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Publication Date

1992-03-01

LBL--30377

DE93 001556

SINGLE-FAMILY HEATING AND COOLING REQUIREMENTS: ASSUMPTIONS, METHODS, AND SUMMARY RESULTS

TOPICAL REPORT

Prepared by

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For

Gas Research Institute
GRI Contract No. 5086-800-1318
GRI Project Manager
James M. Fay
Strategic Planning & Analysis
Through U.S. Department of Energy
under Contract No. DE-AC03-76SF00098

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RESEARCH SUMMARY

TITLE	Single Family Heating and Cooling Requirements: Assumptions, Methods, and Summary Results
CONTRACTOR	Lawrence Berkeley Laboratory Applied Science Division 1 Cyclotron Road Berkeley, California 94720
PRINCIPAL INVESTIGATOR	R.L. Ritschard
REPORT	May 1990 - March 1992
OBJECTIVE	To update previous GRI single-family data base using the latest version of DOE-2, more representative weather tapes, improved modeling techniques, and more recent data on typical building construction practices in the U.S.
TECHNICAL PERSPECTIVE	A building loads data base for single-family detached buildings will help GRI and its contractors to assess new gas technologies and target R&D efforts. This data base of building energy requirements augments the existing GRI loads data for the multifamily and office buildings sectors. The data base includes loads for various building end-uses such as space heating and cooling, water heating, and non-HVAC electricity.
RESULTS	The research has created a data base of hourly building loads using a state-of-the-art building simulation code (DOE-2.1D) for 8 prototypes, representing pre-1940s to 1990s building practices, in 16 U.S. climates. The report describes the assumed modeling inputs and building operations, defines the building prototypes and selection of base cities, compares the simulation results to both surveyed and measured data sources, and discusses the results. The full data base with hourly space conditioning, water heating, and non-HVAC electricity consumption is available from GRI. In addition, the estimated loads on a per square foot basis are included as well as the peak heating and cooling loads.

TECHNICAL APPROACH

Modeling assumptions and building characteristics were developed for 8 building types representing pre-1940s, 1950-1970, 1980s, and 1990s construction practices. The 1980s prototypes were based on a statistical analysis of the 1987 RECS data. The thermal characteristics for the 1990s construction were developed to conform to the proposed ASHRAE 90.2 revision and the 1987 National Appliance Energy Conservation Act and its 1988 Amendments. These prototypes and assumed operating conditions were simulated using the DOE-2 model with WYEC and TMY hourly weather tapes. Engineering calculations were used to calculate water heating loads and non-HVAC electricity use. The results as annual loads data were binned in several formats and presented in the Appendices.

PROJECT IMPLICATIONS

The development of a consistent set of building energy requirements for prototypical single-family detached buildings will provide end-use data that can be used by GRI and its contractors to plan and analyze R&D programs. These single-family loads will provide the basis for future analyses of issues related to the use of advanced gas technologies.

Project Manager

Mr. James M. Fay
Strategic Planning & Analysis

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INTRODUCTION

The Gas Research Institute (GRI) has sponsored research over the past several years to develop building energy requirements for prototypical buildings in three economic sectors: single-family, multifamily, and offices. These heating and cooling requirements have been estimated using a state-of-the-art building energy simulation code (DOE-2.1) and other engineering calculations. Several reports are available that document these studies. Applied Management Sciences, Inc. (AMS) completed a regional characterization of residential buildings and developed heating and cooling requirements for single-family detached houses using DOE-2.1B.[1] AMS also characterized typical multifamily building types for the U.S. Battelle Pacific Northwest Laboratories, using clustering techniques, analyzed and categorized the office building sector and completed a DOE-2 analysis of these prototypical buildings.[3] The Lawrence Berkeley Laboratory (LBL) has also made contributions to GRI's set of building energy studies. LBL recently completed an analysis of the multifamily heating and cooling requirements.[4] These simulated loads were compared to measured data from several areas in the country.[5]

The purpose of this study was to update the previous single-family data base using the latest version of DOE-2, more representative weather tapes, and improved modeling techniques (e.g., infiltration and ventilation). LBL has conducted previous studies of single-family residences as part of the U.S. Department of Energy's program to develop energy guidelines for new construction.[6] Also, the single-family data base, developed to support the DOE guidelines, was used to support recent revisions to the ASHRAE 90.2 standard[7] and DOE's Mandatory Standards for New Federal Residences.[8] In addition to improving GRI's single-family data base, this study covers prototypes for the 1980s that were developed from a statistical analysis of the latest RECS public data tape[9] and the most recent national building characteristics surveys conducted by the National Association of Home Builders (NAHB).[10] Prototypical buildings were also developed to represent 1990s construction practices. The thermal characteristics of the 1990s construction are assumed to conform to the proposed ASHRAE 90.2 Standard, which will be the code requirement in the 1990s.[11] The appliance efficiencies in these buildings also conform to the 1987 National Appliance Energy Conservation Act and 1988 Amendments.[12] The effects of these appliance efficiencies on space contitioning loads were also analyzed in a separate study sponsored by GRI.[13]

In this report, the technical approach used to generate the heating and cooling loads, water heating loads, and aggregate electric usage (i.e., lighting and appliances) is described. This description covers the building prototypes for each vintage (pre-1940s, 1950-70s, 1980s, and 1990s), selection of base cities, and the operating conditions assumed in the simulations. The contents of the single-family data base are summarized, and a brief discussion of these results is presented. In the discussion chapter, a comparison is made of the simulation results to measured data for some cities. Several appendices are also included that contain a sample DOE-2 input file, results for a series of large buildings (1950-70s and 1990s), and sample results binned in different formats. The full data base, covering hourly heating, sensible and latent cooling load capacity, water heating loads, and non-HVAC electricity usage, is available as another output of this study. This data base, which is available from GRI will provide the buildings research community with a standard set of prototypical loads by building type and location for all major U.S. climates.

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TECHNICAL APPROACH

PREVIOUS WORK

GRI initiated the development of building energy requirements for standard buildings with an analysis of single-family detached housing.[1] In that study, six prototypes representing different years of construction and levels of thermal integrity were selected for each of 18 cities. Using the DOE-2.1B building energy simulation code, loads were calculated for each prototype and binned by outdoor temperatures.

To complete the characterization of the residential sector, GRI then supported a survey of all publicly and privately available data on multifamily building characteristics and the development of building prototypes.[2] This work identified 16 prototypical multifamily buildings representative of various vintages (pre-1940s to 1980s) and building characteristics (i.e., levels of insulation, etc.) for each of the four U.S. Census Regions. This characterization was completed by LBL with the development of a multifamily loads data base similar to that for single-family detached housing, using the DOE-2.1D building energy simulation program and related calculational procedures.[4] GRI has also completed a characterization and data base for the office building sector.[3]

Independent of the above-mentioned GRI studies, LBL has developed a methodology for defining DOE-2 inputs and simulating heating and cooling loads in residential buildings.[6,7] These GRI and LBL studies form the technical basis for this effort to update and improve the data base of prototypical single-family building loads.

OUTLINE OF APPROACH

This project updates the previous single-family data base using DOE-2.1D, updated weather tapes, and improved modeling techniques. In addition, new building prototypes were developed to characterize energy requirements in large single-family buildings. The technical approach used to develop the data for the single-family buildings followed these steps:

1. We reviewed the methodology, building prototype descriptions, modeling assumptions, and results of the previous work to assess the accuracy and identify inconsistencies with the current program requirements. We collected more recent data to update and expand the building descriptions and modeling assumptions.
2. We compiled a complete set of input parameters including building construction characteristics (i.e., insulation and glazing levels, building orientation, number of stories, etc.) and typical operating conditions (e.g., thermostat settings, number of occupants, and

internal heat gains) for 8 prototypical single-family buildings in each of the 16 base cities. These parameters are described in detail in this report.

3. We next created DOE-2 input files using these input parameters and selected the appropriate hourly weather data for 16 cities representing the major climate types and population centers of the US. We provide in Appendix A a sample DOE-2 input file for one prototype building in Chicago. For the weather data, we used WYEC (Weather Year for Energy Calculations) weather tapes for 13 of the 16 locations. For three locations (Chicago, New Orleans, and San Francisco) we used TMY weather data. We describe in this report the process used to select the most appropriate weather tape and base city locations.
4. We developed pre- and post-processor programs to allow easy manipulation of the input and output data. For consistency, all building inputs are based on a single master DOE-2 input file. Two binning routines were designed to process the hourly output data into monthly summaries and to bin them by temperature, humidity ratio, and time of day. These post-processing programs were used to produce the sample data tables shown later in the report.
5. We performed the DOE-2 simulations and processed the building space conditioning loads through the binning methods to arrange the results into the various formats presented in the data tables (see Results section and the Appendices).
6. Separate procedures were used to calculate the domestic water heating loads (monthly as well as the hourly profile for each day) and aggregate electricity usage. These calculated values are presented in tabular format and also aggregated with the results from the DOE-2 simulations to derive the total annual loads for each prototype building.

SELECTION OF WEATHER TAPES AND BASE CITIES

Selection of Base Cities

We established three important criteria for determining which cities to use in the single-family building simulations. First, since the prototype buildings are regional characterizations of the building stock, the basic regional division of the US found in the RECS data and GRI regional models should be represented, which includes the Northeast, North Central, South, and West regions. Second, all significant climate types within each region should be represented. Significance should be determined by population and uniqueness of the climate. Third, the choice of cities should be as consistent as possible with the previous AMS single-family study and the LBL multifamily work just completed, and should include about 15 locations.

We relied on earlier work at LBL and GLOM, a computer-based interactive climate agglomeration program, for the analysis.[14] GLOM is a tool for aggregating Standard

Metropolitan Statistical Areas (SMSAs) into climate groups based on climate characteristics and populations. Similarities in heating degree days, cooling degree days, Kt - which measures solar potential, and latent enthalpy hours‡, allow the clustering of SMSAs to their "closest", or most similar, climate center. The Andersson paper provides several examples of climate groupings depending on the desired number of climate groups and the relative importance of climate and population.

GLOM allowed us to construct groupings of cities based on both climate and geographic distributions or census regions. The best result was a grouping of 16 climate zones with two in the Northeast region (one in each the New England and Mid Atlantic census divisions), three in the North Central region (one in the East and two in the West North Central divisions), five in the South region (three in the South Atlantic and two in the West South Central divisions), and six in the West region (three in each the Mountain and Pacific divisions). The population centers of these climate groups were chosen as the base cities for the characterizations and simulations. It should be noted that while each of the four census regions includes between two and six base cities, not all of the nine census *divisions* include a base city. For example, climates in the East South Central census division are represented by the climates of Forth Worth, Washington DC, and Atlanta, yet none of these base cities are actually in the division. The base cities are shown in Table 1.

Description of Weather Tapes

Detailed building energy simulation programs, such as DOE-2, require hourly weather information for temperature, humidity, wind speed, and the amount of sunshine. This information can be derived from weather tapes that have a minimum of three-hour recordings for dry bulb and wet bulb temperatures, direct and diffuse solar radiation, wind speed and direction, and atmospheric pressure.

Depending on the objective of the building simulation, one can choose between TRY (Test Reference Year), TMY (Typical Meteorological Year), WYEC (Weather Year for Energy Calculations), or actual year weather tapes. For benchmark studies such as the multifamily data base, weather data representing long-term mean conditions for any location are preferred. The first three mentioned weather tape types (TRY, TMY and WYEC) are different attempts to produce a year of "typical" weather.

TRY weather tapes were prepared by the National Climatic Data Center and are actual years chosen from 27 years of records as the most representative for a particular location. The selection was done by searching through the historical data and progressively eliminating those

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‡ A measure of the latent heat removal necessary to meet comfort conditions. Enthalpy hours (Btu hour/pound air) are calculated by summing over the year the energy necessary to lower ambient air conditions to a humidity ratio of 0.116 and a dry-bulb temperature of 75°F.

years with the most atypical monthly conditions. TRY tapes do not have solar data, only cloud cover observations that the DOE-2 program uses to estimate the amount of sunshine.

Table 1. Base Cities for Single-Family Data Base.

Census Region/ Division	Base Cities	Weather Tape	Heating Degree Days (60°F)	(65°F)	Cooling Degree Days (65°F)	Cool. Degree Hours/24 (75°F)	Latent Enthalpy Days (75°F, 0.0116 HR)
NORTHEAST							
New England	Boston	WYEC	4396	5627	699	186	48
Mid Atlantic	New York	WYEC	3784	4882	1005	256	118
NORTH CENTRAL							
East North Central	Chicago	TMY	4946	6120	969	318	121
West North Central	Minneapolis	WYEC	6733	8004	727	238	72
	Kansas City	WYEC	3799	4799	1605	632	269
SOUTH							
South Atlantic	Washington	WYEC	3184	4180	1388	403	244
	Atlanta	WYEC	2050	2965	1543	405	284
	Miami	WYEC	91	222	3922	1193	1155
West South Central	Fort Worth	WYEC	1571	2329	2495	1044	490
	New Orleans	TMY	804	1374	2503	789	719
WEST							
Mountain	Denver	WYEC	4621	5879	611	329	0
	Albuquerque	WYEC	3147	4186	1256	540	9
	Phoenix	WYEC	675	1320	3609	2144	97
Pacific	Seattle	WYEC	3583	5136	90	39	0
	San Francisco	TMY	1682	3172	66	28	0
	Los Angeles	WYEC	635	1636	428	54	6

TMY weather tapes were prepared under contract to the U.S. Department of Energy for use in solar design studies. The TMY data are composite years created by merging 12 representative months chosen from climate data for years 1954 through 1972. Solar radiation values were based on SOLMET observations for 26 stations, and extrapolated for other locations. The selection process for the typical months involved comparing monthly data to the long-term cumulative distribution for nine weather indices, such as temperatures and wind speeds, and selecting the month with the closest correlation. Since no single month has the closest correlation for all indices, different weighting were applied to each index.

WYEC weather tapes were prepared under contract to the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) for use in building energy calculations.[15] They are similar to the TMY tapes in being composite years consisting of 12 typical months, but used a different weighting method and adjusted the solar radiation to secure close compliance to the long-term mean conditions. In addition, more time was spent to smooth discontinuities and abnormalities in the data. As of 1989, WYEC weather tapes were available for 44 U.S. locations which give good coverage for major population centers, but with only one location in California (Los Angeles).

Basis of Choice

There are numerous drawbacks to the use of TRY weather tapes. It is unlikely that any year would have "typical" weather each month. Moreover, the selected TRY year may not represent the long-term mean in any of the important weather indices. Finally, unlike TMY and WYEC, the TRY tapes do not include measured solar radiation but rather inferred values in the form of cloud cover. Because of these limitations, ASHRAE no longer recommends using TRY weather tapes for building energy simulations.

The choice between TMY and WYEC weather tapes is somewhat less obvious, since their selection processes are similar. We chose WYEC tapes because they were produced with more care than TMY tapes. In addition, the WYEC tapes are now considered more acceptable to the technical community. The expected difference in weather-sensitive loads for TMY cities (vs using WYEC) should be negligible. For this study, we used WYEC tapes for all cities except for Chicago, New Orleans, and San Francisco. We observed anomalies in the Chicago WYEC weather tape, and WYEC was not available for New Orleans or San Francisco. Weather tapes for each base city are given in Table 1.

We understand that ASHRAE is currently modifying the WYEC weather tapes to adjust for anomalies in local time, etc. The modified WYEC tapes were not available at the time of this project. The WYEC weather tapes used for this analysis were the original tapes with similar modifications performed by the Building Simulation group at LBL.

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MODELING ASSUMPTIONS

STRUCTURAL ASSUMPTIONS

Building Prototypes

The A, A1, B, B1, C, and D single-family building prototypes for each region or base city were selected and characterized in a previous GRI study.[1] The A and A1 prototypes represent as-built and thermally improved buildings (i.e., retrofit) of pre-1940 vintage, respectively. Similarly, the B and B1 prototypes represent 1950-1970 vintage buildings. The C prototypes are 1980 vintage buildings and the D prototypes are 1990 vintage. For this study, we verified the A and B prototype characteristics and updated the C and D prototype descriptions based on the most current available data. In addition, we developed large versions (i.e., more floor area) of two prototypes, the B1+ and D+ buildings. We provide more detail about representation of the building prototypes in Appendix A.

The main source of data for the A and B prototypes in the previous study was the 1980 and 1981 Residential Energy Consumption Surveys (RECS). The C prototype was developed using data from the National Association of Home Builders (NAHB) Surveys, 1978-1982. For the D prototype, the C prototype was thermally improved using the Farm Home Administration (FHA) Thermal Performance Construction Standards and the U.S. Department of Housing and Urban Development (HUD) Minimum Property Standards as guidelines. We consulted similar databases in verifying and updating the AMS prototype descriptions and developing the new B1+ and D+ prototypes. However, we used the 1987 RECS data tape [9] and the 1987 NAHB Builder's Survey [10] as the primary data sources. We supplemented this information with building construction data from U.S. Census Bureau Reports[16], and unpublished data from F.W. Dodge Corporation[17,18] and NAHB.[19,20]

The survey results were processed statistically and cross-referenced to four major criteria: (1) location (census region, census division, or state) (2) year building was constructed, (3) number of stories in the building, and (4) thermal integrity of the building shell. Thus, eight building types in each of the 16 base cities, which combined represent approximately 35% of the single-family building population, were defined from this analysis as the number of building types and locations that most accurately characterized the sector. In Appendix B, we show the portion of the U.S. single-family building stock represented by the prototypes and how the representation is derived.

These generic building types are representative of different vintages (pre-1940s to 1990s), sizes (i.e., number of stories, average floor area, large floor area, etc.), and levels of thermal integrity for each of the nine census divisions and sixteen base cities. Each base city has eight prototypes, ranging from poorly insulated pre-1940s buildings to more energy-efficient ones from the 1980s to large energy-efficient buildings of the 1990s. Each significant combination of climate type and geographically-based building tradition is represented by a base city.

General Building Characteristics

We compared the square footage values for prototypes A and B in the previous study with 1987 RECS data tape results stratified by vintage, census division, and number of stories. For the prototypes where the new data differed by 25% or more from the existing specifications, we changed the building size to match the newer data results. This affected only the prototypes with conditioned floor areas of less than 750 ft^2, found in the West North Central (B prototype), South Atlantic (A prototype), West South Central (A), and Mountain (A) census divisions. The new values were between 975 and 1200 ft^2. The values for all A and B prototypes are provided in Table 2. The wall and foundation types are as assumed in the previous study.

Table 2. General Specifications for A and B Prototypes

Census Division	Base Cities	Proto- type	Year Built	No. Stories	Floor Conditioned Area (ft^2)	Window Area (ft^2)	Wall Type	Foundation Type
New England	Boston	A	pre 1940s	2	1440	280	Wood	Bsmt
		B	1950-1970	2	2220	430	Wood	Bsmt
Mid-Atlantic	New York	A	pre 1940s	2	1400	277	Wood	Bsmt
		B	1950-1970	2	1960	385	Wood	Bsmt
East North Central	Chicago	A	pre 1940s	2	1580	300	Wood	Bsmt
		B	1950-1970	1	1380	264	Brick	Bsmt
West North Central	Minneapolis	A	pre 1940s	2	1580	310	Wood	Bsmt
	Kansas City	B	1950-1970	1	1100	216	Wood	Bsmt
South Atlantic	Washington	A	pre 1940s	1	1165	207	Wood	Crawl
	Atlanta	B	1950-1970	1	1415	249	Brick	Crawl
	Miami							
West South Central	Fort Worth	A	pre 1940s	1	1055	216	Wood	Slab
	New Orleans	B	1950-1970	1	1390	286	Brick	Slab
Mountain	Denver	A	pre 1940s	1	975	177	Wood	Bsmt
	Albuquerque	B	1950-1970	1	1080	196	Brick	Slab
	Phoenix							
Pacific North	Seattle	A	pre 1940s	1	1400	244	Wood	Crawl
		B	1950-1970	1	1390	242	Wood	Crawl
Pacific South	San Francisco	A	pre 1940s	1	1400	244	Wood	Crawl
	Los Angeles	B	1950-1970	1	1390	242	Stucco	Crawl

For the 1980s and 1990s vintages, we developed new C and D prototype characteristics based on current available data that is more representative of construction trends between 1980 and 1989. We gathered square footage estimates for new single-family construction between 1980 and 1989 from the 1987 RECS data tape, U.S Census Bureau reports, the National Association of Home Builders (NAHB), and the F.W. Dodge Corporation. The Census reports for 1980-89 give mean and median square foot data for new construction by census region and for the U.S. as a whole. They also tabulate construction type - one story, two story, and split-level. Average square footage data for new construction, 1979-1988, on both state and national level were also provided to GRI by the NAHB. In addition, we also used state-specific data from the NAHB 1987 Builders Survey in developing construction type, foundation type, and average square footage data for 1980s houses.

Figure 1 presents the various estimates for average floor area through the 1980s, including Census Bureau, Dodge, and NAHB data. While the magnitudes differ, the plot shows that on a national level, floor area is constant from 1980-85, and then rises at constant rates from 35 to 70 square feet per year. Figure 2 shows Census Bureau estimates of construction type in the 1980s. The construction type is important because two-story houses are larger on the average than one story houses. The proportion of two-story houses has been increasing in all parts of the country.

We made estimates of average 1980s square footage for each base city by combining Census Report square footage and construction type data (1980-89) and state-specific data from the 1987 NAHB Builder's Survey. We took the predominant construction type and average one-story and two-story square foot data for each state from the NAHB survey. We used the Census Report data to develop weighted averages of floor area for the 1980s by census region. Using these two data sets, we calculated weighted average square foot estimates for one and two story buildings for each census region. For each state, we then chose the appropriate construction type and square footage from the respective census region. The C prototype construction type and floor areas are given in Table 3.

The 1990s, or D prototype, was assumed to be a slightly modified C prototype. Thus, average floor area was assumed to continue to increase into the 1990s following the trend shown in Figure 1, allowing for the change in construction type as shown in Figure 2. To determine the impact of the trend in construction types on the average square footage data, we calculated the change in average square footage for each census region using the construction type percentages from the Census Bureau data and assumed one- and two-story square footage values taken from the 1987 NAHB builders survey database. We compared these calculated values to the change in mean square footage in Census Bureau reports over the same period. The difference between the two represents the change in average house size irrespective of the trend in construction types. The results show increases in floor area of 188 to 223 square feet between 1980 and 1989 when removing the effect of the change in proportion of one- and two-story houses. We added these values to the 1980s figures to arrive at the 1990 floor area estimates. Prototype floor areas for the D prototypes are given in Table 3.

Figure 1. Average Floor Area for New Construction
U.S. Single Family Buildings, 1980-1989

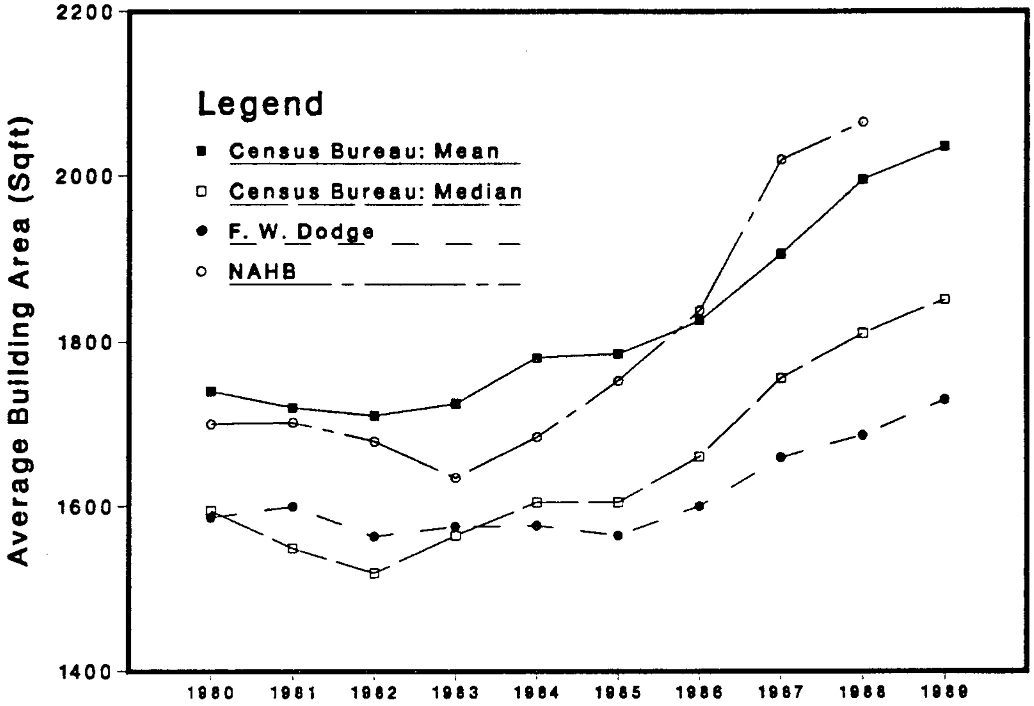

Figure 2. Construction Type for New Construction
U.S. Single Family Buildings, 1980-1989

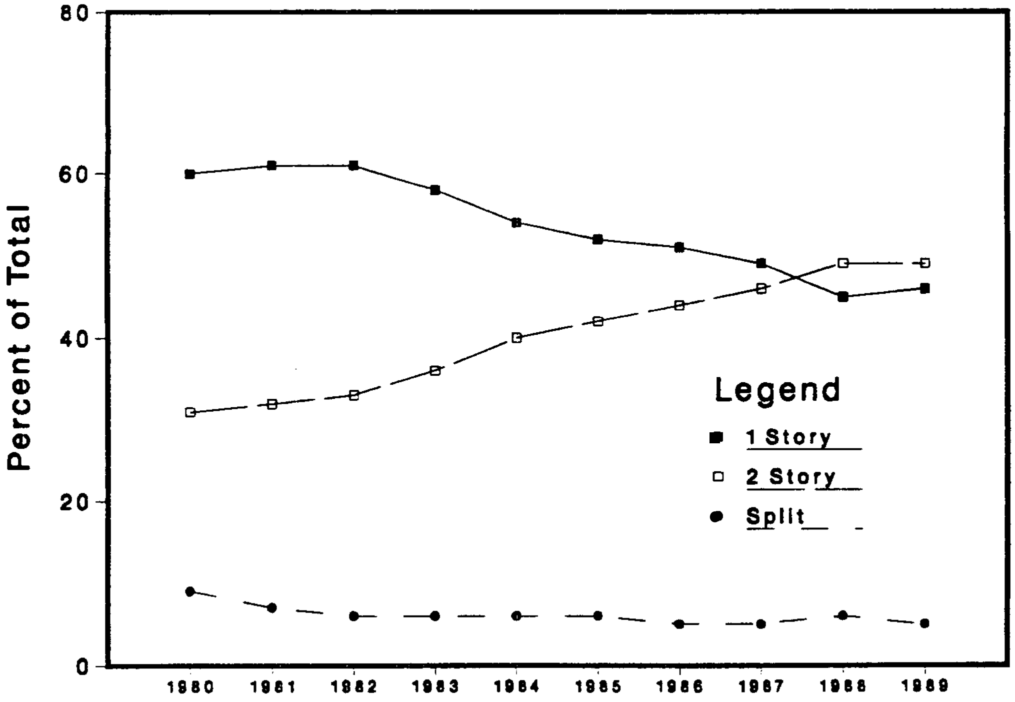

Table 3. General Specifications for C and D Prototypes

Base City	Proto-Type	Year Built	No. Stories	Conditioned Floor Area (ft^2)	Window Area (ft^2)	Wall Type	Foundation Type
Boston	C	1980s	2	2090	261	Wood	Bsmt
	D	1990s	2	2280	285	Wood	Bsmt
New York	C	1980s	2	2090	243	Wood	Bsmt
	D	1990s	2	2280	265	Wood	Bsmt
Chicago	C	1980s	2	2220	275	Alum	Bsmt
	D	1990s	2	2420	300	Alum	Bsmt
Minneapolis	C	1980s	2	2220	242	Wood	Bsmt
	D	1990s	2	2420	264	Wood	Bsmt
Kansas City	C	1980s	2	2220	282	Wood	Bsmt
	D	1990s	2	2420	307	Wood	Bsmt
Washington	C	1980s	2	2180	288	Alum	Bsmt
	D	1990s	2	2390	316	Alum	Bsmt
Atlanta	C	1980s	2	2180	264	Wood	Bsmt
	D	1990s	2	2390	289	Wood	Bsmt
Miami	C	1980s	1	1620	214	Stucco	Slab
	D	1990s	1	1830	242	Stucco	Slab
Fort Worth	C	1980s	1	1620	214	Wood	Slab
	D	1990s	1	1830	242	Wood	Slab
New Orleans	C	1980s	1	1620	214	Brick	Slab
	D	1990s	1	1830	242	Brick	Slab
Denver	C	1980s	2	2070	263	Wood	Bsmt
	D	1990s	2	2290	291	Wood	Bsmt
Albuquerque	C	1980s	1	1660	179	Stucco	Slab
	D	1990s	1	1880	203	Stucco	Slab
Phoenix	C	1980s	1	1660	179	Stucco	Slab
	D	1990s	1	1880	203	Stucco	Slab
Seattle	C	1980s	2	2070	383	Wood	Crawl
	D	1990s	2	2290	424	Wood	Crawl
San Francisco	C	1980s	2	2070	325	Stucco	Slab
	D	1990s	2	2290	360	Stucco	Slab
Los Angeles	C	1980s	2	2070	325	Stucco	Slab
	D	1990s	2	2290	360	Stucco	Slab

Two prototypes, the B1+ and D+, were developed to represent large houses with greater than average space conditioning loads. The RECS data provided the only source for determining the size of the large prototypes. Since the RECS data is provided as a sample of observations, it was possible to determine the range of building sizes within each of the prototype categories of region and vintage. The conditioned area for the large prototypes was defined as two standard deviations above the mean. For the B1+ prototype, we summarized the 1987 RECS conditioned area data for 1950-70 vintage buildings categorized by census division. The 1990 large house floor areas were estimated by adding two standard deviations for 1980s vintage buildings to the 1990 average square footage. Because 1980 vintage homes were not well represented, we summarized the RECS data for 1980 vintage buildings as a whole for the country, stratifying only by construction type. We added twice the standard deviation to the average floor area in each construction type category. Other specifications, including the number of stories and foundation type, were taken as unchanged from the average buildings. The floor areas of the large houses are given in Table 4.

We also analyzed correlations between increasing house size and number of occupants, number of windows, and appliance saturations. We found that number of occupants was not significantly correlated with house size, but larger houses have more windows, and more of certain appliances (see for example Appendix B). These assumptions will be discussed below.

Window Areas

The window area estimates for the prototypes are crucial because of the significant effects of glazing on heat gain and loss in houses. For the A and B prototypes, we use the same window area assumed in the previous study. Where floor areas changed due to new data results, we recalculated window areas based on the same window area to floor area ratio.

For the C and D houses, the estimate was more difficult. Until 1983, the NAHB Builder Survey compiled window area as a percentage of floor area. These data from the 1981 Builder Survey were used to compute the window area for each the C and D prototype. However, the 1987 Survey only includes "number of windows" without reference to window size. The 1987 RECS also contains "number of windows" as a data base entry. We calculated window areas for the C and D prototypes using the same window area to floor area ratio used in the previous study. This assumes that window areas remain consistent through the 1980s and 1990s. For the large prototypes, the B1+ and D+ houses, we used the same method for estimating window area, applying the appropriate percentage for each region/vintage combination to the prototype floor area. Window areas for each prototype are given in Tables 2-4.

Building Thermal Integrity

For the A and B prototypes, and the thermally improved A1 and B1 counterparts, we used the same wall, ceiling, floor, and foundation insulation levels and window glazing layers as specified in the previous study.[1] The A and B prototypes are as-built and primarily uninsulated. The A1 and B1 prototypes represent retrofitted buildings from the same vintage. These two different levels of insulation for each were derived from an analysis of the 1980 RECS data tape. The data were separated into "low" and "high" insulation levels; the average of each was used as the "as-built" and "retrofitted" buildings. These specifications are summarized in Table 5.

