.36	.62
14	1.02	.20	.45	.75	.53	.86
15*	.87	.24	.61	.95	.72	.95
16	.85	.24	.47	.80	.57	.92
17	.90	.23	.51	.85	.61	.95
18	1.11	.19	.32	.56	.39	.66
19*	.75	.28	.62	.95	.73	.95
20*	.84	.25	.49	.80	.59	.91
21*	1.07	.19	.17	.31	.20	.37
22	1.00	.21	.33	.59	.40	.69
23	.85	.24	.49	.80	.58	.90
24*	.86	.24	.66	.95	.77	.95
25	.96	.23	.49	.83	.59	.94
26	.99	.21	.38	.65	.45	.76
27	.91	.23	.39	.68	.47	.79
28	.75	.28	.67	.95	.79	.95
29	1.07	.19	.29	.51	.35	.60
30	.91	.23	.39	.68	.48	.79
31	1.00	.21	.26	.47	.32	.56
32	.92	.23	.48	.81	.58	.93
33	1.02	.2	.37	.64	.44	.74
34	.97	.21	.29	.53	.36	.62
35*	.81	.26	.69	.95	.81	.95
36	1.02	.20	.32	.57	.39	.66
37	1.07	.19	.23	.41	.28	.49
38	1.00	.21	.26	.46	.31	.55
39	.94	.22	.53	.88	.63	.95
40	1.03	.20	.40	.69	.48	.79
41*	.83	.25	.55	.88	.65	.95
42	.87	.24	.48	.81	.58	.93
43	.92	.23	.43	.74	.52	.85
44	1.02	.20	.26	.47	.32	.56
45	.96	.21	.33	.59	.40	.69

* Denotes single glazed collector.
† Location zones are identified in Appendix A.1.

APPENDIX A.1 LOCATION MULTIPLIERS

State and City	Location Number	Location Multipliers Heating	Cooling
Alabama			
Andalusia	10	1.29	.95
Anniston	3	1.00	.96
Auburn	3	.89	1.02
Birmingham	3	1.00	1.00
Dothan	10	.91	1.07
Eufaula	10	1.26	.93
Gadsden	3	1.12	.89
Huntsville	3	1.19	.91
Mobile	23	1.09	.99
Montgomery	10	1.28	.99
Ozark	10	1.05	1.00
Scottsboro	3	1.29	.81
Selma	10	1.12	1.06
Talladega	3	1.00	.91
Tuscaloosa	3	.92	1.12
Alaska			
Anchorage	21	1.24	1.00
Fairbanks	21	1.73	10.00
Juneau	21	1.00	1.00
Kenai	21	1.34	1.00
Arizona			
Casa Grande	35	1.12	.93
Douglas	35	2.25	.42
Flagstaff	1	1.72	.10
Mesa	35	1.12	.88
Nogales	35	2.30	.34
Phoenix	35	1.00	1.00
Prescott	35	4.46	.16
Tempe	35	1.16	.84
Tucson	35	1.48	.70
Yuma	35	.87	.93
Arkansas			
Arkadelphia	27	.87	.99
Benton	27	.97	.87
Blytheville	27	1.10	.97
Camden	27	.85	1.02
Conway	27	.97	.95
El Dorado	16	1.15	.75
Fayetteville	27	1.35	.66
Fort Smith	27	1.10	.95
Hope	27	.93	.95
Hot Springs	27	.90	1.04
Jonesboro	27	1.13	.94
Little Rock	27	.98	.99
Magnolia	16	1.07	.72
Malvern	27	.93	.91
No. Little Rock	27	.98	.97
Paragould	27	1.16	.87
Pine Bluff	27	.83	1.10
Russellville	27	1.05	.93
Searcy	27	1.01	.94
Stuttgart	27	.87	1.08
Texarkana	16	1.03	.82
California			
Antioch	43	1.01	5.00
Bakersfield	17	.76	1.33
Barstow	24	1.00	.74
Berkeley	43	.89	.79
Burbank	25	1.23	1.77
Chico	39	.41	3.96
Chula Vista	42	1.96	.46
Claremont	25	1.60	1.56
Concord	43	1.01	5.00
Corona	25	1.33	1.68
Culver City	25	.91	1.06
Davis	17	1.06	.60
El Centro	35	.76	.99
Escondido	42	2.18	1.16
Eureka	26	.84	.01
Fairfield	17	.96	.46
Fontana	25	1.18	2.60
Fresno	17	1.00	1.00
Hanford	17	1.04	.87
Indio	35	.66	1.09
Laguna Beach	25	1.50	.52
La Mesa	42	1.47	1.17
Lancaster	17	1.12	.99
Livermore	17	1.11	.41
Lodi	17	1.06	.57
Lompoc	25	2.10	.12
Long Beach	25	.98	1.50
Los Angeles	25	1.00	1.00
Los Banos	17	.98	.82
Los Gatos	43	.94	5.14
Madera	17	1.01	.93
Merced	17	.99	.83
Modesto	17	.99	.73
Monterey	43	.95	.42
Napa	17	.93	.24
Newport Beach	25	1.24	.51
Oakland	43	.89	1.51
Oceanside	25	1.52	1.35
Oxnard	25	1.36	.49

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

State and City	Location Number	Location Multipliers Heating	Cooling	State and City	Location Number	Location Multipliers Heating	Cooling
California (continued)				Lakewood	14	.97	.94
Palm Springs	35	.71	1.02	Longmont	14	1.08	.82
Palo Alto	43	.95	2.39	Pueblo	14	.90	1.53
Pasadena	25	1.09	1.78	Sterling	14	1.13	1.06
Petaluma	43	1.01	2.75	**Connecticut**			
Pomona	25	1.55	1.64	Bridgeport	31	1.08	.84
Porterville	17	.90	1.07	Danbury	31	1.21	.59
Redding	17	.96	1.21	Enfield	6	1.13	.95
Redlands	25	1.60	2.16	Groton	6	1.00	.71
Redwood City	43	.85	3.76	Hartford	6	1.13	.95
Richmond	43	.79	1.41	Meriden	31	1.18	.69
Riverside	25	1.39	2.02	Middletown	6	1.08	.87
Sacramento	17	1.03	.68	New Haven	31	1.18	.62
Salinas	43	.95	.42	Norwalk	31	1.15	.67
San Bernardino	25	1.37	2.36	Storrs	6	1.19	.52
San Diego	42	1.00	1.00	Waterbury	6	1.19	.59
San Francisco	43	1.00	1.00	**Delaware**			
San Gabriel	25	1.07	1.76	Dover	45	1.06	.82
San Jose	43	.79	4.33	Newark	34	.99	.93
San Luis Obispo	43	.75	2.48	Wilmington	34	1.01	.94
San Rafael	43	.78	4.20	**Dist. of Columbia**			
Santa Ana	25	.96	1.50	Washington	45	1.00	1.00
Santa Barbara	25	1.32	.54	**Florida**			
Santa Cruz	43	.99	.83	Bartow	28	5.28	.82
Santa Maria	43	.95	.66	Belle Glade	28	3.26	.77
Santa Monica	25	1.16	.60	Bradenton	28	5.19	.77
Santa Paula	25	1.46	.82	Clearwater	28	4.53	.90
Santa Rosa	17	1.04	.22	Daytona Beach	20	.57	1.14
Stockton	17	1.00	.82	Deland	20	.59	1.15
Torrance	25	1.12	.93	Fort Lauderdale	28	1.39	.96
Tracy	17	1.01	.65	Fort Myers	28	3.25	.90
Tustin	25	1.32	1.12	Fort Pierce	28	3.91	.82
Upland	25	1.78	1.68	Gainesville	20	.72	1.13
Vacaville	17	1.04	.66	Hialeah	28	1.67	.93
Visalia	17	.91	1.02	Homestead	28	1.51	.86
Watsonville	43	1.06	.37	Jacksonville	20	1.00	1.00
Woodland	17	1.01	.75	Key West	28	.54	1.16
Yorba Linda	25	1.17	1.54	Lakeland	28	5.39	.85
Colorado				Melbourne	28	5.14	.79
Boulder	14	.89	1.16	Miami	28	1.00	1.00
Canon City	14	.77	1.35	Naples	28	1.88	.90
Colorado Springs	14	1.06	.74	Ocala	20	.57	1.24
Denver	14	1.00	1.00	Orlando	28	5.89	.83
Durango	40	1.18	.21	Palatka	20	.62	1.24
Fort Collins	14	1.09	.69	Pensacola	10	.82	1.16
Grand Junction	40	.99	1.23	Plant City	28	5.30	.80
Greeley	14	1.09	.95	Pompano Beach	28	1.28	.97

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

State and City	Location Number	Location Multipliers Heating	Cooling	State and City	Location Number	Location Multipliers Heating	Cooling
Florida (continued)				Pocatello	40	1.26	.45
St Petersburg	28	4.53	.90	**Illinois**			
Sanford	20	.45	1.24	Alton	22	1.07	.84
Sarasota	28	5.19	.77	Aurora	12	1.08	.77
Tallahassee	20	1.22	.99	Belleville	22	.99	.79
Tampa	20	.46	1.32	Bloomington	12	.90	1.14
Titusville	20	.44	1.26	Carbondale	22	.93	.83
Vero Beach	28	4.16	.80	Champaign	22	1.22	.61
West Palm Beach	28	1.35	.92	Charleston	22	1.12	.69
Winter Haven	28	5.28	.82	Chicago	12	1.05	.77
Georgia				Danville	22	1.18	.60
Albany	20	1.61	.95	Decatur	22	1.15	.70
Americus	10	1.18	.95	De Kalb	12	1.10	.80
Athens	2	.98	1.01	Dixon	12	1.07	.90
Atlanta	2	1.00	1.00	Effingham	22	1.12	.73
Augusta	2	.81	1.16	Elgin	12	1.10	.80
Brunswick	20	1.00	1.06	Galesburg	12	1.03	.96
Carrollton	2	1.03	.86	Jacksonville	22	1.18	.67
Columbus	2	.74	1.29	Joliet	12	1.08	.77
Covington	2	.92	1.00	Kewanee	12	1.04	.96
Dalton	2	1.20	.90	Lincoln	22	1.19	.64
Douglas	10	1.14	.96	Mattoon	22	1.18	.64
Dublin	10	1.32	.94	Monmouth	12	.97	1.00
Fitzgerald	10	.93	1.10	Mount Vernon	22	.98	.81
Gainesville	2	1.14	.84	Ottawa	12	.95	1.10
La Grange	2	.85	1.05	Park Forest	12	1.05	.83
Macon	2	.71	1.33	Peoria	12	1.01	.99
Milledgeville	2	.91	1.06	Peru	12	1.01	1.04
Moultrie	20	1.30	.92	Pontiac	12	.95	1.06
Newnan	2	.88	1.02	Quincy	22	1.23	.67
Rome	2	1.04	.96	Rantoul	22	1.27	.61
Savannah	10	1.04	.99	Rockford	12	1.14	.75
Thomasville	20	1.25	.96	Springfield	22	1.20	.69
Tifton	20	1.54	.90	Urbana	22	1.22	.61
Waycross	10	1.03	1.01	Waukegan	12	1.12	.62
Hawaii				Wheaton	12	1.04	.82
Hilo	19	1.00	.71	**Indiana**			
Honolulu	19	1.00	1.00	Anderson	13	1.22	.77
Kahului	19	1.00	.88	Bloomington	13	1.15	.86
Kaneohe Mauka	19	1.00	.76	Columbus	13	1.13	.83
Lahaina	19	1.00	.86	Crawfordsville	13	1.25	.76
Idaho				Elwood	13	1.30	.65
Boise	5	1.00	1.00	Evansville	13	.95	1.19
Caldwell	5	.96	1.10	Fort Wayne	12	1.02	.82
Coeur D'alene	5	1.12	.53	Frankfort	13	1.28	.70
Idaho Falls	18	1.03	.74	Gary	12	1.01	.92
Moscow	5	1.16	.35	Goshen	12	1.01	.75

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

State and City	Location Number	Location Multipliers Heating	Cooling
Indiana (continued)			
Greenfield	13	1.20	.83
Hobart	12	.97	.88
Huntington	12	.96	.85
Indianapolis	13	1.17	.85
Kokomo	12	.97	1.01
La Porte	12	1.02	.82
Lafayette	13	1.30	.71
Marion	12	1.02	.77
Martinsville	13	1.16	.82
Muncie	13	1.22	.77
New Castle	13	1.28	.68
Richmond	13	1.23	.63
Seymour	13	1.11	.84
Shelbyville	13	1.16	.84
South Bend	12	1.03	.74
Terre Haute	13	1.14	.91
Valparaiso	12	1.01	.72
Vincennes	13	1.05	1.06
Wabash	12	1.05	.72
West Lafayette	12	1.00	.86
Iowa			
Ames	33	1.12	.68
Ankeny	33	1.11	.73
Boone	33	1.14	.69
Cedar Rapids	33	1.08	.71
Clinton	12	1.06	.91
Davenport	12	1.02	1.06
Des Moines	33	1.07	.87
Dubuque	12	1.22	.61
Fort Dodge	33	1.18	.67
Indianola	33	1.02	.85
Iowa City	33	1.03	.83
Keokuk	12	.90	1.29
Marshalltown	33	1.15	.65
Mason City	29	.95	.99
Muscatine	12	1.00	1.05
Newton	33	1.06	.84
Oskaloosa	33	1.01	.84
Ottumwa	33	1.03	.88
Sioux City	33	1.14	.81
Spencer	29	.98	.97
Waterloo	33	1.24	.57
Kansas			
Hutchinson	22	1.00	.96
Manhattan	22	1.07	.91
McPherson	22	1.01	.98

State and City	Location Number	Location Multipliers Heating	Cooling
Newton	22	.99	1.01
Olathe	22	1.05	.81
Ottawa	22	.99	.90
Parsons	22	.84	1.06
Salina	22	1.08	.93
Topeka	22	1.11	.82
Wichita	22	.99	1.00
Winfield	32	1.15	.94
Kentucky			
Ashland	30	1.35	.64
Bowling Green	30	1.17	.86
Covington	13	1.07	.89
Frankfort	13	1.00	.92
Henderson	30	1.17	.85
Hopkinsville	30	1.19	.87
Lexington	30	1.33	.70
Louisville	13	.90	1.16
Madisonville	30	1.13	.85
Mayfield	30	1.08	.90
Middlesboro	30	1.20	.64
Murray	30	1.07	.93
Owensboro	30	1.17	.88
Paducah	30	1.12	.95
Somerset	30	1.19	.64
Louisiana			
Alexandria	23	1.31	.94
Bastrop	16	.90	.90
Baton Rouge	23	1.08	.97
Bogalusa	23	1.24	.94
Hammond	23	1.11	.91
Houma	23	.80	1.03
Jennings	23	1.03	1.03
Lafayette	23	.99	1.00
Lake Charles	23	1.00	1.00
Minden	16	1.01	.81
Monroe	16	.97	.83
Morgan City	23	.88	1.05
Natchitoches	16	.75	.92
New Iberia	23	.99	.99
New Orleans	23	.94	1.00
Ruston	16	1.04	.77
Shreveport	16	.91	.87
Tallulah	16	.99	.79
Maine			
Augusta	37	1.02	1.39
Bangor	37	1.07	.98
Lewiston	37	.99	1.54