Table 4. General Specifications for B1+ and D+ Prototypes

Census Region	Census Division	Base City	Proto-Type	Year Built	No. Stories	Floor Area (ft^2)	Window Area (ft^2)
Northeast	New England	Boston	B1+	1950-1970	2	3934	763
			D+	1990s	2	3850	481
	Mid Atlantic	New York	B1+	1950-1970	2	3898	764
			D+	1990s	2	3850	447
North Central	E N Central	Chicago	B1+	1950-1970	1	3220	615
			D+	1990s	2	3990	495
	W N Central	Minneapolis	B1+	1950-1970	1	2772	543
			D+	1990s	2	3990	435
		Kansas City	B1+	1950-1970	1	2772	543
			D+	1990s	2	3990	507
South	South Atlantic	Washington	B1+	1950-1970	1	2844	500
			D+	1990s	2	3960	523
		Atlanta	B1+	1950-1970	1	2844	500
			D+	1990s	2	3960	479
		Miami	B1+	1950-1970	1	2844	500
			D+	1990s	1	3200	422
	W S Central	Fort Worth	B1+	1950-1970	1	2638	543
			D+	1990s	1	3200	422
		New Orleans	B1+	1950-1970	1	2638	543
			D+	1990s	1	3200	422
West	Mountain	Denver	B1+	1950-1970	1	2362	430
			D+	1990s	2	3860	490
		Albuquerque	B1+	1950-1970	1	2362	430
			D+	1990s	1	3250	351
		Phoenix	B1+	1950-1970	1	2362	430
			D+	1990s	1	3250	351
	Pacific	Seattle	B1+	1950-1970	1	2479	431
			D+	1990s	2	3860	714
		San Francisco	B1+	1950-1970	1	2479	431
			D+	1990s	2	3860	606
		Los Angeles	B1+	1950-1970	1	2479	431
			D+	1990s	2	3860	606

For the C prototypes, we chose average insulation levels for each building component in each base city derived from the 1987 NAHB Builder's Survey. We checked these results for each base city with the data from the surrounding states, and also with published data summaries from NAHB representing the construction years of 1986 and 1987.[19] For the D prototypes, we upgraded the C prototype thermal integrities based on compliance with the proposed ASHRAE 90.2P energy-efficiency standard.[11] Each building component (roof, wall, foundation, floor, windows, etc.) was made in compliance with the ASHRAE code. The insulation

Table 5. Conservation Parameters for A and B Prototypes

Census Division	Proto-type	Year Built	R-Values (hr-ft^2-°F/Btu)			Glazing Layers	Foundation Insulation
			Wall	Ceiling	Floor		
New England	A	pre 1940s	0	0	0	2	none
	A1	pre 1940s	7	22	0	2	none
	B	1950-1970	0	22	0	2	none
	B1	1950-1970	7	22	0	2	none
Mid-Atlantic	A	pre 1940s	0	0	0	2	none
	A1	pre 1940s	7	7	0	2	none
	B	1950-1970	0	7	0	2	none
	B1	1950-1970	7	11	0	2	none
East North Central	A	pre 1940s	0	0	0	2	none
	A1	pre 1940s	7	11	0	2	none
	B	1950-1970	0	11	0	2	none
	B1	1950-1970	7	19	0	2	none
West North Central	A	pre 1940s	0	0	0	2	none
	A1	pre 1940s	7	7	0	2	none
	B	1950-1970	0	7	0	2	none
	B1	1950-1970	7	22	0	2	none
South Atlantic	A	pre 1940s	0	0	0	2	none
	A1	pre 1940s	7	7	0	2	none
	B	1950-1970	0	7	0	2	none
	B1	1950-1970	7	11	0	2	none
West South Central	A	pre 1940s	0	0	0	2	none
	A1	pre 1940s	7	7	0	2	none
	B	1950-1970	0	7	0	2	none
	B1	1950-1970	7	19	0	2	none
Mountain	A	pre 1940s	0	0	0	2	none
	A1	pre 1940s	7	11	0	2	none
	B	1950-1970	0	11	0	2	none
	B1	1950-1970	7	11	0	2	none
Pacific North	A	pre 1940s	0	0	0	2	none
	A1	pre 1940s	7	11	0	2	none
	B	1950-1970	0	11	0	2	none
	B1	1950-1970	7	19	0	2	none
Pacific South	A	pre 1940s	0	0	0	1	none
	A1	pre 1940s	7	7	0	1	none
	B	1950-1970	0	7	0	1	none
	B1	1950-1970	7	11	0	1	none

specifications for the C and D prototypes level are given in Table 6. Conservation specifications for the large prototypes were assumed to be the same as for the average prototypes of the same vintage.

For prototypes with basements, we made assumptions about whether the insulation was located in the floor or on the basement walls. Where basement wall insulation was predominant in the Builder Survey data, we simulated basement wall insulation in the C prototypes. In all other cases, we simulated insulation in the floor cavity.

Table 6. Conservation Parameters for C and D Prototypes

Census Division	Base City	Proto-type	Year Built	R-values (hr-ft^2-°F/Btu)			Glazing Layers	Foundation Insulation
				Wall	Ceiling	Floor		
New England	Boston	C	1980s	13	27	0	2	none
		D	1990s	16	28	19	3	none
Mid Atlantic	New York	C	1980s	13	27	19	2	none
		D	1990s	16	28	19	3	none
East North Central	Chicago	C	1980s	13	32	0	2	none
		D	1990s	16	32	19	3	none
West North Central	Minneapolis	C	1980s	19	32	0	2	R-5 4 ft. bsmt wall
		D	1990s	24	48	19	3	none
	Kansas City	C	1980s	11	29	0	2	none
		D	1990s	16	29	19	3	none
South Atlantic	Washington	C	1980s	13	30	19	2	none
		D	1990s	16	30	19	3	none
	Atlanta	C	1980s	11	27	19	2	none
		D	1990s	16	28	19	2	none
	Miami	C	1980s	11	25	0	1	none
		D	1990s	16	28	0	1	R-5 2 ft. slab edge
West South Central	Fort Worth	C	1980s	11	27	0	1	R-5 2 ft. slab edge
		D	1990s	16	28	0	1	R-5 2 ft. slab edge
	New Orleans	C	1980s	11	19	0	1	none
		D	1990s	16	28	0	1	R-5 2 ft. slab edge
Mountain	Denver	C	1980s	13	31	11	2	none
		D	1990s	16	31	19	3	none
	Albuquerque	C	1980s	13	29	0	2	R-5 2 ft. slab edge
		D	1990s	16	29	0	3	R-5 2 ft. slab edge
	Phoenix	C	1980s	13	27	0	2	none
		D	1990s	16	28	0	2	R-5 2 ft. slab edge
Pacific	Seattle	C	1980s	11	32	19	2	none
		D	1990s	16	32	19	3	none
	San Francisco	C	1980s	11	25	0	2	none
		D	1990s	16	28	0	2	R-5 2 ft. slab edge
	Los Angeles	C	1980s	11	25	0	2	none
		D	1990s	16	25	0	2	none

In addition to these generic building characterizations, numerous other assumptions are needed before complete models of prototype buildings can be developed and used as input to the DOE-2 simulations. For example, factors such as building geometry, average window shading and window operations, and shading from adjacent buildings are not part of the RECS data. We relied on our previous studies of residential buildings to develop the necessary DOE-2 inputs for these parameters as well as several others described below.[6,21,22]

Building Geometry

The prototype descriptions specified the numbers of floors, foundation type, and conditioned floor area in each prototype building, but not the architectural layout of the buildings. To transform these general descriptions into DOE-2 input files, we made assumptions about the architecture of typical single-family detached buildings depending on their climate and building size. The intent was not to create a detailed hypothetical building, but to capture average thermal conditions common to single-family buildings.

The dimensions of the A and B prototype buildings were taken from the AMS input files. For the C, D, D+, and B1+ prototypes, we used a standard width of 28 feet, which is a typical roof truss dimension. This gave some unusually long dimensions for the larger prototypes. While these long dimensions do not represent any actual building, thermally the building can be thought of as pieces arranged in L-shapes or courtyard shapes. The exposed foundation length and wall area are the same for the long building as the contorted building.

For the C, D, and D+ prototypes, we also modeled an attached, uninsulated two-car garage with a slab floor. The attached wall area was 180 square feet for one story and 240 square feet for two story prototypes, with a garage floor area of 460 square feet.

Infiltration

The effects of infiltration on building heating and cooling loads were simulated using the Sherman-Grimsrud model.[23] This is a simplified physical model developed at LBL for air infiltration in residential buildings. The only information needed for the model is the leakage of the building. The leakage quantities, expressed in terms of *effective areas*, are the total leakage areas of the wall, floor and ceiling. Weather parameters used in the model include mean wind speed, terrain class, and average temperature difference. The model separates infiltration into two distinct parts: stack and wind-regimes. Each regime is treated separately, with a sharp transition between the two. The model has been tested with data from several sites that differ in climate and construction methods.[23]

We based the assumed effective-leakage-areas (ELA) on measured single-family results published in the literature and previous studies of single family building simulation.[6,24] Based on engineering judgment, we assumed older buildings had more leakage than those built later. For the pre-1940s A prototypes, we assumed an average fractional-leakage-area of 0.0009 (leakage area/floor area) and for the 1950-1970 prototypes we assumed a fractional-leakage-area of 0.0007. In addition, we assumed the "retrofit" prototypes, A1 and B1, would be tighter than the as-built buildings (ELA = 0.0008 and 0.0006, respectively). Because the ELA is dependent on floor area, we used the same ELA for the large houses as the average prototype for the same vintage. We assumed the C prototype would be slightly tighter than earlier prototypes, with a fractional leakage area of 0.0005. For the D and D+ prototypes, we used the climate-specific guidelines in the ASHRAE Standard 119 for air leakage to upgrade the 1980s prototype numbers to meet the ASHRAE Standard.[25] This affected only Boston, New York, Chicago, Kansas City, and Denver (leakage area of 0.00046) and Minneapolis (leakage area of 0.00033).

Since the net infiltration into a building depends not only on its physical characteristics, but also on the shielding effects of its surroundings, we simulated the surrounding areas as typical residential neighborhoods for all prototypes and in all base cities. For the inputs to the Sherman-Grimsrud model in the DOE-2 simulations we used a shielding-coefficient of 0.19, terrain parameter 1 of 0.85, and terrain parameter 2 of 0.20.

Shading

The solar gain entering a building depends on the orientation of the windows and walls, the amount of shading due to adjacent buildings, and characteristics and operations of window shades, if available. In this study, we modeled *average*, rather than *typical*, building conditions. We created an average building orientation by apportioning the amounts of walls, windows, and doors equally in the four cardinal directions. Similarly, we considered average amounts of shading from two adjacent buildings by modeling semi-transparent shading surfaces with a transmittance of 0.50 with the same height as, and located on all sides of, the prototype building. These building shades were sited 20 feet away for the suburban areas. We accounted for average window shade operations by using a glass shading coefficient of 0.80 during the winter and 0.60 during the summer. We distinguished between the summer and winter operating modes by adding a special Fortran function into the DOE-2 input that counted the number of cooling degree-days over the previous four days (see sample DOE-2 input files in Appendix C).

Foundations

Since the existing DOE-2 program does not adequately model the building-to-ground interface, we used a Fortran function to incorporate into DOE-2 heat fluxes calculated by a two-dimensional finite difference program developed by the Underground Space Center at the University of Minnesota. We used this program to simulate, on a daily time-step basis, the dynamic behavior of a representative one-foot vertical cross-section of the foundation and surrounding soil extending 50 feet down and 30 feet out from the building.

The finite difference simulations yielded daily fluxes at each node of the finite difference grid for the representative section. We then integrated these fluxes over the "foot-print" of the prototype buildings to produce files of average hourly fluxes through their underground surfaces for each day of the year. During the DOE-2.1 simulation, these fluxes are read as a function in LOADS, replacing the standard DOE-2 underground flux calculation. A more complete description of this method is given elsewhere.[26]

OPERATING ASSUMPTIONS

Operating assumptions refer to those actions affecting building energy use that are under the control of the occupants. These include such factors as temperature settings, night thermostat setback, window operations (i.e., opening and closing), and internal loads due to occupants and appliances. For this study, we defined the most average, rather than the optimal, operating conditions in single-family units based on survey data and other studies.

Thermostat Settings

We modeled the prototype buildings with the same thermostat settings. The heating set point in the living spaces was held at 70°F during the day, with a 8-hour setback to 64°F between 11 p.m. and 7 a.m. These assumptions correspond to data from recent RECS surveys that report the mean household temperature in units with heating controls was 69.3°F; over 64% of the respondents turned down their thermostats at night by 3 to 10 degrees.[9] They also agree with information on thermostat management from other sources.[27,28,29]

To account for natural ventilation, we modeled average window operations by building occupants as follows. During the heating season, window venting (i.e., opening windows) was assumed when indoor temperatures rose above 78°F, while during the cooling season venting was assumed down to a level of 72°F if the following criteria were met: (1) the outdoor temperature was lower than indoor temperatures and not higher than 78°F, (2) the enthalpy of outdoor air was less than that of indoor air, and (3) the cooling load that hour could be met totally through window venting. Since occupants typically do not adjust windows after going to bed, window conditions were assumed to be fixed between 11 p.m. and 7 a.m. unless indoor temperatures dropped below the heating set point.

Internal Loads

Under normal occupancy, a building collects heat, which is termed the internal load, released by people, appliances, and lighting. This internal load reduces a building's heating loads during the winter, but adds to its cooling loads during the summer. After reviewing a previous LBL study of internal loads in single-family residences,[6] we developed a method for deriving internal loads values for the prototype buildings. We combined assumptions of occupancy levels, schedules, and typical occupancy heat gains; appliance saturations, appliance heat gain schedules, and typical appliance energy use; and annual lighting energy and lighting schedules.

For average occupancy levels, we assumed 3 persons per household in each prototype based on previous LBL studies [6] and an analysis of the 1987 RECS tape which showed an average of 3.1 occupants per household. We used occupant heat gain of 230 Btu/hr sensible and 190 Btu/hr latent per person from ASHRAE.[30] These values are equivalent to seated, light work and match the numbers used in the multifamily study.[4] When combined with the occupant load profile, the total occupant heat gain is 15,200 Btu/day for each prototype (8360 Btu/day sensible, 6840 Btu/day latent).

We summarized the 1987 RECS data to develop average appliance saturations for calculating internal gains. We stratified the RECS single-family data by the nine census divisions, and calculated average appliance saturations across all vintages of single-family detached dwellings. RECS does not include clothes washers, so based on clothes dryer saturations between 0.7 and 0.9 we used a saturation of 1.0 for clothes washers. We also assumed a saturation of 1.0 for ovens/ranges. For cooking fuel, RECS data give the saturation of electric and gas cooking. Electric predominates in all census divisions except for the West South Central. RECS also gives separate saturations for electric and gas dryers. In calculating internal gains, we assumed that clothes dryers and cooking were electric. The results also show multiple refrigerators per household. We assumed the primary refrigerator was of new vintage while the fractional number of second refrigerators were assumed to be an older variety. The appliance saturations in each census division are given in Table 7.

We further analyzed the RECS 1987 data base to determine the relationship between appliance saturation and building size, in order to more closely characterize the large house appliance load. The only appliances with a strong relationship between appliance saturation and conditioned square footage were refrigerators and black and white and color televisions. For the large houses, we increased the appliance saturations by 0.15, 0.19, and 0.32, respectively, per 1000 square feet of increase in floor area.

We combined these appliance saturations with typical appliance energy use values taken from several sources, including previous LBL work, RECS summaries, the LBL Residential Energy Model, and the 1987 National Appliance Energy Conservation Act (NAECA).[6,13,31,32,33] For the prototypes built before 1990, we used energy use values representative of typical 1980s stock appliances. For the 1990s prototypes, we used appliance energy consumption values modified to meet the NAECA code where applicable. In 1993, new federal appliance efficiency standards will reduce the energy consumption of home appliances, and thus will lower internal heat gains. These standards will affect refrigerators, freezers, dishwashers, clothes washers, and dryers. Miscellaneous small appliance usage and internal gains from water heater standby losses and use were also included. All appliance energy use assumptions are provided in Table 8. We used annual lighting energy of 1 kWh/ft^2, which we have used for previous single-family and multifamily studies.

Table 7. 1987 RECS Data Tape Results for Single-Family Detached Dwellings Appliance Saturations and Types by Census Division

Appliance	New England	Mid Atlantic	E. North Central	W. North Central	South Atlantic	E. South Central	W. South Central	Mountain	Pacific
Refrigerator	1.23	1.27	1.23	1.19	1.14	1.10	1.12	1.13	1.18
Range/Oven*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dishwasher	.55	.51	.34	.42	.36	.41	.45	.59	.46
Clothes Washer*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Electric Dryer	.67	.62	.49	.65	.56	.71	.56	.68	.54
Gas Dryer	.15	.24	.30	.21	.12	.02	.22	.12	.27
FF Freezer	.10	.15	.16	.15	.17	.21	.20	.19	.21
Manual Freezer	.27	.35	.39	.46	.27	.37	.37	.33	.24
B/W TV	.67	.61	.53	.54	.60	.55	.52	.49	.49
Color TV	1.37	1.56	1.35	1.30	1.29	1.25	1.42	1.36	1.45
Refr type 1	FFF	FFF	FFF	FFF	FFF	FFF	FFF	FFF	FFF
Refr type 2	Man	Man	Man	Man	Man	FFF	FFF	Man	Man
Cooking Fuel	Elec	Elec	Elec	Elec	Elec	Elec	Gas	Elec	Elec

FFF = Full Frost Free Freezer
Auto = Automatic Defrost Freezer
Man = Manual Defrost Freezer
* - Not from RECS data

Not all heat generated by appliances is input to the conditioned space. Therefore, we made assumptions about the average location of appliances and venting of the generated heat. We assumed all of the heat generated by the dishwasher and clothes washer and most of the dryer heat and hot water use would be dissipated outside of the dwelling. We also assumed some of the refrigerators, freezers, and water heaters would, on average, be located in unconditioned spaces. For the DOE-2 simulations, we added this portion of the internal gains to the basement, if existing, or else to the garage. Lastly, 10% of the lighting energy was assigned to outdoor lighting. We also assigned latent portions to those end uses which generate moisture. These assumptions are included in Table 8. Calculated internal gains values are given in Table 9.

The internal gains profiles were taken from a California Energy Commission (CEC) study, which includes a daily profile for occupants, appliances, and lighting with seasonal modifications for appliances and lighting.[34] Average daily profiles are shown in Figure 3. Using the CEC lighting schedule, the peak lighting load is 0.43 Watts/ft^2. The peak appliance loads for the prototypes range from 1.03 kW for the large ptototypes to 0.79 kW for the average size 1990s prototypes. The effect of the change in appliance energy consumption for 1990s houses is to decrease internal gains from appliances by about 17%, with total internal gains decreasing by about 9%.

Figure 3. Internal Loads Profile for Prototype Buildings

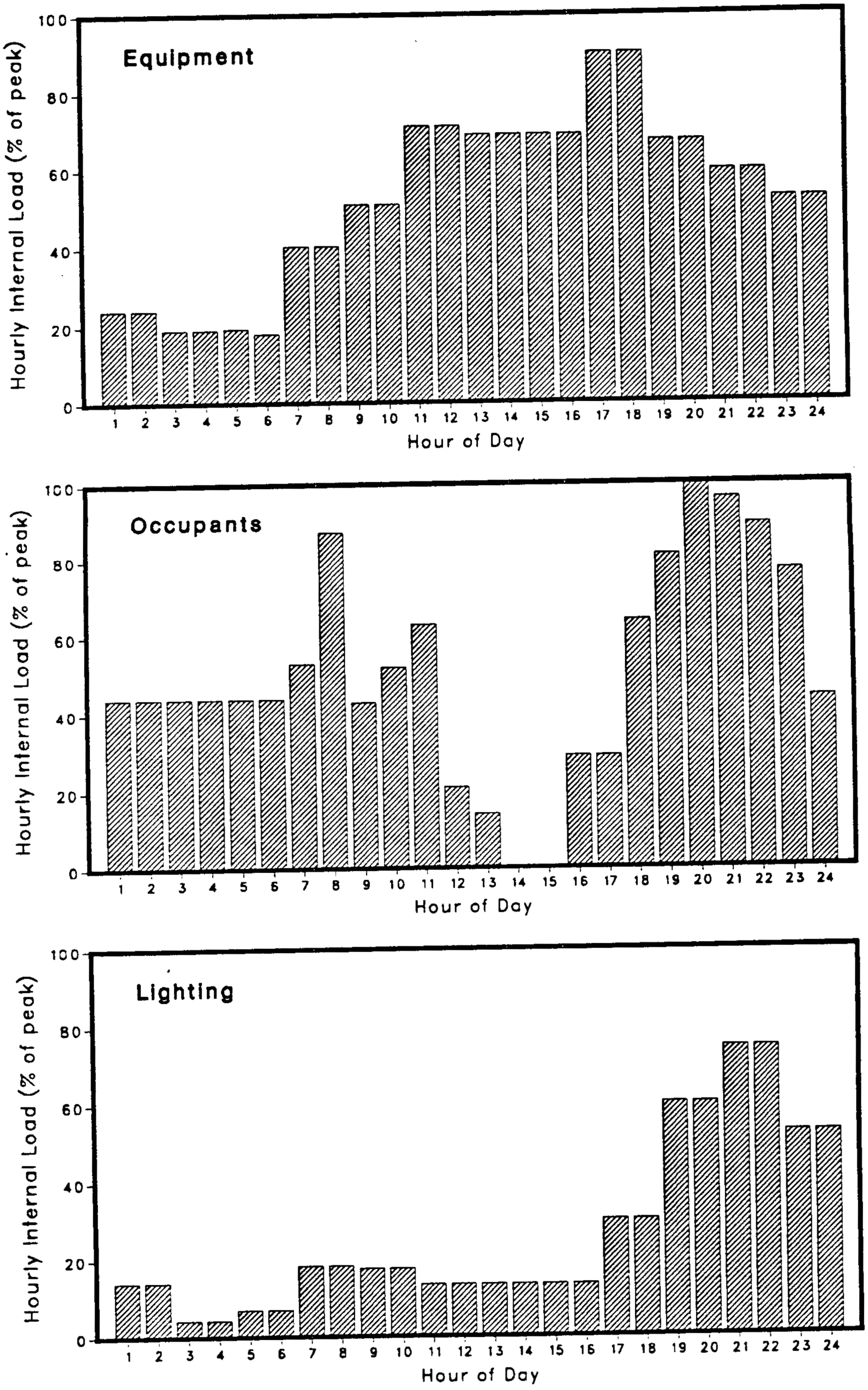

Table 8. Annual Appliance and Lighting Energy Use

Appliance	Units	Stock Usage	1990s Usage	Percent to Conditioned	Percent to Unconditioned	Percent Latent
Refrigerators						
New	kWh	1125	705	100	0	0
Old	kWh	1600	1600	15	85	0
Electric Range	kWh	1200	1010	100	0	35
Gas Range	MMBtu	9	5	100	0	35
Dishwasher	kWh	200	160	0	0	0
Clothes Washer	kWh	110	95	0	0	0
Clothes Dryer	kWh	900	750	10	0	0
Freezer	kWh	950	475	50	50	0
B/W Television	kWh	100	100	100	0	0
Color Television	kWh	320	320	100	0	0
Small Appliances	kWh	300	300	100	0	0
Water Heat †						
Standby	kWh	1320	1320	50	50	0
Use	kWh	2800	2800	10	0	33
Lighting	kWh/ft^2	1	1	90	0	0

† Water heat energy use for internal gains calculation only.

Non-HVAC Loads Methodology

We calculated average annual non-HVAC electricity consumption per building using the same method for calculating internal gains, by combining typical appliance and lighting energy usage with the appliance saturations for each census division derived from the 1987 RECS data tape. Electric dryers were assumed since they are predominate in all census divisions. Electric cooking was assumed in all areas except for the West South Central census division. The resulting values are shown in Table 9. The non-HVAC electric value includes all electricity used by the household, including that which would occur outside the conditioned space.

Domestic Hot Water Loads Methodology

Energy use for heating water is a function of several variables such as water storage temperature, inlet and outlet temperatures, air temperatures, and the rate of usage of hot water. In addition, hot water consumption is highly dependent on behavior and is often influenced by cultural and social norms. Obviously, not all of these variables can be incorporated into the estimates of weekly energy consumption for heating water. To calculate the annual hot water load, we used the methodology developed for the California Residential Building Energy Efficiency Standards,[35] which is mathematically identical to the DOE calculations:[36]

One of the most uncertain parameters in the estimation of hot water loads in any building type is the average per capita water usage. For example, average measured water consumption reported in the literature varies between types of dwellings (single-family, multifamily, etc.),

Table 9. Estimated Average Annual Internal Loads per Building

		Prototype Appliance Loads (Btu/day)			
	Census Division	A,B,C	B+	D	D+
Sensible Internal Loads	New England	36120	38280	30100	32260
	Mid Atlantic	37330	39500	31020	33180
	East North Central	36700	38870	30290	32450
	West North Central	36800	38960	30240	32400
	South Atlantic	35810	37970	29650	31820
	West South Central	36740	38900	30280	32440
	Mountain	36350	38510	30000	32160
	Pacific	36425	38590	30230	32390
Latent Internal Loads	All Census Divisions	4790	4790	4170	4170
Total Sensible Loads (Btu/day) =		Appliance Sensible Loads + 8360 Btu/day (Occupants) + 8.42 Btu/day-ft^2 × conditioned area (ft^2) (Lighting)			
Total Latent Loads (Btu/day) =		Appliance Latent Loads + 6840 Btu/day (Occupants)			

$$\text{Load} = W \times C_p \times (T_T - T_M) \times 365 \text{ days} \qquad [1]$$

where W = average daily hot water consumption (62.4 gallons)[36] (based on 3 occupants)
C_p = energy required per gallon heated (8.25 Btu/gal/°F)
T_T = tank set temperature (140°F)
T_M = city water main temperature (estimated by well temperatures)

geographic regions, and time of year. Standard values include the DOE standard assumption for single-family residences, which is about 21.4 gal/person-day (64.2 gal/household-day) and assumes the presence of a clothes washer in each residence, and the ASHRAE standard value of 62.4 gal/household-day.[37] A recent survey for ASHRAE of available field-measured hot water usage data showed the ASHRAE standard assumption to be valid as an average national value.[38]

This survey also showed significant variation in hot water use between climatic locations and between seasons in each location. Thus, we added both geographical and seasonal variations in consumption levels as a function of outdoor temperatures based on a relationship developed in a study of apartments in New Jersey[39] and modified for use in the previous database project for multifamily buildings.[7] The method is used to calculate both annual average hot water use for each location and monthly hot water use within each location:

The domestic water heating loads are further apportioned by hour using data and hourly water use profiles from other studies.[11,39,40,41] The estimated domestic hot water load reflects only the amount of heat necessary to raise the temperature of the water from the main to the

$$W' = W + (55 - T_A) \times [\, 0.155\ (\text{gal/person–day–°F}) \times 3\ (\text{persons/household})\,] \qquad [2]$$

where W' = daily hot water consumption (gallons)
W = national average daily hot water consumption (62.4 gallons)[36]
55 = national average air temperature (°F)
T_A = air temperature for each base city (°F)

tank temperature of 140° F. The effects of burner efficiency and standby losses are not considered in the calculation of water heating loads, but standby losses are included in the internal loads assumptions (see Table 8). Since the average well temperature in most cities corresponds to the average air temperature, we use data from the weather tapes to estimate city water main temperature (T_M). Table 10 shows the average air and well temperatures for the base cities in this analysis. It also shows the average annual daily hot water use calculated for each base city used in calculating the water heating loads. We provide the average daily and monthly water heating loads in Appendix C.

Table 10. Average Air and Well Temperature and Hot Water Use for Base Cities

City	Annual Average Air Temp. (F)	Well Temp. (F)	Annual Average Hot Water Use (Gal/Day)	City	Annual Average Air Temp. (F)	Well Temp. (F)	Annual Average Hot Water Use (Gal/Day)
Albuquerque	56.6	62.0	61.6	Los Angeles	61.0	62.0	59.6
Atlanta	60.6	64.0	59.8	Miami	75.2	77.0	52.9
Boston	51.0	48.0	64.3	Minneapolis	45.1	45.0	67.1
Chicago	50.7	51.0	64.4	New Orleans	68.0	70.0	56.3
Denver	50.1	47.0	64.7	Phoenix	71.5	66.0	54.6
Fort Worth	65.1	68.0	57.6	San Francisco	55.4	58.0	62.2
New York	54.2	52.0	62.8	Seattle	50.5	52.0	64.5
Kansas City	56.1	54.0	61.9	Washington	57.1	54.0	61.4

4
RESULTS

In this section we present the heating and cooling loads derived from the DOE-2 simulations as well as the non-HVAC electricity and gas usage for the range of prototypical houses representing pre-1940s to 1990s construction practices. The results and discussion are organized by end-use. First, the heating loads are presented according to several end-uses: total annual space heating loads, peak loads, load intensities (i.e., per square foot), and water heating loads. We next cover the annual cooling loads as total space cooling, latent, peak, and load intensities. The other building energy requirements for gas and electric appliances (i.e., non-HVAC) are presented and discussed separately. These non-HVAC loads were estimated by engineering calculations as described in the Methods section. Next, we briefly describe the total annual loads for space heating and cooling on a square foot basis according to the highest and lowest overall users. Finally, we provide a brief comparison of the loads data base to surveyed data from several sources.

HEATING LOADS

The heating loads estimated in this study are used for space heating and hot water systems. The space heating was based on outdoor temperatures on an hourly basis throughout the year, the assumed temperature settings, house size, and thermal integrity (i.e., level of insulation). For this study, we assumed a heating thermostat setting of 70°F with an eight-hour nighttime setback of 6°F. The total annual heating loads would be higher without the thermostat setbacks, but we assumed that these conditions represent the current "average" conditions in single-family buildings. The heating load for domestic hot water systems varied in this study according to the assumed input water temperature and on hot water usage patterns, which in turn, were based on the average air temperature. The other variable (e.g., number of occupants) was held constant in each prototypical house. In reality, these assumptions are good for populations of houses, but they may not be realistic on an individual house basis.

Space Heating

Annual Loads

In Figure 4 (and Table 11) the annual space heating loads (as MMBtu†) are shown for each prototypical house at each location. As shown in Figure 4, the B1+ house, which represents the 1950-70 prototype with thermal upgrades and with greater floor area than the B1

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† MMBtu = 10^6 Btu

Figure 4. Annual Heating Loads for Single Family Prototypes

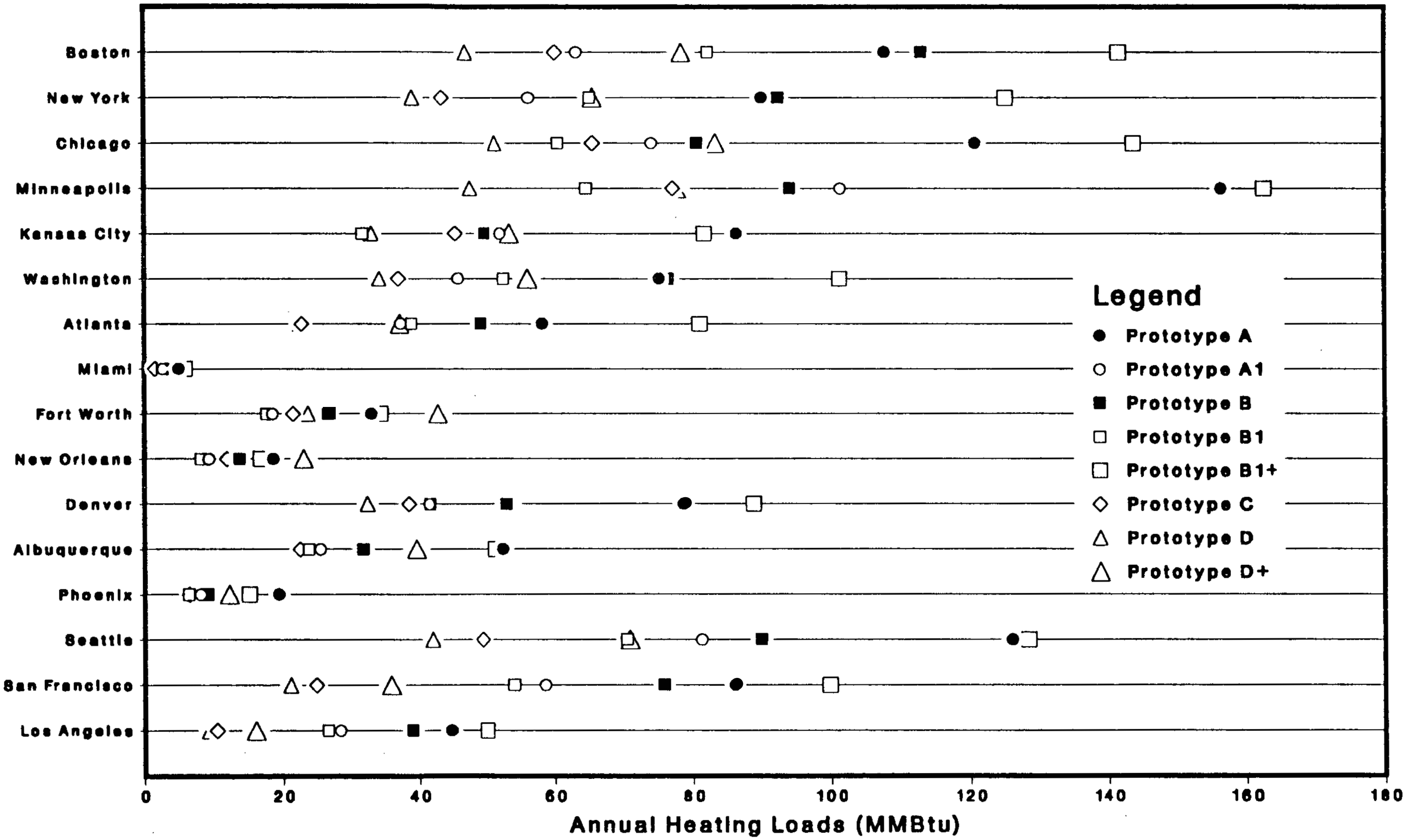


Table 11. Total Building Loads for Single-family Prototypes

REGION/City	Proto-type	Heating Load (MMBtu)	Total Cooling Load (MMBtu)	Latent Cooling Load (MMBtu)	Hot Water Load (MMBtu)	Non-HVAC	
						Electric Load (kWh)	Gas Load (MMBtu)
NORTHEAST							
	A	107.8	10.0	1.7	17.8	6248	0.0
Boston	A1	63.2	8.2	1.6	17.8	6248	0.0
	B	113.1	11.5	2.0	17.8	7029	0.0
	B1	82.2	10.9	1.8	17.8	7029	0.0
	B1+	141.6	17.8	2.9	17.8	9273	0.0
	C	60.1	6.7	1.3	17.8	6898	0.0
	D	46.8	7.7	1.4	17.8	6142	0.0
	D+	78.4	11.8	2.1	17.8	8243	0.0
	A	90.0	12.2	2.2	16.6	6486	0.0
New York	A1	56.3	10.2	2.0	16.6	6486	0.0
	B	92.4	13.1	2.3	16.6	7041	0.0
	B1	65.1	12.1	2.1	16.6	7041	0.0
	B1+	125.2	21.0	3.5	16.6	9507	0.0
	C	43.4	9.2	1.8	16.6	7168	0.0
	D	39.0	8.7	1.8	16.6	6346	0.0
	D+	65.5	12.8	2.5	16.6	8448	0.0
NORTH CENTRAL							
	A	120.8	15.6	2.9	17.3	6466	0.0
Chicago	A1	74.0	12.7	2.7	17.3	6466	0.0
	B	80.6	7.6	1.8	17.3	6270	0.0
	B1	60.5	6.8	1.6	17.3	6270	0.0
	B1+	143.7	12.1	2.7	17.3	8641	0.0
	C	65.5	10.1	2.2	17.3	7110	0.0
	D	51.4	11.8	2.5	17.3	6291	0.0
	D+	83.3	17.5	3.6	17.3	8392	0.0
	A	156.4	13.2	2.2	19.2	6522	0.0
Minneapolis	A1	101.4	11.4	2.4	19.2	6522	0.0
	B	94.1	6.3	1.3	19.2	6046	0.0
	B1	64.6	5.1	1.2	19.2	6046	0.0
	B1+	162.6	9.2	2.0	19.2	8250	0.0
	C	77.1	6.9	1.5	19.2	7166	0.0
	D	47.5	7.9	1.5	19.2	6306	0.0
	D+	77.7	11.5	2.1	19.2	8407	0.0
	A	86.3	28.2	5.0	16.0	6522	0.0
Kansas City	A1	52.2	22.9	4.6	16.0	6522	0.0
	B	49.7	14.2	2.8	16.0	6046	0.0
	B1	31.7	11.6	2.5	16.0	6046	0.0
	B1+	81.7	21.8	4.6	16.0	8250	0.0
	C	45.3	18.9	3.8	16.0	7166	0.0
	D	33.0	20.9	4.1	16.0	6306	0.0
	D+	53.6	31.4	6.1	16.0	8407	0.0

Table 11. Total Building Loads for Single-family Prototypes (cont.)

REGION/City	Proto-type	Heating Load (MMBtu)	Total Cooling Load (MMBtu)	Latent Cooling Load (MMBtu)	Hot Water Load (MMBtu)	Non-HVAC	
						Electric Load (kWh)	Gas Load (MMBtu)
SOUTH							
Washington	A	75.1	20.6	4.4	15.9	5696	0.0
	A1	45.7	16.0	3.2	15.9	5696	0.0
	B	76.4	20.9	3.7	15.9	5949	0.0
	B1	52.7	19.1	3.4	15.9	5949	0.0
	B1+	101.3	33.2	5.8	15.9	7909	0.0
	C	37.0	16.0	3.2	15.9	6714	0.0
	D	34.2	15.7	3.2	15.9	5973	0.0
	D+	56.1	23.5	4.7	15.9	8075	0.0
Atlanta	A	58.2	20.1	3.6	13.7	5696	0.0
	A1	37.3	13.9	2.9	13.7	5696	0.0
	B	49.1	15.0	3.0	13.7	5949	0.0
	B1	38.9	13.7	2.8	13.7	5949	0.0
	B1+	81.0	22.9	4.4	13.7	7909	0.0
	C	22.8	17.4	3.5	13.7	6714	0.0
	D	22.5	17.4	3.5	13.7	5973	0.0
	D+	37.2	25.8	5.1	13.7	8075	0.0
Miami	A	5.0	50.1	12.8	10.0	5696	0.0
	A1	2.7	40.9	12.5	10.0	5696	0.0
	B	3.5	45.8	13.4	10.0	5949	0.0
	B1	2.6	41.9	12.0	10.0	5949	0.0
	B1+	5.9	70.9	20.4	10.0	7909	0.0
	C	1.6	35.1	10.3	10.0	6154	0.0
	D	1.6	35.2	10.6	10.0	5413	0.0
	D+	3.0	53.1	16.0	10.0	7315	0.0
Fort Worth	A	33.0	28.5	6.1	12.5	4617	9.0
	A1	18.5	22.3	5.5	12.5	4617	9.0
	B	26.7	26.4	6.2	12.5	4955	9.0
	B1	17.6	23.3	5.7	12.5	4955	9.0
	B1+	34.4	37.5	9.1	12.5	6736	9.0
	C	21.5	20.8	5.0	12.5	5187	9.0
	D	23.7	21.1	5.1	12.5	4556	4.9
	D+	42.8	32.6	7.8	12.5	6457	4.9
New Orleans	A	18.6	26.1	6.6	11.9	4617	9.0
	A1	9.3	20.5	6.0	11.9	4617	9.0
	B	13.7	23.6	6.6	11.9	4955	9.0
	B1	8.2	21.3	6.3	11.9	4955	9.0
	B1+	16.8	33.3	9.9	11.9	6736	9.0
	C	11.9	18.6	5.4	11.9	5187	9.0
	D	12.5	17.7	5.3	11.9	4556	4.9
	D+	23.1	26.2	7.8	11.9	6457	4.9

Table 11. Total Building Loads for Single-family Prototypes (cont.)

REGION/City	Proto-type	Heating Load (MMBtu)	Total Cooling Load (MMBtu)	Latent Cooling Load (MMBtu)	Hot Water Load (MMBtu)	Non-HVAC	
						Electric Load (kWh)	Gas Load (MMBtu)
WEST							
Denver	A	78.6	9.1	0.1	18.1	5738	0.0
	A1	41.5	4.9	0.1	18.1	5738	0.0
	B	53.1	3.5	0.0	18.1	5839	0.0
	B1	41.6	3.5	0.0	18.1	5839	0.0
	B1+	88.8	6.0	0.0	18.1	7652	0.0
	C	38.5	8.1	0.1	18.1	6829	0.0
	D	32.4	7.8	0.1	18.1	6034	0.0
	D+	53.3	12.1	0.1	18.1	8135	0.0
Albuquerque	A	52.6	15.9	0.3	14.5	5738	0.0
	A1	25.5	9.3	0.3	14.5	5738	0.0
	B	31.8	8.2	0.3	14.5	5839	0.0
	B1	23.8	8.1	0.3	14.5	5839	0.0
	B1+	51.3	14.2	0.3	14.5	7652	0.0
	C	22.5	6.5	0.2	14.5	6419	0.0
	D	22.5	6.1	0.2	14.5	5624	0.0
	D+	39.6	8.8	0.2	14.5	7525	0.0
Phoenix	A	19.4	47.3	2.8	12.2	5738	0.0
	A1	8.1	32.0	2.6	12.2	5738	0.0
	B	9.1	32.7	2.7	12.2	5839	0.0
	B1	6.4	30.3	2.5	12.2	5839	0.0
	B1+	15.1	54.8	3.9	12.2	7652	0.0
	C	6.5	30.2	2.6	12.2	6419	0.0
	D	6.6	30.0	2.6	12.2	5624	0.0
	D+	12.2	46.3	3.7	12.2	7525	0.0
Seattle	A	126.0	3.0	0.2	17.1	6187	0.0
	A1	81.2	1.7	0.1	17.1	6187	0.0
	B	89.9	1.7	0.1	17.1	6176	0.0
	B1	70.4	1.5	0.1	17.1	6176	0.0
	B1+	128.4	2.3	0.2	17.1	7795	0.0
	C	49.4	3.9	0.2	17.1	6854	0.0
	D	42.0	3.8	0.2	17.1	6096	0.0
	D+	70.8	6.1	0.3	17.1	8197	0.0
San Francisco	A	86.0	1.6	0.0	15.4	6187	0.0
	A1	58.6	0.9	0.0	15.4	6187	0.0
	B	75.7	1.0	0.0	15.4	6176	0.0
	B1	54.2	0.8	0.0	15.4	6176	0.0
	B1+	99.8	1.3	0.0	15.4	7795	0.0
	C	24.9	1.1	0.0	15.4	6854	0.0
	D	21.1	1.2	0.0	15.4	6096	0.0
	D+	35.9	2.0	0.0	15.4	8197	0.0
Los Angeles	A	44.7	4.5	0.6	14.0	6187	0.0
	A1	28.4	2.3	0.3	14.0	6187	0.0
	B	39.0	2.5	0.3	14.0	6176	0.0
	B1	26.6	2.1	0.2	14.0	6176	0.0
	B1+	50.1	3.3	0.3	14.0	7795	0.0
	C	10.4	3.2	0.4	14.0	6854	0.0
	D	9.3	3.0	0.3	14.0	6096	0.0
	D+	16.0	5.0	0.5	14.0	8197	0.0

house, had the highest space heating loads in all climates except the West South Central region (Fort Worth and New Orleans). The location with the highest annual heating load was Minneapolis (162.6 MMBtu). Annual heating was also high in other cold climates, e.g., Chicago (143.7 MMBtu), and Boston (141.6 MMBtu). In Fort Worth and New Orleans, the D+ house was 20% and 27% higher than the B1+ house, respectively (see Fig. 4 and Table 11). The annual heating loads (42.8 MMBtu in Fort Worth and 23.1 MMBtu in New Orleans), however, were significantly less than those in the colder climates because of higher internal heat gains assumed in the west south central census region.

The next highest space heating loads are found in the A house (pre-1940s) in most locations. The annual usage is significant in some locations, e.g., Minneapolis (156.4 MMBtu), Seattle (126.0 MMBtu), and Chicago (120.8 MMBtu). In Kansas City, the A house had a slightly higher annual space heating load than the B1+ house (86.3 MMBtu vs. 81.7 MMBtu). This same situation was found in Phoenix where heating loads are generally small. The A house in Phoenix required 19.4 MMBtu/yr vs. 15.1 MMBtu/yr for the B1+ house.

The lowest annual space heating loads in all but three locations (Kansas City, Fort Worth, and New Orleans) were found in the D house (1990s construction practices). The annual loads for the D house ranged from 1.6 MMBtu in Miami to 51.4 MMBtu in Chicago. The annual space heating load in the B1 house in Kansas City was 4% less than that of the D house. The reason for this difference is that the D house is about twice as large and has two-storied rather than single-storied construction. The B1 house was also more efficient than the 1990s house in Fort Worth and New Orleans where the retrofitted 1950-70s house required 26% and 34% less load, respectively. In each case it was demonstrated that even though the D house had higher thermal integrity than the B1 house, the effects of house size were more important.

Annual Peak Heating Loads

In most cases the highest peak heating loads were found in the B1+ prototypical house (see Table 12). For example, the simulated peak requirements were high in Boston (102.2 kBtu), Washington D.C. (94.1 kBtu), and Chicago (91.1 kBtu). The heating peak loads in the A house were also high as shown in Minneapolis (85.5 kBtu) and Kansas City (66 kBtu). In Fort Worth and New Orleans the larger D house (D+) showed relatively high heating peaks (53.1 kBtu in Fort Worth and 45.5 kBtu in New Orleans).

At the other extreme, the lowest heating peaks in the colder climates were found in several prototypical houses depending on the specific location. In the majority of cases, the D house had the lowest heating peak, e.g., New York (32.6 kBtu) and Minneapolis (34.2 kBtu). The B1 house also had small peak heating loads in some climates (38.4 kBtu in Denver and 40.0 kBtu in Chicago). As expected the peak heating loads were smaller in climates with shorter heating seasons, such as Phoenix (27.0 kBtu) and Fort Worth (23.5 kBtu), and Miami (19.7 kBtu).

Table 12. Peak Building Loads for Single-family Prototypes

REGION/City	Proto-type	Peak Heating Load (kBtu/hr)	Peak Heating Temp (°F)	Peak Total Cooling Load (kBtu/hr)	Peak Total Cooling Temp* (°F)	HR† $(\times10^{4})$	Lnt Load‡ (kBtu/hr)	Peak Latent Cooling Load (kBtu/hr)
NORTHEAST								
Boston	A	70.1	-3	35.1	97	128	8.0	8.8
	A1	47.6	-3	27.5	97	128	6.4	7.5
	B	77.0	-3	41.0	97	128	9.4	10.3
	B1	60.4	-3	36.4	97	128	8.3	9.1
	B1+	102.2	-3	61.6	97	128	14.3	15.5
	C	42.8	-3	25.5	97	128	5.9	6.9
	D	40.1	-3	25.9	97	128	6.5	7.0
	D+	65.3	-3	41.8	97	128	10.6	11.4
New York	A	55.6	9	28.5	95	132	5.5	7.1
	A1	40.1	9	22.9	90	169	6.0	6.1
	B	58.8	9	31.3	90	169	7.5	7.6
	B1	46.5	9	26.7	90	169	6.4	6.6
	B1+	85.6	9	49.2	90	169	12.3	12.7
	C	34.2	9	20.2	90	169	5.4	5.7
	D	32.6	9	19.4	90	169	5.4	5.6
	D+	52.4	9	31.0	90	169	8.8	9.1
NORTH CENTRAL								
Chicago	A	78.3	-9	35.3	94	148	6.9	10.9
	A1	55.4	-9	28.5	94	148	6.4	9.6
	B	50.1	-9	20.8	99	135	3.4	7.0
	B1	40.0	-9	18.3	91	139	4.1	6.1
	B1+	91.1	-9	37.6	91	139	8.6	13.2
	C	47.4	-9	25.4	94	148	5.7	8.5
	D	43.2	-9	26.5	91	139	5.8	8.8
	D+	70.3	-9	41.4	91	139	9.0	14.0
Minneapolis	A	85.5	-28	36.9	91	168	9.9	9.9
	A1	60.4	-28	32.7	91	168	9.9	9.9
	B	49.2	-28	21.0	91	168	6.1	6.1
	B1	35.8	-28	18.0	91	168	5.4	5.4
	B1+	83.9	-28	39.5	91	168	12.1	12.1
	C	46.0	-28	24.9	91	168	8.1	8.1
	D	34.2	-28	23.2	91	168	6.8	6.8
	D+	54.0	-28	36.3	91	168	10.7	10.7
Kansas City	A	66.0	-7	35.8	99	165	7.1	8.9
	A1	46.1	-7	27.9	96	180	6.4	7.8
	B	38.1	-7	18.8	99	165	3.9	4.9
	B1	27.4	-7	14.8	92	180	3.8	4.2
	B1+	63.8	-7	33.2	92	180	8.9	9.7
	C	39.7	-7	24.3	96	180	5.6	6.9
	D	38.1	-7	24.2	96	180	5.7	7.0
	D+	60.1	-7	38.2	96	180	9.1	11.2

* Peak temperature on day of peak load, timing of peak load may differ between prototype in the same location.

† Humidity ratio at peak temperature.

‡ Latent portion of total load at peak load.

Table 12. Peak Building Loads for Single-family Prototypes (cont.)

		Peak Heating		Peak Total Cooling				Peak Latent
REGION/City	Proto- type	Load (kBtu/hr)	Temp (°F)	Load (kBtu/hr)	Temp• (°F)	HR† ($\times10^4$)	Ltnt Load‡ (kBtu/hr)	Cooling Load (kBtu/hr)
SOUTH								
Washington	A	54.6	11	37.0	93	212	10.8	10.8
	A1	40.1	11	24.1	93	212	7.9	7.9
	B	57.8	11	33.4	93	212	9.9	9.9
	B1	50.8	12	29.4	93	212	8.7	8.7
	B1+	94.1	12	53.8	93	212	16.3	16.3
	C	40.6	11	24.0	93	212	7.7	7.7
	D	40.6	11	24.1	93	212	8.2	8.2
	D+	64.2	11	37.9	93	212	13.0	13.0
Atlanta	A	49.3	12	26.6	90	176	4.2	7.4
	A1	34.3	12	18.9	91	175	4.1	5.7
	B	42.4	12	21.8	91	175	4.4	6.1
	B1	34.3	12	19.3	91	175	4.0	5.6
	B1+	68.1	12	35.6	91	175	7.2	10.4
	C	35.4	12	21.4	90	167	4.6	6.5
	D	36.5	12	22.0	90	167	4.9	6.9
	D+	57.9	12	34.2	90	167	7.6	10.8
Miami	A	31.1	38	25.2	92	138	5.3	8.1
	A1	21.9	38	19.5	89	201	7.2	7.2
	B	25.7	38	22.2	89	201	7.8	7.9
	B1	21.4	38	18.8	89	201	6.7	6.8
	B1+	40.1	38	35.4	89	201	12.7	13.1
	C	19.7	38	18.7	89	201	6.6	6.6
	D	20.7	38	19.2	89	201	7.1	7.1
	D+	35.6	38	31.3	92	156	9.3	11.8
Fort Worth	A	33.6	20	27.9	101	140	5.0	7.4
	A1	23.5	20	21.0	101	140	4.4	6.2
	B	31.3	20	25.8	101	140	5.0	7.3
	B1	24.7	20	22.1	101	140	4.6	6.4
	B1+	45.3	20	38.8	101	140	8.1	11.4
	C	28.5	20	22.0	101	140	4.5	6.3
	D	31.0	20	23.5	101	140	4.9	6.8
	D+	53.1	20	38.7	101	140	8.1	11.3
New Orleans	A	30.2	27	25.7	89	154	7.6	11.7
	A1	21.5	27	20.1	86	189	9.8	9.8
	B	28.4	27	23.7	86	189	11.5	11.5
	B1	22.6	27	20.8	86	189	10.3	10.3
	B1+	41.6	27	36.1	86	189	18.1	18.1
	C	26.7	27	20.7	86	189	10.1	10.1
	D	27.8	27	21.6	86	189	10.8	10.8
	D+	45.5	27	35.2	86	189	17.8	17.8

• Peak temperature on day of peak load, timing of peak load may differ between prototypes in the same location.

† Humidity ratio at peak temperature.

‡ Latent portion of total load at peak load.

Table 12. Peak Building Loads for Single-family Prototypes (cont.)

		Peak Heating		Peak Total Cooling				Peak Latent Cooling Load (kBtu)
REGION/City	Proto-type	Load (kBtu/hr)	Temp (°F)	Load (kBtu/hr)	Temp* (°F)	HR† ($\times 10^4$)	Ltnt Load‡ (kBtu/hr)	
WEST								
Denver	A	47.0	-8	18.6	95	61	0.0	2.0
	A1	29.4	-8	12.3	90	65	0.0	1.8
	B	34.7	-8	10.9	94	25	0.0	1.6
	B1	29.4	-8	9.9	94	25	0.0	1.5
	B1+	59.3	-8	18.8	92	61	0.0	2.5
	C	39.0	-8	19.4	90	65	0.0	2.4
	D	38.4	-8	19.2	90	65	0.0	2.5
	D+	62.5	-8	30.7	90	65	0.0	3.7
Albuquerque	A	39.1	12	23.1	99	66	0.0	3.4
	A1	26.5	12	14.7	95	74	0.3	2.7
	B	27.6	12	14.0	95	74	0.3	2.6
	B1	23.5	12	13.1	95	74	0.3	2.4
	B1+	48.3	12	24.7	95	74	0.2	4.7
	C	26.0	12	12.7	95	74	0.3	2.6
	D	27.0	12	12.7	95	74	0.2	2.8
	D+	45.2	12	19.8	95	74	0.0	4.5
Phoenix	A	31.2	23	36.0	103	104	3.8	7.7
	A1	20.8	23	26.7	103	104	3.3	6.3
	B	20.8	23	27.5	103	104	3.2	6.6
	B1	17.7	23	24.4	103	104	2.8	5.7
	B1+	36.5	23	49.0	103	104	5.6	10.8
	C	20.6	23	27.0	103	104	3.4	6.7
	D	22.0	23	28.8	103	104	3.7	7.0
	D+	37.2	23	48.1	103	104	6.1	11.0
Seattle	A	54.4	14	25.4	87	104	1.8	2.3
	A1	37.3	14	17.5	87	104	1.6	2.0
	B	39.4	14	18.1	87	104	1.5	1.9
	B1	31.4	14	15.9	87	104	1.4	1.7
	B1+	54.4	14	25.9	87	104	2.0	2.5
	C	41.4	16	24.6	89	100	1.3	2.5
	D	40.0	16	24.7	89	100	1.4	2.6
	D+	65.1	16	39.8	89	100	2.1	4.1
San Francisco	A	42.7	37	26.0	92	37	0.0	1.4
	A1	33.7	37	19.0	92	37	0.0	0.9
	B	38.3	37	21.6	92	37	0.0	1.0
	B1	31.0	33	17.6	92	37	0.0	0.8
	B1+	50.8	33	29.0	92	37	0.0	1.3
	C	28.0	37	21.9	92	37	0.0	1.2
	D	28.0	37	22.6	92	37	0.0	1.3
	D+	45.5	37	36.2	92	37	0.0	2.1
Los Angeles	A	37.4	40	34.9	102	47	0.9	3.5
	A1	29.0	40	24.6	102	47	0.8	2.7
	B	33.7	40	28.8	102	47	0.8	2.6
	B1	27.8	40	22.3	102	47	0.7	2.4
	B1+	48.5	40	37.5	102	47	0.7	3.8
	C	24.8	40	27.1	103	81	0.7	3.0
	D	25.2	40	27.9	103	81	0.7	3.1
	D+	40.7	40	45.3	103	81	1.0	4.9

* Peak temperature on day of peak load, timing of peak load may differ betweeen prototypes in the same location.

† Humidity ratio at peak temperature.

‡ Latent portion of total load at peak load.

For illustrative purposes, we present hourly space heating loads for a typical winter day in Chicago in Figure 5. In this illustration, the hourly loads are compared by building type along with the daily outdoor temperature on an hourly basis. The greatest loads are in the early morning to meet the heating requirements of the night-time 6°F setback. The lowest heating loads are during the early afternoon when the outside temperatures are the highest.

Heating Load Intensities

The highest heating load intensity, i.e., space heating per floor area (kBtu/ft^2), were found in the oldest house with the least thermal integrity (i.e., A house). Some typical high heating load intensities, on a square foot basis, were: 99.3 kBtu (Minneapolis), 89.8 kBtu (Seattle), and 80.3 kBtu (Denver). These intensities were all found in the pre-1940s construction. Table 13 contains the heating load intensities for all prototypes and locations. The peak heating load intensities are also provided in Table 13.

The lowest space heating load intensities for colder climates were found in either the D or D+ house. The difference in load intensities between these two prototypes was 1-2%. Load intensities, on a square foot basis, in the colder climates ranged from 13.8 kBtu in Denver to 20.9 kBtu in Chicago. The lowest heating load intensities were found in locations with the smallest space heating loads (e.g., 4.2 kBtu/ft^2 in Los Angeles and 3.7 kBtu/ft^2 in Phoenix).

In Figure 6 we present the monthly heating load intensities for several single-family buildings in Chicago. This figure is presented to illustrate the seasonal variability of heating loads, on a square foot basis, for thermal conditions ranging from the pre-1940s house (Prototype A) to 1990s building practices (Prototype D). In addition, we show in Figure 7 the monthly heating load intensities (kBtu/ft^2) for the retrofitted pre-1940s house in four climates: cold (Minneapolis), hot and humid (Miami), hot and dry (Phoenix), and moderate (San Francisco). An important observation in this illustration is the significant heating loads in San Francisco during the summer months (June, July, and August). These summer heating load intensities in San Francisco account for a large fraction of the annual heating loads in this "mild" climate.

Water Heating Loads

The domestic water heating loads ranged from 10.0 MMBtu/yr in Miami to 19.2 MMBtu/yr in Minneapolis (see Table 11). These loads were influenced primarily by the input water temperatures and hot water usage, which were based on air temperatures. Therefore, colder climates will generally have higher annual water heating loads because the assumed input water temperatures are colder. For example, the assumed average well temperatures (i.e., input water temperatures) were 49.9°F in the colder climates and 59.2°F in the warmer climates.

Figure 5. Heating Loads on Typical Winter Day for Four Prototype Buildings in Chicago

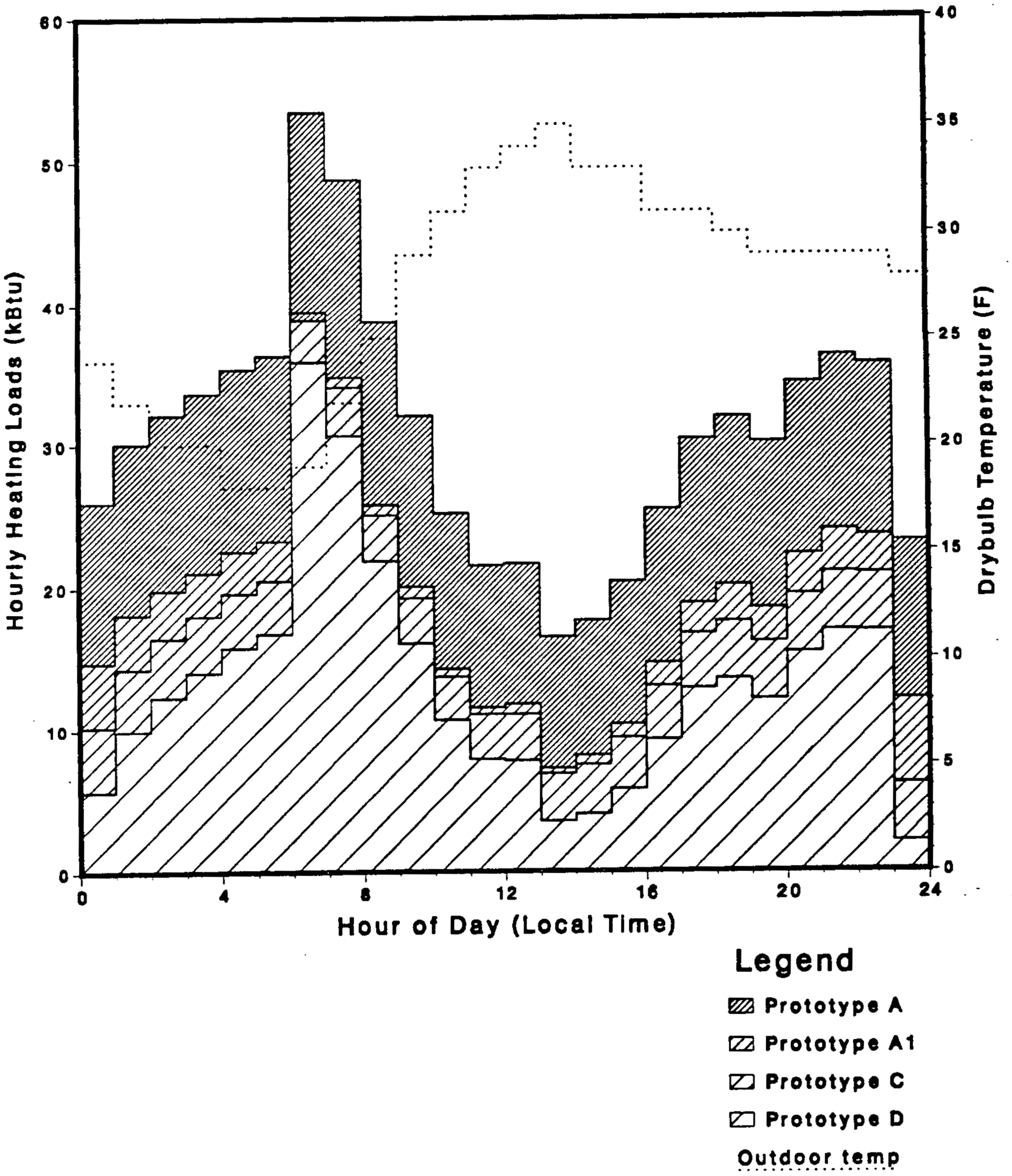


Table 13. Total and Peak Building Load Intensities for Single-family Prototypes

REGION/City	Proto-Type	Heating Load/ft^2 (kBtu)	Total Cooling Load/ft^2 (kBtu)	Latent Cooling Load/ft^2 (kBtu)	Peak Heating Load/ft^2 (Btu)	Peak Cooling Load/ft^2		Peak Latent Cooling Load/ft^2 (Btu)
						Total (Btu)	Latent (Btu)	
NORTHEAST								
	A	74.9	6.9	1.2	48.7	24.4	5.5	6.1
Boston	A1	43.9	5.7	1.1	33.1	19.1	4.4	5.2
	B	50.9	5.2	0.9	34.7	18.5	4.3	4.7
	B1	37.0	4.9	0.8	27.2	16.4	3.7	4.1
	B1+	36.0	4.5	0.7	26.0	15.7	3.6	4.0
	C	28.7	3.2	0.6	20.5	12.2	2.8	3.3
	D	20.5	3.4	0.6	17.6	11.4	2.8	3.1
	D+	20.4	3.1	0.6	16.9	10.9	2.7	3.0
	A	63.9	8.7	1.6	39.5	20.3	3.9	5.1
New York	A1	40.0	7.2	1.4	28.5	16.2	4.3	4.3
	B	47.1	6.7	1.2	30.0	16.0	3.8	3.9
	B1	33.2	6.2	1.1	23.7	13.6	3.3	3.4
	B1+	32.1	5.4	0.9	22.0	12.6	3.2	3.3
	C	20.8	4.4	0.9	16.4	9.7	2.6	2.7
	D	17.1	3.8	0.8	14.3	8.5	2.4	2.5
	D+	17.0	3.3	0.7	13.6	8.1	2.3	2.4
NORTH CENTRAL								
	A	76.7	9.9	1.8	49.7	22.4	4.4	6.9
Chicago	A1	47.0	8.0	1.7	35.2	18.1	4.0	6.1
	B	58.4	5.5	1.3	36.3	15.1	2.5	5.1
	B1	43.9	4.9	1.1	29.0	13.2	3.0	4.4
	B1+	44.6	3.8	0.8	28.3	11.7	2.7	4.1
	C	29.5	4.5	1.0	21.4	11.4	2.6	3.8
	D	21.2	4.9	1.0	17.8	11.0	2.4	3.6
	D+	20.9	4.4	0.9	17.6	10.4	2.2	3.5
	A	99.3	8.4	1.4	54.3	23.4	6.3	6.3
Minneapolis	A1	64.4	7.2	1.5	38.3	20.7	6.3	6.3
	B	85.5	5.7	1.2	44.7	19.1	5.6	5.6
	B1	58.7	4.7	1.1	32.6	16.4	4.9	4.9
	B1+	58.7	3.3	0.7	30.3	14.3	4.4	4.4
	C	34.8	3.1	0.7	20.7	11.2	3.7	3.7
	D	19.6	3.3	0.6	14.1	9.6	2.8	2.8
	D+	19.5	2.9	0.5	13.5	9.1	2.7	2.7
	A	54.8	17.9	3.2	41.9	22.7	4.5	5.7
Kansas City	A1	33.1	14.5	2.9	29.3	17.7	4.0	5.0
	B	45.2	12.9	2.6	34.6	17.1	3.6	4.4
	B1	28.8	10.6	2.3	24.9	13.5	3.5	3.8
	B1+	29.5	7.9	1.7	23.0	12.0	3.2	3.5
	C	20.4	8.5	1.7	17.9	10.9	2.5	3.1
	D	13.7	8.6	1.7	15.7	10.0	2.3	2.9
	D+	13.4	7.9	1.5	15.1	9.6	2.3	2.8

Table 13. Total and Peak Building Load Intensities for Single-family Prototypes (cont.)

REGION/City	Proto-Type	Heating Load/ft² (kBtu)	Total Cooling Load/ft² (kBtu)	Latent Cooling Load/ft² (kBtu)	Peak Heating Load/ft² (Btu)	Peak Cooling Load/ft²		Peak Latent Cooling Load/ft² (Btu)
						Total (Btu)	Latent (Btu)	
SOUTH								
Washington	A	53.3	14.7	3.1	38.7	26.3	7.7	7.7
	A1	32.4	11.4	2.3	28.5	17.1	5.6	5.6
	B	38.9	10.7	1.9	29.4	17.0	5.0	5.0
	B1	26.9	9.7	1.8	25.9	15.0	4.4	4.4
	B1+	26.0	8.5	1.5	24.1	13.8	4.2	4.2
	C	17.0	7.4	1.5	18.6	11.0	3.5	3.5
	D	14.3	6.6	1.4	17.0	10.1	3.4	3.4
	D+	14.2	5.9	1.2	16.2	9.6	3.3	3.3
Atlanta	A	50.1	17.3	3.1	42.5	22.9	3.6	6.3
	A1	32.1	11.9	2.5	29.5	16.2	3.5	4.9
	B	34.7	10.6	2.1	30.0	15.4	3.1	4.3
	B1	27.5	9.7	2.0	24.3	13.6	2.8	3.9
	B1+	28.5	8.0	1.6	24.0	12.5	2.5	3.6
	C	10.5	8.0	1.6	16.2	9.8	2.1	3.0
	D	9.4	7.3	1.5	15.3	9.2	2.0	2.9
	D+	9.4	6.5	1.3	14.6	8.6	1.9	2.7
Miami	A	4.3	43.1	11.0	26.8	21.7	4.5	6.9
	A1	2.3	35.2	10.8	18.9	16.8	6.2	6.2
	B	2.5	32.4	9.5	18.2	15.7	5.5	5.6
	B1	1.8	29.6	8.5	15.1	13.3	4.7	4.8
	B1+	2.1	24.9	7.2	14.1	12.4	4.5	4.6
	C	1.0	21.6	6.4	12.2	11.5	4.1	4.1
	D	0.9	19.2	5.8	11.3	10.5	3.9	3.9
	D+	0.9	16.6	5.0	11.1	9.8	2.9	3.7
Fort Worth	A	31.5	27.1	5.8	32.0	26.5	4.7	7.1
	A1	17.6	21.3	5.2	22.4	20.0	4.2	5.9
	B	19.3	19.1	4.5	22.6	18.6	3.6	5.2
	B1	12.7	16.8	4.1	17.8	15.9	3.3	4.6
	B1+	13.0	14.2	3.4	17.2	14.7	3.1	4.3
	C	13.3	12.9	3.1	17.6	13.6	2.8	3.9
	D	13.0	11.5	2.8	16.9	12.8	2.7	3.7
	D+	13.4	10.2	2.4	16.6	12.1	2.5	3.5
New Orleans	A	17.7	24.9	6.2	28.8	24.5	7.2	11.1
	A1	8.8	19.5	5.7	20.4	19.2	9.4	9.4
	B	9.9	17.0	4.8	20.4	17.1	8.3	8.3
	B1	5.9	15.3	4.6	16.3	15.0	7.4	7.4
	B1+	6.4	12.6	3.8	15.8	13.7	6.9	6.9
	C	7.4	11.5	3.4	16.5	12.8	6.3	6.3
	D	6.8	9.7	2.9	15.2	11.8	5.9	5.9
	D+	7.2	8.2	2.4	14.2	11.0	5.6	5.6

Table 13. Total and Peak Building Load Intensities for Single-family Prototypes (cont.)