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

State and City	Location Number	Location Multipliers Heating	Cooling
Maine (continued)			
Portland	37	1.00	1.00
Presque Isle	9	1.17	.43
Waterville	9	.93	.92
Maryland			
Baltimore	45	1.17	.80
Cambridge	45	1.05	.82
College Park	45	1.09	.84
Cumberland	34	1.03	.84
Hagerstown	34	1.03	.87
Laurel	45	1.11	.85
Rockville	45	1.15	.74
Salisbury	45	.96	.84
Massachusetts			
Amherst	6	1.22	.72
Boston	6	1.00	1.00
Brockton	6	1.13	.65
Clinton	6	1.21	.68
Fitchburg	6	1.22	.75
Framingham	6	1.13	.88
Haverhill	6	1.09	.95
Lawrence	6	1.14	.81
Lowell	6	1.14	.81
New Bedford	6	.93	1.03
Pittsfield	6	1.34	.39
Springfield	6	1.08	1.00
Taunton	6	1.13	.65
Worcester	6	1.28	.51
Michigan			
Adrian	12	1.07	.63
Alpena	29	1.02	.27
Ann Arbor	12	1.02	.76
Battle Creek	12	1.09	.63
Bay City	29	.83	.84
Benton Harbor	12	1.01	.67
Big Rapids	29	.93	.59
Cadillac	29	1.03	.35
Detroit	12	1.06	.64
Escanaba	29	1.04	.28
Flint	12	1.15	.48
Grand Haven	12	1.04	.51
Grand Rapids	12	1.12	.60
Holland	12	1.05	.61
Jackson	12	1.11	.64
Kalamazoo	12	1.01	.79
Lansing	12	1.13	.55
Marquette	29	1.03	.34
Midland	29	.83	.84
Monroe	12	1.00	.80
Mt Pleasant	29	.86	.77
Muskegon	12	1.12	.47
Owosso	12	1.12	.52
Pontiac	12	1.08	.67
Port Huron	12	1.07	.65
Saginaw	12	1.16	.52
Sault Ste Marie	29	1.15	.20
Traverse City	12	1.27	.40
Ypsilanti	12	1.05	.74
Minnesota			
Albert	29	.99	.95
Austin	29	.99	.81
Bemidji	4	1.14	.59
Cloquet	29	1.20	.31
Duluth	29	1.24	.23
Fairmont	29	.98	1.03
Faribault	29	.99	.96
Fergus Falls	4	1.00	1.12
Marshall	29	1.02	1.00
Minn-St. Paul	29	1.00	1.00
Rochester	29	1.03	.72
St Cloud	4	.99	.84
Virginia	4	1.09	.56
Willmar	29	1.05	.88
Mississippi			
Biloxi	23	.92	.99
Brookhaven	16	.81	.80
Canton	16	1.06	.77
Clarksdale	27	.92	1.10
Cleveland	27	.89	1.04
Columbus	27	.87	.97
Corinth	27	1.00	.91
Greenville	16	1.10	.80
Greenwood	27	.82	1.08
Gulfport	23	.95	.98
Hattiesburg	10	1.11	1.01
Jackson	16	.97	.82
Laurel	10	1.29	.99
Meridian	3	.84	1.15
Natchez	23	1.30	.92
Picayune	23	1.02	.94
Tupelo	27	.95	.95
Vicksburg	16	.88	.82
Yazoo City	16	1.02	.82

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

State and City	Location Number	Location Multipliers Heating	Cooling	State and City	Location Number	Location Multipliers Heating	Cooling
Missouri				**New Hampshire**			
Carthage	32	1.16	.82	Concord	9	.93	.93
Columbia	22	1.09	.75	Keene	9	.87	1.07
Fulton	22	1.13	.74	Lebanon	9	.99	.80
Hannibal	22	1.19	.68	Manchester	9	.90	1.01
Jefferson City	22	1.01	.79	Nashua	6	1.31	.50
Joplin	32	1.18	.85	**New Jersey**			
Kansas City	22	1.11	.79	Atlantic City	45	1.26	.55
Kirksville	22	1.25	.61	Freehold	34	1.07	.75
Mexico	22	1.18	.73	Glassboro	34	1.00	.90
Moberly	22	1.11	.74	Hammonton	45	1.25	.69
Poplar Bluff	22	.82	.94	Jersey City	31	1.03	.96
St. Charles	22	1.03	.84	Little Falls	31	1.06	.95
St. Joseph	22	1.15	.80	Long Branch	34	1.04	.72
St. Louis	22	1.02	.87	Millville	45	1.23	.69
Sedalia	22	1.03	.87	Moorestown	34	1.05	.86
Sikeston	22	.85	.93	Newark	31	.96	1.23
Springfield	22	.95	.82	New Brunswick	34	1.06	.77
Warrensburg	22	1.01	.91	Paterson	31	1.06	.95
Montana				Plainfield	31	1.02	.97
Billings	18	.92	1.41	Somerville	31	1.10	.88
Bozeman	18	1.02	.62	Trenton	34	1.00	.91
Butte	18	1.26	.27	Vineland	45	1.23	.69
Great Falls	18	1.00	1.00	**New Mexico**			
Havre	18	1.14	1.07	Alamogordo	1	.64	1.40
Helena	18	1.06	.75	Albuquerque	1	1.00	1.00
Kalispell	5	1.51	.24	Artesia	15	1.34	.84
Missoula	5	1.41	.29	Carlsbad	15	1.09	1.03
Nebraska				Clovis	15	1.66	.57
Beatrice	33	.91	1.13	Gallup	1	1.45	.33
Columbus	33	1.05	.93	Hobbs	15	1.10	.88
Fremont	33	.99	.95	Las Cruces	15	1.20	.77
Grand Island	33	1.04	.88	Los Alamos	14	1.06	.44
Hastings	33	.97	.94	Roswell	15	1.22	.89
Kearney	14	1.13	1.47	Santa Fe	14	1.06	.44
Lincoln	33	1.03	.96	**New York**			
Norfolk	33	1.14	.80	Albany	9	.86	1.30
North Platte	11	.96	2.50	Batavia	8	1.00	.97
Omaha	33	1.00	1.00	Binghamton	8	1.09	.69
Scottsbluff	11	.92	2.36	Buffalo	8	1.00	1.00
Nevada				Canandaigua	8	.99	1.06
Carson City	39	.95	1.04	Cortland	8	1.09	.72
Ely	39	1.35	.54	Dobbs Ferry	31	1.02	1.00
Las Vegas	24	1.00	1.00	Elmira	8	1.02	.86
Reno	39	1.00	1.00	Fredonia	8	.92	1.16
Sunrise Manr	24	1.09	.83	Geneva	8	1.01	.95
Winnemucca	39	1.09	1.41	Gloversville	9	.91	.97

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

State and City	Location Number	Location Multipliers Heating	Cooling	State and City	Location Number	Location Multipliers Heating	Cooling
New York (continued)				Statesville	45	.90	.88
Ithaca	8	1.06	.69	Wilmington	30	.59	1.15
Lockport	8	.99	1.00	Wilson	30	.83	.97
Massena	9	1.03	.91	Winston-Salem	45	.79	.97
Mineola	31	1.01	.97	**North Dakota**			
New York	31	1.00	1.00	Bismarck	4	1.00	1.00
Ogdensburg	9	.98	1.08	Dickinson	4	.97	.93
Oswego	8	1.00	.90	Grand Forks	4	1.10	.88
Patchogue	31	1.11	.69	Jamestown	4	1.04	.92
Poughkeepsie	31	1.28	.67	Mandan	4	1.01	.96
Rochester	8	.99	1.12	Minot	4	1.04	.89
Rome	8	1.10	.89	Williston	4	1.02	.93
Scarsdale	31	1.06	.88	**Ohio**			
Schenectady	9	.86	1.30	Akron	8	.91	1.31
Syracuse	8	1.00	1.06	Ashland	8	.93	1.29
Utica	8	1.10	.89	Ashtabula	8	.92	1.22
Watertown	9	.94	1.12	Athens	13	1.11	.63
North Carolina				Bellefontaine	13	1.23	.66
Albemarle	30	.85	.85	Bowling Green	12	.97	.86
Asheboro	30	.84	.86	Bucyrus	12	1.03	.66
Asheville	30	1.12	.51	Cambridge	36	.92	1.16
Boone	36	.88	.50	Canton	8	.91	1.31
Burlington	45	.83	1.03	Cincinnati	13	1.00	1.00
Chapel Hill	30	.97	.79	Circleville	13	1.03	.87
Charlotte	45	.77	1.08	Cleveland	8	.90	1.29
Concord	45	.80	1.09	Columbus	13	1.17	.74
Durham	30	.94	.84	Coshocton	36	.98	1.15
Elizabeth City	30	.82	.89	Dayton	13	1.17	.82
Fayetteville	30	.80	1.00	Defiance	12	1.07	.71
Gastonia	45	.72	1.11	Delaware	13	1.27	.63
Goldsboro	30	.79	1.03	Dover	36	1.00	.94
Greensboro	45	.92	.91	Elyria	8	.88	1.49
Hickory	45	.88	.89	Findlay	12	1.01	.79
High Point	45	.79	.97	Greenville	13	1.31	.58
Kinston	30	.79	.97	Hamilton	13	1.02	.91
Laurinburg	30	.65	1.11	Ironton	13	.89	1.08
Lenoir	45	.85	.80	Lancaster	13	1.19	.72
Lexington	45	.75	1.17	Lima	12	.94	.89
Lumberton	30	.77	1.01	Mansfield	12	1.00	.68
Monroe	30	.78	.92	Middletown	13	1.02	.91
Morganton	45	.84	.87	Newark	13	1.16	.67
New Bern	30	.68	1.06	Norwalk	12	1.00	.68
Raleigh	30	.91	.84	Painesville	8	.87	1.29
Reidsville	45	.91	.91	Portsmouth	13	.94	.98
Rocky Mount	30	.87	.90	Sandusky	12	.96	.86
Salisbury	45	.79	1.02	Steubenville	36	.93	1.18
Shelby	45	.85	.95	Tiffin	12	.94	.83

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

State and City	Location Number	Location Multipliers Heating	Cooling	State and City	Location Number	Location Multipliers Heating	Cooling
Ohio (continued)				**Pennsylvania**			
Toledo	12	1.06	.65	Allentown	34	1.20	.70
Urbana	13	1.28	.61	Bradford	8	1.18	.31
Van Wert	12	.95	.85	Carlisle	34	1.09	.94
Warren	8	.91	1.22	Chambersburg	34	1.15	.69
Washington	13	1.12	.73	Coatesville	34	1.16	.69
Wilmington	13	1.16	.75	Erie	8	.99	.84
Wooster	8	.93	1.08	Hanover	34	1.09	.83
Xenia	13	1.14	.69	Harrisburg	34	1.09	.94
Youngstown	8	.96	1.02	Indiana	36	1.04	.76
Zanesville	36	.97	1.11	Johnstown	36	.97	1.13
Oklahoma				Lancaster	34	1.11	.75
Ada	16	1.35	.75	Meadville	8	1.01	.75
Altus	32	.81	1.23	New Castle	8	.85	1.35
Ardmore	16	1.09	.90	Philadelphia	34	1.00	1.00
Bartlesville	32	1.04	.99	Phoenixville	34	1.06	.82
Chickasha	32	.89	1.09	Pittsburgh	36	1.00	1.00
Claremore	32	1.07	.97	Reading	34	1.19	.60
Duncan	32	.78	1.20	Scranton	31	1.27	.64
El Reno	32	.99	1.02	Uniontown	36	.89	1.19
Enid	32	1.01	1.08	Warren	8	.97	.91
Guthrie	32	.97	1.08	West Chester	34	1.10	.83
Lawton	32	.84	1.16	Wilkes-Barre	31	1.27	.64
McAlester	16	1.47	.74	Williamsport	34	1.26	.61
Miami	32	1.06	.95	York	34	1.06	.84
Oklahoma City	32	1.00	1.00	**Rhode Island**			
Okmulgee	32	.89	1.03	Providence	6	1.06	.82
Ponca City	32	1.18	.99	Woonsocket	6	1.18	.62
Stillwater	32	1.02	1.00	**South Carolina**			
Tulsa	32	1.00	1.07	Aiken	30	.57	1.20
Woodward	32	1.19	.94	Anderson	45	.66	1.14
Oregon				Charleston	10	1.18	.91
Ashland	26	1.07	.64	Columbia	30	.64	1.22
Bend	5	1.22	.14	Conway	10	1.41	.85
Corvallis	38	1.07	.61	Florence	30	.67	1.09
Eugene	38	1.02	.79	Georgetown	10	1.23	.90
Forest Grove	38	1.03	.95	Greenville	45	.74	1.05
Grants Pass	26	.87	.92	Greenwood	30	.81	.98
Klamath Falls	5	1.14	.42	Laurens	45	.74	1.14
La Grande	5	1.04	.62	Orangeburg	10	1.48	.86
McMinnville	38	1.06	.64	Sumter	30	.60	1.18
Medford	26	1.00	1.00	Union	45	.79	1.02
Oregon City	38	.93	1.15	**South Dakota**			
Pendleton	5	.88	.98	Aberdeen	29	1.08	.89
Portland	38	1.00	1.00	Brookings	29	1.08	.72
Roseburg	26	.88	.58	Huron	29	1.01	1.11
Salem	38	1.07	.72	Mitchell	33	1.22	.78

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

State and City	Location Number	Location Multipliers Heating	Cooling	State and City	Location Number	Location Multipliers Heating	Cooling
South Dakota (continued)				Dallas	16	1.00	1.00
Pierre	29	.93	1.29	Del Rio	41	.92	1.10
Rapid City	11	1.01	2.16	Denison	16	1.21	.81
Sioux Falls	29	.98	1.13	Denton	16	1.02	.90
Watertown	4	.97	1.08	El Paso	15	1.00	1.00
Yankton	33	1.23	.69	Fort Worth	16	1.00	1.00
Tennessee				Gainesville	16	1.31	.83
Bristol	30	1.17	.64	Galveston	23	.73	1.11
Chattanooga	2	1.23	.94	Greenville	16	1.23	.80
Clarksville	30	1.08	.91	Harlingen	7	1.45	1.00
Columbia	30	1.00	.90	Henderson	16	.94	.82
Dyersburg	27	1.14	.89	Hereford	15	1.80	.56
Franklin	30	.97	.88	Houston	23	.97	1.03
Greeneville	30	1.08	.70	Huntsville	23	1.25	1.00
Jackson	27	1.13	.87	Killeen	16	.85	.98
Kingsport	30	1.03	.70	Kingsville	7	1.59	.96
Knoxville	30	.96	.87	Lamesa	15	1.27	.91
McMinnville	30	.96	.83	Laredo	41	.52	1.36
Memphis	27	1.00	1.00	Lufkin	16	.75	.94
Murfreesboro	30	.99	.95	Marshall	16	1.04	.83
Nashville	30	1.00	1.00	McAllen	41	.41	1.28
Oak Ridge	30	1.06	.78	Midland	15	1.00	1.01
Paris	30	1.10	.86	Mineral Wells	32	.61	1.37
Shelbyville	30	.95	.89	Mount Pleasant	16	1.22	.76
Springfield	30	1.17	.83	Odessa	15	1.00	1.01
Tullahoma	3	1.33	.74	Palestine	16	.92	.88
Union City	30	1.15	.86	Paris	16	1.25	.82
Texas				Plainview	15	1.55	.71
Abilene	32	.65	1.29	Port Arthur	23	.92	1.07
Alice	7	2.07	.94	Port Lavaca	7	2.30	.88
Amarillo	15	1.76	.68	San Angelo	41	1.57	.87
Angleton	23	.87	1.00	San Antonio	41	1.00	1.00
Austin	41	1.13	.98	San Marcos	41	1.22	.89
Bay City	23	.81	1.10	Snyder	15	1.23	.99
Beaumont	23	.92	1.07	Sulphur Springs	16	1.19	.77
Beeville	7	2.76	.83	Taylor	41	1.38	.92
Big Spring	15	1.01	1.10	Temple	16	.85	.98
Borger	15	1.54	.78	Tyler	16	1.10	.79
Brenham	23	1.14	1.08	Uvalde	41	.96	1.02
Brownsville	7	1.00	1.00	Vernon	32	.70	1.36
Brownwood	32	.61	1.36	Victoria	23	.77	1.19
Bryan	16	.69	1.00	Waco	16	.86	1.03
Canyon	15	1.50	.69	Waxahachie	16	.98	.95
Cleburne	16	.90	.95	Weatherford	16	1.23	.84
College Station	16	.69	1.00	Weslaco	7	1.07	1.05
Corpus Christi	7	1.83	.95	Wichita Falls	32	.77	1.31
Corsicana	16	.98	.92				