REGION/City	Proto-Type	Heating Load/ft^2 (kBtu)	Total Cooling Load/ft^2 (kBtu)	Latent Cooling Load/ft^2 (kBtu)	Peak Heating Load/ft^2 (Btu)	Peak Cooling Load/ft^2		Peak Latent Cooling Load/ft^2 (Btu)
						Total (Btu)	Latent (Btu)	
WEST								
Denver	A	80.3	9.3	0.1	48.0	19.0	0.0	2.0
	A1	42.4	5.0	0.1	30.0	12.5	0.0	1.8
	B	49.2	3.2	0.0	32.1	10.1	0.0	1.5
	B1	38.5	3.2	0.0	27.2	9.2	0.0	1.4
	B1+	37.6	2.5	0.0	25.1	8.0	0.0	1.1
	C	18.6	3.9	0.0	18.8	9.4	0.0	1.2
	D	14.1	3.4	0.0	16.8	8.4	0.0	1.1
	D+	13.8	3.1	0.0	16.2	7.9	0.0	1.0
Albuquerque	A	53.7	16.3	0.3	39.9	23.6	0.0	3.5
	A1	26.1	9.5	0.3	27.1	15.1	0.3	2.8
	B	29.4	7.6	0.3	25.5	12.9	0.3	2.4
	B1	22.0	7.5	0.3	21.8	12.1	0.3	2.2
	B1+	21.7	6.0	0.1	20.4	10.5	0.1	2.0
	C	13.5	3.9	0.1	15.6	7.6	0.2	1.6
	D	12.0	3.2	0.1	14.4	6.8	0.1	1.5
	D+	12.2	2.7	0.1	13.9	6.1	0.0	1.4
Phoenix	A	19.9	48.4	2.8	31.9	36.8	3.9	7.8
	A1	8.2	32.7	2.6	21.3	27.3	3.4	6.4
	B	8.4	30.2	2.5	19.3	25.5	3.0	6.1
	B1	6.0	28.0	2.3	16.4	22.6	2.6	5.3
	B1+	6.4	23.2	1.6	15.5	20.8	2.4	4.6
	C	3.9	18.2	1.6	12.4	16.3	2.0	4.0
	D	3.5	16.0	1.4	11.7	15.3	2.0	3.7
	D+	3.7	14.2	1.1	11.4	14.8	1.9	3.4
Seattle	A	89.8	2.2	0.1	38.7	18.1	1.3	1.7
	A1	57.9	1.2	0.1	26.6	12.4	1.1	1.4
	B	64.6	1.2	0.1	28.3	13.0	1.1	1.3
	B1	50.6	1.1	0.1	22.6	11.4	1.0	1.2
	B1+	51.8	0.9	0.1	21.9	10.4	0.8	1.0
	C	23.9	1.9	0.1	20.0	11.9	0.6	1.2
	D	18.4	1.7	0.1	17.5	10.8	0.6	1.1
	D+	18.4	1.6	0.1	16.9	10.3	0.5	1.1
San Francisco	A	61.3	1.1	0.0	30.4	18.5	0.0	1.0
	A1	41.8	0.6	0.0	24.0	13.5	0.0	0.7
	B	54.4	0.7	0.0	27.6	15.5	0.0	0.7
	B1	38.9	0.6	0.0	22.3	12.7	0.0	0.6
	B1+	40.2	0.5	0.0	20.5	11.7	0.0	0.5
	C	12.0	0.5	0.0	13.5	10.6	0.0	0.6
	D	9.2	0.5	0.0	12.2	9.9	0.0	0.6
	D+	9.3	0.5	0.0	11.8	9.4	0.0	0.5
Los Angeles	A	31.9	3.2	0.4	26.7	24.9	0.6	2.5
	A1	20.2	1.6	0.2	20.6	17.5	0.6	2.0
	B	28.1	1.8	0.2	24.2	20.7	0.6	1.9
	B1	19.1	1.5	0.2	20.0	16.1	0.5	1.7
	B1+	20.2	1.3	0.1	19.6	15.1	0.3	1.5
	C	5.0	1.5	0.2	12.0	13.1	0.3	1.4
	D	4.1	1.3	0.1	11.0	12.2	0.3	1.4
	D+	4.2	1.3	0.1	10.5	11.7	0.3	1.3

Figure 6. Heating Loads/Sq.Ft.
Four Prototype Single Family Buildings in Chicago

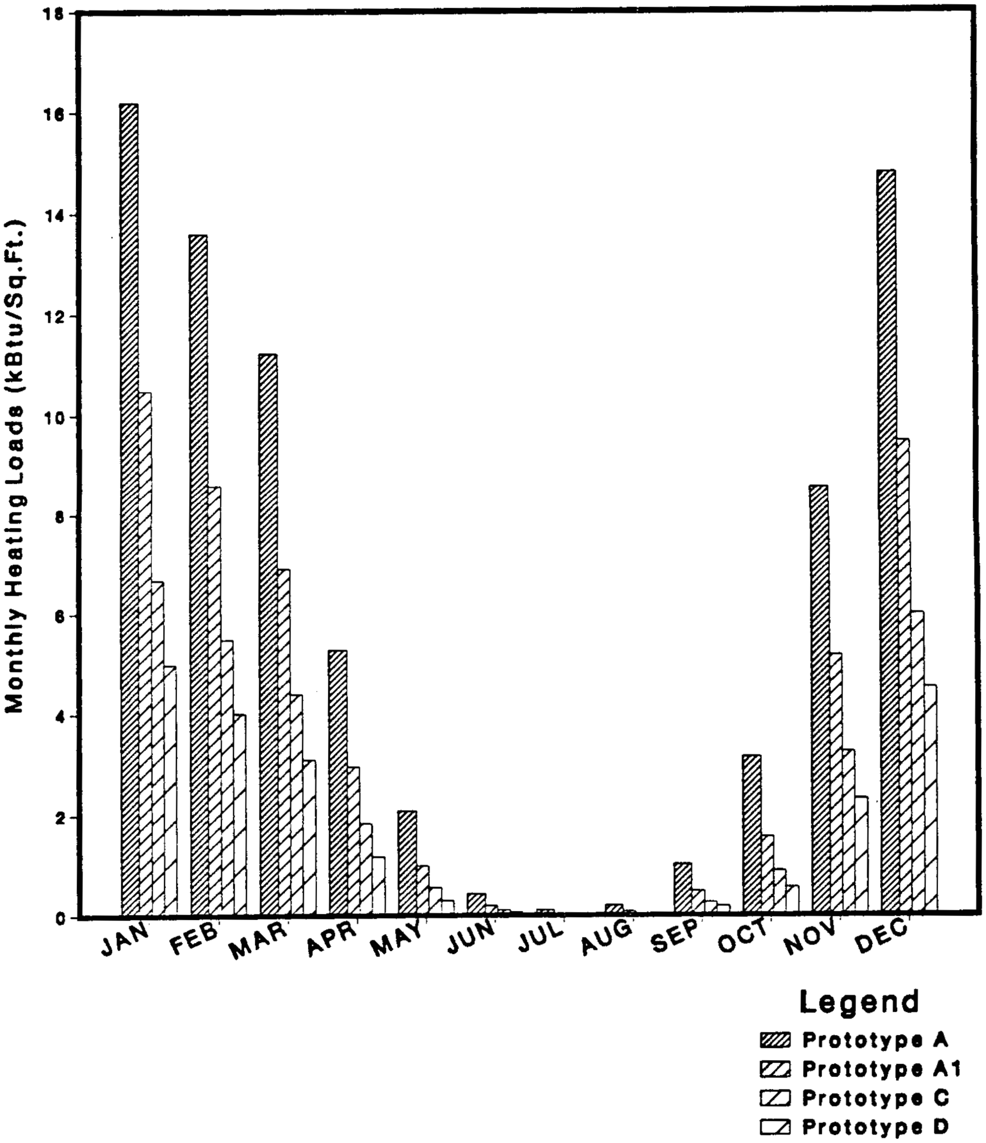
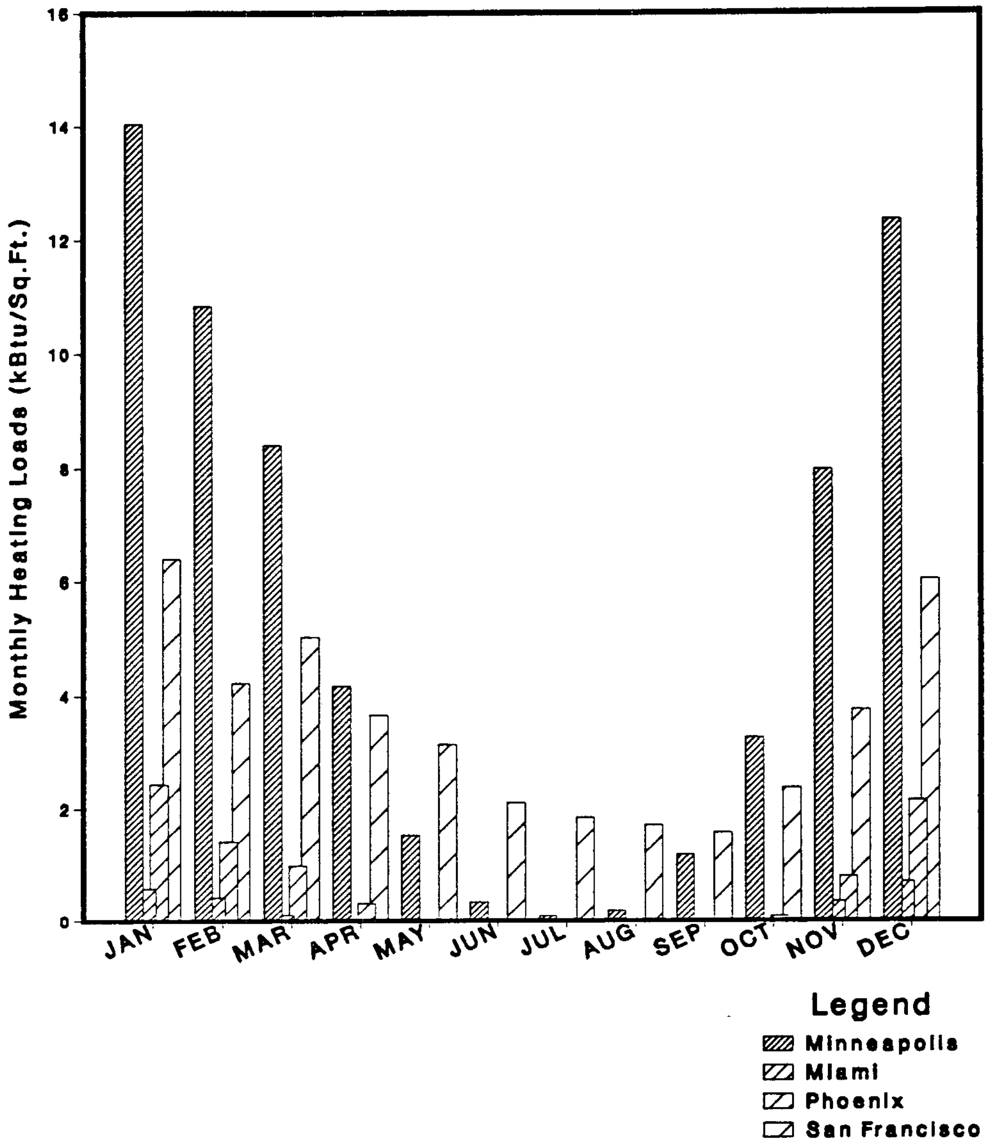


Figure 7. Heating Loads/Sq.Ft.
A1 Prototype Buildings in Four Cities



Although there was no variation in the annual water heating loads among the different prototypical houses at any locations because we assumed the same occupancy regarless of house size, there were considerable differences in the hot water use loads on a daily, weekly, and seasonal basis. A broader discussion of this topic is found in several cited references.[38,39]

In Figure 8 we present the domestic hot water loads, on a monthly basis, for four cities that illustrate the monthly and seasonal variation of these heating loads. This figure also shows the relationship of regional temperature differences and hot water loads. The full single-family data base will contain daily, weekly, and seasonal water heating load profiles in addition to the annual data presented in Table 11.

COOLING LOADS

The discussion of annual cooling loads generally follows the same pattern established for the heating loads data. We will first discuss the total annual space cooling loads and arrange the results in four categories: total annual loads, latent loads, peak loads, and load intensities (kBtu/ft^2). As part of the peak loads, we describe both the peak cooling loads and peak latent loads since this distinction is important to those who develop and use equipment that cools interior spaces and maintains thermal comfort. The space cooling loads represent the energy requirements for the central air-conditioning system within a house that is usually fueled by electricity. Unlike the space heating loads, estimates of space cooling do not involve any temperature setups to conserve energy. However, the most recent version of the DOE-2 simulation code allows for the use of natural ventilation through the opening and closing of windows depending on the outside temperature and humidity conditions except during the assumed occupants' sleeping period (11 p.m. to 7 a.m.). As with the heating loads, the resulting cooling loads are based on "average" conditions for a population of houses and they may deviate somewhat on individual house basis.

Space Cooling

Total Annual Loads

The B1+ house (i.e., larger 1950-70 house with energy upgrades) had the highest annual cooling loads. As shown in Table 11 and Figure 9, the highest total annual loads were found in Miami (70.9 MMBtu) and Phoenix (54.8 MMBtu). In all cases, the total annual cooling loads follow the severity of weather conditions such as cooling degree-days.

Figure 8. Domestic Hot Water Loads in Single Family Buildings for Four Cities

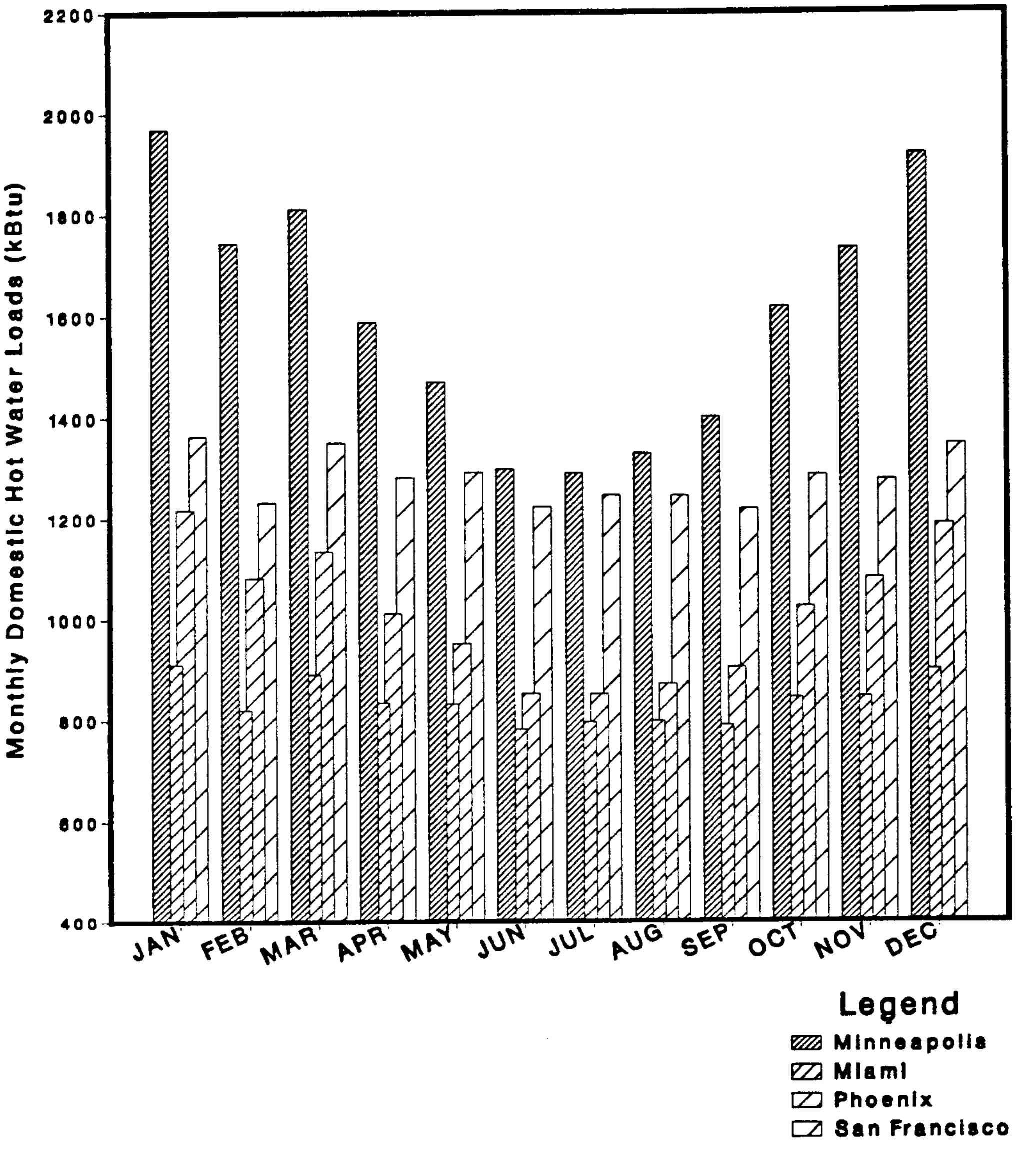
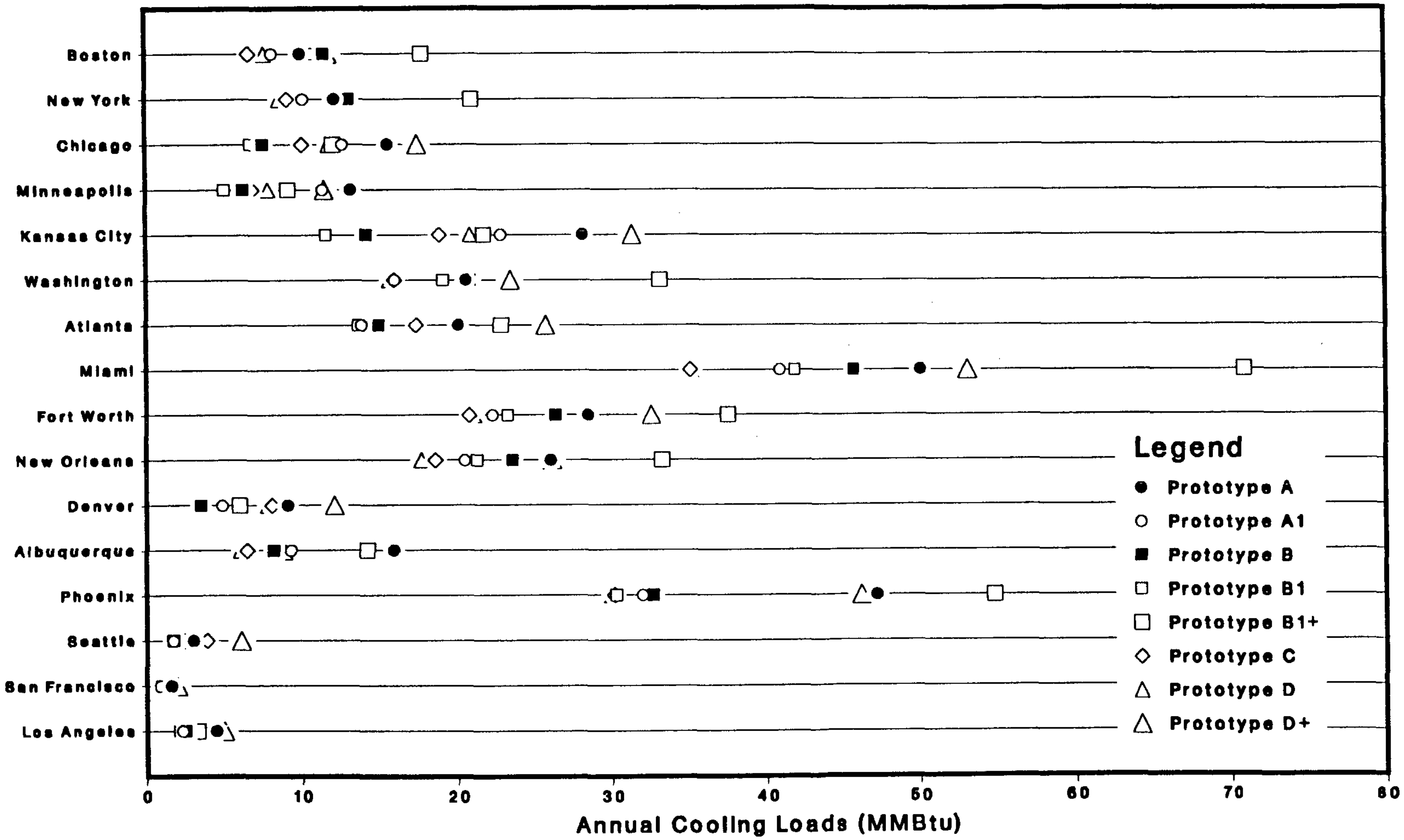


Figure 9. Annual Cooling Loads for Single Family Prototypes



The lowest cooling loads for these same "hot climates" are found in the C or D house. The difference between these two building types is 1% to 5% on an annual basis in all locations. As an example, the annual total cooling loads in the New Orleans D house were 17.7 MMBtu, and in the Fort Worth C house they were 20.8 MMBtu. In the more intermediate cooling climates the B1 house has the lowest annual cooling loads. For example, the B1 house required 4.7 MMBtu in Kansas City and 11.6 MMBtu in Atlanta. The cooling loads for a typical summer day in Chicago are shown in Figure 10. This figure shows the hourly profile over a 24-hour period for four prototypical houses. Note that cooling loads are greater for the D prototype than for the C prototype on this day. In addition, we also plotted the daily profile of outdoor temperatures for this summer day.

Annual Latent Cooling Loads

The highest latent cooling loads were found in Miami (see Table 11). The latent loads in Miami were highest in the larger houses (20.4 MMBtu for the B1+ house and 16.0 MMBtu for the D+ house). In comparison, the annual latent loads in other hot cities were significantly less. For example, the B1+ houses in New Orleans and Fort Worth each required greater than 9 MMBtu/yr and in Kansas City (D+ house) had 6.1 MMBtu/yr. In Figure 11, we show the hourly latent cooling loads (kBtu/hr) for a typical summer day in Chicago. This figure contains hourly data on two prototypical buildings as well as the outdoor temperature for this 24-hour period.

Peak Cooling Loads

Peak cooling loads are shown in Table 12 by location and by prototype. The highest peak cooling loads were found in the B1+ house, however, the D+ house also had sizable peak loads. The highest peak cooling loads were found in Phoenix. The B1+ house had peak loads of 49 kBtu/hr while the D+ house had peak cooling requirements of 48.1 kBtu/hr. Surprisingly, the larger prototypes in Los Angeles where the cooling demand is generally not significant also showed large peak loads (37.5 kBtu/hr and 45.3 kBtu/hr for the B1+ and D+ houses, respectively). The lowest requirements for peak cooling were found in either the C or D house (about 1% difference) or the B1 house. The B1+ also had the highest peak latent loads (see Table 12). In the case of peak latent loads, New Orleans (18.1 kBtu/hr) and Washington D.C. (16.3 kBtu/hr) had the highest peak loads. Peak latent loads in the B1+ house in Boston and Miami were also sizable (15.5 kBtu/hr and 13.1 kBtu/hr, respectively).

Figure 10. Cooling Loads on Typical Summer Day for Four Prototype Buildings in Chicago

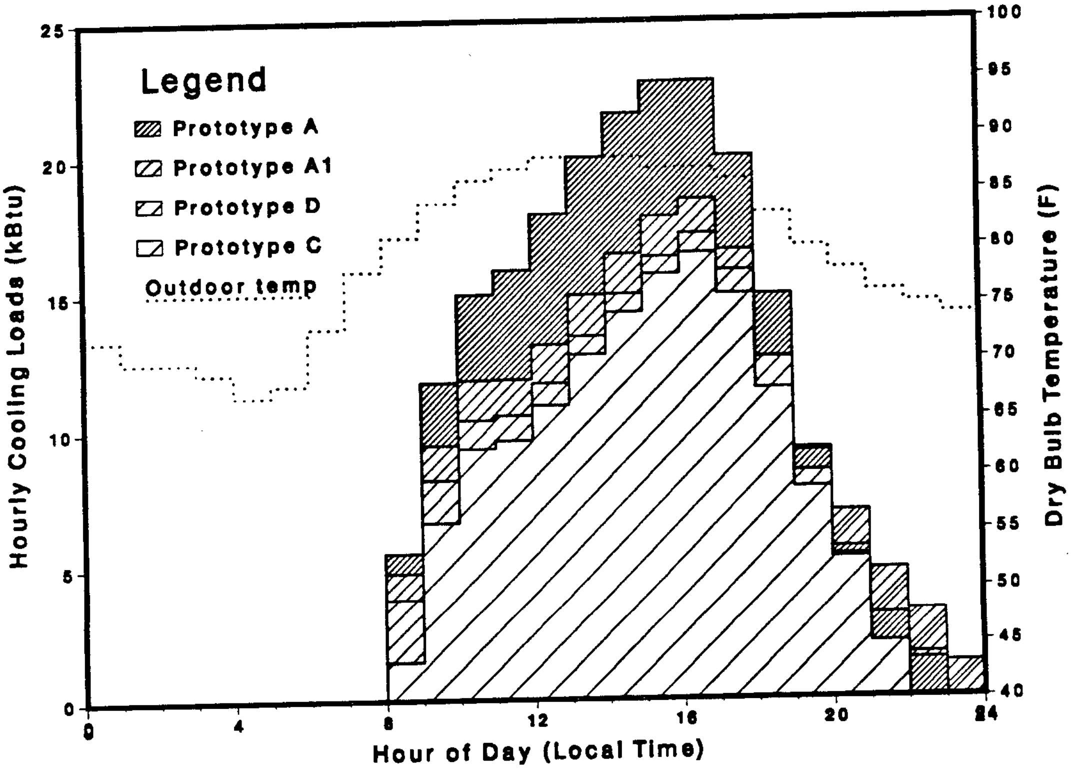
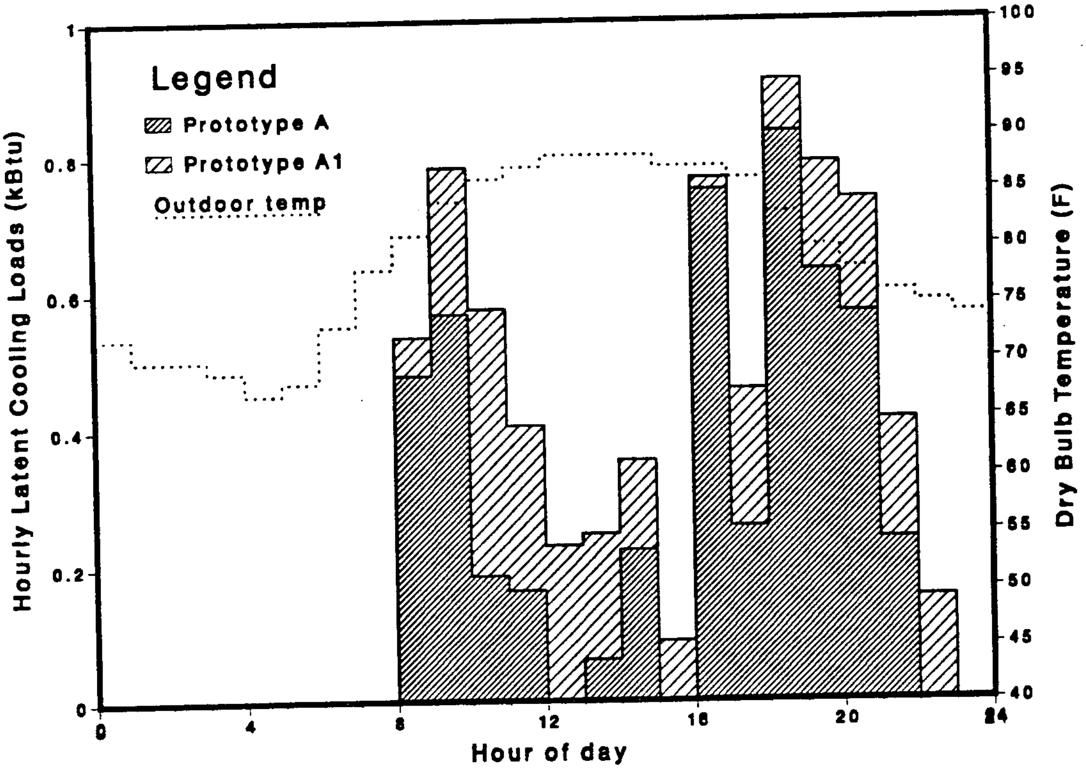


Figure 11. Latent Cooling Loads on Typical Summer Day for Two Prototype Buildings in Chicago



Cooling Load Intensities

Total cooling load intensities, as kBtu/ft^2, are shown in Table 13. The highest total cooling intensities were found in the pre-1940s house (A). The total cooling load intensities on a per square foot basis for the A house were 48.4 kBtu in Phoenix and 43.1 kBtu in Miami. The lowest intensities for these hot cities were all recorded in the D+ (larger 1990s) house.

As an example, total cooling load intensities in these houses were 8.2 kBtu in New Orleans and 10.2 kBtu in Fort Worth. Total cooling load intensities are shown for Chicago in Figure 12 where the 1990s house had higher demand (kBtu/ft^2) than the 1980s house. In Figure 13, the total cooling load intensities are shown on a monthly basis for the A1 house in four cities (Miami, Minneapolis, Phoenix, and San Francisco) that represent the major U.S. climates. This figure illustrates that there is some cooling load intensity during each month in Miami with the highest levels in the summer. On the other hand, intensities in Phoenix, which are the highest on an annual basis for the A1 house, are mostly found during the cooling months. Also, Figure 13 shows the small total cooling load intensities in the San Francisco climate.

Latent cooling load intensities as shown in Table 13 were highest in the humid climates: Miami, New Orleans, and Fort Worth. The high intensities were found in the Miami A house (11.0 kBtu/ft^2 and A1 house (10.8 kBtu/ft^2). High latent intensities were also found in the New Orleans A house (6.2 kBtu/ft^2). In Figure 14 we show the latent cooling load intensities in four single-family prototypes in Chicago. We also illustrate the latent cooling load intensities of the A1 house in the four major climates (see Fig. 15). As with the total cooling loads, the Miami intensities were found throughout the year with the highest values during the summer months. The major latent cooling intensities in Phoenix were shown to occur during the so-called "monsoon months" (July through September) with a peak in August.

For peak cooling load intensities, the pre-1940s house (A house) required the highest loads per square foot. Typical load intensities in the hotter climates were 36.8 kBtu/ft^2 in Phoenix, 26.5 kBtu/ft^2 in Fort Worth and, 26.3 kBtu/ft^2. The lowest peak cooling load intensities were in either the D or D+ house (average and larger 1990s prototype). The difference between these prototypes on a square foot basis was 4-5%. The lowest loads were found in Kansas City (9.6 kBtu/ft^2 and in Atlanta (8.6 kBtu/ft^2).