APPENDIX A.1 LOCATION MULTIPLIERS (continued)

		Location Multipliers				Location Multipliers	
State and City	Location Number	Heating	Cooling	State and City	Location Number	Heating	Cooling
Utah				Yakima	5	1.04	.65
Cedar City	40	1.03	.69	**West Virginia**			
Logan	40	1.19	.60	Beckley	36	.91	.72
Ogden	40	1.01	.97	Bluefield	36	.85	.81
Provo	40	.99	.90	Charleston	36	.76	1.56
Saint George	24	1.36	.70	Clarksburg	36	.90	1.18
Salt Lake City	40	1.00	1.00	Fairmont	36	.88	1.18
Tooele	40	1.03	.85	Huntington	36	.76	1.74
Vermont				Martinsburg	45	1.30	.65
Burlington	9	1.00	1.00	Morgantown	36	.88	1.28
Rutland	9	.89	.99	Parkersburg	36	.81	1.57
Virginia				Wheeling	36	.91	1.30
Blacksburg	36	.90	.91	**Wisconsin**			
Charlottesville	45	1.02	.85	Appleton	29	.95	.78
Danville	45	.92	.97	Beloit	12	1.08	.83
Fredericksburg	45	1.07	.84	Eau Claire	29	1.06	.71
Hopewell	45	.79	1.10	Fond Du Lac	12	1.25	.55
Lynchburg	45	1.05	.75	Germantown	12	1.23	.46
Martinsville	45	1.05	.69	Green Bay	29	1.00	.58
Newport	30	.85	1.01	Janesville	12	1.11	.82
Norfolk	30	.88	.88	Kenosha	12	1.14	.51
Richmond	45	.95	.93	La Crosse	29	.93	1.03
Roanoke	45	1.04	.76	Madison	12	1.26	.49
Staunton	45	1.26	.57	Manitowoc	12	1.23	.41
Suffolk	30	.94	.83	Marinette	29	.91	.77
Winchester	45	1.20	.69	Marshfield	29	1.06	.49
Washington				Milwaukee	12	1.19	.49
Aberdeen	44	1.02	.14	Oshkosh	12	1.28	.55
Bellingham	44	1.11	.31	Racine	12	1.12	.62
Bremerton	44	1.01	.72	Sheboygan	12	1.17	.45
Centralia	44	.99	.93	Stevens Point	29	1.00	.64
Everett	44	1.04	.41	Superior	29	1.16	.29
Kennewick	5	.81	1.11	Two Rivers	12	1.26	.24
Kent	44	.99	.79	Watertown	12	1.18	.65
Longview	38	1.08	.42	Waukesha	12	1.18	.60
Moses Lake	5	1.09	.65	Wausau	29	1.06	.56
Olympia	44	1.14	.51	West Allis	12	1.12	.74
Port Angeles	44	1.11	.08	Whitewater	12	1.13	.67
Pullman	5	1.17	.33	Wisconsin Rapids	29	1.03	.64
Richland	5	.78	1.27	Casper	11	1.06	1.48
Seattle	44	1.00	1.00	Cheyenne	11	1.00	1.00
Spokane	5	1.21	.55	Gillette	11	1.08	1.55
Tacoma	44	.92	.86	Green River	11	1.17	.83
Vancouver	38	1.09	.81	Laramie	11	1.25	.29
Walla Walla	5	.80	1.16	Rock Springs	11	1.09	.92
Wenatchee	5	.98	1.00	Sheridan	18	1.01	1.07

APPENDIX A.2 WINDOW ORIENTATION MODIFIERS

(in MBtu, - = load reduction, + = load increase)

		Heating Energy Savings				Cooling Energy Savings		Cooling Energy Increase	
Location Number	Glazing Layers	Bldg Faces South	Decrease North Windows (per 100 ft^2)	Increase South Windows (per 100 ft^2)	Increase South Windows with Mass (per 100 ft^2)	Bldg Faces South	Decrease North Windows (per 100 ft^2)	Increase South Windows (per 100 ft^2)	Increase South Windows with Mass (per 100 ft^2)
1	1	-.74	-6.84	-.20	-.84	-2.09	-3.16	+4.86	+3.24
	2	-.66	-2.22	-3.62	-4.28	-1.90	-2.71	+4.25	+2.77
	3	-.60	-.78	-3.84	-4.51	-1.73	-2.47	+3.89	+2.41
2	1	-.39	-4.85	+.79	+.48	-1.64	-3.41	+5.16	+4.35
	2	-.34	-1.45	-1.91	-2.22	-1.55	-3.66	+5.33	+4.58
	3	-.30	-.45	-2.19	-2.51	-1.51	-3.52	+5.22	+4.47
3	1	-.39	-4.03	-.03	-.34	-1.64	-4.36	+6.11	+5.30
	2	-.34	-1.27	-2.09	-2.40	-1.55	-4.47	+6.14	+5.39
	3	-.30	-.37	-2.27	-2.59	-1.51	-4.22	+5.92	+5.17
4	1	-.72	-16.14	+9.94	+9.73	-1.10	-1.69	+3.45	+2.41
	2	-.72	-5.96	+.41	+.28	-1.02	-1.36	+2.98	+1.98
	3	-.71	-3.28	-1.66	-1.72	-.95	-1.28	+2.75	+1.75
5	1	-.44	-9.71	+4.58	+4.44	-.82	-2.95	+4.15	+3.19
	2	-.45	-3.38	-1.10	-1.19	-.81	-2.34	+3.51	+2.63
	3	-.46	-1.73	-2.11	-2.15	-.75	-2.28	+3.28	+2.39
6	1	-.44	-10.41	+5.28	+5.14	-.82	-1.57	+2.77	+1.81
	2	-.45	-2.96	-1.52	-1.61	-.81	-1.31	+2.48	+1.60
	3	-.46	-1.28	-2.56	-2.60	-.75	-1.40	+2.40	+1.51
7	1	+.00	-.56	+.39	+.30	-2.03	-8.74	+13.71	+12.57
	2	+.00	+.06	-.19	-.25	-1.91	-7.43	+12.04	+11.10
	3	+.00	+.14	-.22	-.26	-1.82	-7.00	+11.25	+10.31
8	1	-.72	-12.95	+6.75	+6.54	-1.10	-.73	+2.49	+1.45
	2	-.72	-4.47	-1.08	-1.21	-1.02	-.63	+2.25	+1.25
	3	-.71	-2.40	-2.54	-2.60	-.95	-.54	+2.01	+1.01
9	1	-.72	-13.97	+7.77	+7.56	-1.10	-.54	+2.30	+1.26
	2	-.72	-4.87	-.68	-.81	-1.02	-.43	+2.05	+1.05
	3	-.71	-2.57	-2.37	-2.43	-.95	-.51	+1.98	+.98
10	1	-.39	-3.83	-.23	-.54	-1.64	-5.71	+7.46	+6.65
	2	-.34	-1.31	-2.05	-2.36	-1.55	-5.64	+7.31	+6.56
	3	-.30	-.47	-2.17	-2.49	-1.51	-5.27	+6.97	+6.22
11	1	-.77	-12.45	+5.02	+4.60	-.90	-1.22	+2.29	+1.17
	2	-.75	-3.75	-2.68	-3.01	-.81	-1.10	+2.04	+1.02
	3	-.74	-1.77	-3.72	-4.10	-.74	-.98	+1.83	+.95
12	1	-.44	-10.43	+5.30	+5.16	-.82	-2.07	+3.27	+2.31
	2	-.45	-3.32	-1.16	-1.25	-.81	-1.75	+2.92	+2.04
	3	-.46	-1.58	-2.26	-2.30	-.75	-1.73	+2.73	+1.84

APPENDIX A.2 WINDOW ORIENTATION MODIFIERS (Continued)

(in MBtu, - = load reduction, + = load increase)

Location Number	Glazing Layers	Heating Energy Savings: Bldg Faces South	Heating Energy Savings: Decrease North Windows (per 100 ft^2)	Heating Energy Savings: Increase South Windows (per 100 ft^2)	Heating Energy Savings: Increase South Windows with Mass (per 100 ft^2)	Cooling Energy Savings: Bldg Faces South	Cooling Energy Savings: Decrease North Windows (per 100 ft^2)	Cooling Energy Increase: Increase South Windows (per 100 ft^2)	Cooling Energy Increase: Increase South Windows with Mass (per 100 ft^2)
13	1	-.61	-8.95	+3.38	+3.35	-1.00	-3.40	+4.97	+4.09
	2	-.59	-2.89	-1.89	-1.89	-.93	-3.11	+4.51	+3.67
	3	-.58	-1.41	-2.70	-2.73	-.87	-3.01	+4.34	+3.55
14	1	-.77	-9.86	+2.43	+2.01	-.90	-1.78	+2.85	+1.73
	2	-.75	-2.95	-3.48	-3.81	-.81	-1.54	+2.48	+1.46
	3	-.74	-1.34	-4.15	-4.53	-.74	-1.40	+2.25	+1.37
15	1	-.74	-5.17	-1.87	-2.51	-2.09	-5.68	+7.38	+5.76
	2	-.66	-2.37	-3.47	-4.13	-1.90	-4.81	+6.35	+4.87
	3	-.60	-1.32	-3.30	-3.97	-1.73	-4.48	+5.90	+4.42
16	1	-.17	-3.01	+.78	+.38	-2.00	-5.69	+8.21	+7.14
	2	-.15	-.39	-1.42	-1.77	-1.89	-4.93	+7.38	+6.44
	3	-.13	+.29	-1.67	-1.98	-1.80	-4.46	+6.83	+5.89
17	1	-.39	-4.06	-.00	-.31	-1.64	-4.32	+6.07	+5.26
	2	-.34	-1.33	-2.03	-2.34	-1.55	-3.87	+5.54	+4.79
	3	-.30	-.50	-2.14	-2.46	-1.51	-3.46	+5.16	+4.41
18	1	-.72	-14.14	+7.94	+7.73	-1.10	-.51	+2.27	+1.23
	2	-.72	-4.65	-.90	-1.03	-1.02	-.32	+1.94	+.94
	3	-.71	-2.39	-2.55	-2.61	-.95	-.29	+1.76	+.76
19	1	+.00	-.10	-.07	-.16	-2.03	-10.62	+15.59	+14.45
	2	+.00	-.08	-.05	-.11	-1.91	-10.15	+14.76	+13.82
	3	+.00	-.05	-.03	-.07	-1.82	-9.67	+13.92	+12.98
20	1	-.17	-1.76	-.47	-.87	-2.00	-6.33	+8.85	+7.78
	2	-.15	-.44	-1.37	-1.72	-1.89	-5.91	+8.36	+7.42
	3	-.13	-.05	-1.33	-1.64	-1.80	-5.57	+7.94	+7.00
21	1	-.72	-18.60	+12.40	+12.19	-1.10	+1.58	+.18	-.86
	2	-.72	-7.77	+2.22	+2.09	-1.02	+1.48	+.14	-.86
	3	-.71	-4.96	+.02	-.04	-.95	+1.36	+.11	-.89
22	1	-.61	-9.06	+3.49	+3.46	-1.00	-3.97	+5.54	+4.66
	2	-.59	-3.10	-1.68	-1.68	-.93	-3.32	+4.72	+3.88
	3	-.58	-1.68	-2.43	-2.46	-.87	-3.20	+4.53	+3.74
23	1	-.17	-2.65	+.42	+.02	-2.00	-5.98	+8.50	+7.43
	2	-.15	-.74	-1.07	-1.42	-1.89	-5.50	+7.95	+7.01
	3	-.13	-.18	-1.20	-1.51	-1.80	-5.20	+7.57	+6.63
24	1	-.39	-5.30	+1.24	+.93	-1.64	-5.00	+6.75	+5.94
	2	-.34	-2.34	-1.02	-1.33	-1.55	-3.83	+5.50	+4.75
	3	-.30	-1.34	-1.30	-1.62	-1.51	-3.22	+4.92	+4.17

APPENDIX A.2 WINDOW ORIENTATION MODIFIERS (Continued)

(in MBtu, - = load reduction, + = load increase)

		Heating Energy Savings				Cooling Energy Savings		Cooling Energy Increase	
Location Number	Glazing Layers	Bldg Faces South	Decrease North Windows (per 100 ft^2)	Increase South Windows (per 100 ft^2)	Increase South Windows with Mass (per 100 ft^2)	Bldg Faces South	Decrease North Windows (per 100 ft^2)	Increase South Windows (per 100 ft^2)	Increase South Windows with Mass (per 100 ft^2)
25	1	+.44	-3.16	-2.04	-2.61	-.09	-.90	+1.25	+1.10
	2	+.24	-1.56	-2.50	-3.12	-.09	-.88	+1.23	+1.09
	3	+.07	-.96	-2.00	-2.68	-.08	-.82	+1.16	+1.02
26	1	-.61	-7.49	+1.92	+1.89	-1.00	-2.11	+3.68	+2.80
	2	-.59	-2.73	-2.05	-2.05	-.93	-1.79	+3.19	+2.35
	3	-.58	-1.45	-2.66	-2.69	-.87	-1.69	+3.02	+2.23
27	1	-.39	-4.81	+.75	+.44	-1.64	-4.53	+6.28	+5.47
	2	-.34	-1.46	-1.90	-2.21	-1.55	-4.30	+5.97	+5.22
	3	-.30	-.41	-2.23	-2.55	-1.51	-3.92	+5.62	+4.87
28	1	+.00	-.20	+.03	-.06	-2.03	-9.59	+14.56	+13.42
	2	+.00	-.05	-.08	-.14	-1.91	-8.42	+13.03	+12.09
	3	+.00	-.01	-.07	-.11	-1.82	-8.07	+12.32	+11.38
29	1	-.72	-14.54	+8.34	+8.13	-1.10	-2.28	+4.04	+3.00
	2	-.72	-5.29	-.26	-.39	-1.02	-2.00	+3.62	+2.62
	3	-.71	-2.88	-2.06	-2.12	-.95	-1.92	+3.39	+2.39
30	1	-.39	-5.96	+1.90	+1.59	-1.64	-3.86	+5.61	+4.80
	2	-.34	-1.95	-1.41	-1.72	-1.55	-3.89	+5.56	+4.81
	3	-.30	-.74	-1.90	-2.22	-1.51	-3.65	+5.35	+4.60
31	1	-.61	-8.37	+2.80	+2.77	-1.00	-2.46	+4.03	+3.15
	2	-.59	-2.39	-2.39	-2.39	-.93	-2.27	+3.67	+2.83
	3	-.58	-1.06	-3.05	-3.08	-.87	-2.22	+3.55	+2.76
32	1	-.39	-6.97	+2.91	+2.60	-1.64	-3.97	+5.72	+4.91
	2	-.34	-1.79	-1.57	-1.88	-1.55	-3.69	+5.36	+4.61
	3	-.30	-.40	-2.24	-2.56	-1.51	-3.36	+5.06	+4.31
33	1	-.44	-10.18	+5.05	+4.91	-.82	-3.63	+4.83	+3.87
	2	-.45	-3.11	-1.37	-1.46	-.81	-3.09	+4.26	+3.38
	3	-.46	-1.37	-2.47	-2.51	-.75	-3.03	+4.03	+3.14
34	1	-.61	-9.34	+3.77	+3.74	-1.00	-2.75	+4.32	+3.44
	2	-.59	-2.91	-1.87	-1.87	-.93	-2.47	+3.87	+3.03
	3	-.58	-1.40	-2.71	-2.74	-.87	-2.52	+3.85	+3.06
35	1	-.40	-2.08	-.68	-1.53	-2.71	-5.72	+9.25	+7.62
	2	-.32	-.74	-1.41	-2.11	-2.65	-4.79	+8.18	+6.68
	3	-.26	-.16	-1.33	-1.89	-2.59	-4.31	+7.52	+6.02
36	1	-.44	-10.20	+5.07	+4.93	-.82	-2.92	+4.12	+3.16
	2	-.45	-3.34	-1.14	-1.23	-.81	-2.63	+3.80	+2.92
	3	-.46	-1.61	-2.23	-2.27	-.75	-2.72	+3.72	+2.83

APPENDIX A.2 WINDOW ORIENTATION MODIFIERS (Continued)

(in MBtu, - = load reduction, + = load increase)

		Heating Energy Savings				Cooling Energy Savings		Cooling Energy Increase	
Location Number	Glazing Layers	Bldg Faces South	Decrease North Windows (per 100 ft²)	Increase South Windows (per 100 ft²)	Increase South Windows with Mass (per 100 ft²)	Bldg Faces South	Decrease North Windows (per 100 ft²)	Increase South Windows (per 100 ft²)	Increase South Windows with Mass (per 100 ft²)
37	1	-.44	-11.49	+6.36	+6.22	-.82	-1.24	+2.44	+1.48
	2	-.45	-3.38	-1.10	-1.19	-.81	-.98	+2.15	+1.27
	3	-.46	-1.38	-2.46	-2.50	-.75	-1.08	+2.08	+1.19
38	1	-.25	-8.57	+4.20	+4.08	-.33	-1.24	+1.63	+1.35
	2	-.29	-2.88	-.90	-.99	-.29	-1.12	+1.46	+1.21
	3	-.34	-1.48	-1.70	-1.78	-.26	-1.02	+1.33	+1.08
39	1	-.61	-6.39	+.82	+.79	-1.00	-2.10	+3.67	+2.79
	2	-.59	-1.06	-3.72	-3.72	-.93	-1.78	+3.18	+2.34
	3	-.58	+.17	-4.28	-4.31	-.87	-1.63	+2.96	+2.17
40	1	-.44	-9.91	+4.78	+4.64	-.82	-3.69	+4.89	+3.93
	2	-.45	-2.98	-1.50	-1.59	-.81	-2.92	+4.09	+3.21
	3	-.46	-1.25	-2.59	-2.63	-.75	-2.76	+3.76	+2.87
41	1	-.17	-2.84	+.61	+.21	-2.00	-5.75	+8.27	+7.20
	2	-.15	-.65	-1.16	-1.51	-1.89	-5.17	+7.62	+6.68
	3	-.13	-.02	-1.36	-1.67	-1.80	-4.71	+7.08	+6.14
42	1	+.44	-3.07	-2.13	-2.70	-.09	-1.35	+1.70	+1.55
	2	+.24	-1.98	-2.08	-2.70	-.09	-1.32	+1.67	+1.53
	3	+.07	-1.34	-1.62	-2.30	-.08	-1.13	+1.47	+1.33
43	1	+.44	-4.83	-.37	-.94	-.09	-.16	+.51	+.36
	2	+.24	-1.15	-2.91	-3.53	-.09	-.16	+.51	+.37
	3	+.07	-.07	-2.89	-3.57	-.08	-.15	+.49	+.35
44	1	-.25	-9.05	+4.68	+4.56	-.33	-.39	+.78	+.50
	2	-.29	-2.60	-1.18	-1.27	-.29	-.33	+.67	+.42
	3	-.34	-1.15	-2.03	-2.11	-.26	-.29	+.60	+.35
45	1	-.61	-7.19	+1.62	+1.59	-1.00	-3.90	+5.47	+4.59
	2	-.59	-2.18	-2.60	-2.60	-.93	-3.34	+4.74	+3.90
	3	-.58	-1.00	-3.11	-3.14	-.87	-3.17	+4.50	+3.71

APPENDIX A.3 HEAT ABSORBING AND REFLECTIVE GLASS MODIFIERS

(in MBtu's per 100 sq.ft. of glass)

		Cooling Load Reduction		Heating Load Increase	
Location Number	Glazing Layers	Heat Absorbing Glass	Reflective Glass	Heat Absorbing Glass	Reflective Glass
1	Single	17	30	19	38
	Double	17	28	21	34
	Triple	19	27	17	30
2	Single	17	40	12	27
	Double	19	39	13	23
	Triple	21	38	11	19
3	Single	21	45	11	23
	Double	28	44	12	20
	Triple	27	43	10	17
4	Single	9	19	17	36
	Double	13	19	19	32
	Triple	12	18	15	27
5	Single	9	20	17	35
	Double	12	20	19	31
	Triple	12	18	15	27
6	Single	10	16	18	38
	Double	11	16	20	34
	Triple	10	15	16	29
7	Single	36	72	4	8
	Double	45	71	4	7
	Triple	44	70	4	6
8	Single	8	13	16	33
	Double	9	13	18	29
	Triple	8	11	14	25
9	Single	8	12	17	36
	Double	8	12	19	31
	Triple	8	11	15	27
10	Single	20	51	9	18
	Double	26	51	10	16
	Triple	31	49	8	14
11	Single	8	13	21	44
	Double	9	13	24	39
	Triple	8	12	18	34
12	Single	9	19	17	35
	Double	8	18	19	31
	Triple	10	17	16	27
13	Single	17	31	13	28
	Double	20	30	15	24
	Triple	19	29	12	21
14	Single	9	16	19	44
	Double	7	14	21	40
	Triple	9	13	18	35
15	Single	20	38	12	26
	Double	24	38	14	23
	Triple	23	36	11	20

APPENDIX A.3. HEAT ABSORBING AND REFLECTIVE GLASS MODIFIERS (Continued) (in MBtu's per 100 sq.ft. of glass)

Location Number	Glazing Layers	Cooling Load Reduction: Heat Absorbing Glass	Cooling Load Reduction: Reflective Glass	Heating Load Increase: Heat Absorbing Glass	Heating Load Increase: Reflective Glass
16	Single	25	48	11	23
	Double	30	48	12	21
	Triple	30	46	10	18
17	Single	18	34	12	27
	Double	21	33	14	23
	Triple	21	32	11	20
18	Single	7	11	17	37
	Double	8	11	20	32
	Triple	7	10	16	28
19	Single	46	93	1	1
	Double	58	92	1	1
	Triple	57	90	1	1
20	Single	29	57	7	15
	Double	35	56	8	13
	Triple	35	54	7	11
21	Single	0	0	19	40
	Double	0	0	21	35
	Triple	0	0	17	30
22	Single	17	31	14	30
	Double	20	31	16	26
	Triple	19	29	12	22
23	Single	27	52	8	17
	Double	33	51	9	14
	Triple	32	51	7	12
24	Single	25	48	12	25
	Double	30	47	13	23
	Triple	29	45	11	19
25	Single	6	7	15	31
	Double	5	7	16	27
	Triple	5	6	13	24
26	Single	10	18	13	27
	Double	12	17	14	23
	Triple	11	16	11	20
27	Single	21	41	12	25
	Double	26	40	13	23
	Triple	25	39	11	19
28	Single	39	83	1	2
	Double	48	81	1	1
	Triple	47	79	0	1
29	Single	13	24	18	35
	Double	15	23	20	32
	Triple	15	21	17	30
30	Single	21	40	11	24
	Double	25	39	13	21
	Triple	24	37	10	18

APPENDIX A.3. HEAT ABSORBING AND REFLECTIVE GLASS MODIFIERS (Continued) (in MBtu's per 100 sq.ft. of glass)

Location Number	Glazing Layers	Cooling Load Reduction: Heat Absorbing Glass	Cooling Load Reduction: Reflective Glass	Heating Load Increase: Heat Absorbing Glass	Heating Load Increase: Reflective Glass
31	Single	12	25	17	34
	Double	12	24	18	30
	Triple	14	23	15	26
32	Single	20	37	14	29
	Double	23	36	15	25
	Triple	23	35	12	22
33	Single	15	27	16	34
	Double	17	26	18	30
	Triple	16	25	14	26
34	Single	15	28	14	31
	Double	18	28	16	27
	Triple	17	26	13	23
35	Single	30	46	8	17
	Double	34	46	7	15
	Triple	34	45	6	13
36	Single	13	23	14	30
	Double	15	23	16	26
	Triple	14	21	13	23
37	Single	8	13	19	41
	Double	9	12	22	19
	Triple	8	11	17	31
38	Single	5	7	17	36
	Double	5	7	19	31
	Triple	5	6	15	27
39	Single	11	19	16	34
	Double	12	18	18	30
	Triple	12	17	14	26
40	Single	15	27	17	36
	Double	17	26	19	31
	Triple	17	25	15	27
41	Single	28	54	8	17
	Double	34	53	9	15
	Triple	33	52	8	13
42	Single	7	10	13	28
	Double	7	10	15	24
	Triple	7	9	12	21
43	Single	3	2	12	47
	Double	1	2	13	40
	Triple	2	1	11	33
44	Single	5	4	17	37
	Double	3	3	19	32
	Triple	2	3	16	28
45	Single	16	30	14	29
	Double	18	30	15	25
	Triple	18	29	12	22

APPENDIX A.4 MOVABLE NIGHT INSULATION MULTIPLIERS

Location Number	R-Value	Single Glazing Al Sash	Single Glazing Al/TB Sash	Single Glazing Wd Sash	Double Glazing Al Sash	Double Glazing Al/TB Sash	Double Glazing Wd Sash	Triple Glazing Al Sash	Triple Glazing Al/TB Sash	Triple Glazing Wd Sash
1	R-1	2.0	1.8	1.7	.8	.6	.6	.5	.3	.3
	R-3	3.0	2.7	2.5	1.5	1.2	1.0	.9	.7	.6
	R-5	3.3	2.9	2.8	1.7	1.4	1.2	1.2	.9	.7
2	R-1	1.0	.9	.8	.4	.3	.3	.2	.2	.1
	R-3	1.5	1.3	1.2	.7	.6	.5	.4	.3	.3
	R-5	1.6	1.4	1.4	.8	.7	.6	.5	.4	.3
3	R-1	.8	.7	.7	.4	.3	.3	.2	.2	.1
	R-3	1.2	1.1	1.0	.8	.6	.5	.5	.3	.3
	R-5	1.4	1.2	1.1	.9	.7	.6	.6	.4	.4
4	R-1	3.6	3.2	3.0	1.8	1.4	1.3	1.0	.8	.6
	R-3	5.3	4.7	4.5	3.3	2.6	2.3	2.1	1.6	1.3
	R-5	5.9	5.2	4.9	3.9	3.1	2.7	2.7	2.0	1.6
5	R-1	1.8	1.6	1.5	.9	.7	.6	.5	.4	.3
	R-3	2.6	2.3	2.2	1.6	1.3	1.1	1.0	.8	.6
	R-5	2.9	2.5	2.4	1.9	1.5	1.3	1.3	1.0	.8
6	R-1	1.8	1.6	1.5	.9	.7	.6	.5	.4	.3
	R-3	2.6	2.3	2.2	1.6	1.3	1.1	1.0	.8	.6
	R-5	2.9	2.6	2.5	2.0	1.6	1.4	1.3	1.0	.8
7	R-1	.3	.2	.2	.1	.1	.1	.1	.0	.0
	R-3	.4	.3	.3	.3	.2	.2	.1	.1	.1
	R-5	.4	.4	.4	.3	.2	.2	.2	.1	.1
8	R-1	2.4	2.1	2.0	1.2	1.0	.8	.7	.5	.4
	R-3	3.5	3.1	3.0	2.2	1.8	1.5	1.4	1.0	.8
	R-5	3.9	3.5	3.3	2.6	2.1	1.8	1.8	1.3	1.1
9	R-1	2.9	2.5	2.4	1.4	1.1	1.0	.8	.6	.5
	R-3	4.2	3.7	3.5	2.6	2.1	1.8	1.7	1.2	1.0
	R-5	4.6	4.1	3.9	3.1	2.5	2.2	2.1	1.6	1.3
10	R-1	.7	.6	.6	.4	.3	.3	.2	.1	.1
	R-3	1.0	.9	.9	.7	.5	.5	.4	.3	.2
	R-5	1.2	1.0	1.0	.8	.6	.6	.5	.4	.3
11	R-1	2.7	2.4	2.3	1.4	1.1	.9	.8	.6	.5
	R-3	4.0	3.5	3.4	2.5	2.0	1.7	1.6	1.2	.9
	R-5	4.4	3.9	3.7	3.0	2.4	2.1	2.0	1.5	1.2
12	R-1	2.5	2.2	2.1	1.0	.8	.7	.5	.4	.3
	R-3	3.6	3.2	3.1	1.7	1.4	1.2	1.1	.8	.7
	R-5	4.0	3.5	3.4	2.1	1.7	1.4	1.4	1.0	.8

Al = aluminum, Al/TB = aluminum with thermal breaks, Wd = wood sash

APPENDIX A.4 MOVABLE NIGHT INSULATION MULTIPLIERS (continued)

Location Number	R-Value	Single Glazing Al Sash	Single Glazing Al/TB Sash	Single Glazing Wd Sash	Double Glazing Al Sash	Double Glazing Al/TB Sash	Double Glazing Wd Sash	Triple Glazing Al Sash	Triple Glazing Al/TB Sash	Triple Glazing Wd Sash
13	R-1	1.6	1.4	1.4	.8	.7	.6	.5	.3	.3
	R-3	2.4	2.1	2.0	1.5	1.2	1.0	.9	.7	.6
	R-5	2.6	2.3	2.2	1.8	1.4	1.2	1.2	.9	.7
14	R-1	2.5	2.2	2.1	1.0	.8	.7	.5	.4	.3
	R-3	3.7	3.3	3.1	1.8	1.4	1.2	1.1	.8	.7
	R-5	4.1	3.6	3.5	2.1	1.7	1.5	1.4	1.0	.8
15	R-1	1.0	.8	.8	.5	.4	.3	.3	.2	.2
	R-3	1.4	1.2	1.2	.9	.7	.6	.5	.4	.3
	R-5	1.5	1.4	1.3	1.1	.8	.7	.7	.5	.4
16	R-1	.7	.6	.6	.4	.3	.3	.2	.1	.1
	R-3	1.1	1.0	.9	.7	.5	.5	.4	.3	.2
	R-5	1.2	1.1	1.0	.8	.7	.6	.5	.4	.3
17	R-1	.8	.7	.7	.4	.3	.3	.2	.2	.1
	R-3	1.2	1.1	1.0	.8	.6	.5	.5	.3	.3
	R-5	1.3	1.2	1.1	.9	.7	.6	.6	.4	.3
18	R-1	2.7	2.4	2.3	1.3	1.1	.9	.8	.6	.5
	R-3	4.0	3.5	3.3	2.5	2.0	1.7	1.6	1.2	.9
	R-5	4.4	3.9	3.7	2.9	2.3	2.0	2.0	1.5	1.2
19	R-1	.1	.1	.1	.1	.1	.1	.0	.0	.0
	R-3	.2	.2	.1	.1	.1	.1	.0	.0	.0
	R-5	.2	.2	.2	.2	.1	.1	.1	.0	.0
20	R-1	.5	.4	.4	.2	.2	.2	.1	.1	.1
	R-3	.7	.6	.6	.4	.4	.3	.3	.2	.2
	R-5	.8	.7	.6	.5	.4	.4	.3	.2	.2
21	R-1	2.6	2.3	2.2	1.3	1.0	.9	.7	.5	.4
	R-3	3.8	3.4	3.2	2.4	1.9	1.6	1.5	1.1	.9
	R-5	4.2	3.7	3.5	2.8	2.2	2.0	1.9	1.4	1.1
22	R-1	1.8	1.6	1.5	.9	.7	.6	.5	.4	.3
	R-3	2.6	2.4	2.2	1.7	1.3	1.1	1.0	.8	.6
	R-5	2.9	2.6	2.5	2.0	1.6	1.4	1.3	1.0	.8
23	R-1	.7	.7	.6	.3	.2	.2	.2	.1	.1
	R-3	1.1	1.0	.9	.5	.4	.4	.3	.2	.2
	R-5	1.2	1.1	1.0	.6	.5	.4	.4	.3	.3
24	R-1	.6	.5	.5	.3	.2	.2	.1	.1	.1
	R-3	.8	.7	.7	.5	.4	.4	.3	.2	.2
	R-5	.9	.8	.8	.6	.5	.4	.4	.3	.2