NON-HVAC LOADS

The non-space conditioning electric loads result from the type and saturation of appliances and lighting level, which is based on the house size. Therefore the highest non-HVAC electric loads, on an annual basis, were found in the largest houses (see Table 11). The highest annual loads were either in the B1+ (1950-70) or D+ (1990s) prototypes. For example, annual

Figure 12. Total Cooling Loads/Sq.Ft.
Four Prototype Single Family Buildings in Chicago

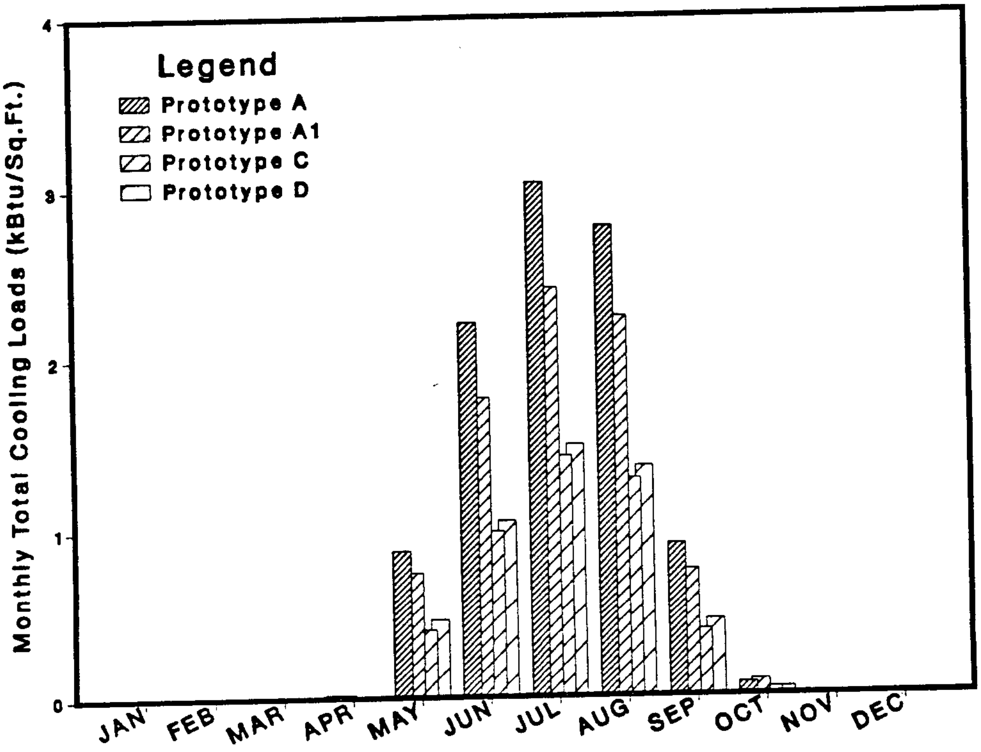


Figure 13. Total Cooling Loads/Sq.Ft.
A1 Prototype Buildings in Four Cities

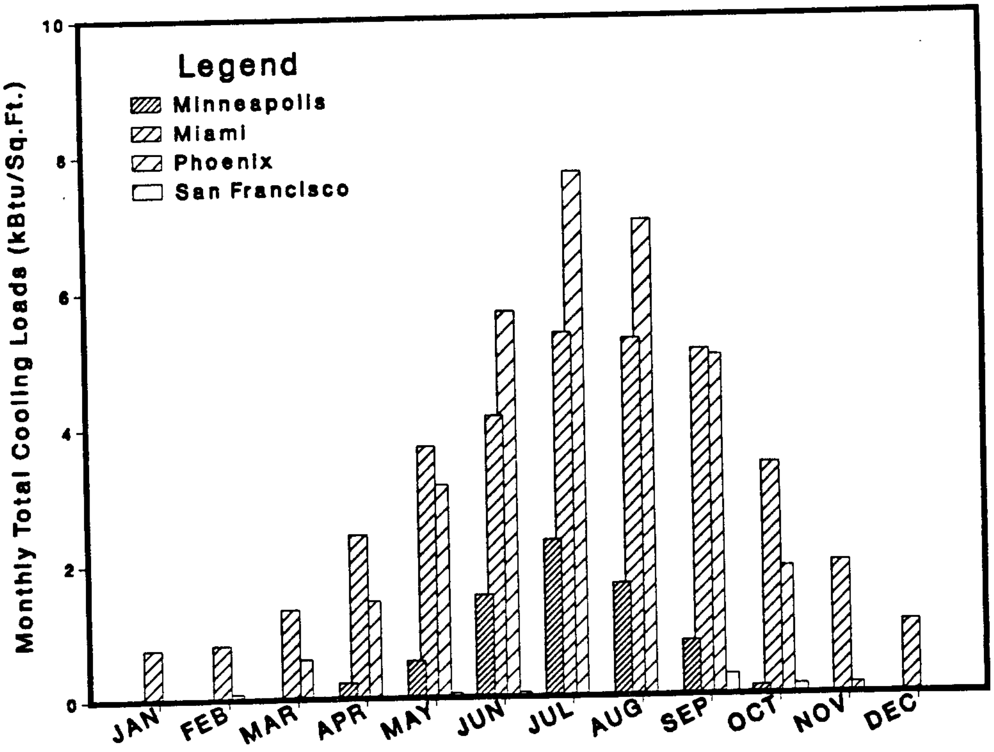


Figure 14. Latent Cooling Loads/Sq.Ft.
Four Prototype Single Family Buildings in Chicago

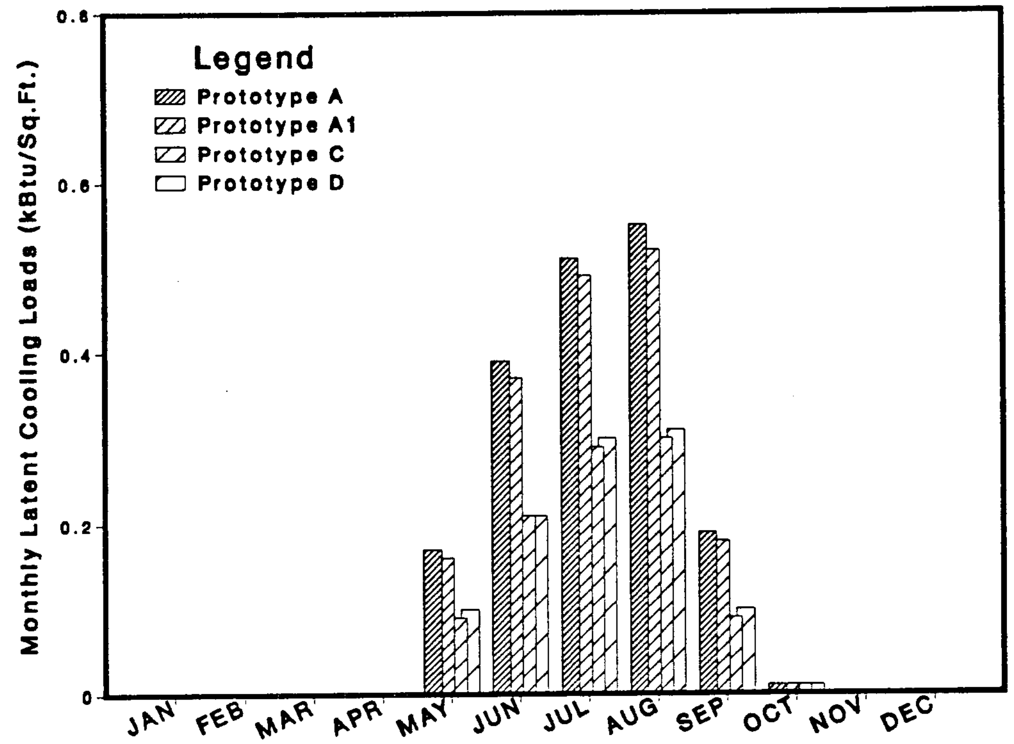
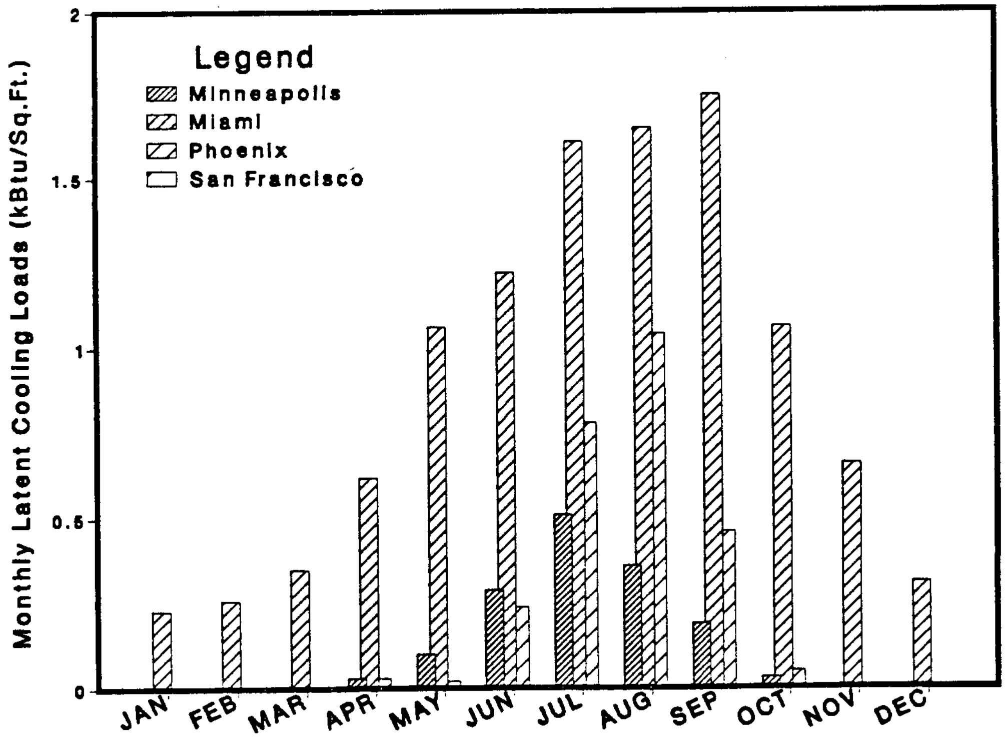


Figure 15. Latent Cooling Loads/Sq.Ft.
A1 Prototype Buildings in Four Cities



electricity loads in New York were 9507 kWh, Boston followed with 9207 kWh, and Chicago with 8641 kWh. In general, the non-HVAC electricity loads in the colder climates were greater than 8000 kWh per year.

The non-HVAC gas loads were only represented in the West South Central Census Division (i.e., Fort Worth and New Orleans) where natural gas was assumed as the major cooking fuel. The difference between the older houses (pre-1940s to 1980s prototypes) had an estimated annual gas load of 9.0 MMBtu, while the 1990s houses had annual loads that were reduced by about 46% (4.9 MMBtu/yr).

TOTAL ANNUAL SPACE CONDITIONING LOADS

To provide some estimate of the total annual loads, we calculated the total annual space conditioning loads on a square foot basis. Load intensities were used to remove the bias of house size. In all cases, the pre-1940s houses had the largest total loads. Since the loads were driven by space heating, the highest total annual loads were found in Minneapolis (107.7 MMBtu/ft^2), followed by the other cities with more than 5500 heating degree-days (at base 65°F), i.e., Denver (89.6 MMBtu/ft^2) and Chicago (86.6 MMBtu/ft^2). In the case of those cities with high cooling degree-days (greater than 1600), Kansas City had the highest total annual space conditioning loads (72.7 MMBtu/ft^2). Unlike the other hot climates, Kansas City also has an average of 4799 heating degree-days.

COMPARISON TO MEASURED AND SURVEYED DATA

This section provides a preliminary comparison between the single-family data base heating and cooling loads and surveyed and measured building energy use data. Since the loads data base will be used to assess new gas technologies, it is important to determine how well the calculated loads agree with actual building loads. A more thorough comparison was recently completed for the multifamily data base that showed good agreement with measured and surveyed data.[42]

The simulated loads are compared to energy use data from two sources. The first is surveyed energy data from the 1987 Residential Energy Consumption Survey (RECS) Public Use Data Tape.[9] The second source is measured energy use from the BECA-B compilation at LBL, which is a data base of retrofit energy savings in single-family buildings in the US.[42]

Several issues make the comparison between the simulated loads and measured energy use data a difficult task. First, measured and surveyed data are typically recorded as energy use, not building loads. Thus, measured data include the effects of equipment efficiency, and some estimation of the typical efficiency must be made before the data are comparable. Secondly, energy use data are often collected from utility bills or in some other aggregated form. Direct comparison of end uses such as heating, cooling, or hot water heating is impossible without making some further assumptions. Third, the use of alternative heating fuels such as wood heat and portable heaters may reduce the apparent space heat use by the primary heating fuel in many locations. Lastly, the simulated loads represent average buildings and average operating conditions. On the other hand, there is a great deal of variation in building characteristics and occupant behavior in real buildings which can not be simulated. The intent is that the building loads will be representative of average conditions for large samples of buildings.

To make the comparison easier and more robust, we first aggregated the simulated loads by census division and vintage. For each census division we developed three sets of loads; for pre-1940s (average of A and A1 prototypes, referred to here as A), 1950-1970 (average of B and B1 prototypes, referred to as B), and 1980 (C Prototype) vintage buildings. The aggregated loads, shown in Table 14, are calculated as weighted average values based on the building populations given in Appendix B. These aggregations allow the comparison to regional average or smaller samples of building energy use data.

RECS Survey Data

One of the most comprehensive sources of measured energy consumption data is the RECS data available from the Energy Information Administration. For this study, we analyzed the 1987 RECS data tape. The data contains a sample of 3799 single-family detached buildings, each of which is weighted so that 55.2 million buildings are represented by the sample. We sorted the sample of single-family buildings and energy use data in the RECS data base by census division and vintage to match the aggregated loads data. The sampled buildings were further categorized according to space and water heating fuel and system type (e.g., electric resistance vs. heat pumps) and by the presence of electric air-conditioning.

Because RECS contains only fuel use data, we used simple techniques to disaggregate the energy use values into broad end uses for the comparison. The data allowed us to separate the entire space and water heat sample into those with and without fuel cooking, and determine a fuel use value for cooking of 8.2 kBtu/ft^2. This value was subtracted from the fuel use for buildings with fuel cooking to derive combined energy use for space and water heating. We then removed those buildings with air-conditioning from this sample, and calculated median electric use for buildings with and without electric cooking. This calculation showed no significant difference in electricity use between buildings with and without electric cooking. However, the calculation showed a median value of 13.2 kBtu/ft^2 for non-HVAC electric consumption. We subtracted this value from electricity usage in all buildings so that electricity use represented only space heat, water heat, and cooling, where applicable.

By far the greatest proportion of the buildings in the RECS data use fuel for space and water heating. In fact, after sorting the sample buildings by census division and vintage and

Table 14. Aggregated Building Loads for Single-family Database Comparison

Census Division	Proto-Type	Floor Area (ft^2)	Population (1000s)	Heat (MMBtu)	Cool (MMBtu)	DHW (MMBtu)	non-HVAC Elec (MMBtu)	Heat (kBtu/ft^2)	Cool (kBtu/ft^2)	Heat+ DHW (MMBtu)	Heat+ DHW (kBtu/ft^2)
NEW ENGLAND	A	1440	235	107.8	10.0	17.8	21.3	74.9	6.9	125.6	87.2
	A1	1440	454	63.2	8.2	17.8	21.3	43.9	5.7	81.0	56.3
	Total	1440	689	78.4	8.8	17.8	21.3	54.5	6.1	96.2	66.8
	B	2220	93	113.1	11.5	17.8	24.0	50.9	5.2	130.9	59.0
	B1	2220	417	82.2	10.9	17.8	24.0	37.0	4.9	100.0	45.0
	Total	2220	510	87.8	11.0	17.8	24.0	39.6	5.0	105.6	47.6
	C	2090	279	60.1	6.7	17.8	23.5	28.8	3.2	77.9	37.3
MID-ATLANTIC	A	1400	527	90.0	12.2	16.6	22.1	64.3	8.7	106.6	76.2
	A1	1400	1050	56.3	10.2	16.6	22.1	40.2	7.3	72.9	52.1
	Total	1400	1577	67.6	10.9	16.6	22.1	48.3	7.8	84.2	60.1
	B	1960	184	92.4	13.1	16.6	24.0	47.1	6.7	109.0	55.6
	B1	1960	606	65.1	12.1	16.6	24.0	33.2	6.2	81.7	41.7
	Total	1960	790	71.5	12.3	16.6	24.0	36.5	6.3	88.1	44.9
	C	2090	436	43.4	9.2	16.6	24.5	20.8	4.4	60.0	28.7
EAST NORTH CENTRAL	A	1580	596	120.8	15.6	17.3	22.1	76.5	9.9	138.1	87.4
	A1	1580	1431	74.0	12.7	17.3	22.1	46.8	8.0	91.3	57.8
	Total	1580	2027	87.8	13.6	17.3	22.1	55.5	8.6	105.0	66.5
	B	1380	291	80.6	7.6	17.3	21.4	58.4	5.5	97.9	70.9
	B1	1380	1526	60.5	6.8	17.3	21.4	43.8	4.9	77.8	56.4
	Total	1380	1817	63.7	6.9	17.3	21.4	46.2	5.0	81.0	58.7
	C	2220	442	65.5	10.1	17.3	24.3	29.5	4.5	82.8	37.3
WEST NORTH CENTRAL	A	1580	203	121.4	20.7	17.6	22.3	76.8	13.1	139.0	87.9
	A1	1580	598	76.8	17.2	17.6	22.3	48.6	10.9	94.4	59.8
	Total	1580	801	88.1	18.0	17.6	22.3	55.8	11.4	105.7	66.9
	B	1100	186	71.9	10.3	17.6	20.6	65.4	9.3	89.5	81.4
	B1	1100	943	48.2	8.4	17.6	20.6	43.8	7.6	65.8	59.8
	Total	1100	1129	52.1	8.7	17.6	20.6	47.3	7.9	69.7	63.3
	C	2220	175	59.3	13.6	17.4	24.5	26.7	6.1	76.7	34.6
SOUTH ATLANTIC	A	1165	302	46.1	30.3	13.2	19.4	39.6	26.0	59.3	50.9
	A1	1165	379	28.6	23.6	13.2	19.4	24.5	20.3	41.8	35.9
	Total	1165	681	36.3	26.6	13.2	19.4	31.2	22.8	49.5	42.5
	B	1415	533	43.0	27.2	13.2	20.3	30.4	19.2	56.2	39.7
	B1	1415	847	31.4	24.9	13.2	20.3	22.2	17.6	44.6	31.5
	Total	1415	1380	35.9	25.8	13.2	20.3	25.4	18.2	49.1	34.7
	C	1910	1367	16.6	25.5	12.5	22.0	7.7	14.4	29.1	14.3
WEST SOUTH CENTRAL	A	1055	106	25.8	27.3	12.2	15.8	24.5	25.9	38.0	36.0
	A1	1055	46	13.9	21.4	12.2	15.8	13.2	20.3	26.1	24.7
	Total	1055	152	22.2	25.5	12.2	15.8	21.0	24.2	34.4	32.6
	B	1390	270	20.2	25.0	12.2	16.9	14.5	18.0	32.4	23.3
	B1	1390	454	12.9	22.3	12.2	16.9	9.3	16.0	25.1	18.0
	Total	1390	724	15.6	23.3	12.2	16.9	11.2	16.8	27.8	20.0
	C	1620	270	19.5	20.4	12.4	17.7	12.1	12.6	31.9	19.7
MOUNTAIN	A	975	60	50.2	24.1	14.9	19.6	51.5	24.7	65.1	66.8
	A1	975	129	25.0	15.4	14.9	19.6	25.7	15.8	40.0	41.0
	Total	975	189	33.0	18.2	14.9	19.6	33.9	18.6	47.9	49.2
	B	1080	81	31.3	14.8	14.9	19.9	29.0	13.7	46.3	42.8
	B1	1080	239	23.9	14.0	14.9	19.9	22.2	12.9	38.9	36.0
	Total	1080	320	25.8	14.2	14.9	19.9	23.9	13.1	40.7	37.7
	C	1816	292	20.5	19.1	14.7	22.4	10.6	11.2	35.2	18.6
PACIFIC	A	1400	395	85.6	3.0	15.5	21.1	61.1	2.2	101.1	72.2
	A1	1400	328	56.1	1.6	15.5	21.1	40.0	1.2	71.6	51.1
	Total	1400	723	72.2	2.4	15.5	21.1	51.6	1.7	87.7	62.6
	B	1390	779	68.2	1.7	15.5	21.1	49.1	1.2	83.7	60.2
	B1	1390	1498	50.4	1.5	15.5	21.1	36.3	1.1	65.9	47.4
	Total	1390	2277	56.5	1.6	15.5	21.1	40.6	1.1	72.0	51.8
	C	2070	388	25.2	2.6	15.3	23.4	12.2	1.2	40.4	19.5

then further by heating and DHW fuel, some categories had too few data points to be reliable and gave widely varying energy use values. Since the space heat and water heat category was well represented in all categories, the analysis focuses on those buildings. Air conditioning usage was also derived from buildings in this subsample which used electricity for space cooling. The results from these calculations are compared with the simulated loads in Table 15 and Figures 16 through 19.

Because the RECS data are reported as energy use, and not loads, we made assumptions about the range of efficiencies that is expected in residential fuel heating systems. We used similar combustion equipment efficiencies as in the multifamily data comparison study[5], except that the lower range was set at 60% rather than 55% to account for the absence of large central heating systems in single-family buildings. The range in annual coefficient of performance (COP) for the cooling end use was assumed to range from 1.8 to 2.2 based on simulated annual cooling system performance in the DOE-2 calculations using a steady-state air-conditioner COP of 2.7.

BECA Measured Data

The BECA-B data base contains measured data from a large number of retrofit projects across the U.S., including utility programs, research projects, and state and local loan programs. In almost all of the projects in the sample, space heating is the targeted end use. Space heat usage is either measured directly or it is derived from aggregate fuel use using regression or degree-day analysis. Pre- and post-retrofit energy and/or space heat use is recorded along with other building and project data.

We chose projects from the BECA sample that contained good quality energy data (based on the authors' rating), the presence of building floor area data, and a suitable number of buildings in the sample. We calculated energy use per unit area from the data as given in the report. Loads were calculated at efficiencies of 65% for fuel end uses and 3.413 kBtu/kWh for electric end uses, and are compared with the pre- and post-retrofit data with the aggregated building loads in Table 16 and Figures 20 and 21.

Comparison Results

While this comparison is a preliminary analysis, it allows us to make some broad observations about the simulated data. The first observation is that the simulated heating loads are within the range covered by the RECS energy use values for most prototypes and locations. However, the simulated loads for the A and B prototypes in the East North Central and West North Central census divisions differ by up to 20%. The comparison of the simulated loads with the BECA data for these locations is much better. The RECS data for these locations appears to be low, since these census divisions contain the coldest climates in the country. The simulated and RECS data for the C prototypes are more comparable.

Table 15. RECS Analysis Summary - Building Loads by Census Division and Prototype

Division/ Prototype	Simulated Loads Heat (kBtu/ft²)	Simulated Loads Cool (kBtu/ft²)	Simulated Loads Heat+ DHW (kBtu/ft²)	RECS Fuel Heat Sample Pop. n	RECS Fuel Heat Sample Wtd. Pop. (1000s)	RECS Fuel Heat Sample Heat+ DHW (kBtu/ft²)	RECS Fuel Heat Sample Efficiency 75% (kBtu/ft²)	RECS Fuel Heat Sample Efficiency 60% (kBtu/ft²)	RECS Fuel Heat w/Cooling Sample Pop. n	RECS Fuel Heat w/Cooling Sample Wtd. Pop. (1000s)	RECS Fuel Heat w/Cooling Sample Elec Cool (kBtu/ft²)	RECS Fuel Heat w/Cooling Sample COP 1.8 (kBtu/ft²)	RECS Fuel Heat w/Cooling Sample COP 2.2 (kBtu/ft²)
NeE A	54.5	6.1	66.8	49	408	106.0	79.5	63.6					
NeE B	39.6	5.0	47.6	64	596	65.1	48.8	39.1					
NeE C	28.8	3.2	37.3	5	70	38.0	28.5	22.8					
MdA A	48.3	7.8	60.1	91	1560	82.1	61.6	49.3					
MdA B	36.5	6.3	44.9	116	1911	75.0	56.3	45.0					
MdA C	20.8	4.4	28.7	13	291	49.9	37.4	29.9					
ENC A	55.5	8.6	66.5	153	2313	70.2	52.7	42.1	27	481	2.1	3.8	4.6
ENC B	46.2	5.0	58.7	99	1969	69.4	52.1	41.6	35	745	2.4	4.3	5.3
ENC C	29.5	4.5	37.3	18	299	60.4	45.3	36.2					
WNC A	55.8	11.4	66.9	134	1177	70.8	53.1	42.5	39	368	3.9	7.0	8.6
WNC B	47.3	7.9	63.3	116	1006	57.4	43.1	34.4	77	692	4.1	7.4	9.0
WNC C	26.7	6.1	34.6	20	224	40.5	30.4	24.3	16	185	6.5	11.7	14.3
SoA A	31.2	22.8	42.5	44	701	61.3	46.0	36.8					
SoA B	25.4	18.2	34.7	68	1423	55.5	41.6	33.3	42	922	6.3	11.3	13.9
SoA C	7.7	14.4	14.3	5	123	49.5	37.1	29.7					
ESC A				50	361	100.9	75.7	60.5					
ESC B				52	590	60.2	45.2	36.1	32	406	11.0	19.8	24.2
ESC C				5	71	48.5	36.4	29.1					
WSC A	21.0	24.2	32.6	43	553	61.1	45.8	36.7					
WSC B	11.2	16.8	20.0	138	2698	54.9	41.2	32.9	58	1371	13.6	24.5	29.9
WSC C	12.1	12.6	19.7	12	261	29.8	22.4	17.9					
Mtn A	33.9	18.6	49.2	49	436	84.6	63.5	50.8					
Mtn B	23.9	13.1	37.7	88	796	60.2	45.2	36.1	24	220	7.4	13.3	16.3
Mtn C	10.6	11.2	18.6	19	202	36.9	27.7	22.1					
Pac A	51.6	1.7	62.6	60	905	41.2	30.9	24.7					
Pac B	40.6	1.1	51.8	127	2036	44.6	33.5	26.8	29	470	3.2	5.8	7.0
Pac C	12.2	1.2	19.5	24	405	38.3	28.7	23.0	11	205	1.1	2.0	2.4

Table 16. BECA-B Results Summary - Building Loads by Census Division and Prototype

Division/ Prototype	BECA Code	Loc.	Pop. n	Avg. Area (ft²)	Retro fits	Fuel End uses	Fuel End Use Pre (MMBtu/ kWh)	Fuel End Use Post (MMBtu/ kWh)	Space Heat Pre (MMBtu/ kWh)	Space Heat Post (MMBtu/ kWh)	Fuel Use/ft² Pre (kBtu/ kWh)	Fuel Use/ft² Post (kBtu/ kWh)	Space Heat/ft² Pre (kBtu/ kWh)	Space Heat/ft² Post (kBtu/ kWh)
MdA A	G025	NJ	18	1372	HD	all gas	161.3	140.0	117.8	89.6	117.8	102.2	86.0	65.3
									eff.	65%	76.6	66.4	55.9	42.5
MdA B	G005/	NY/	120	1655	HD	all gas	141	119	92.4	72.8	90.2	77.0	58.9	47.6
	G026	NJ							eff.	65%	58.6	50.0	38.3	30.9
ENC A	G055	MI	57	1231	furn	sp ht			118.0	105.5			98.4	87.5
									eff.	65%			64.0	56.9
ENC B	G055	MI	24	1137	furn	sp ht			117.4	119.3			103.3	105.0
									eff.	65%			67.1	68.2
WNCA	G052	MN	21	1210	frepl/	all gas	154.0	134.4			127.2	111.0		
					wins				eff.	65%	82.7	72.1		
Mtn B	G029	CO	24	2488		all gas	127.1	100.9	95.9	71.0	51.1	40.6	38.5	28.5
									eff.	65%	33.2	26.4	25.1	18.5
PaN A	O26	OR	92	1144	burnr	sp ht			89.7	68			78.4	59.4
									eff.	65%			51.0	38.6
PaN B	E011/	NW	940	1650	audit	all elec	26345	22778	13295	9801	16.0	13.8	8.1	5.9
	E030								eff.	3.413	54.5	47.2	27.5	20.3
PaS B	G027	CA	19	2322	audit	all gas			130.2	114.5			56.2	49.4
									eff.	65%			36.5	32.1

Figure 16. Fuel Space and Water Heat
Prototype A,A1 Comparison with RECS Data

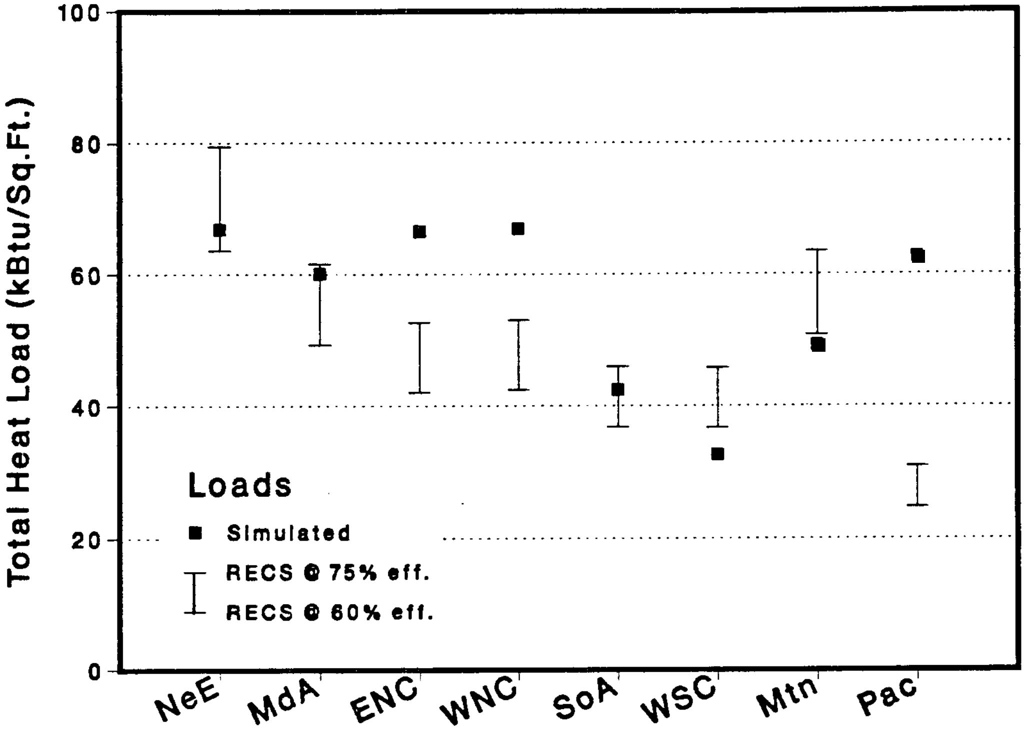
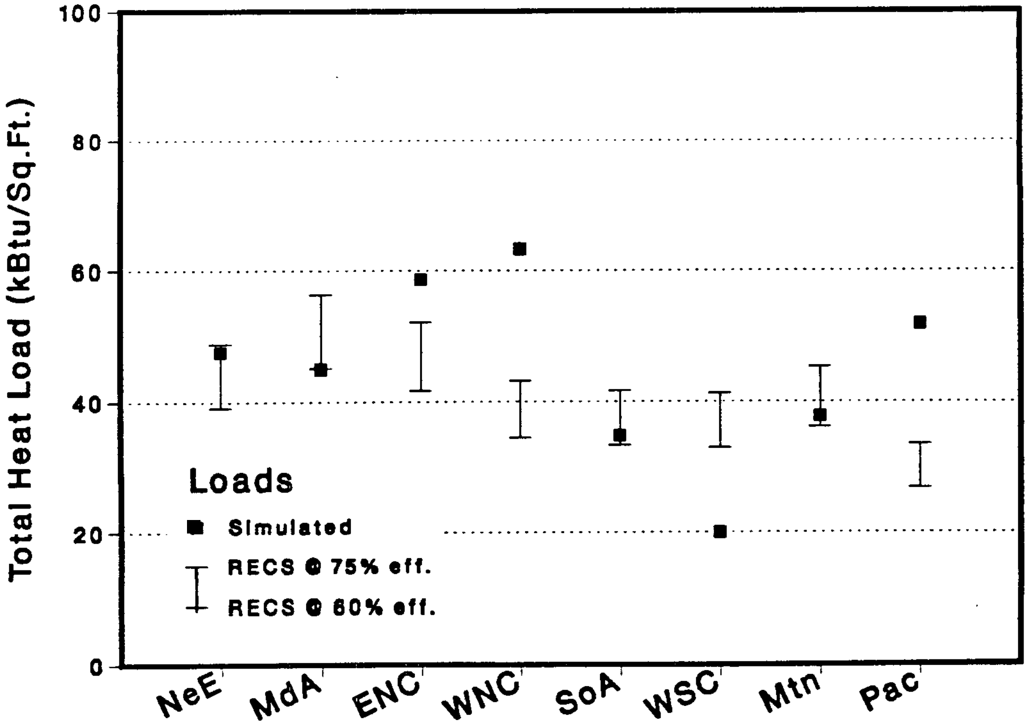


Figure 17. Fuel Space and Water Heat
Prototype B,B1 Comparison with RECS Data



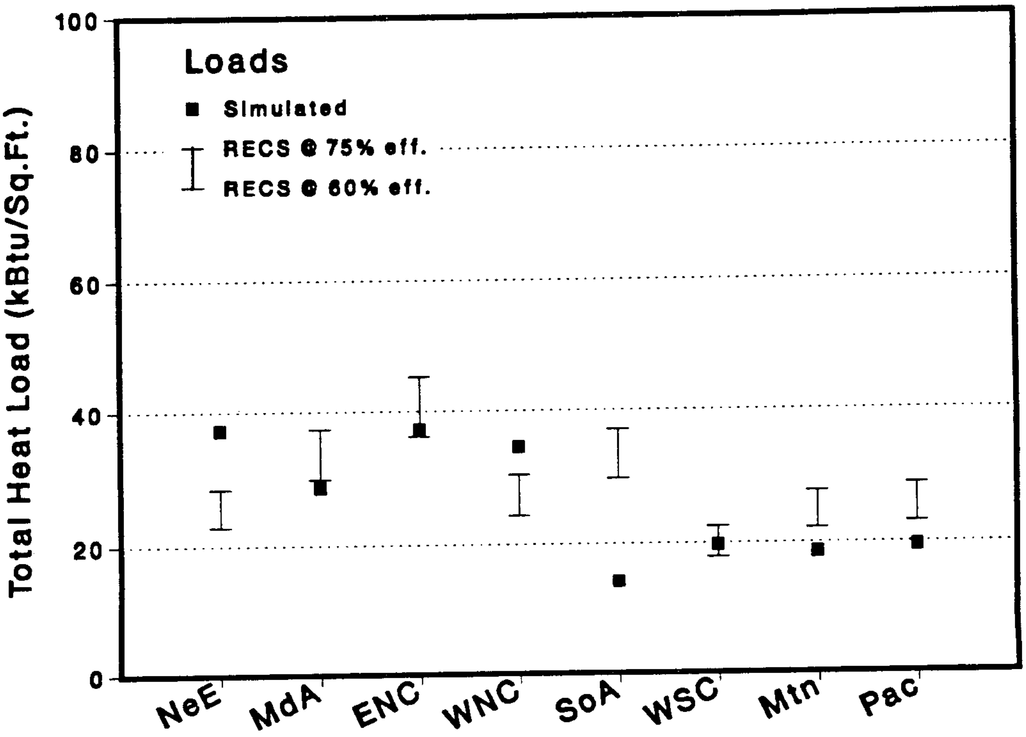


Figure 18. Fuel Space and Water Heat Prototype C Comparison with RECS Data

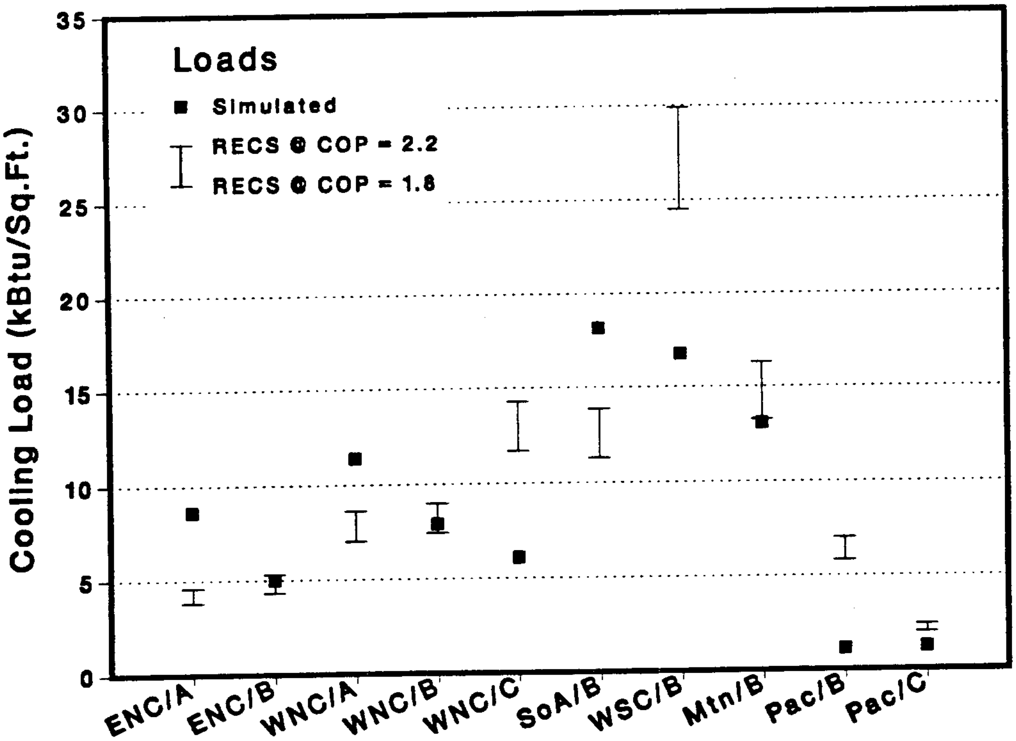


Figure 19. Electric Space Cooling Various Prototypes, Comparison with RECS Data

The second issue is that compared to the RECS data, the simulated loads slightly underestimate heating loads in the West South Central census divisions for the A and B prototypes. Once again, the RECS data give counter-intuitive results for these locations, since these locations are some of the warmest in the U.S. yet the RECS loads are similar to other climates.