Al = aluminum, Al/TB = aluminum with thermal breaks, Wd = wood sash

APPENDIX A.4 MOVABLE NIGHT INSULATION MULTIPLIERS (continued)

		Single Glazing			Double Glazing			Triple Glazing		
Location Number	R-Value	Al Sash	Al/TB Sash	Wd Sash	Al Sash	Al/TB Sash	Wd Sash	Al Sash	Al/TB Sash	Wd Sash
25	R-1	.4	.3	.3	.2	.2	.1	.1	.1	.1
	R-3	.5	.5	.5	.4	.3	.2	.2	.1	.1
	R-5	.6	.5	.5	.4	.3	.3	.2	.2	.1
26	R-1	1.6	1.4	1.3	.8	.6	.6	.4	.3	.3
	R-3	2.3	2.1	2.0	1.5	1.2	1.0	.9	.7	.5
	R-5	2.6	2.3	2.2	1.7	1.4	1.2	1.2	.9	.7
27	R-1	1.2	1.1	1.0	.6	.5	.4	.3	.3	.2
	R-3	1.8	1.6	1.5	1.1	.9	.8	.7	.5	.4
	R-5	2.0	1.8	1.7	1.4	1.1	.9	.9	.7	.5
28	R-1	.1	.1	.1	.0	.0	.0	.0	.0	.0
	R-3	.1	.1	.1	.1	.0	.0	.0	.0	.0
	R-5	.1	.1	.1	.1	.1	.0	.0	.0	.0
29	R-1	4.0	3.6	3.4	1.6	1.3	1.1	.9	.7	.5
	R-3	5.9	5.2	5.0	2.9	2.3	2.0	1.9	1.4	1.1
	R-5	6.5	5.8	5.5	3.5	2.8	2.4	2.4	1.8	1.4
30	R-1	1.3	1.1	1.1	.6	.5	.5	.4	.3	.2
	R-3	1.9	1.7	1.6	1.2	.9	.8	.7	.5	.4
	R-5	2.1	1.8	1.7	1.4	1.1	1.0	.9	.7	.6
31	R-1	2.2	1.9	1.8	.8	.6	.6	.5	.3	.3
	R-3	3.2	2.8	2.7	1.5	1.2	1.0	.9	.7	.6
	R-5	3.5	3.1	3.0	1.7	1.4	1.2	1.2	.9	.7
32	R-1	1.5	1.3	1.3	.8	.6	.5	.4	.3	.3
	R-3	2.2	2.0	1.9	1.4	1.1	1.0	.9	.6	.5
	R-5	2.5	2.2	2.1	1.7	1.3	1.2	1.1	.8	.7
33	R-1	2.6	2.3	2.2	1.3	1.0	.9	.7	.5	.4
	R-3	3.8	3.3	3.2	2.3	1.9	1.6	1.5	1.1	.9
	R-5	4.1	3.7	3.5	2.8	2.2	1.9	1.9	1.4	1.1
34	R-1	1.8	1.6	1.5	.9	.7	.6	.5	.4	.3
	R-3	2.6	2.3	2.2	1.6	1.3	1.1	1.0	.8	.6
	R-5	2.9	2.6	2.4	1.9	1.6	1.4	1.3	1.0	.8
35	R-1	.9	.8	.7	.3	.3	.2	.2	.1	.1
	R-3	1.3	1.1	1.1	.6	.5	.4	.4	.3	.2
	R-5	1.4	1.3	1.2	.7	.6	.5	.5	.4	.3
36	R-1	1.8	1.6	1.5	.9	.7	.6	.5	.4	.3
	R-3	2.6	2.4	2.2	1.7	1.3	1.1	1.0	.8	.6
	R-5	2.9	2.6	2.5	2.0	1.6	1.4	1.3	1.0	.8

Al = aluminum, Al/TB = aluminum with thermal breaks, Wd = wood sash

APPENDIX A.4 MOVABLE NIGHT INSULATION MULTIPLIERS (continued)

		Single Glazing			Double Glazing			Triple Glazing		
Location Number	R-Value	Al Sash	Al/TB Sash	Wd Sash	Al Sash	Al/TB Sash	Wd Sash	Al Sash	Al/TB Sash	Wd Sash
37	R-1	2.8	2.5	2.4	1.4	1.1	1.0	.8	.6	.5
	R-3	4.1	3.7	3.5	2.6	2.0	1.8	1.6	1.2	1.0
	R-5	4.6	4.0	3.8	3.1	2.4	2.1	2.1	1.5	1.2
38	R-1	1.4	1.2	1.2	.7	.6	.5	.4	.3	.2
	R-3	2.0	1.8	1.7	1.3	1.0	.9	.8	.6	.5
	R-5	2.2	2.0	1.9	1.5	1.2	1.1	1.0	.7	.6
39	R-1	2.0	1.8	1.7	1.0	.8	.7	.6	.4	.3
	R-3	2.9	2.6	2.5	1.8	1.5	1.3	1.2	.9	.7
	R-5	3.2	2.9	2.7	2.2	1.7	1.5	1.5	1.1	.9
40	R-1	2.1	1.8	1.7	1.0	.8	.7	.6	.4	.3
	R-3	3.0	2.7	2.6	1.9	1.5	1.3	1.2	.9	.7
	R-5	3.3	3.0	2.8	2.2	1.8	1.6	1.5	1.1	.9
41	R-1	.7	.6	.6	.3	.3	.2	.2	.1	.1
	R-3	1.0	.9	.8	.6	.5	.4	.4	.3	.2
	R-5	1.1	.9	.9	.7	.6	.5	.5	.3	.3
42	R-1	.4	.3	.3	.2	.2	.1	.1	.1	.1
	R-3	.5	.5	.5	.4	.3	.3	.2	.1	.1
	R-5	.6	.5	.5	.4	.3	.3	.3	.2	.1
43	R-1	.8	.8	.7	.3	.3	.2	.2	.1	.1
	R-3	1.2	1.1	1.1	.6	.5	.4	.4	.3	.2
	R-5	1.4	1.2	1.2	.7	.6	.5	.5	.4	.3
44	R-1	1.8	1.6	1.5	.7	.6	.5	.4	.3	.2
	R-3	2.6	2.3	2.2	1.3	1.0	.9	.8	.6	.5
	R-5	2.9	2.5	2.4	1.5	1.2	1.1	1.0	.7	.6
45	R-1	1.4	1.2	1.2	.7	.6	.5	.4	.3	.2
	R-3	2.1	1.8	1.7	1.3	1.0	.9	.8	.6	.5
	R-5	2.3	2.0	1.9	1.5	1.2	1.1	1.0	.8	.6

Al = aluminum, Al/TB = aluminum with thermal breaks, Wd = wood sash

APPENDIX A.5 ROOF AND WALL COLOR MODIFIERS

(in MBtu's per 1000 sq.ft. of roof or wall area)

	Light or White Roof			Light or White Walls		
Location Number	R-0 Ceiling	R-19 Ceiling	R-38 Ceiling	R-0 Wall	R-11 Wall	R-19 Wall
1	-6.14	-1.17	-0.75	-1.79	-0.73	-0.46
2	-5.36	-1.13	-0.77	-2.10	-0.67	-0.73
3	-6.11	-1.34	-0.86	-2.40	-1.16	-0.85
7	-5.84	-1.27	-0.88	-2.46	-1.12	-0.79
10	-5.13	-1.05	-0.75	-2.19	-0.93	-0.68
15	-6.62	-1.24	-0.82	-2.19	-0.94	-0.57
16	-5.53	-1.21	-0.83	-2.17	-0.98	-0.68
17	-6.34	-1.29	-0.86	-3.05	-1.00	-0.62
19	-9.82	-1.92	-1.21	-3.90	-1.52	-1.09
20	-6.36	-1.30	-0.89	-2.57	-1.11	-0.76
23	-6.24	-1.36	-0.95	-2.55	-1.14	-1.01
27	-5.19	-1.15	-0.81	-1.99	-0.87	-0.64
28	-8.08	-1.74	-1.19	-3.45	-1.62	-1.13
32	-3.47	-0.72	-0.49	-1.25	-0.56	-0.41
35	-7.27	-1.85	-1.25	-2.40	-0.09	-0.16
41	-5.58	-1.20	-0.80	-2.12	-0.97	-0.68

APPENDIX A.6 NIGHT TEMPERATURE SETBACK MODIFIERS

Percent Heating Energy Increase			Percent Heating Energy Increase		
Location Number	Ranch, Two-Story, & Split-Level	Town-houses	Location Number	Ranch, Two-Story, & Split-Level	Town-houses
1	8.8	7.8	23	9.9	10.3
2	9.7	8.3	24	9.2	9.7
3	9.8	9.3	25	24.2	32.0
4	5.1	3.0	26	7.9	7.5
5	7.0	5.9	27	8.5	8.0
6	7.0	5.5	28	18.5	27.7
7	17.4	21.2	29	5.0	3.8
8	6.1	4.5	30	8.4	8.2
9	5.7	3.9	31	7.6	5.7
10	10.2	10.5	32	7.6	6.6
11	6.7	5.4	33	6.2	4.6
12	6.4	5.6	34	6.9	5.6
13	7.0	5.8	35	14.9	17.2
14	7.7	6.6	36	6.6	5.2
15	10.3	10.5	37	6.2	4.6
16	10.0	10.4	38	8.4	8.1
17	11.1	12.8	39	7.3	6.4
18	6.2	4.6	40	6.8	5.1
19	36.7	41.0	41	10.7	11.5
20	12.0	13.5	42	26.0	32.2
21	5.5	3.8	43	15.0	20.2
22	6.3	5.2	44	8.1	8.5
			45	6.9	5.7

APPENDIX A.7. ATTACHED SUNSPACE MODIFIERS *

		Opaque Roof Sunspace		Glass Roof Sunspace	
Location Number	House Thermal Integrity†	Single Glazed	Double Glazed	Single Glazed	Double Glazed
1	Loose	30	-	43	-
	Medium	20	25	30	35
	Tight	15	20	21	25
2	Loose	15	-	22	-
	Medium	8	12	12	16
3	Loose	15	-	22	-
	Medium	8	12	12	16
4	Loose	7	-	10	-
	Medium	1	12	1	24
	Tight	-5	7	+3	16
5	Loose	11	-	20	1
	Medium	5	12	12	24
	Tight	1	7	5	17
6	Loose	11	-	20	-
	Medium	5	12	12	24
	Tight	1	7	5	17
7	Loose	1	-	+3	
	Medium	1	1	+3	+3
8	Loose	7	-	10	-
	Medium	1	12	1	24
	Tight	-5	7	+5	16
9	Loose	7	-	10	-
	Medium	1	12	1	24
	Tight	-5	7	+5	16
10	Loose	15	-	22	-
	Medium	8	12	12	16
11	Loose	19	-	36	-
	Medium	13	20	26	38
	Tight	8	15	10	29
12	Loose	11	-	20	-
	Medium	5	12	12	24
	Tight	1	7	5	17
13	Loose	13	-	24	-
	Medium	7	13	16	25
	Tight	4	9	9	19
14	Loose	19	-	36	-
	Medium	13	20	26	38
	Tight	8	15	10	29
15	Loose	30	-	43	
	Medium	20	25	30	35

APPENDIX A.7. ATTACHED SUNSPACE MODIFIERS * (Continued)

Location Number	House Thermal Integrity†	Opaque Roof Sunspace Single Glazed	Opaque Roof Sunspace Double Glazed	Glass Roof Sunspace Single Glazed	Glass Roof Sunspace Double Glazed
16	Loose	11	-	15	-
	Medium	7	9	6	9
17	Loose	15	-	22	-
	Medium	8	12	12	16
18	Loose	7	-	10	-
	Medium	1	12	1	24
	Tight	-5	7	+5	16
19	Loose	1	-	+3	
	Medium	1	1	+3	+3
20	Loose	11	-	15	-
	Medium	7	9	6	9
21	Loose	7	-	10	-
	Medium	1	12	1	24
	Tight	-5	7	+5	16
22	Loose	13	-	24	-
	Medium	7	13	16	25
	Tight	4	9	9	19
23	Loose	11	-	15	-
	Medium	7	9	5	9
24	Loose	15	-	22	-
	Medium	8	12	12	16
25	Loose	21		42	-
	Medium	13	17	26	33
26	Loose	13		24	-
	Medium	7	13	16	25
	Tight	4	9	9	19
27	Loose	15	-	22	-
	Medium	8	12	12	16
28	Loose	1	-	+3	
	Medium	8	1	+3	+3
29	Loose	7	-	10	-
	Medium	1	12	1	24
	Tight	-5	7	+5	16
30	Loose	15	-	22	-
	Medium	8	12	12	16
31	Loose	13	-	24	-
	Medium	7	13	16	25
	Tight	4	9	9	19
32	Loose	15	-	22	-
	Medium	8	123	12	16

APPENDIX A.7. ATTACHED SUNSPACE MODIFIERS * (Continued)

		Opaque Roof Sunspace		Glass Roof Sunspace	
Location Number	House Thermal Integrity†	Single Glazed	Double Glazed	Single Glazed	Double Glazed
33	Loose	11	-	20	-
	Medium	5	12	12	24
	Tight	1	7	5	17
34	Loose	13	-	24	-
	Medium	7	13	16	25
	Tight	4	9	9	19
35	Loose	12	-	16	-
	Medium	7	8	8	
36	Loose	11	-	20	-
	Medium	5	12	12	24
	Tight	1	7	5	17
37	Loose	11	-	20	-
	Medium	5	12	12	24
	Tight	1	7	5	17
38	Loose	10	-	22	-
	Medium	5	10	13	23
	Tight	1	6	7	16
39	Loose	13	-	24	-
	Medium	7	13	16	19
	Tight	4	9	9	25
40	Loose	11	-	20	-
	Medium	5	12	12	24
	Tight	1	7	5	17
41	Loose	11	-	15	-
	Medium	7	9	6	9
42	Loose	21	-	42	-
	Medium	13	17	26	33
43	Loose	21	-	42	-
	Medium	13	17	26	33
44	Loose	10	-	22	-
	Medium	5	10	13	23
	Tight	1	6	7	16
45	Loose	13	-	24	-
	Medium	7	13	16	25
	Tight	4	9	9	19

* Modifier = average glass foot (GF) factor x 1000; GF factor is calculated as the ratio of delta heating load savings and the width of sunspace.

† Loose = R-19 ceiling, R-11 wall, uninsulated foundation, 0.7 ach, single glazing;
Medium = R-19 or R-30 ceiling, R-11 wall, R-5 2' slab perimeter or 4' basement wall, 0.7 ach, double glazing;
Tight = R-38 ceiling, R-19 wall, R-10 basement foundation wall, 0.7 ach, triple glazing.

APPENDIX B: SENSITIVITY ANALYSIS OF PART LOAD PERFORMANCE OF COOLING EQUIPMENT

Appendix B contains information on the seasonal efficiencies of the space conditioning equipment. Table 4.5a lists the Seasonal Coefficients Of Performance (SCOP) for the 45 base city locations. These seasonal efficiencies were obtained from DOE-2.1A simulations of one-story ranch houses with typical thermal integrities (e.g., R-19 ceiling, R-11 walls, and an infiltration level of 0.7 ach).

Appendix B also provides the results of a sensitivity analysis of part load performance of cooling equipment.

As described in the text of Section 4.5, we have chosen the following part load curve for cooling equipment in our energy analysis for residential buildings:

$$\frac{COP_{PLR}}{COP_{Full\ Load}} = \frac{1}{1.197-.197(PLR)} \qquad (1)$$

In order to determine the sensitivity of our results to the part load performance of the cooling equipment we have also simulated the following part load performance curve for several options in Lake Charles.

$$\frac{COP_{PLR}}{COP_{Full\ Load}} = \frac{1}{1.6-.16(PLR)} \qquad (2)$$

Both of these equations were obtained from the NBS study referred to in Section 4.5. Equation (2) is appropriate for a house where the cooling equipment is cycled at a rate of 1 cycle per hour (cph) whereas Equation (1) is more appropriate for 2-3 cycles per hour. Since there is a lack of experimental data on part load performance of cooling equipment, we have had to use our best judgment in choosing a part load performance curve for the DOE-2.1A simulations. We have assumed that well-insulated, tight houses will have relatively low cycling rates since the rate of heat gains is lower for such houses relative to looser, uninsulated houses. Therefore we have chosen a cycling rate of 1 cph for our base case simulations and 2-3 cph for the sensitivity analysis.

Figure B.1 shows the part load performance plotted as a function of part load ratio (PLR) for both of the above equations. As can be seen, the original part load performance is better than the alternate simulation (equation 2). Table B.a summarizes the results obtained from the DOE-2.1A simulations for a ranch house with a slab foundation in Lake Charles. We have not altered the air conditioner size for these simulations. The percentage difference between the original DOE-2.1A simulations (using equation 1) and the sensitivity runs (using equation 2) is substantial (the range is 11 to 23%). Thus, the uncertainty in our energy estimates for cooling may be as great as

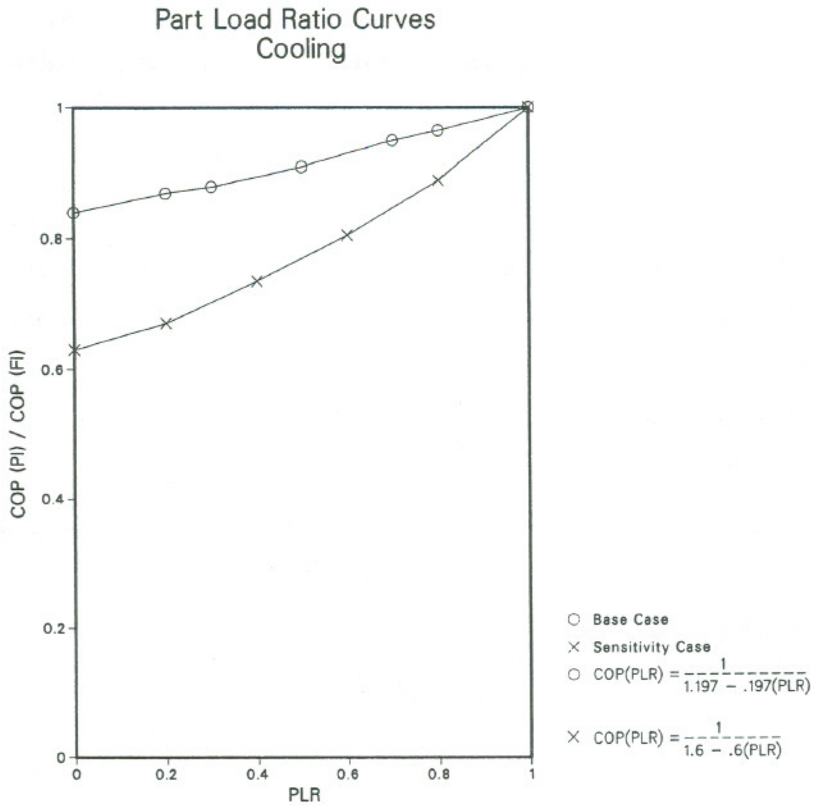


Fig. B.1

23% or 1,000 kWh in Lake Charles.

Table B.a Cooling Energy Versus Part Load Performance for Lake Charles

Option					Annual Energy Use (KWh)		
Ceil	Wall	Fdn	Glaz	Inf	Base Case	Sensitivity Case	% Difference
R-0	R-0	R-0	1	.7	7,122	7,892	10.8
R-11	R-0	R-0	1	.7	6,080	7,045	15.9
R-19	R-11	R-5(2')	2	.7	4,826	5,839	21.0
R-38	R-19	R-5(2')	3	.7	4,483	5,496	22.6
R-38	R-27	R-5(4')	3	.7	4,350	5,347	22.9

Several additional simulations were performed in New York City and Chicago. Again, cooling energy use increased, the range was from 15% to 21% compared to the base case runs. Therefore, assuming the cycling rate is closer to 2.5 cph than 1 cph, cooling energy use estimates should be increased by 15% to 20% over the base case number.

APPENDIX C: FOUNDATION MODELS

The following three types of foundation are modeled in this analysis: slab-on-grade, heated and unheated basements. Accurate modeling of heat transfer through building foundations is still beyond the state-of-the-art capabilities of the DOE-2.1A simulation program. However, an approximation has been developed that yields reasonable energy values for the purposes of the current work. This approximation consists of two separate steps.

(1) Determination of steady-state U-values for each of the three foundation types.

(2) Incorporation of these U-values into the DOE-2.1A model to obtain their impact on building loads.

The following discussion describes these two steps, gives some typical examples of their use, and assesses their validity.

(1) Steady-State Foundation U-Values.

A two dimensional heat conduction model is used to calculate U-values for different foundation types. The solution of such a two-dimensional conduction problem with the appropriate boundary conditions has been done using a tested finite element program.[1,2] The finite element approach is particularly suitable for this type of problem; furthermore, foundation heat loss values shown in the 1981 ASHRAE *Handbook of Fundamentals* are also based on finite element program solutions to the two-dimensional heat flow problem.

The three foundation types have been modeled with the resultant steady-state U-values. The insulation measures modeled for each foundation type reflect commonly used practices.

1. Slab on Grade

Boundary conditions:	$T_{in} = 70$ F $T_{out} = 10$ F
Slab:	4 in. concrete covered by carpet on the inside
Insulation:	rigid board perimeter insulation extending downwards

1. F.S. Wang, "Mathematical Modeling and Computer Simulation of Insulation Systems in Below Grade Applications", DOE/ASHRAE Conference on Thermal Performance of the Exterior Envelopes of Buildings, Orlando, Florida (December 1979).

2. J. S. Burright, "User's Manual for the Finite Element Heat Conduction Computer Program", Dow Chemical Co. (1984).

U-values: Btu/hr·F·lineal foot of perimeter			
	Type of Slab		
Type of Slab Insulation	No Heat element	Heating Duct in Slab	Baseboard Heater
No Insulation	1.18	1.42	1.63
Two ft., R-5 insulation (exterior)	0.40	0.486	0.483
Four ft, R-5 insulation (exterior)	0.28	0.344	0.359
Two ft., R-10 insulation (exterior)	0.32	0.404	0.387
Four ft.,R-10 insulation (exterior)	0.18	0.229	0.223

The appropriate temperature difference in F used with the above U-values is that between indoor and outdoor temperatures. The dependence of the above U-values on T_{in} and T_{out} is insignificant in the range of -30 F to 120 F.[1]

2. Heated and Unheated Basements

Boundary conditions: $T_{in} = 70$ F
$T_{basement} = 70$ F
$T_{out} = 10$ F

Basement walls and floor lumped together in U-value.

Basement wall: 1 foot exposed above grade
7 feet below grade

Insulation: Rigid board insulation on either the exterior or interior of the basement wall extending downwards

U-values: Btu/hr·F·lineal foot of perimeter	
No Insulation	1.86
Four feet, R-5 exterior	1.05
Four feet, R-10 exterior	0.81
Eight feet, R-5 exterior	0.766
Eight feet, R-10 exterior	0.485
Four feet, R-5 interior	1.23
Eight feet, R-11 interior	0.68

The appropriate temperature difference in F used with the above U-values is that between the basement and the outdoors. The dependence of the above U-values on $T_{basement}$ and T_{out} is insignificant in the range -30 to 120 F. Basement temperatures can be treated as constant, since they vary less than 5 F from top to bottom.[3]

3. American Society of Heating and Air-conditioning Engineers, *Handbook of Fundamentals*, 1977, ASHRAE, Atlanta GA 30329.

(2) Incorporation of Steady-State U-Values into DOE-2.1A

The U-values calculated earlier for the various foundation types cannot be used directly in DOE-2.1A because they apply to steady-state heat flow conditions. In the DOE-2.1A simulation, the outdoor temperature T_{out} is obtained from the weather tape and changes on an hourly basis, while the steady-state U-value assumes a constant T_{out}. To dampen the hourly fluctuations in T_{out}, the foundation layer is described as an exterior "surface" with a long delay period but the same U-value as that of the steady-state model. In the LBL foundation model, the delay factor has been incorporated using a large thermal mass (soil) with the resultant conductance correspondence to that of the steady-state model. For example, if A is the area of this soil layer, R_v its resistance, U_p the steady-state U-value per lineal foot of perimeter, and P the perimeter length, then:

$$A/R_v = U_p\,P \qquad (1)$$

A does not have to equal the actual floor area of the foundation. R_V has been chosen to correspond to a soil layer with the maximum thermal mass, i.e., delay, that the DOE-2.1A code can handle. At present, the DOE-2.1A program calculates up to 100 hourly response factors prior to requiring a common ratio to calculate the remaining sequence of response factors. A delay introduced by a soil layer with thickness of 5.25 feet does just that, assuming the following properties for soil: conductivity = 0.5 Btu/ft·hr·F; specific heat = 0.2 Btu/lb·F; and density = 60 lb/ft.

In generating the data base for foundation effects, R_v has been kept fixed, while the area A is varied according to Equation (1) to produce the correct net conductance $U_p \cdot P$.

The total heat transfer across the foundation "surface" is given by: [4]

$$q_{out,t} = \sum_{j=o}^{\infty} T_{out,t-j}\,X_j - \sum_{j=o}^{\infty} T_{in,t-j}\,Y_j \qquad (2)$$

$$q_{in,t} = \sum_{j=o}^{\infty} T_{out,t-j}\,Y_j - \sum_{j=o} T_{in,t-j}\,Z_j \qquad (3)$$

where X_j, Y_j and Z_j are the response factors. In the present calculation DOE-2.1A calculates these factors up to j=95, while for $j > 95$ we have:

$$X_{j+1}/X_j = Y_{j+1}/Y_j = Z_{j+1}/Z_j = R \qquad (j > 95)$$

with R_j the common ratio also calculated by DOE-2.1A. Each j interval corresponds to 1 hour in DOE-2.1A. The magnitude of the response factors changes as the thermal mass of fixed U-value

4. American Society of Heating and Air-conditioning Engineers, *Handbook of Fundamentals*, 1977, ASHRAE, Atlanta GA 30329.

soil layer increases. Thus, the introduction of thermal mass results in a sequence of response factors that vary less from interval to interval and do not decay as fast when compared to the response factors of a material layer of the same conductance U, but much less thermal mass. (See Figure C.1)

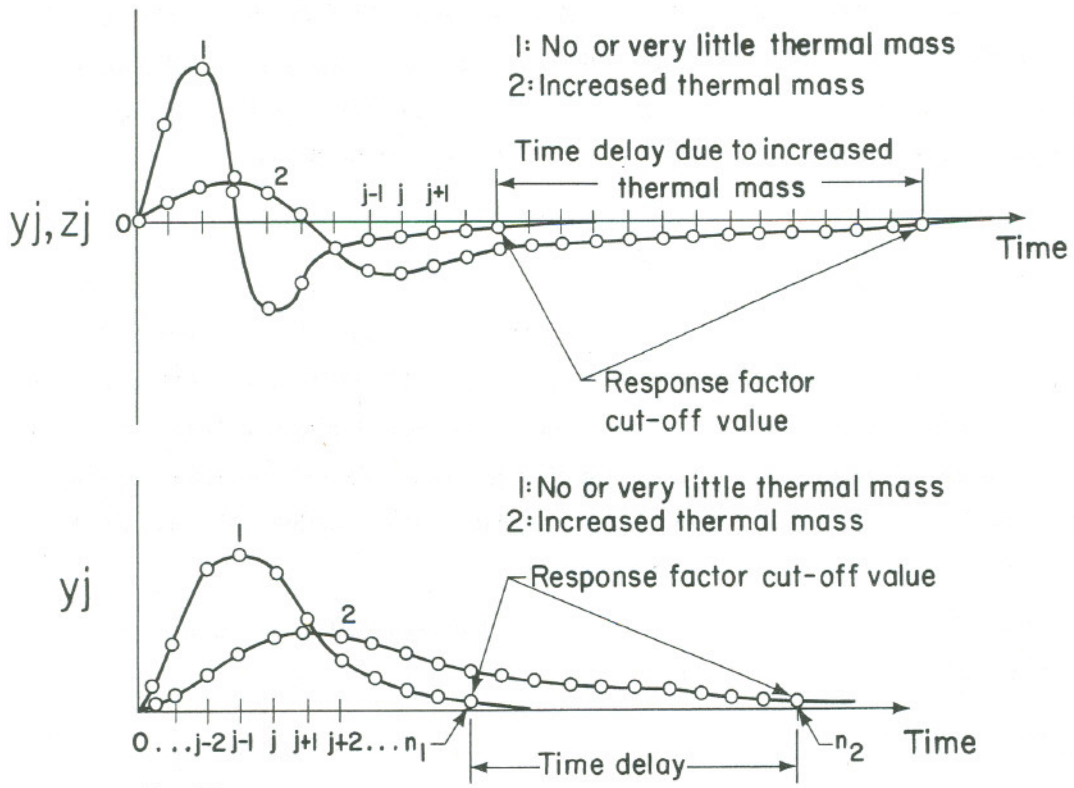


Fig. C.1

XBL 823-271

Consequently, as more thermal mass is introduced, while keeping conductance constant, equations (2) and (3) tend asymptotically to the equations:

$$q_{out,t} = q_{in,t} = U\,(T_{out} - T_{in}) \tag{4}$$

with

$$T_{out} = T_{out,t}\ ;\ T_{in} = T_{in,t} \quad \text{for all t} \tag{5}$$

and

$$\sum_{j=o}^{\infty} X_j = \sum_{j=o}^{\infty} Y_j = \sum_{j=o}^{\infty} Z_j = U \tag{6}$$

Equations (4) and (5) can be easily recognized as the one representing the steady-state heat conduction across a layer of conductivity equal to U.

The equivalence of equations (2) and (3), with a thermal mass delay incorporated, to equations (4) and (5) can be intuitively regarded as the decoupling of any temperature excitation from its response. Consequently, the temperature variation effects tend to average out, leading to a virtually steady-state response.

With regard to the DOE-2.1A load calculations, it should be noted that in the case of slab foundation only one zone (living space) has been considered. However, in basement foundations the basement comprises a second zone.