A third issue is that heating loads for the Pacific census division are somewhat higher for the A and B prototypes compared to both the RECS and, to a lesser extent, the BECA data. The agreement with RECS data for the C prototype, however, is quite good. This disagreement is partly due to the RECS data, which shows extremely low use for the A prototypes. It is also difficult to compare building loads from the wide variety of climates in the Pacific census division. For example, the RECS fuel heating loads may be dominated by buildings in the Los Angeles climate, while the comparison includes both San Francisco and Los Angeles in the southern part of the region. Furthermore, in these locations the moderate climates produce mild, yet long heating seasons (see San Francisco in Figure 7 for example). Increased thermal integrity quickly reduces the annual heating load, which may explain why the prototype C loads are more comparable to the RECS data.

The comparison of cooling loads with the RECS data is difficult to assess, yet it is apparent that the DOE-2 simulated loads are not consistently high or low. The small number of cooling data points in the RECS data made this comparison difficult. We made no distinction between central air-conditioning or room air-conditioning (which may cool only a portion of the building) in the RECS data, while in the simulations we modeled full house cooling loads. This may account for some of the differences.

Based on this preliminary comparison the simulated loads appear to give reasonable estimates of heating, and to a lesser extent cooling, loads in the range of single-family buildings and climate types in the U.S. In a previous comparison of simulated and surveyed loads in multifamily buildings, it was noted that the typical customers surveyed were from the northern, colder climates.[5] Therefore, we would expect the greatest difference in these comparisons to occur in the southern locations. Finally, we contend that the comparison was adequate and that the building load data are reasonable and useful for future assessments of different equipment options.

Figure 20. Space and Water Heat Various Prototypes, Comparison with BECA Data

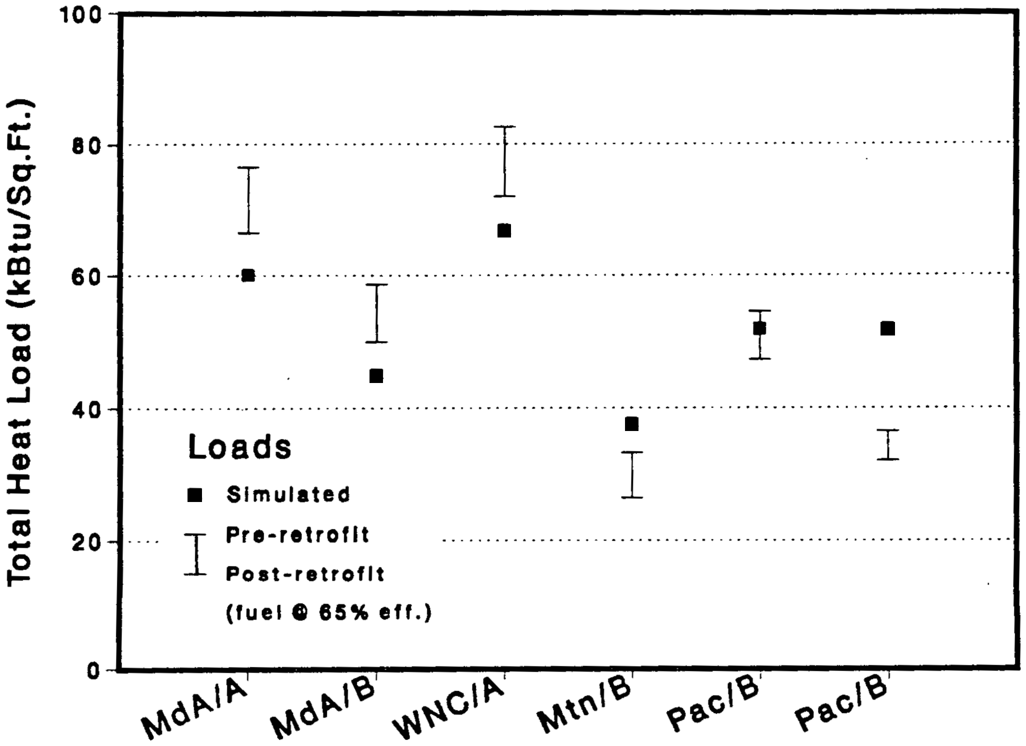
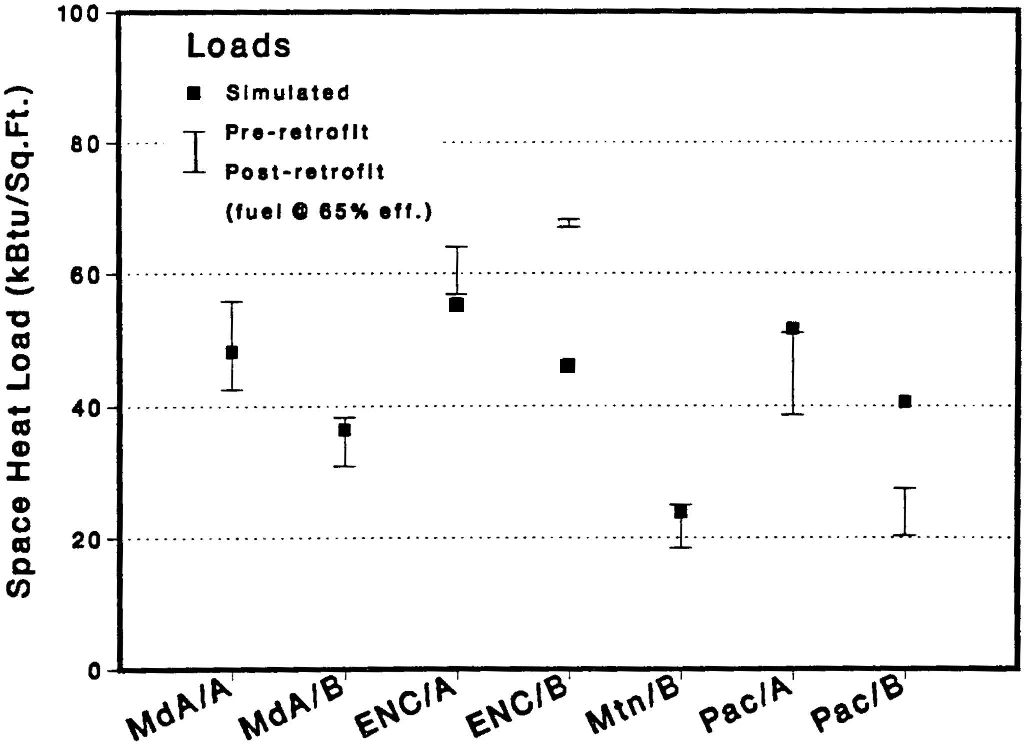


Figure 21. Space Heat Only Various Prototypes, Comparison with BECA Data



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INPUT DEVELOPMENT AND SENSITIVITIES

APPENDIX A: SAMPLE REPRESENTATION OF PROTOTYPES

The table which follows gives the distribution of single-family detached building stock by vintage and census division, and the portions of that stock which are represented by the prototype buildings in the single-family database. Because of the large number of prototypes (55) and the even larger number of prototype/climate combinations (80), the numbers have been consolidated to the level of census division. These numbers are updated versions of the figures in the previous single-family database report based on 1) updated B1+ and C prototype descriptions, 2) the new distribution of base cities, 3) new estimates of building populations from more current data sources, and 4) a slightly different method of determining representativeness.

The stock populations for pre-1980s buildings in each census division were derived from the 1984 RECS database. Stock populations for 1980s buildings were derived from Census Bureau data for the period 1980-1989, which contain single-family detached building construction by census region. This stock was broken down to census division level using data from NAHB which report single family housing *starts* by *state*.

The method used to determine the level of representation for each of the prototypes was to follow the same method used in determining prototype characteristics. However, the level of detail in the prototype buildings represents a combination of building characteristics which would be found in few actual buildings. Therefore, in determining representation we used major building characteristics which would be important in creating unique building energy use profiles. Thus, the calculation is somewhat arbitrary, since if more building characteristics are used to evaluate the representation of the sample by the prototype, the less "representative" the prototype becomes.

The primary data sources, both the 1984 RECS for the pre-1980s prototypes and the 1987 NAHB Builders Survey for the 1980s prototypes, were cross-referenced to five major criteria which directly affect building construction and thus building energy use: 1) building vintage, 2) census division, 3) construction type (one story, two story, or other), 4) ceiling insulation, and 5) window glazing layers. Ceiling insulation and window layers were considered to be proxies for overall building thermal integrity. Within each vintage and census division, the data provided factors for percentage of buildings with similar characteristics to the prototype descriptions. These factors were then applied to the stock populations to determine the number represented by each prototype.

For the B1+ prototypes, size was assumed to be the determining factor, so the B1+ prototype distributions are based only on vintage, census division, construction type, and the number of buildings with conditioned square footage equal to or greater than the prototype square footage (defined as the mean plus two standard deviations).

Overall, the level of representation is similar to the numbers provided in the previous report. Thirty-five percent of the total housing stock is represented by the prototype descriptions. The range within census divisions is from over 50% in New England and South Pacific to about 20% in the West South Central and North Pacific. The lower numbers reflect a greater variability in building characteristics and thus a less immediately characterizable population. In terms of prototypes, the C prototypes represent almost 40% of the 1980s building population, while 45% and 51% of the pre-1940 and 1950-1969 populations are represented, respectively.

ESTIMATES OF SINGLE FAMILY DETACHED HOUSE POPULATION (THOUSANDS)

	NEW ENGLAND	MID ATLANTIC	E NORTH CENTRAL	W NORTH CENTRAL	SOUTH ATLANTIC	E SOUTH CENTRAL	W SOUTH CENTRAL	MOUNTAIN	NORTH PACIFIC	SOUTH PACIFIC	TOTAL VINTAGE
BEFORE 1940	**988**	**2549**	**4296**	**1706**	**2124**	**942**	**1470**	**498**	**621**	**792**	**15986**
Prototype A	235	527	596	203	302	186	106	60	47	348	2610
Prototype A1	454	1050	1431	598	379	173	46	129	101	227	4588
1940 to 1949	**157**	**438**	**980**	**317**	**1210**	**293**	**738**	**219**	**248**	**502**	**5102**
1950 to 1969	**965**	**2255**	**2279**	**1377**	**4188**	**1634**	**2706**	**1097**	**845**	**2394**	**19740**
Prototype B	93	184	291	186	533	228	270	81	57	722	2645
Prototype B1	417	606	1526	943	847	173	454	239	197	1301	6703
Prototype B1+	16	46	26	120	111	78	137	99	39	111	783
1970 to 1979	**315**	**1090**	**1507**	**908**	**2055**	**1090**	**1256**	**793**	**496**	**423**	**9933**
1980 to 1989	**486**	**846**	**1006**	**598**	**2715**	**487**	**1347**	**746**	**269**	**1193**	**9693**
Prototype C	279	436	442	175	1367	196	270	292	92	296	3845
TOTAL STOCK	**2911**	**7178**	**10068**	**4906**	**12292**	**4446**	**7517**	**3353**	**2479**	**5304**	**60454**
Total Prototypes	1494	2849	4312	2225	3539	1034	1283	900	533	3005	21174

Note: Pacific Division has been split into two divisions to account for varied climates.
No cities in the East South Central Division were included in the simulation climates.
ESC prototypes and climates are represented by West South Central and South Atlantic prototypes and climates.

APPENDIX B: BUILDING SIZE ANALYSIS FOR 1980s/1990s HOUSE

We analyzed several data sources in developing building size estimates for 1980s construction and one data set projecting average size into the 1990s. Based on an analysis of these data, our conclusions were to derive average 1980 building size using weighted average floor areas from Census Bureau reports combined with 1987 NAHB builder survey data on construction type in the base cities. Furthermore, we concluded that the 1980 prototype house size should be increased by about 200 square feet to make the 1990 prototype. The analysis is summarized below.

1980s BUILDING SIZE DATA

We gathered average square footage estimates for new single family construction between 1980 and 1989 from U.S Census Bureau reports, the National Association of Home Builders (NAHB), and the F.W. Dodge Corporation. The types of data are summarized as follows.

Census Bureau Reports. The Census reports give mean and median square foot data for new construction by census region and for the U.S. as a whole. They also tabulate construction type; one story, two story, and split-level. These data are shown in Table 1.

NAHB data. Average square footage data for new construction, 1979-1988, on both state and national level were provided to GRI by the NAHB. These data are shown in Table 2. We also compiled floor area data from the NAHB 1987 Builders Survey. The predominant construction type and average square footage for that construction type are shown in Table 3 for each GRI base city. Where the average square footage given in the Builders Survey seemed unreasonable compared with the other cities, we combined square footage data from neighboring states to develop a better estimate.

DODGE data. We also obtained estimates of average new single-family construction square footage, 1971-1990, from the F.W. Dodge Corporation. These data were provided as national averages and by census division, and are given in Table 4.

Discussion

Figure 1, in the main body of the report, presents the various estimates for average floor area through the 1980s, including Census Bureau, Dodge, and NAHB data. While the magnitudes differ, the plot shows that on a national level, floor area is constant from 1980-85, and then rises at rates between 35 and 70 square feet per year. Tables 1, 2, and 4 show that this general trend has been true in all areas of the country.

Table 1. Average Floor Area and Construction Type, 1980-89
US Bureau of Census, New Single Family Construction

		Avg. Area (ft^2)		Number	Construction Type (%)		
	Year	Mean	Median	(1000s)	1Story	2+Story	Split
All US	1980	1740	1595	957	60	31	9
	1981	1720	1550	819	61	32	7
	1982	1710	1520	632	61	33	6
	1983	1725	1565	924	58	36	6
	1984	1780	1605	1025	54	40	6
	1985	1785	1605	1072	52	42	6
	1986	1825	1660	1120	51	44	5
	1987	1905	1755	1123	49	46	5
	1988	1995	1810	1085	45	49	6
	1989	2035	1850	1026	46	49	5
North East	1980	1770	1660	100	33	58	9
	1981	1805	1655	87	30	62	8
	1982	1755	1605	79	35	56	9
	1983	1795	1650	106	28	64	8
	1984	1860	1665	129	27	66	7
	1985	1830	1655	168	25	70	5
	1986	1850	1695	193	26	69	5
	1987	1955	1840	125	25	70	5
	1988	2005	1810	186	21	76	3
	1989	2075	1870	159	19	77	4
North Central	1980	1685	1520	170	53	30	17
	1981	1670	1480	140	50	32	19
	1982	1655	1405	92	51	35	14
	1983	1735	1515	142	50	36	14
	1984	1800	1600	156	47	40	13
	1985	1820	1625	151	47	39	14
	1986	1855	1685	170	47	40	13
	1987	1890	1740	201	46	42	12
	1988	2015	1840	191	43	46	11
	1989	1970	1800	191	44	45	11
South	1980	1750	1615	455	69	27	4
	1981	1715	1540	408	72	25	3
	1982	1700	1500	340	70	27	3
	1983	1720	1565	476	65	32	3
	1984	1750	1590	508	62	36	2
	1985	1765	1590	514	60	37	3
	1986	1825	1655	505	60	37	3
	1987	1915	1755	467	59	39	2
	1988	1985	1790	457	57	41	2
	1989	2030	1815	420	57	41	2
West	1980	1735	1570	233	60	29	11
	1981	1735	1580	183	59	32	9
	1982	1740	1595	121	60	31	9
	1983	1695	1545	200	61	31	8
	1984	1785	1610	233	57	36	7
	1985	1770	1595	239	55	37	8
	1986	1800	1635	253	53	40	7
	1987	1870	1730	259	52	43	5
	1988	1995	1845	245	48	47	5
	1989	2065	1910	257	46	50	4

Source: U. S. Department of Commerce, Bureau of the Census, 1980-1989. Characteristics of New Housing: 1980-1989. Current Construction Reports, Series C25.

Table 2. Average Floor Area by State, 1979-1988
NAHB, New Single Family Detached Construction

STATE	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
CT	1990	2082	2246	2395	2123	2259	2340	2356	2634	2554
ME	1273	1241	1256	1413	1465	1170	1596	1730	2336	2444
MA	1754	1802	1839	1971	1912	1845	1926	2151	2513	2428
NH	1620	1583	1678	1771	1493	1433	1728	1712	1775	2043
RI	1815	1763	1689	1929	1950	1913	1350	2090	1830	2066
VT	1513	1551	1690	1602	1527	1915	2027	1983	1982	2224
NJ	1883	2012	2106	2131	1662	1936	1745	1851	2205	2462
NY	2019	1907	1983	2041	1730	1743	2096	2058	2459	2184
PA	1936	1748	1578	1575	1583	1381	1962	1929	2321	1994
IL	1910	1861	1928	1861	1794	1968	2331	1952	2079	2110
IN	1808	1546	1599	1668	1771	1551	1606	1588	2003	2066
MI	1749	1839	1749	1852	1707	1708	1642	1596	1682	2008
OH	1816	1879	1887	1595	1890	1955	2101	2083	2217	2246
WI	1587	1451	1527	1439	1451	1578	1446	1778	1739	1927
IA	1572	1618	1586	1368	1443	1748	1615	1750	2000	2116
KS	1989	1910	1763	1893	1756	1604	1860	1904	1923	2261
MN	1611	1718	1742	1725	1398	1521	1834	1765	1859	2574
MO	1697	1662	1606	1670	1827	1906	1750	1724	2010	2091
NB	1432	6283	1689	1798	1648	1504	1615	1889	1789	1728
ND	1904	1693	1280	1133	1172	1400	1650	1700	1850	1796
SD	1250	1250	1255	2043	1728	1321	1371	1450	1600	1603
DE	1592	1673	1634	1811	2563	1554	1549	1700	1734	1951
FL	1573	1491	1525	1465	1432	1501	1455	1684	1855	1705
GA	1913	1730	1681	1723	1641	1600	1726	1877	2294	1968
MD	2077	2028	2013	1823	1777	2047	2107	2209	2274	2078
NC	1646	1564	1544	1573	1605	1703	1692	1778	2010	1812
SC	1693	1586	1599	1724	1426	1409	1423	1580	1782	1926
VA	1805	1876	1939	1845	1780	1969	1915	2225	2010	2400
WV	1411	1838	1679	1162	1441	1940	1870	1267	1377	1612
AL	1552	1562	1431	1487	1546	1744	1681	1660	2109	1779
KY	1659	1719	1649	1461	1488	1592	1454	1637	1767	2096
MS	1435	1488	1334	1636	1638	1700	1339	1875	1775	1394
TN	1548	1526	1671	1728	1790	1869	1963	1697	1877	2172
AR	1419	1471	1517	1547	1400	1830	1398	1446	1879	1487
LA	1791	1668	1662	1545	1611	1666	1837	1806	1890	2260
OK	1657	1644	1586	1716	1477	1567	1707	1800	1837	2098
TX	1692	1716	1608	1694	1622	1665	1675	1686	2215	2175
AZ	1547	1515	1583	1594	1549	1554	1637	1798	1648	1952
CO	1704	1785	1581	1410	1486	1766	1713	1786	1746	2100
ID	1602	1557	1562	1519	1453	1636	1731	1800	1820	2102
MT	1356	1289	1253	1248	1728	1577	1522	1883	1700	2738
NV	1516	1676	1541	1731	1662	1601	1534	1726	1692	1738
NM	1645	1437	1371	1662	1268	1377	1594	1487	1642	1865
UT	1467	1465	1519	1607	1522	1187	1665	1815	1695	1804
WY	1710	1600	1651	1542	1466	1498	1694	1501	1480	1377
CA	1856	1956	1887	1738	1737	1684	1690	1801	1935	2166
OR	1642	1548	1587	1505	1495	1515	1612	1614	1854	2049
WA	1712	1815	1728	1461	1754	1646	1633	1472	1832	1988
US	1714	1700	1702	1679	1635	1684	1752	1837	2019	2065

Source: Unpublished data. National Association of Home Builders, personal communication with Ken Kazmer, Gas Research Institute, Sept. 21, 1990.

Table 3. Predominant Construction Type and Average Floor Area for Base Cities Calculated from NAHB Builder Survey Data, 1987

City	State	Number Stories	Area (ft^2)	City	State	Number Stories	Area (ft^2)
Boston	MA	2	2450	New Orleans	LA	1	1690
New York	NY	2	2450	Fort Worth	TX	1	1790
Chicago	IL	2	2230	Denver	CO	2	2030
Minneapolis	MN	2	2220	Albuquerque	NM	1	1590
Kansas City	MO	2	2290	Phoenix	AZ	1	1590
Washington	DC	2	2300	Seattle	WA	2	2120
Atlanta	GA	2	2400	San Francisco	CA	2	2020
Miami	FL	1	1790	Los Angeles	CA	2	2020

Source: Calculated from NAHB National Research Center, 1989. 1987 Builder Practices Survey Data, prepared for Lawrence Berkeley Laboratory, P.O. No. 4556710, March 1, 1989.

Table 4. Average Floor Area by Census Division, 1980-1989 F.W. Dodge Corporation Data, New Single Family Construction

Year	US	NENG	MATL	ENC	WNC	SATL	ESC	WSC	PNW	PSW
1980	1587	1538	1522	1559	1537	1596	1487	1678	1493	1641
1981	1600	1552	1525	1560	1534	1604	1534	1605	1535	1730
1982	1564	1546	1539	1554	1556	1559	1517	1596	1496	1596
1983	1576	1559	1552	1570	1565	1570	1531	1596	1573	1604
1984	1577	1561	1563	1563	1535	1575	1560	1618	1533	1592
1985	1565	1590	1558	1571	1519	1572	1542	1569	1559	1569
1986	1600	1635	1610	1559	1561	1620	1605	1570	1595	1584
1987	1659	1665	1677	1656	1633	1669	1649	1604	1618	1675
1988	1686	1681	1694	1673	1653	1691	1652	1642	1664	1718
1989	1729	1690	1726	1763	1670	1725	1633	1643	1747	1785

Source: Unpublished data. Doug Poutasse, F. W. Dodge Corporation, Personal Communication with Y. Joe Huang, LBL, June 8, 1990.

Figure 2, also in the main body of the report, shows Census Bureau estimates of construction type in the 1980s. The construction type is important because two-story houses are larger on the average than one story houses. The proportion of two-story houses has been increasing in all parts of the country (see Table 1). This increasing proportion of two-story houses is apparent from the greater number of base cities with two-story prototypes from the NAHB data compared with those in the previous report.

Because it was important to take account of construction type, we chose to use the Census Bureau data as the primary source. These data appear to be more robust than the NAHB state-by-state data and the F.W. Dodge data. In addition, we could not use building area estimates directly from the 1987 NAHB Builder Survey because the NAHB sample shows 1987 to be an abnormally high year for several states which include base cities used in this analysis. However, we did use construction type and building size estimates from these data in calculating average size from the Census Bureau data.

We made estimates of average 1980s square footage for each base city by combining Census Bureau square footage and construction type data (1980-89) for each census region with data from the 1987 NAHB Builder's Survey. We first used the Census Bureau data to develop weighted averages of floor area for the 1980s by census region. We then took typical construction type and 1-story/2-story square foot data for each state from the NAHB survey. Using these two data sets, we calculated weighted average square foot estimates for one and two story buildings for each census region. The results are shown in Table 5.

Table 5. Calculation of Floor Area for New Single Family Buildings By Construction Type - Using Census Bureau and NAHB Data

Census Region	Census Bureau Data, 1980-89					NAHB 1987 Data		Calculated Average Area for Construction Type (ft^2)	
	Number (1000s)	Area (ft^2)	Construction Type (%)			Const. Type	Area (ft^2)		
			1 Story	2 Story	Split				
US	9783	1832	53	41	6	2 Story	2280	2 Story	2174
						1 Story	1670	1 Story	1564
						Difference	610		
Northeast	1332	1888	26	68	6	2 Story	2455	2 Story	2094
						1 Story	1743	1 Story	1382
						Difference	712		
North Centra	1604	1827	47	39	14	2 Story	2243	2 Story	2217
						1 Story	1521	1 Story	1495
						Difference	722		
South	4550	1816	63	34	3	2 Story	2319	2 Story	2177
						1 Story	1760	1 Story	1618
						Difference	559		
West	2223	1831	55	38	7	2 Story	2000	2 Story	2066
						1 Story	1598	1 Story	1664
						Difference	402		

1990s BUILDING SIZE DATA

The only existing estimates of house size for 1990s construction came from cumulative floor area and stock estimates provided by F.W. Dodge Corporation. We calculated average square footage for new construction in each state by subtracting existing stock and existing cumulative floor area from each year's data and then dividing total new floor area by total new stock. The results are shown in Table 6.

We also analyzed the Census Bureau data to develop an estimate for 1990s construction based on trends in the 1980s data. To account for the impact of the trend in construction types, we calculated the change in average square footage for each census region using the construction type percentages from the Census Bureau data and assumed one- and two-story square footage values taken from the 1987 NAHB builders survey database. We compared these calculated values to the change in mean square footage in Census Bureau reports over the same period. The difference between the two represents the change in average house size irrespective of the trend in construction types. The results are shown in Table 7, both for the period 1980-1989 and 1987-1989.

Table 7. Analysis of Building Size Trends, 1980-1989
Calculated from Census Bureau Data, New Single Family Construction

	1980-1989			1987-1989		
Census Region	Δ Mean	Δ Calc'd	Difference	Δ Mean	Δ Calc'd	Difference
All US	295	97	198	130	18	112
Northeast	305	117	188	120	46	74
N. Central	285	87	198	80	18	62
South	280	73	207	115	11	104
West	330	107	223	195	39	156

Δ Mean = difference in mean square footage between years indicated from Census Bureau report data.

Δ Calculated = difference in area calculated using construction type from Census Bureau reports and constant building size. Estimate of change due to increasing proportion of 2-story buildings.

Difference = difference between Δ mean and Δ calculated. Estimate of change in average house size removing effect of increasing proportion of 2-story buildings.

Table 6. Calculated Average Square Footage for New Construction, 1991-2000
From Data provided by F.W. Dodge Corporation

ST	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	1990's
AL	1794	1836	1823	1809	1798	1802	1806	1811	1817	1823	1812
AK	1688	1691	1662	1644	1634	1636	1638	1642	1651	1650	1654
AZ	1759	1768	1765	1763	1757	1759	1763	1768	1772	1777	1765
AR	1800	1825	1805	1800	1795	1798	1801	1810	1814	1819	1806
CA	1903	1926	1919	1916	1911	1913	1918	1923	1929	1934	1919
CO	1941	1924	1877	1849	1832	1835	1840	1843	1849	1854	1864
CT	1923	1950	1915	1884	1864	1866	1871	1876	1883	1887	1892
DE	1739	1779	1786	1780	1782	1785	1790	1795	1801	1805	1784
DC	1500	1531	1547	1568	1580	1579	1578	1575	1577	1573	1561
FL	1771	1778	1772	1765	1760	1763	1767	1771	1776	1781	1770
GA	1761	1796	1810	1817	1822	1824	1829	1833	1839	1843	1817
HI	1654	1633	1606	1575	1547	1549	1553	1557	1561	1565	1580
ID	1935	2035	2029	2014	2001	1998	2003	2010	2020	2020	2007
IL	1811	1836	1834	1830	1825	1827	1833	1838	1844	1851	1833
IN	1873	1912	1898	1881	1869	1873	1877	1884	1890	1895	1885
IA	2230	2354	2214	2079	2025	2029	2036	2039	2055	2063	2112
KS	1823	1863	1852	1839	1832	1834	1836	1846	1851	1855	1843
KY	1809	1856	1842	1827	1816	1817	1824	1828	1835	1841	1830
LA	1754	1767	1755	1750	1744	1748	1751	1758	1763	1768	1756
ME	1796	1846	1850	1856	1856	1859	1862	1868	1874	1878	1855
MD	1782	1816	1843	1868	1880	1882	1887	1892	1898	1903	1865
MA	1853	1884	1875	1862	1851	1853	1857	1863	1869	1874	1864
MI	1914	1988	1967	1942	1929	1931	1937	1944	1951	1958	1946
MN	1816	1841	1830	1814	1806	1808	1813	1819	1824	1829	1820
MS	1811	1870	1854	1840	1825	1828	1832	1838	1844	1849	1839
MO	1852	1904	1885	1858	1845	1847	1851	1859	1864	1869	1863
MT	1956	2077	2045	2020	1997	1998	2000	2008	2013	2021	2014
NE	1879	1931	1890	1851	1829	1835	1839	1846	1849	1858	1861
NV	1667	1688	1702	1718	1724	1726	1731	1734	1739	1743	1717
NH	1742	1779	1784	1790	1790	1793	1795	1801	1806	1810	1789
NJ	1891	1919	1889	1866	1853	1855	1859	1864	1870	1875	1874
NM	1828	1883	1857	1848	1846	1848	1852	1857	1862	1866	1855
NY	1931	2003	1995	1987	1983	1985	1989	1996	2004	2010	1988
NC	1788	1803	1799	1793	1789	1791	1796	1800	1805	1810	1797
ND	1809	1825	1782	1744	1732	1731	1739	1740	1752	1752	1761
OH	1864	1902	1893	1882	1872	1875	1881	1887	1893	1900	1885
OK	1688	1707	1701	1709	1706	1709	1713	1719	1725	1730	1711
OR	2016	2088	2069	2056	2035	2040	2043	2049	2057	2064	2052
PA	1993	2057	2038	2015	2004	2006	2010	2016	2024	2031	2019
RI	2053	2089	2037	1984	1951	1952	1954	1960	1969	1974	1992
SC	1764	1790	1784	1772	1766	1769	1773	1779	1783	1789	1777
SD	1911	1929	1859	1794	1771	1769	1773	1781	1789	1789	1816
TN	1791	1828	1816	1804	1791	1794	1797	1803	1809	1814	1805
TX	1815	1824	1809	1801	1794	1797	1801	1806	1812	1817	1808
UT	1895	1930	1912	1901	1897	1899	1903	1908	1914	1919	1908
VT	1730	1774	1793	1810	1821	1821	1826	1832	1836	1842	1808
VA	1836	1824	1805	1786	1769	1772	1777	1781	1786	1791	1793
WA	1913	1970	1977	1983	1977	1980	1984	1990	1997	2002	1977
WV	4044	-2014	5207	2477	2352	2351	2353	2368	2402	2390	2393
WI	1898	1939	1913	1891	1878	1881	1885	1891	1897	1903	1898
WY	1874	1936	1920	1905	1882	1892	1891	1900	1903	1912	1901

Source: Unpublished data. Doug Poutasse, F. W. Dodge Corporation, Personal Communication with Y. Joe Huang, LBL, May 14, 1990.

Discussion

The data from F.W. Dodge for 1990s construction shown in Table 6 implies that for states which include base cities, average square footage of new single family construction in the 1990s will increase between 0 and 80 square feet from 1991 to 2000. In Colorado, however, average square footage is projected to decrease by 87 square feet.

The analysis of the Census Bureau data shows that, in each census region, house size grew about 188 to 223 square feet between 1980 and 1989 even when removing the effect of the change in proportion of one- and two-story houses. In just the last three years of the decade, 1987 to 1989, average house size grew by 62 to 156 square feet, depending on the region.

CONCLUSIONS

Because the trend towards increasing house size seems to be strong and prevalent through all areas of the country, we assumed that house size would continue to increase at approximately the same rate per decade into the 1990s. The most straightforward method for estimating the size of 1990s vintage houses is to add the 1980 to 1989 square footage increase identified above to the 1980s house size for each base city in the appropriate census region. An alternative method, adding the 1987 to 1989 house size increase to the Dodge data projections through the 1990s gives similar results of between 100 and 200 square foot increase. Based on the former method, the 1980 and 1990 prototype house type and sizes will be as given in Table 8. The D+ house sizes were estimated using the methodology described in the main body of the report. The expected impact on the resulting space conditioning loads of a 10% increase in floor area is approximately 50-80%, depending on whether heating or cooling loads are considered.

Table 8. Prototype Size for 1980s and 1990s Single Family buildings

		Floor Area (ft^2)					Floor Area (ft^2)		
Base City	Stories	1980s	1990s	1990+	Base City	Stories	1980s	1990s	1990+
Boston	2	2090	2280	3850	Fort Worth	1	1620	1830	3200
New York	2	2090	2280	3850	New Orleans	1	1620	1830	3200
Chicago	2	2220	2420	3990	Denver	2	2070	2290	3860
Minneapolis	2	2220	2420	3990	Albuquerque	1	1660	1880	3250
Kansas City	2	2220	2420	3990	Phoenix	1	1660	1880	3250
Washington	2	2180	2390	3960	Seattle	2	2070	2290	3860
Atlanta	2	2180	2390	3960	San Francisco	2	2070	2290	3860
Miami	1	1620	1830	3200	Los Angeles	2	2070	2290	3860

APPENDIX C: SAMPLE DOE-2 INPUT FILE FOR PROTOTYPE C, CHICAGO

DOE-2 INPUT FILE FOR PROTOTYPE C, CHICAGO

```
        POST-PROCESSOR PARTIAL  ..
$
$ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
$ *(*)*(*)*(*)*(*)*(*)                      (*)*(*)*(*)*(*)*(*)*
$ *(*)*(*)*(*)*(*)*(*) File name: LDS.1FAM  (*)*(*)*(*)*(*)*(*)*
$ *(*)*(*)*(*)*(*)*(*)  Date: Aug 31 1989   (*)*(*)*(*)*(*)*(*)*
$ *(*)*(*)*(*)*(*)*(*)                      (*)*(*)*(*)*(*)*(*)*
$ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
$
$--------------------------------------------------------
      INPUT  LOADS ..
TITLE LINE-1  * ChiC- c      (13-32-00-dbl)  Bsmt       *
      LINE-2  * Alumi R0-B  C33   2-sto gar-y           *
      LINE-3  * Chicago IL         TMY    Furn/AC       *
      LINE-4  *                                         *
      LINE-5  *                                         *
                ..
$-----------------------------------------------------------------
        PARAMETER
$----------------------------------------------------------------
$                                                             $
$   FLOORAREA = AMS area of conditioned space
$   BSMTAREA = FLOORAREA/(AMS # stories)
$   IWALLAREA = 2 times area of interior walls
$            = 2 x (31.7 + .0715*FLOORAREA)
$              note: doubled area accounted for in
$                   I-W Layers model
$   LENGHT, WIDTH = AMS plan view house dimensions
$                 note: these parameters are only used in
$                       calculating foundation fluxes
$   WALLHT = ht of house E-W = 8*(# stories)
$   WALLWD = width of house E-W = AMShouseE-Warea/(WALLHT*4)
$   PERIM = total length  of all E-W = E-Warea/WALLHT
$Garage                note: for homes with garages, E-Warea is
$Garage                      GIWALLAREA less than a calculated
$Garage              plan view E-Warea
$Garage        GIWALLAREA = AMS gar-house interior wall area
$Garage                   = 184 (1 story) ; = 239.2 (2 story)
 $   WINDOWWD = width of house WI = AMShousewindowarea/(#stories*4*4)
 $   ROOFHT =  height of house roofs = sqrt(BSMTAREA/(cos(22.6)*4))
 $   ROOFWD = ROOFHT = width of house roofs
 $   WALLX = length  to end of house property = WALLWD + 20
 $   SHADEX = length  to surrounding shades = WALLWD + 40
```

```
 $
$ChiC-        input obtained from Census/NAHB data for Chicago
$ChiC-   2-story $ CONDAREA = 2220.
$ChiC-   2-story $ FLOORAREA=2220 PERIM=120.336
$ChiC-   2-story $ IWALLAREA=380.86
$ChiC-   2-story   foundation length = 39.64, width = 28.00
$ChiC-   2-story $ BSMTAREA=1110
$ChiC-   2-story $ WALLWD=30.0839 WALLHT=16 WINDOWWD= 8.60
$ChiC-   2-story $ WALLX=50.0839 SHADEX=70.0839
$ChiC-   2-story $ ROOFHT=17.3373 ROOFWD=17.3373
$Garage   $          GARAREA=460
$2-stgarage $         GIWALLAREA=239.2
 $---Regional based equipment load-----------------------------------
$ENCC-Load$     RECSVAL=0.96   SENSLD=0.885   LATLD=0.115   UNCLD=0.141
 $---- Conservation parameters ---------------------------------------
$Infl5 $INFILT=.0005
$dbl  2-pane window $        WINDOWGT = WINDOW-2
$Chicag ChiC Bsmt  R13   $ FDNUEFF =.3312  $ GndU=.1409 GndT=53
$ROBsmt   $                BlWALLHT=8  B2WALLHT=0.00001
$2x4stud$        MS = 0.25
$2x4stud$        MNS = 0.75
 $E-W siding thickness (from doe2 layers library)
$Alumi   $        EWSTH=.005  $doe2 library code: AS01
 $E-W Insulation board thickness (from doe2 layers library)
            IN61TH=.0417$doe2 library code: IN61
            IN34TH=.1042$doe2 library code: IN34
            IN35TH=.1667$doe2 library code: IN35
 $E-W other materials (from doe2 layers library)
            GPTH=0.0417 $doe2 library code: GP01
 $Roof insulation thicknesses
 $RFINTH is the thickness of the insulation in the cavity
 $RFINJTH is the thickness of insulation on top of joist
$R32RF     $ RFINTH= 0.8416   RFINJTH= 0.3419
 $ ---  end of parameters -------------------------------------------
               ..
       RUN-PERIOD          JAN 1 1986 THRU DEC 31 1986  ..
       DIAGNOSTIC          CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
       BUILDING-LOCATION   LAT=41.8  LON=87.8   T-Z=6  ALT=658
                           WS-HEIGHT-LIST=
                            (20,20,20,20,20,20,20,20,20,20,20,20)
                           AZIMUTH=0 SHIELDING-COEF=0.19
                           TERRAIN-PAR1=.85 TERRAIN-PAR2=.20
                           WS-TERRAIN-PAR1=.85 WS-TERRAIN-PAR2=.20
```

```
                            FUNCTION =(*SHADING*,*NONE*)
                            ..
           ABORT     WARNINGS ..
           LOADS-REPORT       SUMMARY=(LS-E) ..
  $--------------------------------------------------------------------
  $----- Loads Schedules ---------------------------------------------
  $--------------------------------------------------------------------
  $-------------------------------------------------------------------
  $  the following were taken from A.M.S. input files:
  $--------------------------------------------------------------------
     $ OCCUPANCY HEAT GAIN SCHEDULES
     $ ocup. magnitudes and schedules taken from C.E.C. study
OCC1=SCH THRU DEC 31 (ALL)
(1,24)  (0.44,0.44,0.44,0.44,0.44,0.44,0.53,0.87,0.43,0.52,0.63,0.21,
0.14,0.00,0.00,0.29,0.29,0.64,0.81,1.00,0.96,0.89,0.77,0.44) ..
     $ EQUIPMENT SCHEDULES $
         $ equip schedule shapes taken from C.E.C. study
     $ Winter
EQP-W=W-SCH (ALL)
(1,24)  (0.22,0.22,0.17,0.17,0.17,0.14,0.41,0.41,0.57,0.57,0.81,0.81,
0.79,0.79,0.74,0.74,1.00,1.00,0.73,0.73,0.61,0.61,0.53,0.53) ..
     $ Spring/Fall
EQP-SF=W-SCH (ALL)
(1,24)  (0.24,0.24,0.19,0.19,0.19,0.18,0.40,0.40,0.51,0.51,0.71,0.71,
0.69,0.69,0.69,0.69,0.90,0.90,0.67,0.67,0.60,0.60,0.52,0.52) ..
     $ Summer
EQP-S=W-SCH (ALL)
(1,24)  (0.26,0.26,0.21,0.21,0.22,0.22,0.40,0.40,0.45,0.45,0.62,0.62,
0.59,0.59,0.64,0.64,0.80,0.80,0.62,0.62,0.57,0.57,0.52,0.52) ..
EQUIP1=SCH  THRU FEB 28 WEEK-SCHEDULE=EQP-W THRU MAY 31
WEEK-SCHEDULE=EQP-SF
THRU AUG 31 WEEK-SCHEDULE=EQP-S THRU NOV 30 WEEK-SCHEDULE=EQP-SF
THRU DEC 31 WEEK-SCHEDULE=EQP-W ..
     $ LIGHTING SCHEDULES $
         $ lite magnitude and schedule shapes taken from C.E.C. study
     $ Winter
LITG-W=W-SCH (ALL)
(1,24)  (0.18,0.18,0.09,0.09,0.09,0.09,0.27,0.27,0.18,0.18,0.09,0.09,
0.09,0.09,0.09,0.09,0.46,0.46,1.00,1.00,0.91,0.91,0.55,0.55) ..
     $ Spring/Fall
LITG-SF=W-SCH (ALL)
(1,24)  (0.14,0.14,0.04,0.04,0.07,0.07,0.18,0.18,0.18,0.18,0.14,0.14,
0.14,0.14,0.14,0.14,0.29,0.29,0.57,0.57,0.75,0.75,0.54,0.54) ..
     $ Summer
LITG-S=W-SCH (ALL)
(1,24)  (0.10,0.10,0.00,0.00,0.05,0.05,0.10,0.10,0.16,0.16,0.16,0.16,
0.16,0.16,0.16,0.16,0.16,0.16,0.26,0.26,0.57,0.57,0.47,0.47) ..
LTG1=SCH  THRU FEB 28 WEEK-SCHEDULE=LITG-W THRU MAY 31
```

```
WEEK-SCHEDULE=LITG-SF
THRU AUG 31 WEEK-SCHEDULE=LITG-S THRU NOV 30 WEEK-SCHEDULE=LITG-SF
THRU DEC 31 WEEK-SCHEDULE=LITG-W ..
 $--------------------------------------------------------------------
 $ The following shading schedule is modified by function SHADING
 $ to give .63 during the cooling season defined as periods with
 $ more than 5 cooling degree days for the four previous days.
 $-------------------------------------------------------------------
SHADCO    SCHEDULE  THRU DEC 31 (ALL) (1,24) (0.80) ..
 $-------------------------------------------------------------
 $----- Glass types ------------------------------------------
 $-------------------------------------------------------------
         $ Windows modeled using glass-type code.
         $ U-values based on ASHRAE winter values with
         $ outside film coefficients subtracted:
         $           ASHRAE      input
         $sgl          1.1        1.35
         $dbl          .49        .535
         $tri          .31        .327
         $ .5 inch air gaps assumed for 2- and 3-pane
         $
     WINDOW-1  GLASS-TYPE
     PANES=1 GLASS-TYPE-CODE=1
     GLASS-CONDUCTANCE=1.35   ..
     WINDOW-2  GLASS-TYPE
     PANES=2 GLASS-TYPE-CODE=1
     GLASS-CONDUCTANCE=.535   ..
     WINDOW-3  GLASS-TYPE
     PANES=3 GLASS-TYPE-CODE=1
     GLASS-CONDUCTANCE=.327  ..
 $----------------------
 $----- materials ------
 $----------------------
WOOD    =  MATERIAL  $ Ref ashrae
                     $ 1/2" th= .0417 ft, 2x4 th=.2917ft, 2x6 th=.4583 ft
            $ 2x10=.7917 ft
                     THICKNESS=1.        CONDUCTIVITY=.0667
                     DENSITY=34.         SPECIFIC-HEAT=.29 ..
INSUL   =  MATERIAL $ Ref ashrae - mid-range values
                     THICKNESS=1.        CONDUCTIVITY=.0263
                     DENSITY=1.15        SPECIFIC-HEAT=.20 ..
SHINGLE =  MATERIAL $ Asphalt shingle ref ashrae
                     $ Usually .0208 ft thick
                     THICKNESS=1.        CONDUCTIVITY=.0472
                     DENSITY=70.         SPECIFIC-HEAT=.3 ..
ATTIC   =  MATERIAL $ Ave summer, winter of hor+45 deg
                     $ Film resistances. ref ashrae
                     RESISTANCE=1.455  ..
```

```
DRYWALL =  MATERIAL $ Ref ashrae  usually 0.5in thick (.0417 ft)
                    THICKNESS=1.          CONDUCTIVITY=.0925
                    DENSITY=50.           SPECIFIC-HEAT=.26 ..
AIRLAYV =  MATERIAL $ vertical air layer
                    RESISTANCE=1.01  ..
AIRLAYH =  MATERIAL $ horizontal air layer
                  RESISTANCE = 1.085 ..
POLYISO =  MATERIAL $ Polyisocyanurate sheathing ref ashrae
                    $ Usually 1 in thick (.0833 ft)
                    THICKNESS=1.          CONDUCTIVITY=.0117
                    DENSITY=2.0           SPECIFIC-HEAT=.22 ..
CONCRETE = MATERIAL $ Heavy construction grade concrete
                    THICKNESS=1.          CONDUCTIVITY=.8
                    DENSITY=144.          SPECIFIC-HEAT=.139  ..
DAMPSOIL =  MATERIAL
                    THICKNESS=1.          CONDUCTIVITY=1.0
                    DENSITY=115.          SPECIFIC-HEAT=.28   ..
RUGNPAD =  MATERIAL $ Resistance of carpet and pad
                    RESISTANCE=2.08 ..
           $-------------------------------------------------------
           $      the following materials which end in s
           $      have their conductivities and specific-heats
           $      scaled up by the ratio of the roof area
           $      to the ceiling area (a fix value of .9232 for all
           $      prototypes, corresponding to an AMS roof tilt of
           $      22.6 degrees), so as to increase the
           $      ceiling resistance without changing the
           $      temporal properties of the materials.
           $-------------------------------------------------------
INSULS   =  MATERIAL  LIKE INSUL
                    CONDUCTIVITY=.02428
                    SPECIFIC-HEAT=.1846  ..
WOODS    =  MATERIAL  LIKE WOOD
                    CONDUCTIVITY=.06158
                    SPECIFIC-HEAT=.2677  ..
DRYWALLS =  MATERIAL  LIKE DRYWALL
             CONDUCTIVITY=.08540
                    SPECIFIC-HEAT=.2400  ..
           $-------------------------------------------------------
           $ The following materials were created to model
           $ the stud/nonstud (20%/80% unless otherwise noted)
           $    interior walls as a single
           $ composite.  Conductivities, specific
           $ heats, and densities of these materials were
           $ derived using area-weighted averages of their
           $ individual parts.
           $ Note: density & sp.heat of air were assumed negligible
           $-------------------------------------------------------
```

```
HALFWDROV= MATERIAL     $1/2thickness,2x4wood & vertical air composite
       THICKNESS = 1.  CONDUCTIVITY=.1171
       DENSITY=6.8 SPECIFIC-HEAT=.058   ..
HALFWDROH= MATERIAL  $1/2thickness,2x10wood & horiz. air composite
              $ note: 10%joist 90%nonjoist ratio used
       THICKNESS = 1.  CONDUCTIVITY=.2521
       DENSITY=3.4 SPECIFIC-HEAT=.029   ..
WDR11    = MATERIAL  $2x4wood & R-11 insulation composite
       THICKNESS = 1.  CONDUCTIVITY=.03015
       DENSITY=7.72 SPECIFIC-HEAT=0.218 ..
WDR13    = MATERIAL  $2x4wood & R-7+airlayv insulation composite
       THICKNESS = 1.  CONDUCTIVITY=.04005
       DENSITY=7.72 SPECIFIC-HEAT=0.218 ..
WDR19    = MATERIAL  $2x6wood & R-19 insulation composite
       THICKNESS = 1.  CONDUCTIVITY=.02905
       DENSITY=7.72 SPECIFIC-HEAT=0.218 ..
 $-------------------
 $----- layers  -----$
 $-------------------
    $----------------------------------------------------------
    $
    $ Wall and roof section notes :
    $
    $ EXTERIOR WALLS
$2x4stud        of R-11 and less are modeled as built of
$2x4stud        2x4s on 16 inch frames (25 % stud).
$2x4stud        R-13 insulation was acheived using R-7 insulation
$2x4stud        plus additional polystyrene sheathing.
    $ This percentage is reflected in the wall multipliers
    $ MNS (multiplier for no stud) and MS (multipler for stud).
    $
    $ R-#+ surpasses it's
    $ counterpart R-# with the addition of polystyrene insulating
    $ sheathing (IN61 to IN34).  IN34 was used to approximate R-13
    $ walls (which only have R-7 insulation)
    $ and therefore R-13+s counterpart is improved w/IN35.
    $
    $ The multipliers for exterior walls have a greater percentage
    $ of stud than interior walls, floors and roofs.
    $
    $ INTERIOR WALLS are modeled as built of 2x4s on 16 inch frames
    $ (i.e. 20 % stud).  To reduce the number of layers needed,
    $ the stud/nonstud portions of interior walls were lumped
    $ together in one layer using composite materials.
    $ Walls completely internal to a zone were modeled half as thick,
    $ with twice the cross-sectional area. Internal floors/ceilings
    $ were also modeled as composites (w/a 10% joist ratio)
    $
```

```
    $ CEILINGS AND ATTICS are modeled in the roof layer.  Roofs are
    $ built of 2x6 joists (10 % joist).  Ceiling conductivities
    $ and specific heats have been reduced to account for their
    $ enlarged area (all materials ending in S).
    $
    $ FLOORS are modeled as 2x10 joists on 3/4 in plywood. (10 % joist)
    $ With this exception, all the previously mentioned surfaces
    $ have 1/2 in plywood.
    $
 $------exterior wall layer, no stud-----------------------------------
$UNCA    $ UNCWALLNSL=LAYERS $R-0uncond.wall:alum frame & siding,no stud
$UNCA      $                      MATERIAL=(AS01,IN61)
$UNCA      $                      THICKNESS=(EWSTH,IN61TH)
$UNCA      $                      INSIDE-FILM-RES=.68  ..
$R13A       $ WALLNSL=LAYERS $R-13wall:alum frame & siding,no stud
$R13A      $                      MATERIAL=(AS01,IN34,INSUL,AIRLAYV,GP01)
$R13A       $                      THICKNESS=(EWSTH,IN34TH,.1841,1,GPTH)
$R13A       $                      INSIDE-FILM-RES=.68  ..
 $-----------exterior wall layer w/stud--------------------------------
$UNCA     $  UNCWALLSL - LAYERS  $R-0uncond.wall:alum frame & siding,stud
$UNCA      $                      MATERIAL=(AS01,IN61,WOOD)
$UNCA      $                      THICKNESS=(EWSTH,IN61TH,.2917)
$UNCA      $                      INSIDE-FILM-RES=.68 ..
$R13A       $  WALLSL - LAYERS  $R-13wall:alum frame & siding,stud
$R13A       $                      MATERIAL=(AS01,IN34,WOOD,GP01)
$R13A       $                      THICKNESS=(EWSTH,IN34TH,.2917,GPTH)
$R13A       $                      INSIDE-FILM-RES=.68 ..
 $------roof+ceiling+attic  w/joist----------------
$UNCRF     $ GROOFJL - LAYERS  $R-0 uncond. gar roof with joist
$UNCRF     $                  $1/2in plywood,5.5in joist lumped together
$UNCRF     $            MATERIAL=(SHINGLE,WOOD)
$UNCRF     $            THICKNESS=(.0208,.5)
$UNCRF     $            INSIDE-FILM-RES=.765 ..   $avg heat up and down
           ROOFJL - LAYERS  $House roof with joist
                     MATERIAL=(SHINGLE,WOOD,ATTIC,INSULS,WOODS,
                     DRYWALLS)
                     THICKNESS=(.0208,.0417,1,RFINJTH,.4583,
                     .0417)
                     INSIDE-FILM-RES=.765 ..   $avg heat up and down
 $----roof+attic+ceiling , no joist------------
$UNCRF     $ GROOFNJL - LAYERS  $R-0 uncond. gar-roof with no joist
$UNCRF     $            MATERIAL=(SHINGLE,WOOD)
$UNCRF     $            THICKNESS=(.0208,.0417)
$UNCRF     $            INSIDE-FILM-RES=.765 ..   $avg heat up and down
           ROOFNJL - LAYERS  $House roof with no joist
                    MATERIAL=(SHINGLE,WOOD,ATTIC,INSULS,DRYWALLS)
                    THICKNESS=(.0208,.0417,1,RFINTH,.0417)
                    INSIDE-FILM-RES=.765 ..   $avg heat up and down
```

```
 $------ground layer-----------------------------------
$Conslab     uninsul.bsmt wall/slab & gar slab on dampsoil
$Conslab     note:in order to decrease # of layers needed,
$Conslab         R-0 bsmt.wall and slab is modeled as the same layer,
$Conslab         with an ave. 6 " thickness (4" slab,8" wall)
$Conslab         Garage slab is also modeled with this layer
$Conslab $ BGRNDL - LAYERS
$Conslab $                         MATERIAL=(DAMPSOIL,CONCRETE)
$Conslab $                         THICKNESS=(3.5,.5)
$Conslab $                         INSIDE-FILM-RES=0.765 ..
$Bsmt -----------basement wall layers---------------------------------
$R0Bsmt   $ BWALL2L - LAYERS  $ uninsulated basement wall dampsoil
$R0Bsmt   $                        MATERIAL=(DAMPSOIL,CONCRETE)
$R0Bsmt   $                        THICKNESS=(3.50,.667)
$R0Bsmt   $                    INSIDE-FILM-RES=0.68 ..
 $----------interior layers--------------------------------------
IWALLL   - LAYERS    $1/2Interior Wall layer stud/nostud composite
        MATERIAL - (DRYWALL,HALFWDROV)
        THICKNESS - (.0417,.1459)
        INSIDE-FILM-RES - .68 ..
$Garage--------gar-house interior layers---------------------------
$Garage      gar-house interior wall layers defined w.r.t. house space
$Garage       (i.e. rightmost gypboard: element nearest house space)
$R13G       $  GIWALLL - LAYERS  $R-13wall: 2x4stud/insul composite
$R13G       $                        MATERIAL=(GP01,IN34,WDR13,GP01)
$R13G       $                        THICKNESS=(GPTH,IN34TH,.2917,GPTH)
$R13G       $                        INSIDE-FILM-RES=.68 ..
$2-story-------------layers between 1st and 2nd story-----------------
$2-story    $   IFLOORL - LAYERS        $.75"plywood Int. floor w/joist
$2-story    $                           $1/2 2x10joist/airlayh composite
$2-story    $           MATERIAL - (HALFWDROH,WOOD,RUGNPAD)
$2-story    $        THICKNESS - (.3958,.0625,1)
$2-story    $        INSIDE-FILM-RES - .765 ..
$2-story    $   ICEILL - LAYERS         $drywall Int. ceiling w/joist
$2-story    $                           $1/2 2x10joist/airlayh composite
$2-story    $           MATERIAL - (HALFWDROH,DRYWALL)
$2-story    $        THICKNESS - (.3958,.0417)
$2-story    $        INSIDE-FILM-RES - .765 ..
 $-----------floor over unconditioned space layers-------------------
$ROOFL      $   FLOORJL - LAYERS $R-0floor w/joist;over uncond.
$ROOFL      $       MATERIAL - (WOOD,RUGNPAD)
$ROOFL      $       THICKNESS - (.8542,1)
$ROOFL      $       INSIDE-FILM-RES - .765 ..
$ROOFL      $   FLOORNJL- LAYERS $R-0floor no joist;over uncond.
$ROOFL      $       MATERIAL - (WOOD,RUGNPAD)
$ROOFL      $       THICKNESS - (.0625,1)
$ROOFL      $       INSIDE-FILM-RES - .765 ..
 $
```

```
 $------------------------------------------------------------------
 $-----  Constructions  --------------------------------------------
 $------------------------------------------------------------------
 $
 $ House constructions---------------------------------------------------
           WALLNSCON  CONSTRUCTION   $ Wall non-stud section
                        LAYERS=WALLNSL ..
           WALLSCON   CONSTRUCTION   $ Wall stud section
                        LAYERS=WALLSL ..
           IWALLCON  CONSTRUCTION    $ Interior wall (int. to theroom)
                        LAYERS=IWALLL ..
$2-story  $ IFLOORCON  CONSTRUCTION   $floor of 2nd story
$2-story  $             LAYERS=IFLOORL ..
$2-story  $ ICEILCON  CONSTRUCTION    $ceil over 1st floor
$2-story  $             LAYERS=ICEILL ..
            FSLABCON   CONSTRUCTION   $ Floor slab in contact with soil
$Bsmt     $             LAYERS=BGRNDL  ..
            ROOFNJCON  CONSTRUCTION   $ Roof non-joist section
                        LAYERS=ROOFNJL ..
            ROOFJCON   CONSTRUCTION   $ Roof joist section
                        LAYERS=ROOFJL ..
$new-door type(c,d)       $   DOORCON1  CONSTRUCTION  $solid ureth. door
$new-door type(c,d)       $   U-VALUE=.19 ..          $w/thermal T-B
$Bsmt     $  FLRNJCON   CONSTRUCTION   $ Flr over uncond.space, nonjois
$Bsmt     $             LAYERS=FLOORNJL  ..
$Bsmt     $  FLRJCON    CONSTRUCTION   $ Flr over uncond. space, joist
$Bsmt     $             LAYERS=FLOORJL  ..
$Bsmt     $  BWALL1CON CONSTRUCTION    $ Uninsulated Basement wall
$Bsmt     $             LAYERS=BGRNDL ..
$Bsmt     $  BWALL2CON CONSTRUCTION    $ Insulated Basement wall
$Bsmt     $            LAYERS=BWALL2L  ..
$Garage    $  GIWALLCON CONSTRUCTION    $Gar-House Interior wall
$Garage    $              LAYERS=GIWALLL ..
$Garage    $      GWALLNSCON  CONSTRUCTION $Uninsul gar-wall, no stud
$Garage    $            LAYERS=UNCWALLNSL ..
$Garage    $      GWALLSCON  CONSTRUCTION  $Uninsul gar-wall, w/stud
$Garage    $            LAYERS=UNCWALLSL ..
$Garage    $   GSLABCON  CONSTRUCTION $Garage slab in contact w/soil
$Garage    $         LAYERS=BGRNDL  ..
$Garage    $      GROOFNJCON  CONSTRUCTION $Uninsul gar-roof, no joist
$Garage    $       LAYERS=GROOFNJL ..
$Garage    $   GROOFJCON   CONSTRUCTION $Uninsul gar-roof, w/joist
$Garage    $         LAYERS=GROOFJL ..
$Garage    $      DOORCON2  CONSTRUCTION          $Garage door
$Garage    $            U-VALUE=0.943 ..
  $------------------------------------------------------------------
  $-----  Shades  ---------------------------------------------------
  $------------------------------------------------------------------
```

```
SURROUNDN BUILDING-SHADE      $ Effect of neighboring houses north
                    HEIGHT=10 WIDTH=SHADEX
                    X=0 Y=SHADEX AZIMUTH=180
                    TRANSMITTANCE=0.50 TILT=90 ..
SURROUNDS BUILDING-SHADE      $ Effect of neighboring houses south
                    LIKE SURROUNDN
                    X=SHADEX Y=0 AZIMUTH=0 ..
SURROUNDE BUILDING-SHADE      $ Effect of neighboring houses east
                    LIKE SURROUNDN
                    X=SHADEX Y=SHADEX AZIMUTH=270 ..
SURROUNDW BUILDING-SHADE      $ Effect of neighboring houses west
                    LIKE SURROUNDN
                    X=0 Y=0 AZIMUTH=90 ..
 $------------------------------------------------------------------
 $-----  Space -----------------------------------------------------
 $------------------------------------------------------------------
 $ A.M.S. space loads are based on the following:
 $  1. 0.75 kW/sqft task lighting (dependent upon FLOORAREA)
 $  2. E-KW based on regional utility peak values (RECS tape)
 $  3. a 3 person load (constant)
 $
 $  Note: Occupant Heat gain changed from AMS values (325 Btuh
 $  sensible and 325 Btuh latent) to 230 Btuh sensible and
 $  190 Btuh latent - see ASHRAE Fundamentals Table 16 Chpt 25
 $      Lighting power changed from AMS values (0.75 watts/sqft)
 $  to 0.388 watts/sqft based on Utility ests. and LBL Res Energy
 $  model.
 $  JH, 6/19/90.
 $
ROOMCOND  SPACE-CONDITIONS
                   TEMPERATURE = (74)
                   INF-METHOD=S-G
                   FRAC-LEAK-AREA = INFILT
                   FLOOR-WEIGHT=0
                   FURNITURE-TYPE=LIGHT
                   FURN-FRACTION=0.29
                   FURN-WEIGHT=3.30
                   $ A.M.S.SPACE CONDITIONS $
            P-SCH=OCC1
            N-O-P=3
            P-H-S=230
            P-H-L=190
            T-L-SCH=LTG1
            T-L-W=0.388
            E-SCH=EQUIP1
            E-KW=RECSVAL
            E-S=SENSLD
            E-L=LATLD
```

```
                    ..
 $
 $ Conditioned space ------------------------------------------------------
 $
THEROOM   SPACE
                    SPACE-CONDITIONS=ROOMCOND
                AREA=FLOORAREA
                    VOLUME=FLOORAREA TIMES 8. ..
         IWALL  INTERIOR-WALL
                    INT-WALL-TYPE=INTERNAL
                    AREA=IWALLAREA
                CONSTRUCTION=IWALLCON ..
$Garage   $  GIWALL INTERIOR-WALL
$Garage   $         AREA=GIWALLAREA
$Garage   $         CONSTRUCTION=GIWALLCON
$Garage   $         NEXT-TO=GARAGE  ..
NWALLS    EXTERIOR-WALL
                    WIDTH=WALLWD  CONSTRUCTION=WALLSCON
                    X=WALLX Y=WALLX HEIGHT=WALLHT
                    MULTIPLIER = MS ..
NDOORS     DOOR     HEIGHT=6.5 WIDTH=.75 CONSTRUCTION=DOORCON1 X=3.0 ..
NWIND1S    WINDOW    GLASS-TYPE=WINDOWGT X=5.0 Y=3
                    HEIGHT=4.0 WIDTH=WINDOWWD SHADING-SCHEDULE=SHADCO
                     ..
$2-story  $         NWIND2S    WINDOW  LIKE NWIND1S Y=11.0
$2-story  $         OH-A=5.0  OH-B=1.0 OH-W=WALLWD  OH-D=2.0  ..
NWALLNS    EXTERIOR-WALL    LIKE NWALLS
                    CONSTRUCTION=WALLNSCON
             MULTIPLIER = MNS ..
NDOORNS   DOOR      LIKE NDOORS ..
NWIND1NS  WINDOW    LIKE NWIND1S ..
$2-story  $         NWIND2NS  WINDOW  LIKE NWIND1S Y=11.0  ..
SWALLS     EXTERIOR-WALL     LIKE NWALLS X=20 Y=20 AZIMUTH=180 ..
SDOORS    DOOR      LIKE NDOORS  ..
SWIND1S   WINDOW    LIKE NWIND1S ..
$2-story  $         SWIND2S   WINDOW  LIKE NWIND1S Y=11.0 ..
SWALLNS    EXTERIOR-WALL     LIKE NWALLNS X=20 Y=20 AZIMUTH=180 ..
SDOORNS   DOOR      LIKE NDOORNS  ..
SWIND1NS  WINDOW    LIKE NWIND1NS ..
$2-story  $         SWIND2NS  WINDOW  LIKE NWIND1NS Y=11.0 ..
EWALLS    EXTERIOR-WALL     LIKE NWALLS X=WALLX Y=20 AZIMUTH=90 ..
EDOORS     DOOR      LIKE NDOORS   ..
EWIND1S    WINDOW    LIKE NWIND1S  ..
$2-story  $         EWIND2S    WINDOW  LIKE NWIND1S Y=11.0 ..
EWALLNS   EXTERIOR-WALL     LIKE NWALLNS X=WALLX Y=20 AZIMUTH=90 ..
EDOORNS     DOOR      LIKE NDOORNS   ..
EWIND1NS    WINDOW    LIKE NWIND1NS  ..
$2-story  $         EWIND2NS    WINDOW  LIKE NWIND1NS Y=11.0 ..
```

```
WWALLS    EXTERIOR-WALL     LIKE NWALLS X=20 Y=WALLX AZIMUTH=270 ..
WDOORS     DOOR      LIKE NDOORS   ..
WWIND1S   WINDOW    LIKE NWIND1S  ..
$2-story  $         WWIND2S    WINDOW  LIKE NWIND1S Y=11.0 ..
WWALLNS    EXTERIOR-WALL     LIKE NWALLNS X=20 Y=WALLX AZIMUTH=270 ..
WDOORNS     DOOR      LIKE NDOORNS   ..
WWIND1NS   WINDOW    LIKE NWIND1NS  ..
$2-story  $         WWIND2NS    WINDOW  LIKE NWIND1NS Y=11.0 ..
$Bsmt   $ IFLOOR1J   INTERIOR-WALL    $ Floor bet Theroom and Basement
$Bsmt   $            TILT=180 CONSTRUCTION=FLRJCON
$Bsmt   $            AREA=BSMTAREA TIMES .1  NEXT-TO=BASEMENT ..
$Bsmt   $ IFLOOR1NJ  INTERIOR-WALL    $ Floor bet Theroom and Basement
$Bsmt   $            TILT=180 CONSTRUCTION=FLRNJCON
$Bsmt   $            AREA=BSMTAREA TIMES .9 NEXT-TO=BASEMENT ..
$2-story  $          IFLOOR2 INTERIOR-WALL INT-WALL-TYPE=INTERNAL
$2-story  $          AREA=BSMTAREA
$2-story  $          CONSTRUCTION=IFLOORCON TILT=180 ..
$2-story  $          ICEIL   INTERIOR-WALL INT-WALL-TYPE=INTERNAL
$2-story  $          AREA=BSMTAREA
$2-story  $          CONSTRUCTION=ICEILCON TILT=180 ..
NROOFJ     ROOF      X=WALLX Y=WALLX Z=WALLHT HEIGHT=ROOFHT WIDTH=ROOFWD
            MULTIPLIER=0.1
                     CONSTRUCTION=ROOFJCON TILT=22.6       ..
NROOFNJ    ROOF      LIKE NROOFJ
            MULTIPLIER=0.9 CONSTRUCTION=ROOFNJCON ..
SROOFJ     ROOF      LIKE NROOFJ AZIMUTH=180 X=20 Y=20     ..
SROOFNJ    ROOF      LIKE NROOFNJ AZIMUTH=180 X=20 Y=20     ..
EROOFJ     ROOF      LIKE NROOFJ AZIMUTH=90 X=WALLX Y=20 ..
EROOFNJ    ROOF      LIKE NROOFNJ AZIMUTH=90  X=WALLX Y=20  ..
WROOFJ     ROOF      LIKE NROOFJ AZIMUTH=270 X=20 Y=WALLX  ..
WROOFNJ    ROOF      LIKE NROOFNJ AZIMUTH=270 X=20 Y=WALLX  ..
$Bsmt
$Bsmt Space--------------------------------------------------------------------
$Bsmt
$Bsmt   $  BASEMENT  SPACE
$Bsmt   $            AREA=BSMTAREA VOLUME=BSMTAREA TIMES 8.
$Bsmt   $            FURNITURE-TYPE=LIGHT
$Bsmt   $            FLOOR-WEIGHT=0
$Bsmt   $            E-KW=UNCLD
$Bsmt   $            E-SCH=EQUIP1
$Bsmt   $            ZONE-TYPE=UNCONDITIONED T=(70) ..
$Bsmt   $ FND1WALL   UNDERGROUND-WALL  $ Basement wall w/o insulation
$Bsmt   $            HEIGHT=B1WALLHT WIDTH=PERIM
$Bsmt   $            CONSTRUCTION=BWALL1CON TILT=90
$Bsmt   $            U-EFFECTIVE=FDNUEFF
$Bsmt   $            FUNCTION =(*NONE*,*FNDQ*) ..
$Bsmt   $ FND2WALL   UNDERGROUND-WALL  $ Basement wall with insulation
$Bsmt   $            HEIGHT=B2WALLHT WIDTH=PERIM
```

```
$Bsmt  $            U-EFFECTIVE=FDNUEFF
$Bsmt  $            CONSTRUCTION=BWALL2CON TILT=90  ..
$Bsmt  $ FOUNDATION UNDERGROUND-FLOOR  $ basement concrete floor
$Bsmt  $            HEIGHT=10 WIDTH=BSMTAREA TIMES .1
$Bsmt  $            U-EFFECTIVE=FDNUEFF
$Bsmt  $            CONSTRUCTION=FSLABCON TILT=180 ..
$Garage
$Garage Space-------------------------------------------------------
$Garage
$Garage      GARAGE AREA = AMS sq footage of garage foundation
$Garage      GARAGE VOL = AMS garage volume = (10.4 x GAREA)
$Garage      GARAGE E-WALL HT = AMS garE-Warea/AMS garE-Wperim
$Garage      GARAGE WALL WIDTH = AMS garE-Wperim/4
$Garage      GARAGE ROOF HT & WIDTH = wi/ht of horizontal, square
$Garage                   garage roof = sqrt(GARAGE AREA)
$Garage      GARAGE DOOR WIDTH = AMS garagedoorwidth/4
$Garage      GARAGE DOOR HT= AMS garage door ht = 7
$Garage
$Garage$  GARAGE SPACE
$Garage$            AREA=GARAREA  VOLUME=4784
$Garage$            INF-METHOD=S-G
$Garage  assume 1 ft2 of vents per 150 ft2 of garage space area,
$Garage   effective-leakage-area = 75% of vent area
$Garage$            FRAC-LEAK-AREA= .005
$Garage$            FLOOR-WEIGHT=0
$Garage$            ZONE-TYPE=UNCONDITIONED T=(60)
$Garage$             ..
$Garage$ NGWALLS    EXTERIOR-WALL   LIKE NWALLS
$Garage$            CONSTRUCTION=GWALLSCON
$Garage$            HEIGHT=8.876
$Garage$            WIDTH=15.75  ..
$Garage$ NGDOORS    DOOR
$Garage$            HEIGHT = 7 WIDTH = 4.625
$Garage$    CONSTRUCTION=DOORCON2 X=5.56 ..
$Garage$ NGWALLNS   EXTERIOR-WALL   LIKE NWALLNS
$Garage$            CONSTRUCTION=GWALLNSCON
$Garage$            HEIGHT=8.876
$Garage$            WIDTH=15.75  ..
$Garage$ NGDOORNS   DOOR    LIKE NGDOORS ..
$Garage$ SGWALLS    EXTERIOR-WALL   LIKE SWALLS
$Garage$            CONSTRUCTION=GWALLSCON
$Garage$            HEIGHT=8.876
$Garage$            WIDTH=15.75  ..
$Garage$ SGDOORS    DOOR    LIKE NGDOORS ..
$Garage$ SGWALLNS   EXTERIOR-WALL   LIKE SWALLNS
$Garage$            CONSTRUCTION=GWALLNSCON
$Garage$            HEIGHT=8.876
$Garage$            WIDTH=15.75  ..
```

```
$Garage$ SGDOORNS   DOOR    LIKE NGDOORS ..
$Garage$ EGWALLS    EXTERIOR-WALL   LIKE EWALLS
$Garage$            CONSTRUCTION=GWALLSCON
$Garage$            HEIGHT=8.876
$Garage$            WIDTH=15.75  ..
$Garage$ EGDOORS    DOOR    LIKE NGDOORS ..
$Garage$ EGWALLNS   EXTERIOR-WALL   LIKE EWALLNS
$Garage$            CONSTRUCTION=GWALLNSCON
$Garage$            HEIGHT=8.876
$Garage$            WIDTH=15.75  ..
$Garage$ EGDOORNS   DOOR    LIKE NGDOORS ..
$Garage$ WGWALLS    EXTERIOR-WALL   LIKE WWALLS
$Garage$            CONSTRUCTION=GWALLSCON
$Garage$            HEIGHT=8.876
$Garage$            WIDTH=15.75  ..
$Garage$ WGDOORS    DOOR    LIKE NGDOORS ..
$Garage$ WGWALLNS   EXTERIOR-WALL   LIKE WWALLNS
$Garage$            CONSTRUCTION=GWALLNSCON
$Garage$            HEIGHT=8.876
$Garage$            WIDTH=15.75  ..
$Garage$ WGDOORNS   DOOR    LIKE NGDOORS ..
$Garage$ GFOUNDATION UNDERGROUND-FLOOR  $ Slab floor
$Garage$            HEIGHT=10 WIDTH=GARAREA TIMES .1
$Garage$            TILT=180 CONSTRUCTION=GSLABCON
$Garage$            U-EFFECTIVE= .143  .. $ ref j.huang - ashrae paper
$Garage$ GROOFJ  ROOF
$Garage$    LIKE NROOFJ
$Garage$            HEIGHT=21.45  WIDTH=21.45
$Garage$            TILT=0   Z=8.876
$Garage$    CONSTRUCTION=GROOFJCON ..
$Garage$ GROOFNJ  ROOF
$Garage$            LIKE NROOFNJ
$Garage$            HEIGHT=21.45  WIDTH=21.45
$Garage$            TILT=0   Z=8.876
$Garage$    CONSTRUCTION=GROOFNJCON ..
         END ..
FUNCTION NAME=SHADING
         LEVEL=BUILDING    ..
ASSIGN   Y-SCHEDULE-NAME(SHADCO)  ..
ASSIGN   IHR=IHR IDAY=IDAY IMO=IMO DBT=DBT    ..
ASSIGN   IPRDFL=IPRDFL ISUNUP=ISUNUP ..
CALCULATE    ..
      IF (IPRDFL .LE. 0) GO TO 2
      SC=Y
      GO TO 70
    2 IF (IHR .NE. 1) GO TO 5
      CDH=0
      HDH=0
```

```
  VTYPE=-1                  $ enthalpic venting
$Furn $         FHIR=1.51   $ 73% efficiency + 10% duct losses
$Furn $         MAXTEMP=120
                CBF=.098      CEIR=.4     $ 2,7 COP air conditioner
$2-story      $ HCAPF=-100000. HPHCAP=-48000  HPBKUP=-17000
$2-story      $ ACCFM=2100      CTCAP=48000     CSCAP=38400.
                    ..
 $-------------------------------------------------------------
 $-----  Systems Schedules  -----------------------------------
 $-------------------------------------------------------------
HTSCH      SCHEDULE  $ heat temperature schedule, 7 hour night setback
                     THRU DEC 31 (ALL) (1,6)   (SETBACK)
                                       (7,23)  (HEATSET)
                                       (24)    (SETBACK)  ..
CTSCH      SCHEDULE  $ cool temperature schedule, 7 hour day setup
                     THRU DEC 31 (ALL) (1,9)   (COOLSET)
                                       (10,16) (SETUP)
                                       (17,24)   (COOLSET)  ..
VTSCH      SCHEDULE  $Vent schedule based on previous 4 days load
                     THRU MAY 14 (ALL) (1,24)  (-4)
                     THRU SEP 30 (ALL) (1,24)  (-4)
                     THRU DEC 31 (ALL) (1,24)  (-4) ..
VOPSCH     SCHEDULE  $Vent operation schedule
                     THRU DEC 31 (ALL) (1,24)  (VTYPE) ..
WINDOPER   SCHEDULE  $No window operation between 11 p.m. and 6 a.m.
                     THRU DEC 31 (ALL) (1,6)   (0.0)
                                       (7,23)  (1.0)
                                       (24)    (0.0)  ..
 $-------------------------------------------------------------
 $-----  Zones  -----------------------------------------------
 $-------------------------------------------------------------
ZC1                  ZONE-CONTROL
                               DESIGN-HEAT-T=70.
                               DESIGN-COOL-T=78.
                               COOL-TEMP-SCH=CTSCH
                               HEAT-TEMP-SCH=HTSCH
                               THERMOSTAT-TYPE=TWO-POSITION ..
THEROOM              ZONE      ZONE-CONTROL=ZC1
                               ZONE-TYPE=CONDITIONED ..
$Bsmt  $ BASEMENT    ZONE      ZONE-TYPE=UNCONDITIONED  ..
$Garage    $ GARAGE     ZONE      ZONE-TYPE=UNCONDITIONED ..
 $-------------------------------------------------------------
 $-----  Systems  ---------------------------------------------
 $-------------------------------------------------------------
SYSCONTRL SYSTEM-CONTROL
                  MAX-SUPPLY-T=MAXTEMP
                  MIN-SUPPLY-T=50
                    ..
```

```
SYSAIR    SYSTEM-AIR
                 NATURAL-VENT-SCH=VOPSCH
                 VENT-TEMP-SCH=VTSCH
                 OPEN-VENT-SCH=WINDOPER
                 HOR-VENT-FRAC=0.0
 $ assume 1/4 of total window area opened for venting,
 $ and discharge coefficient of 0.6
                 FRAC-VENT-AREA=0.018
                 VENT-METHOD=S-G
                 MAX-VENT-RATE=20
                   ..
SYSEQP    SYSTEM-EQUIPMENT
                 COOLING-EIR=CEIR
                 COIL-BF=CBF
                 COMPRESSOR-TYPE=SINGLE-SPEED
$Furn     Furnace specifications    $
$Furn  $         FURNACE-AUX=0.
$Furn  $         FURNACE-HIR=FHIR $ duct losses in FHIR already
                   ..
RESIDEN  SYSTEM  SYSTEM-TYPE=RESYS
$Bsmt  $       ZONE-NAMES=(THEROOM,BASEMENT
$Garage $                  ,GARAGE
                                 )
                 SYSTEM-CONTROL=SYSCONTRL
                 SYSTEM-AIR=SYSAIR
                 SYSTEM-EQUIPMENT=SYSEQP
$Furn  $         HEAT-SOURCE=GAS-FURNACE
                 ..
          RB1    REPORT-BLOCK
                 VARIABLE-TYPE = GLOBAL
                 VARIABLE-LIST = (5,8,10)
                 ..
          RB2    REPORT-BLOCK
                 VARIABLE-TYPE = RESIDEN
                 VARIABLE-LIST = (5,6,8,33,47,48,61,62)
                 ..
          HRSCH  SCHEDULE    $ Hourly report schedule
                 THRU DEC 31  (ALL)  (1,24)  (1)
                 ..
          SHR    HOURLY-REPORT
                 REPORT-SCHEDULE = HRSCH
                 REPORT-BLOCK = (RB1,RB2)
                 ..
          END ..
          COMPUTE  SYSTEMS ..
          STOP  ..
```

```
      IDAYH=0
    5 CONTINUE
      IF (ISUNUP .EQ. 0) GO TO 25
      DELTA=DBT-65.0
      IF (DELTA .GT. 0.00) GO TO 10
      HDH=HDH+ABS(DELTA)
      GO TO 20
   10 CDH=CDH+DELTA
   20 CONTINUE
      IDAYH=IDAYH+1
   25 IF (IHR .NE. 24) GO TO 70
      CDDD=CDH/IDAYH
      HDDD=HDH/IDAYH
      IF (CDDD .LT. 5.00) GO TO 29
      IF (SC .NE. 0.80) GO TO 27
      ICOUNT=ICOUNT+1
      IF (ICOUNT .LE. 4) GO TO 40
   27 IHCOUNT=0
      SC=0.60
      GO TO 70
   29 IF (SC .NE. 0.60) GO TO 30
      IHCOUNT=IHCOUNT+1
      IF (IHCOUNT .GE. 4) GO TO 30
      SC=0.60
      GO TO 70
   30 ICOUNT=0.0
   40 SC=0.80
   70 CONTINUE
      Y=SC
C     PRINT 80,Y,IMO,IDAY,IHR,CDDD,CDH,ICOUNT,IHCOUNT
   80 FORMAT( ' SHADING : ADD=' ,8F10.2)
      END
END-FUNCTION   ..

FUNCTION NAME = FNDQ
         LEVEL = UNDERGROUND-WALL  ..
ASSIGN   DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN   QTABL = TABLE
(  0,-12008.7)(  1,-12119.2)(  2,-12274.9)(  3,-12414.2)(  4,-12538.4)
(  5,-12647.6)(  6,-12740.2)(  7,-12817.7)(  8,-12877.2)(  9,-12921.5)
( 10,-12949.1)( 11,-12960.1)( 12,-12954.2)( 13,-12931.6)( 14,-12892.1)
( 15,-12837.2)( 16,-12765.4)( 17,-12676.6)( 18,-12572.3)( 19,-12452.3)
( 20,-12316.7)( 21,-12166.7)( 22,-12002.4)( 23,-11823.7)( 24,-11630.6)
( 25,-11424.5)( 26,-11206.7)( 27,-10975.8)( 28,-10733.2)( 29,-10481.5)
( 30,-10218.1)( 31, -9945.7)( 32, -9665.6)( 33, -9376.4)( 34, -9081.0)
( 35, -8777.9)( 36, -8469.8)( 37, -8158.1)( 38, -7841.6)( 39, -7521.5)
( 40, -7200.5)( 41, -6877.4)( 42, -6553.6)( 43, -6230.4)( 44, -5907.8)
( 45, -5588.6)( 46, -5271.4)( 47, -4957.6)( 48, -4650.1)( 49, -4346.0)
```

```
( 50, -4049.6)( 51, -3759.4)( 52, -3478.3)( 53, -3204.9)( 54, -2940.7)
( 55, -2686.4)( 56, -2443.0)( 57, -2210.9)( 58, -1990.9)( 59, -1783.2)
( 60, -1588.8)( 61, -1407.9)( 62, -1241.1)( 63, -1089.0)( 64,  -951.6)
( 65,  -829.6)( 66,  -723.2)( 67,  -632.8)( 68,  -558.5)( 69,  -500.6)
( 70,  -459.2)( 71,  -434.3)( 72,  -426.2)( 73,  -434.8)( 74,  -460.0)
( 75,  -501.9)( 76,  -560.3)( 77,  -635.0)( 78,  -725.9)( 79,  -832.7)
( 80,  -955.2)( 81, -1092.9)( 82, -1245.5)( 83, -1412.7)( 84, -1594.0)
( 85, -1788.8)( 86, -1996.7)( 87, -2217.0)( 88, -2450.0)( 89, -2692.7)
( 90, -2947.1)( 91, -3212.0)( 92, -3485.9)( 93, -3767.5)( 94, -4058.1)
( 95, -4355.0)( 96, -4658.2)( 97, -4966.3)( 98, -5279.5)( 99, -5596.1)
(100, -5916.4)(101, -6238.7)(102, -6561.9)(103, -6885.8)(104, -7207.7)
(105, -7530.5)(106, -7849.8)(107, -8165.6)(108, -8478.1)(109, -8785.7)
(110, -9087.1)(111, -9383.6)(112, -9671.1)(113, -9952.2)(114,-10224.3)
(115,-10485.8)(116,-10738.2)(117,-10980.0)(118,-11209.9)(119,-11428.9)
(120,-11633.4)(121,-11825.6)(122,-11947.1) ..
      CALCULATE  ..
      WEEK = DOY / 3.0
      UGWQ = 0.0
      UGFQ = PWL(QTABL, WEEK)
C     PRINT 10, DOY, WEEK, UGWQ, UGFQ
   10 FORMAT('FNDQ',4F10.2)
      END-FUNCTION  ..
         COMPUTE LOADS ..
          POST-PROCESSOR PARTIAL ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                      (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name:SYS.PROD  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date:  Nov 3 1986  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                      (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
          INPUT     SYSTEMS ..
 TITLE  LINE-1  * ChiC- c     (13-32-00-dbl)  Bsmt        *
        LINE-2  * Alumi RO-B  C33   2-sto gar-y           *
        LINE-3  * Chicago IL        TMY    Furn/AC        *
        LINE-4  *                                         *
        LINE-5  *                                         *
                      ..
          DIAGNOSTIC    CAUTIONS ECHO ..
          SYSTEMS-REPORT
                 HOURLY-DATA-SAVE = YES
                 SUMMARY=(SS-A,SS-B,SS-C,SS-F,SS-H,SS-I) ..
 $---------------------------------------------------------------
          PARAMETER
 $---------------------------------------------------------------
   HEATSET=70    SETBACK=64    $ no night setback
   COOLSET=78    SETUP=78      $ no day setup
```