APPENDIX D: INTERNAL LOADS

Introduction

All hourly building energy use simulation models require input for internal loads. These loads consist of heat energy added to the indoor environment by occupants, lighting, and appliances. Internal loads increase total cooling loads and decrease total heating loads. In order to calculate a schedule of internal loads it is necessary to know the annual energy use of lighting and appliances, their saturations, and their use schedules. Additionally, an activity schedule for the building occupants is required. There is a significant uncertainty in the internal loads schedules used in most modelling efforts. This uncertainty is due to the lack of information on average appliance and lighting energy use in new or existing housing stock and also on the schedule of use for these appliances. The loads calculated in this appendix are for new (1982) appliances in new buildings. They were computed using estimates of lighting and appliance energy use for new 1982 equipment. These internal load schedules served as input to a large series of DOE-2 simulations from which data was gathered to construct the slide rules.

Calculation of Internal Loads from Occupants

Even while asleep, people generate metabolic heat. Metabolic heat energy is both sensible and latent in form. The latent portion is due to moisture exhaled from the lungs and to evaporation through the skin. As one's activity level increases, so does the generation of sensible and latent heat. In the case of internal loads used in the slide rule analyses, it was assumed that there were 3.2 occupants who spent 30% of their time asleep, 30% at rest or performing light work, and 40% of their time away from the house. While asleep, it was assumed that the sensible and latent heat generation rates averaged (for this family of 3.2) 147 Btu/hr and 98 Btu/hr, respectively.[1] During the other 30% of indoor activities, it was assumed that the occupants averaged 230 Btu/hr and 200 Btu/hr, respectively of sensible and latent heat generation.[2] On an annual basis, the total amount of sensible and latent heat generated is 3.17 MBtu and 2.50 MBtu, respectively.

Calculation of Internal Loads from Lighting

Most of the electrical energy input to incandescent bulbs and fluorescent lamps is converted to heat energy. The small percentage that is converted to light energy, will end up mostly as

1. American Society of Heating and Air-conditioning Engineers, *Handbook of Fundamentals,* 1977 Chapter 8, ASHRAE, Atlanta GA 30329.

2. American Society of Heating and Air-conditioning Engineers, *Handbook of Fundamentals,* 1977 Chapter 26, ASHRAE, Atlanta GA 30329.

internal heat energy also. Some lighting is outdoors and some indoor lighting will escape through the windows. It is assumed that 90% of the electrical energy input to lights results in a sensible heat gain indoors. Assuming an annual electric energy input of 1 kWh/ft^2 and 1540 ft^2 of floor area, the annual sensible heat gain for the base case ranch house is 1386 kWh (4.73 MBtu). Since we have assumed that lighting energy use is proportional to floor area, we can obtain the internal load from lighting for the other prototypes by scaling the load to the floor area of each of the other four prototypes.

Calculation of Internal Loads from Appliances

There are several major appliances that contribute to internal loads in residential buildings. These are refrigerators, freezers, ranges, dryers, and hot water heaters. In our analysis, we also include the contribution to internal loads from televisions and miscellaneous electrical equipment.

Refrigerators and Freezers

Our analysis assumed that on average the saturation level for refrigerators was 100% and 15% per household for new and old models respectively. The new refrigerators use 1125 kWh/yr and the old ones 1600 kWh/yr. The sales weighted efficiency of new refrigerators is increasing rapidly compared to other appliances. Internal load estimates for refrigerators should be updated often to obtain more accurate values for their contribution to total loads. We assumed that most (85%) of the old refrigerators were located in non-conditioned areas and that all of the new refrigerators were located in space conditioned areas. Therefore, the total annual contribution from refrigerators is 1160 kWh. The annual energy consumption for freezers is assumed to be equal to 950 kWh. The saturation level for new houses is approximately 45% but, half of these are assumed to be in unconditioned locations. Therefore, the contribution of freezers to the total internal load is 214 kWh/yr.

Cooking

The internal load from cooking is strongly dependent on whether a vented or unvented stove is used in a residence. According to ASHRAE standards, for a vented commercial gas range, 20% of the input energy is sensible load, and for electrical ranges, 32% is sensible load.[3] For an unvented range, approximately 33% of the input energy results in a latent load and 67% results in sensible heat.

The gas stove contribution was calculated as follows. It was assumed that 33% of the cooking is vented (primarily baking) and therefore the sensible load from this activity is 20% of the gas

3. American Society of Heating and Air-conditioning Engineers, *Handbook of Fundamentals,* 1977 Chapter 26, ASHRAE, Atlanta GA 30329.

energy input. It was assumed that gas stoves consume a total of 60 therms each year, thus 4 therms/year is the sensible load from vented activities. Of the remaining 40 therms/yr, 4 are latent heat from the combustion process and the other 36 therms/yr result in a 67% sensible heat (24 therms/yr) and 33% latent heat (12 therms/yr) load. Therefore, total sensible and latent loads from cooking with natural gas are 28 and 16 therms/yr, respectively.

For electric ranges, it is assumed that the energy input is 1200 kWh/yr. If the electric range is unvented, it is assumed that 67% of the input energy (800 kWh/yr) results in sensible heat and 33% of the input energy (400 kWh/yr) results in latent heat. The saturations of electric and gas ranges in new U.S. residences are approximately 78% and 19% respectively. Therefore, the average internal loads from a range are about 805 kWh/yr sensible and 415 kWh/yr latent heat.

Dryers

Clothes dryers can be electric or gas powered. In either case, most of the heat energy generated is vented to the outside. Additionally, in many houses, dryers are located in unconditioned spaces and do not contribute to the internal loads at all. For the DOE-2 internal load schedules, it was assumed that electric dryers used 900 kWh/yr. It was also assumed that only 10% of this energy input appears as sensible heat indoors. If the saturation of dryers in new U.S. households is 70%, the sensible internal loads from electric dryers is 63 kWh/yr. The saturation of new gas dryers in new residences is very small (about 8%) and their annual energy consumption is lower (500 kWh) than for electric dryers. Therefore, gas dryers contribute only 4 kWh/yr of sensible load.

Hot Water Heaters

Hot water heaters require energy input for both standby losses and heating of incoming cold water. The assumed annual energy use for gas and electric hot water heaters was 275 therms and 4000 kWh (136.5 therms) respectively. It was also assumed that half of gas water heaters are located in conditioned areas and that all electric water heaters are located in conditioned areas. Therefore, electric water heaters will produce the same internal loads as gas water heaters. For the DOE-2 analysis, it was assumed that standby losses amounted to 90 therms/yr for gas water heaters and that half of the standby losses are conductive. Since half of the gas hot water heaters are located in conditioned spaces, 22.5 therms/yr is the sensible load from standby losses.

The energy used to heat hot water is calculated from the product of water use, specific heat of water and water temperature change. We assumed 39 gallons per day per household for water consumption and a Δ temperature of 80 F. Since the specific heat of water is 8.3 Btu/gal·F, the heat energy needed to raise the temperature of 39 gallons of water per day by 80 F is 95 therms/yr. If 10% of this heat energy appears as sensible heat, then 9.5 therms/yr will appear as sensible heat energy. Most of the sensible heat energy resulting from this heat energy added to incoming cold water is lost to the outside when this water is sent down the drain. Therefore, the total sensible heat energy input is 32 therms/yr.

The latent heat load from water use is more difficult to estimate. Hot water is used for showers, baths, and hand, dish, and clothes washing. The greatest contribution to latent heat production will probably be from shower usage. Much of this latent load is likely to be vented through natural or mechanical ventilation. It was assumed that 5% of the hot water energy is converted to latent heat. Therefore, .05 x 95 therms/yr =4.75 therms/yr is the latent load from hot water use.

Television and Miscellaneous

Televisions require about 100W of electrical power input. Assuming that they operate for 2000 hours per year per set, the annual energy consumption is 200 kWh. If we also assume that only one set is in operation per household for these 2000 hours, then 200 kWh/yr is the energy use per household. Miscellaneous appliances are assumed to use 300 kWh/yr.

Table D.a summarizes the sensible and latent loads from people, lighting, and appliances. These loads are applicable to the ranch house prototype. As noted earlier, for other prototypes, the lighting energy use most be scaled up or down for the appropriate floor areas. The following formula can be used to calculate the sensible internal load as a function of floor space area (Area) expressed in square feet:

$$\text{Sensible internal load (kWh)} = 4614 + 1386\ (\text{Area})/1540$$

Table D.a Estimated Average Annual Internal Loads For Residences

Use	Saturation	Annual Energy Use	% Indoors	Sensible Load	Latent Load
New Refrigerator	1.0	1125 kWh	100	1125 kWh	0
Old Refrigerator	0.15	1600 kWh	15	35 kWh	0
Freezer	0.45	950 kWh	50	214 kWh	0
Range gas	0.19	60 therms	100	805 kWh	415 kWh
electric	0.78	1200 kWh			
Hot Water gas	0.37	275 therms	50	940 kWh	140 kWh
electric	0.59	1285 kWh	100		
Dryer electric	0.70	900 kWh	10	63 kWh	0
gas	0.08	500 kWh	10	4 kWh	
Television	1.0	100 W	100	200 kWh	0
Miscellaneous	1.0	-	100	300 kWh	0
Lighting	1.0	1 kWh/ft^2	90	1386 kWh	0
People	3.2	-	-	930 kWh	735 kWh
Totals	-	-	-	6000 kWh/yr	1290 kWh/yr

APPENDIX E: INTERACTIONS BETWEEN CEILING, WALL AND FOUNDATION MEASURES

The approach that is used in the slide rule assumes that the impact on building loads of each variable (ceiling, wall and floor insulation, infiltration, window type and size) is independent and additive.

This hypothesis has been investigated using DOE-2.1A simulations for two test locations (Minneapolis and Lake Charles). Only the results from Minneapolis are presented here as an illustration. The impact of varying ceiling and wall insulation on the heating loads have been calculated for a one-story ranch house with a basement in Minneapolis. The floor insulation (R-5 extending down 8 ft.) and infiltration level (0.7 ach) have been kept constant, while the ceiling and wall insulation are varied independently. Twenty-eight computer runs have been performed to test the effects of various combinations of ceiling and wall insulation. The total heating loads for these test runs are shown in Table E.a, while the heating load savings due changing wall and ceiling insulation levels are shown in Table E.c. These tables illustrate that the savings due to either ceiling or wall insulation can be regarded as constant irrespective of variations in the other component. The level of accuracy is quite satisfactory (within 0.2 MBtu) for reasonable conservation measures (when both components are at comparable levels of thermal integrity), but tends to diminish at the extremes near R-0.

A similar analysis has been done to test the impact of ceiling and floor insulation on the total heating load of a one-story ranch house in Minneapolis. In this case, wall insulation (R-11) and the infiltration level (0.7 ach) have been held constant while varying ceiling and floor insulation levels. Table E.b shows the resultant total heating loads for these test runs, while Table E.d show the heating load savings due to the variations in ceiling and floor insulation levels. The results follow those presented above for wall and ceiling insulation.

Table E.a Heating Loads for Minneapolis Ranch House (in MBtu, Floor insulation and infiltration constant)

	Wall			
Ceiling	R-0	R-11	R-19	R-27
R-0	160.1	139.7	133.8	130.8
R-11	114.3	87.8	87.6	78.2
R-19	107.9	89.1	74.9	71.4
R-30	103.2	76.3	70.0	66.6
R-38	101.5	74.5	68.2	64.8
R-49	100.0	73.0	66.7	63.3
R-60	99.1	72.0	65.7	62.3

Table E.b Heating Load for Minneapolis Ranch House
(MBtu, with wall R-value and infiltration level constant)

	Floor				
Ceiling	R-0	R5(4')	R5(8')	R10(8')	R19(Flr)
R-0	148.7	142.5	139.1	135.0	133.7
R-11	99.3	91.8	87.8	83.0	81.4
R-19	92.7	85.1	81.1	76.3	74.7
R-30	87.9	80.3	76.3	71.4	69.8
R-38	86.1	78.5	74.5	69.7	68.1
R-49	84.6	77.0	73.0	68.1	66.5
R-60	83.7	76.1	72.0	67.2	65.6

Table E.c Δ Heating Loads Due to Variations in Wall and Ceiling Insulation for Minneapolis (MBtu)

	Fixed Wall Measures			
Δ Ceiling	R-0	R-11	R-19	R-27
R-0→ R11	45.8	51.3	52.2	52.6
R-11→R19	6.4	6.7	6.7	6.8
R-19→R30	4.7	4.8	4.9	4.8
R-30→R38	1.7	1.8	1.8	1.8
R-38→R49	1.5	1.5	1.5	1.5
R-49→R60	0.9	1.0	1.0	1.0

Fixed Ceiling	Δ Wall		
Measures	RO→R11	R11→R19	R19→R27
R-0	21.0	5.3	3.0
R-11	26.5	6.2	3.4
R-19	26.8	6.2	3.5
R-30	26.9	6.3	3.5
R-38	27.0	6.3	3.4
R-49	27.0	6.3	3.4
R-60	27.1	6.3	3.4

Table E.d Δ Heating Loads (MBtu) for Floor Insulation due to Variations in Ceiling Insulation for Minneapolis

Fixed Ceiling	Δ Floor			
Measures	R0→R5(4')	R5(4')→R5(8')	R5(8')→R10(8')	R10(8')→R19
R-0	6.2	3.4	4.1	1.3
R-11	7.5	4.0	4.8	1.6
R-19	7.6	4.0	4.8	1.6
R-30	7.6	4.0	4.9	1.6
R-38	7.6	4.0	4.8	1.6
R-49	7.6	4.0	4.9	1.6
R-60	7.6	4.1	4.8	1.6

APPENDIX F: MAIN-FRAME AND PC PROGRAMS USED IN PEAR

In this Appendix, we provide a listing and brief summary of the various main-frame and auxiliary programs used to develop the data input for the PEAR microcomputer programs. In all cases, the main-frame programs were written in FORTRAN, while the PC programs were written with TURBO Pascal.* In addition, there are numerous other programs and subroutines developed to analyze the sensitivity results and compute regression equations, which we do not include here for lack of space. Figure F.1 is a diagram that summarizes the interaction between the various main-frame programs, which use the output from the DOE-2 computer code and the PC programs in PEAR.

Main frame programs:

We wrote and executed three programs on the main-frame computer that converted output data from the DOE-2 parametric simulations and climate information (i.e., degree-day data) into files that could be moved to the PC. These are:

DBASE - This program reads the DOE-2 database (annual heating and cooling system loads) and computes normalized component loads. We made separate calculations for the five prototypes, which are saved in five binary files of normalized component loads.

MERGE - This program combines the five binary component loads files produced by DBASE into a single E format text file. This text file was then moved to the PC. This program also creates an index to this file that is incorporated into the PEAR program code.

SHORTRAT - The third program combines information from three files containing NOAA degree-day data for over 800 locations, and a list of cities included in PEAR to produce a file of location multipliers for the PEAR cities. This text is then moved to the PC for use with the PEAR program.

PC Programs:

We created eight auxiliary programs which run on the PC that are used to convert the text files mentioned above, as well as other files, into the appropriate format for PEAR. There are actually two versions of PEAR, a demonstration version (DPEAR or PEAR 1.0) containing data for 19 U.S. cities and a full version (PEAR or PEAR 2.0) covering 800 locations. The auxiliary PC programs are:

DATAGEN - This program reads the text file of component loads the main-frame computer, and produces a binary file of the same data for use by the PEAR program.

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* TURBO Pascal is a registered trademark of BORLAND INTERNATIONAL, Inc.

Flowchart of Programs and Data Supporting PEAR

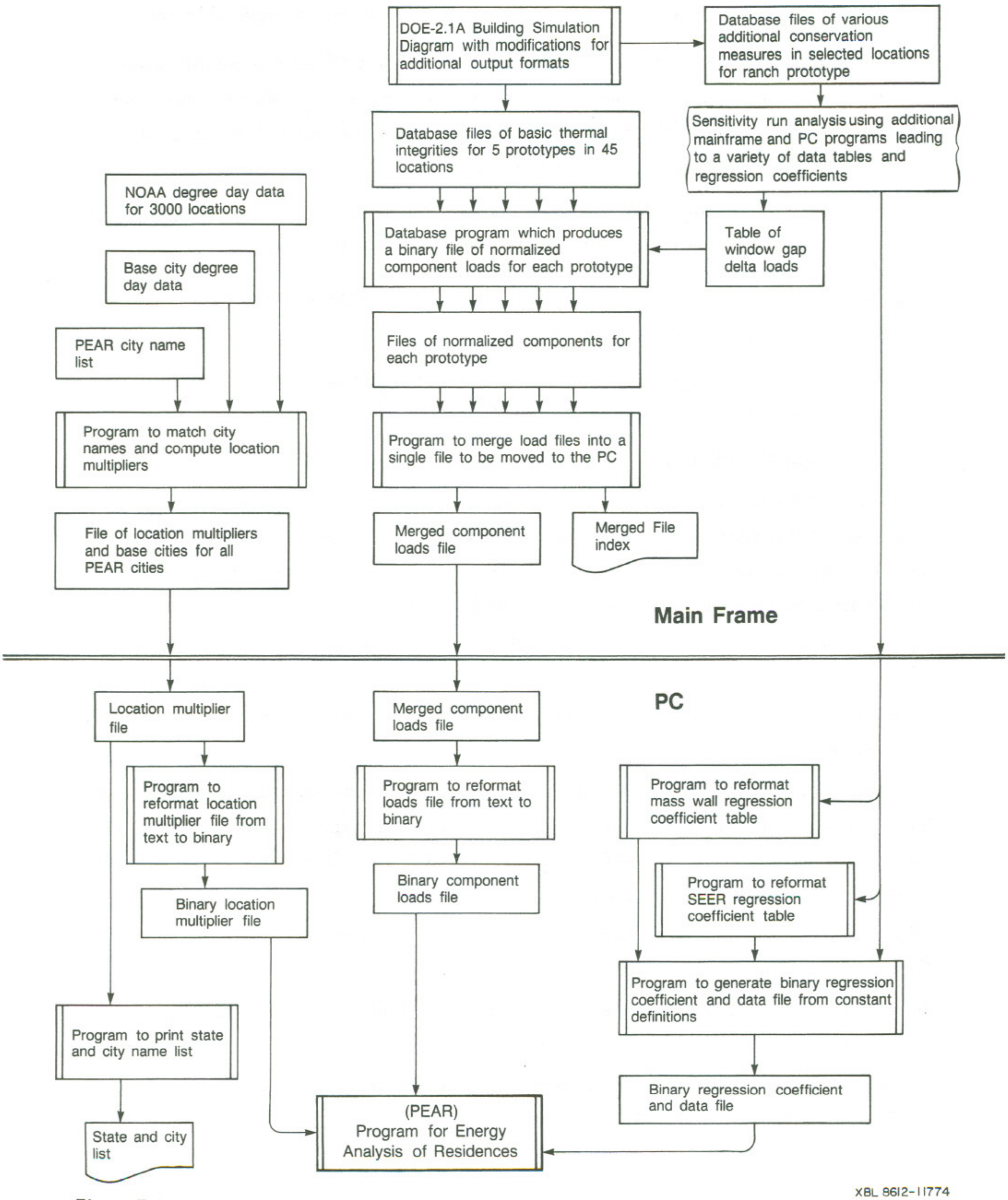

Figure F.1

CITYGEN - The program converts the text file of city names and heating and cooling location multipliers to a binary file that is used by the PEAR program. There are two city name files, one for the full program and an abridged version used in the demonstration version.

CONSTGEN - This program processes tables of regression coefficients, equipment information, and various degree-day values needed in PEAR. The program produces a binary file of these values readable by PEAR. These constants are put into PEAR in this manner because of the memory allocation used by TURBO Pascal 2.0.

LSTCITY - This program reads the same text file of city names as CITYGEN and prints the state and city name list covered in PEAR and found in the User's Manual.

SEERGEN - This program converts a text file of SEER coefficients into constant definition statements for inclusion into CONSTGEN.

MASSFORM - This program converts the text file of mass wall regression coefficients into constant definition statements for inclusion into CONSTGEN.

Procedures and Functions Used in PEAR

We now present a list of procedures and functions, defined in the PEAR program. We include a brief description of the purpose of each procedure, the procedure by which it is called, those that it calls, and those in which each procedure is defined. Because of PEAR's size, we organize the procedures into several *compiler include files.*

PEAR - The main program, which contains all global type, constant and variable definitions. This program opens the database file and calls the procedures to execute the option selected from the Menu procedure. It calls StartUp, Menu, ModelIn, BarGraph, SaveData, ReadData, EconOut, and FindFile.

FindName - Function that locates an input run name in the active user data file, and positions the file to that name. It returns a boolean value, which is true if the name was found, and false otherwise. It is called by SaveData and ReadData. It calls ReadString, DisplayNames, and Box, and is defined within PEAR (Main program).

DisplayNames - Procedure that displays run names in the active user data file. It is called by FindName and defined there.

Box - Procedure that draws the border in which the user data file run names are displayed. It is called by FindName and is defined within PEAR.

ErrorBox - Procedure that displays error messages during user data file operations. It is called by FindFile, and defined within PEAR.

FilName - Function that reads in user data file name, adds default extension '.SLD', and returns the string with file name. It is called by FindFile, calls ReadString, and is defined within PEAR.

FindFile - Procedure that opens a new or existing user data file. It is called by PEAR, SaveData, ReadData, and EconOut, and calls FilName and ErrorBox. It is defined within PEAR.

ReadData - Procedure that reads a run from a user data file. It is called by PEAR, calls FindFile and FindName, and is defined within PEAR.

SaveData - Procedure that saves a run in a user data file under a new or existing run name. It is called by PEAR and calls FindFile and FindName. It is defined within PEAR.

Screenb - Procedure that displays all but the menu line of the main menu screen. It is called by Menu and is defined within PEAR.

Menu - Function that displays the menu line on the main menu screen. It reads and returns the user selected option. It is called by PEAR and calls Screenb. It is defined within PEAR.

Include file UTILITY

Noise - Procedure that produces error warning noise for approximately one second. It is called by Error, ReadReal, and CursorControl and is defined within PEAR.

ReadString - Procedure that reads and returns a character string of the specified length. It is called by LimitAndRecord, Cursor, FindName, and FindFile, and is defined within PEAR.

WriteReal - Procedure that writes a real number in a six place field. It is called by WriteScreen, ReadReal, Screen0, Screen1, Screen2, Screen3, Cursor, and DisplayCase, and is defined within PEAR.

ReadReal - Procedure that reads a numeric character string, and converts it to a real number which it returns. It is called by LimitAndRecord and Cursor and calls WriteReal and Noise. It is defined within PEAR.

Error - Procedure that displays error messages on input and economics screens. It is called by Screen0, Screen1, Screen2, Screen3, Cursor and calls Noise. It is defined within PEAR.

Lim - Procedure that displays input numeric limits or input string choices. It is called by Screen0, Screen1, Screen2, Screen3, and Cursor, and is defined within PEAR.

StrUpCase - Function that converts an input character string to all upper case and returns the new string. It is called by Screen0, Screen1, Screen2, and Screen3. It is defined within PEAR.

Include file SLIDEINF

GetState - Function that searches for input state name in name list, and if found, sets state number to corresponding value. It returns a boolean value, which is true if the state is found, and false otherwise. It is called by Screen0 and is defined within PEAR.

GetCity - Function that searches for input city name in the subset of the city file corresponding to the current state number. It sets the base city, location multipliers and other values. It returns a boolean value, which is true if the city is found and false otherwise. It is called by Screen0 and defined within PEAR.

GetData - Function that searches the subset of database file corresponding to current base city for a record with the current foundation and prototype combination, and if found, reads the values. It returns a boolean value, which is true if the record is found, and false otherwise. It is called by Screen0 and LimitAndRecord, and defined within PEAR.

Include file STARTUP

StartUp - Overlay procedure containing calls to the initializing routines. It is called by PEAR, and calls Logo, Init, and GetCoef. This procedure is only in memory when the program starts. It uses the same memory space as Compute and EconOut, and is defined within PEAR.

Logo - Procedure that displays the PEAR logo screen. It is called by StartUp, and calls Rect. It is defined within StartUp.

Rect - Procedure that draws rectangles on the logo screen. It is called by Logo and is defined there.

Init - Procedure that initializes all of the variables for the base run condition. It is called by StartUp, and is defined there.

GetCoef - Procedure that reads the file COEF.DAT and stores the coefficients and climate values in the proper arrays. It is called by StartUp and is defined there.

Include file SLIDECMP

Compute - Overlay procedure that computes residential energy use. It contains the main computational procedures and calls all other necessary computational procedures. It uses the same memory space as StartUp and EconOut. It is called by LimitAndRecord and BarGraph, and calls ClWl, Fnd, Infl, Wnd, WMass, SSpace, RWColor, Fan, SetBack, and HCEnergy, and is defined within PEAR.

Reg - Function that returns a real value from a linear interpolation. It is defined within Compute.

ClWl - Procedure that interpolates a component load between normalized component loads in the database. It is used for ceiling, wall, and crawlspace loads. It is called by Compute and Fnd and calls Reg. It is defined within Compute.

Fnd - Procedure used to compute foundation component loads for all three foundation types. It is called by compute and calls ClWl, Reg, and Utotal. It is defined within Compute.

Utotal - Function used to compute total basement U-values. It is called by Fnd and is defined there.

Infl - Procedure used to compute infiltration component loads. It is called by Compute and is defined there.

WindOr - Procedure used to compute window orientation and size modifiers. It is called by Wnd and is defined within Compute.

MovIns - Procedure used to compute movable insulation heating load modifiers. It is called by Wnd and is defined within Compute.

Sash - Procedure used to compute sash type modifiers. It is called by Wnd and is defined within Compute.

RefAbs - Procedure used to compute glass type modifiers for refelective and heat absorbing glass. It is called by Wnd and is defined within Compute.

Wnd - Procedure used to compute window component loads. It is called by Compute and calls WindOr, MovIns, Sash, and RefAbs. It is defined within Compute.

SetBack - Procedure used to compute night setback modifiers. It is called by Compute and calls Reg. It is defined within Compute.

WMass - Procedure used to compute the mass wall modifiers. It is called by Compute and is defined there.

SSpace - Procedure used to compute sunspace modifiers. It is called by Compute and is defined there.

RWColor - Procedure used to compute roof and wall color modifiers. It is called by Compute, calls Reg, and is defined within Compute.

HCEnergy - Procedure used to compute heating and cooling energy from heating and cooling loads, and to compute component energies and costs for the bargraph. It is called by Compute and is defined there.

Apliance - Procedure used to sum appliance rating values. Rating values are adjusted for fuel price, loads per week and domestic hot water conservation measures, if they are input. It is called by Compute and is defined there.

Include file ECONOUT

EconOut - Overlay procedure that performs economic calculations. It contains all procedures used for economics and occupies the same memory space as StartUp and Compute. It is called by the main program (PEAR), and calls FindFile, DisplayIndex, Cursor, and FillUpIndex. It is defined within PEAR.

Economics - Procedure that calculates simple payback and savings-to-investment ratio. It is called by Cursor, calls Power, and is defined within EconOut.

Power - Function that returns the results of raising a real number to a real power. It is called by Economics, and is defined there.

Cost - Procedure used to sum space conditioning costs only and appliances plus space conditioning costs for each fuel type. It is called from DisplayCase and DisplayIndex, and is defined within EconOut.

DisplayCase - Procedure that displays the data for a run on the economics screen. It is called by DisplayIndex and Cursor, calls WriteReal, and is defined within EconOut.

FindRun - Function that searches for and reads a run in the active user data file. It returns the boolean value true if the run is found, or false otherwise. It is called by Cursor and defined within EconOut.

FillUpIndex - Function that reads consecutive runs from the active user data file into the economics data array. It reads five runs unless the end of file is reached. A byte containing the number of runs read is returned. It is called by Cursor and defined within EconOut.

DisplayIndex - Procedure that displays data from the base run and all runs in the economics data array on the economics screen. It is defined within EconOut.

Cursor - Procedure that controls cursor position and data entry on the economics section screen. It is called by EconOut, and calls Lim, WriteReal, ReadReal, ReadString, Error, FindRun, DisplayIndex, DisplayCase, FillUpIndex, and Economics. It is defined within EconOut.

Include file EDITOR

ModelIn - Procedure that initializes input screen flags and cursor position. It is called by PEAR, calls TextScreen and CorsorControl, and is defined within PEAR.

WriteScreen - Procedure that displays data values from the curent run on the input screens. It is called by TextScreen, calls WriteReal, and is defined within ModelIn.

TextScreen - Procedure that displays the fixed or nondata portion of the input screens. It is called by ModelIn and CursorControl, calls WriteScreen, and is defined within ModelIn.

LimitAndRecord - Procedure that reads a data value from the keyboard and calls a screen procedure for error checking and storage in the current run. It is called by CursorControl, and calls ReadString, ReadReal, Screen0, Screen1, Screen2, Screen3, GetData, and Compute. It is defined within ModelIn.

ChngOther - Procedure that changes the display of other data values which have been automatically changed as the result of their relationship to a new value entered by the user. It is called by

Screen0 and Screen2, and is defined within LimitAndRecord.

Screen0 - Procedure that sets data value validity and range limits, tests entered data values against these limits, stores the entered values, and sets or adjusts related data values for values on the left side of the input screen. It is called by LimitAndRecord, and calls WriteReal, Lim, Error, StrUpCase, CheckParams, GetState, GetCity, and GetData. It is defined within LimitAndRecord.

CheckParams - Procedure that checks for consistency between the floor area input and will adjust the perimeter length, and wall area if discrepancies are found. It is called by Screen0, calls ChngOther, and is defined within Screen0.

Screen1 - Procedure that sets data value validity and range limits, tests entered data values against these limits, stores the entered values, and sets or adjusts related data values for entries on the conservation measures input screen. It is called by LimitAndRecord, calls WriteReal, Lim, and Error, and is defined within LimitAndRecord.

Screen2 - Procedure that sets data value validity and range limits, tests entered data values against these limits, stores the entered values, and sets or adjusts related values for entries on the optional measures input screen. It is called by LimitAndRecord, calls WriteReal, Lim, Error, and ChngOther, and is defined within LimitAndRecord.

Screen3 - Procedure that sets data value validity and range limits, tests entered data values against these limits, stores the entered values, and sets or adjusts related values for entries on the Economic Input Screen. It is called by LimitAndRecord, calls WriteReal, Lim, and Error, and is defined within LimitAndRecord.

CursorControl - Procedure that controls the cursor position on the input screens and switching between screens. It is called by ModelIn, calls TextScreen, Noise, and LimitAndRecord, and is defined within ModelIn.

Include file BARGRAPH

BarGraph - Procedure that draws the basic elements of the bargraph output screen. It is called by PEAR, calls Grid, DrawBar, and Titles, and is defined within PEAR.

DrawBar - Procedure that draws the bars on the bargraph output screen. It is called by BarGraph and is defined there.

Grid - Procedure that draws the horizontal grid lines on the bargraph screen, and displays the minimum and maximum component energy cost values. It is called by BarGraph and is defined there.

Titles - Procedure that displays the component titles for the bars on the bargraph. It is called by BarGraph and is defined there.