APPENDIX D: B1+ PROTOTYPE COOLING LOAD SENSITIVITY STUDY

The B1+ prototype was developed to include a series of buildings in the database with peak cooling loads above three tons (36,000 Btu/hr). It is an enlarged version of the standard B1 prototype, which was defined as built between 1950 and 1969, and had been been retrofitted with insulation, weatherstripping, and window treatments as appropriate for each climate. The goal of the sensitivity analysis described here was to determine the effect of important building operating assumptions used in the simulations on the magnitude of the peak and annual cooling loads.

As described in the main body of the report, the configuration and thermal characteristics of the B1 houses were determined in the previous study using the 1980 Residential Energy Consumption Survey (RECS) data tape. To develop a prototype with large loads, we increased the floor area of the prototypes by twice the standard deviation in building floor area. All other building characteristic and operation inputs were left unchanged except for increases in internal gains from lighting and some small appliances.

SENSITIVITIES

In order to determine the sensitivity of the loads in these houses with respect to infiltration levels, ventilation schedules (no ventilation with windows closed vs. typical ventilation schedule based on outside temperature and latent enthalpy hours), and temperature setpoints and setback and setups, we performed a series of sensitivity runs using DOE-2.1D. These sensitivity tests were conducted on two base cities (Chicago and Fort Worth). The base case conditions are given in Table 1.

Table 1. Base Heating and Cooling Loads for B1+ Prototypes

Location	Number Stories	Area (ft^2)	Cooling Loads Annual (MMBtu)	Cooling Loads Peak (kBtu)	Heating Loads Annual (MMBtu)	Heating Loads Peak (kBtu)
Chicago	1	3220	11.8	37.3	144.6	91.1
Fort Worth	1	2638	36.8	38.6	34.9	45.4

Notes: Base conditions: ELF = 0.0006 (infiltration); 78 F cooling setpoint; no cooling setup.

The parameters chosen for the sensitivity tests were as follows: *infiltration*: several effective leakage fractions (.0005, .0006 - the base case, .0007, and .008); *ventilation*: no venting and base case ventilation schedule; and *air-conditioning settings*: 76 F with no setup; 78 F with no setup (base case), 78 F, and 80 F with setups of 80 F, 82 F, and 84 F. We also conducted some combined parametric simulations with different ranges of infiltration rate, ventilation, and temperature settings and setbacks/ups. The results of these sensitivity tests are presented in the tables for both the Chicago and Fort Worth houses. We also include graphic presentations of the one-dimensional and multidimensional sensitivity results for both heating and cooling in Chicago and Fort Worth.

SUMMARY

The sensitivities provide some interesting results. The effect of changing *infiltration* rates on annual and peak heating and cooling loads is generally linear. For Chicago, the change in annual load per change in effective leakage area (per 1/1000) is 6.5% for heating and 4.2% for cooling. Similar changes for Fort Worth are 7.5% for heating and 4.5% for cooling. For peak loads, the changes are 8.8% heating and 5.1% cooling in Chicago and 5.3% heating and 5.4% cooling in Fort Worth. In general, the changes were not significant for this range of infiltration levels.

The ventilation sensitivity also showed fairly little difference between the ventilation and no ventilation cases for annual loads and does not affect peak loads. The reduction in annual cooling load due to the ventilation schedule is calculated to be about 1 MMBtu/yr, or 9% for Chicago and 5% for Fort Worth. The most sensitive parameter in our analysis was air-conditioner setpoints and setups, (i.e, setting temperature higher during unoccupied periods) usually during daytime hours (8:00 a.m.- 5:00 p.m.). Using the setup or setting the setpoint to a slightly higher temperature level causes substantial decreases in annual cooling loads. For Chicago, using a setup of 84 F reduces the cooling loads by 25%, while setting the cooling setpoint to 80 F with an 84 F setup reduces cooling loads by 50%. We found similar cooling load reductions for Fort Worth. The results for Fort Worth show an 18% reduction for 84 F setup and a 33% reduction for an 80 F setpoint with an 84 F setup.

For peak loads, increasing the thermostat setpoint by 2 F reduces peak cooling by 4.4 kBtu (12%) in Chicago and 2.5 kBtu (7%) in Fort Worth. Setups, while reducing the annual loads, have a large effect on peak loads in Chicago, with an 84 F setup increasing the peak load by 35%. The loads in Fort Worth are not so drastically affected, showing a 7% increase in peak load.

All of the results are shown in Tables 2 through 5.

Table 2. Summary of Simple Parametric Simulations for Prototypical B1+ House in Chicago

Measure	Case	Load (MMBtu) Heat	Load (MMBtu) Cool	Load (kBtu/ft^2) Heat	Load (kBtu/ft^2) Cool	Peak Load (kBtu) Heat	Peak Load (kBtu) Cool
Base Case*		144.6	11.8	44.9	3.7	91.1	37.3
Infiltration	0.0005elf	135.0	11.3	41.9	3.5	83.1	35.4
	0.0007elf	154.1	12.3	47.9	3.8	99.6	39.2
	0.0008elf	163.6	12.9	50.8	4.0	107.6	41.9
AC Setting	76(76)**	144.7	17.2	44.9	5.3	91.1	41.7
	76(84)	144.6	12.3	44.9	3.8	91.1	52.8
	78(84)	144.5	8.8	44.9	2.7	91.1	50.2
	80(80)	144.4	7.6	44.9	2.3	91.1	33.0
	80(84)	144.4	5.9	44.8	1.8	91.1	42.0
	82(82)	144.4	4.4	44.8	1.4	91.1	29.4
	82(84)	144.3	3.8	44.8	1.2	91.1	32.5
Ventilation	No Venting	144.2	12.9	44.8	4.0	91.1	37.3

* Base Case is for the prototype model with the following properties: AC setting 78 F; AC setup 78 F; infiltration 0.0006 elf; with venting.

** In A(B), A denotes the cooling setpoint and B denotes the setup temperature.

Table 3. Summary of Combined Parametric Simulations for Prototypical B1+ House in Chicago

Measure Infiltration	Measure Setpoint	Measure Setup	Measure Ventilation	Load (MMBtu) Heat	Load (MMBtu) Cool	Load (kBtu/ft^2) Heat	Load (kBtu/ft^2) Cool	Peak Load (kBtu) Heat	Peak Load (kBtu) Cool
0.0006elf	78	78	No Venting	144.2	12.9	44.8	4.0	91.1	37.3
0.0006elf	78	78	Venting	144.6	11.8	44.9	3.7	91.1	37.3
0.0005elf	78	78	Venting	135.0	11.3	41.9	3.5	83.1	35.4
0.0005elf	78	84	Venting	135.0	8.5	41.9	2.6	83.1	46.3
0.0005elf	80	80	Venting	134.9	7.2	41.9	2.2	83.1	31.4
0.0005elf	80	84	Venting	134.9	5.7	41.9	1.8	83.1	40.0

Table 4. Summary of Simple Parametric Simulations for Prototypical B1+ House in Forth Worth

		Load (MMBtu)		Load (kBtu/ft^2)		Peak Load (kBtu)	
Measure	Case	Heat	Cool	Heat	Cool	Heat	Cool
Base Case*		34.9	36.8	13.2	14.0	45.4	38.6
Infiltration	0.0005elf	32.3	35.1	12.3	13.3	43.1	36.4
	0.0007elf	37.5	38.4	14.2	14.6	47.8	40.7
	0.0008elf	40.1	40.0	15.2	15.2	50.2	42.8
AC Setting	76(76)**	35.1	46.4	13.3	17.6	45.4	40.9
	76(78)	34.9	36.5	13.2	13.9	45.4	41.2
	78(84)	34.8	30.1	13.2	11.4	45.4	41.3
	80(80)	34.8	28.7	13.2	10.9	45.4	35.9
	80(84)	34.7	24.6	13.2	9.3	45.4	38.9
	82(82)	34.7	21.8	13.2	8.3	45.4	33.1
	82(84)	34.7	19.9	13.2	7.5	45.4	34.1
Ventilation	No Venting	34.6	38.7	13.1	14.7	45.4	38.6

* Base Case is for the prototype model with the following properties: AC setting 78 F; AC setup 78 F; infiltration 0.0006 elf; with venting.

** In A(B), A denotes the cooling setpoint and B denotes the setup temperature.

Table 5. Summary of Combined Parametric Simulations for Prototypical B1+ House in Forth Worth

Measure				Load (MMBtu)		Load (kBtu/ft^2)		Peak Load (kBtu)	
Infiltration	Setpoint	Setup	Ventilation	Heat	Cool	Heat	Cool	Heat	Cool
0.0006elf	78	78	No Venting	34.6	38.7	13.1	14.7	45.4	38.6
0.0006elf	78	78	Venting	34.9	36.8	13.2	14.0	45.4	38.6
0.0005elf	78	78	Venting	32.3	35.1	12.3	13.3	43.1	36.4
0.0005elf	78	84	Venting	32.2	28.9	12.2	11.0	43.1	38.7
0.0005elf	80	80	Venting	32.2	27.4	12.2	10.4	43.1	33.9
0.0005elf	80	84	Venting	32.2	23.6	12.2	9.0	43.1	36.8

APPENDIX E: PEAK COOLING LOAD SENSITIVITY ANALYSIS

We analyzed several issues related to prototype peak cooling loads in the single family database simulation.

PEAK WEATHER CONDITIONS

For example, it was noted that a "cold" location like Chicago had higher peak cooling loads than a "hot" location like Miami. These peak loads are determined by peak summer weather conditions that are unrelated to either the length of the cooling season or average summer temperatures. To clarify this distinction, we suggested that we show the coincident weather conditions when peak cooling loads occur. In fact, the maximum temperature and humidity ratio on the peak cooling day are more relevant as weather indicators. The reason is that buildings typically take several hours to respond to peak weather conditions, so that the coincident conditions at the peak hour can be misleading. Table 1 gives the results for selected buildings and locations, along with the design-day conditions from the ASHRAE *Handbook of Fundamentals*.

Table 1. Comparison of the Peak Weather Conditions from Weather Tapes to ASHRAE Design-Day Conditions

	ASHRAE (97.5%) *		Concident to peak load			Max. on peak cooling day		
City	Dry Bulb (°F)	Wet Bulb (°F)	Dry Bulb (°F)	Wet Bulb (°F)	Date and Hour	Dry Bulb (°F)	Wet Bulb (°F)	Date and Hour
Chicago	91	74	90	74	5/12(18)	91	73	5/12(15)
Miami	90	77	87	78	9/10(18)	89	80	9/10(13)
Phoenix	107	71	103	72	7/3 (19)	103	72	7/3 (16)
Seattle	82	66	89	68	8/1 (16)	89	68	8/1 (16)

* Source : *ASHRAE Handbook, 1977 Fundamentals*

Table 1 shows several things: (1) Peak cooling conditions do not vary greatly between cities despite differences in the lengths of their cooling seasons. For example, the peak drybulb temperature in Chicago is higher than that in Miami using any of the three weather criteria, while the wetbulb is only 3 to 7 degrees lower. (2) The maximum temperatures on the peak cooling day are only slightly higher than the coincident temperatures, despite time differences of 3 to 5 hours. This suggests that peak cooling loads occur on days when temperatures remain high for many hours. (3) The peak temperatures on the weather tapes are very similar to

ASHRAE design-conditions. This indicates that the relatively small peak loads in the data base cannot be attributed to unrealistically mild data on the weather tapes. The following paragraph discusses the issue of peak loads in more detail.

PEAK COOLING LOADS

The peak cooling loads on the data base are significantly lower than both the earlier data base results and typical air-conditioner capacities. For example, it was noted that only some of the poorly insulated old and large prototype houses (A, B1+ and D+), and none of the others, had peak loads in the three-ton (36,000 Btu) range found in typical air-conditioners.

The differences from the earlier data can be attributed to the following modeling improvements that tend to lower the calculated cooling loads : 1. better "weighting-factor" calculations in DOE-2.1D to account for the effects of thermal mass, 2. varying infiltration rates depending on outdoor wind speed and temperature (Sherman-Grimsrud model) instead of fixed air-change rates, 3. window shading schedules varying with season instead of constant all year, 4. windows assumed open for natural ventilation instead of of closed at all times, and 5. lower heat gains from occupants and appliances. A quantitative assessment of the individual impacts of these modeling differences would require diagnostic computer simulations and further analysis.

It is important that the data base peak loads not be misinterpreted as *design loads*. The data base loads do not include duct losses or sizing factors to account for unexpected conditions. In practice, designers typically add a duct loss factor of 10 to 20%, a sizing factor of 1.15 for cooling and 1.20 for heating, and then select the equipment of the next available size.* To compare and contrast these differences, we have explored the following:

a. Calculate peak loads assuming design-day conditions. We checked the equipment capacities calculated by DOE-2 based on the yearly weather data against design-day calculations using ASHRAE 97.5% design conditions. This was done for both Phoenix and Miami. For Phoenix, using the design-day data resulted in smaller peak loads. For Miami, similar cooling capacities are picked up in both methods. This clearly shows that there was no peak smoothing due to the weather data used in the DOE-2 simulations. This observation is consistent with the analysis of peak weather conditions described earlier in this section.

b. Calculate peak loads using standard ASHRAE design procedures. Since the above calculation was still done by the DOE-2 program, we used the *Comply-24* computer program (copyright Mike Gabel Associates, 1984) to do standard ASHRAE design calculations for several of the prototypical houses. The ASHRAE design calculation for residential buildings is identical to the Manual-J used by contractors for residential air-conditioner sizing. Since the ASHRAE design calculation accounts for latent loads only as a fractional value of the sensible

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* Adrian Tuluca, Steven Winters Associates, personal communication.

load, we assumed typical values of 0.20 for Chicago, Seattle and Phoenix, and 0.30 for humid Miami. We also used a typical duct loss factor of 10% and then added to the Comply-24 results a sizing factor of 1.15. Table 2 compares the results from these ASHRAE design calculations to building peak loads from the data base. The ASHRAE Design Loads are shown both with and without duct losses and sizing factors.

Table 2. Loads from ASHRAE Design Calculations Compared to Building Peak Loads from the Data Base

Location	House Size (ft^2)	House Type	ASHRAE Design Loads w/o duct loss & size factor (kBtu/hr)	ASHRAE Design Loads w/ duct loss & size factor (kBtu/hr)	Peak Loads from DOE-2 data base (kBtu/hr)
Chicago	2420	D	27.4	34.6	26.3
Miami	1830	D	27.1	34.3	19.2
Phoenix	1880	D	28.8	36.4	28.8

c. Checked the impact of modified operations on building peak loads. Another consideration is that in our building models the air-conditioner is never turned off nor is there a thermostat setup during the day. Since many houses are not occupied during the day, their occupants will typically turn the equipment off when they leave in the morning, and then it back on when they return. This causes a larger peak load because the equipment will then have to cool down the house in the late afternoon. Because of the high probability of such transient loads, contractors generally add a safety factor into their design calculations. To investigate their impact on peak cooling loads, we made a series of simulations using such a modified schedule. At the same time, we disabled the natural ventilation routine for those hours when the people are not home. Table 3 shows the effect of this modified schedule on peak cooling loads.

It becomes clear looking at Table 3 that a 15-20% safety margin makes sense when sizing the cooling equipment. Based on discussions with practicing architects and engineers, such a "sizing factor" is indeed used by many people in the field.

Concluding remarks on peak loads : In the course of this investigation, we talked to three independent sources †, all of whom stated that residential air-conditioner sizing was inexact and follows tradition rather than rigorous calculations. The comparison of weather tape to

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† Adrian Tuluca, Steven Winters Associates; Bruce Birdsall, Lawrence Berkeley Laboratory; Jim Brodrick, Pacific Northwest Laboratory, formerly with Carrier.

Table 3. Percent Increase in Peak Cooling Loads due to Modified Schedule

City	Percent increase in peak cool. load	City	Percent increase in peak cool. load
Boston	20	Fort Worth	-4
New York	25	New Orleans	10
Chicago	20	Denver	28
Minneapolis	13	Albuquerque	42
Kansas	10	Phoenix	18
Washington	10	Seattle	25
Atlanta	16	San Francisco	20
Miami	0	Los Angeles	43

design-day climate data indicates that the data base peak loads are not being "damped" by the weather tape conditions. The comparison of the peak loads to ASHRAE design loads shows that the two are roughly comparable if the safety factors in the design load calculations are eliminated. However, the spot check of a plausible modification to the operating condition shows that such safety factors are prudent and necessary.

The ultimate test of the validity of the simulated loads is that they compare well with metered and billed data. This section confirms the quality of the data. The modeling improvements inherent in version DOE 2.1D were made to improve the realism of the model and improve the validity of the results. The modeling enhancements were made after significant peer review.

APPENDIX F: LATENT LOAD SENSITIVITY ANALYSIS

We analyzed the impact of different latent load assumptions on the simulated prototype cooling loads. LBL was asked by GRI to verify the latent loads in the data base results, as well as the possibility of window venting introducing additional latent load.

a. Comparison of data base latent loads to measured results. We contacted the Florida Solar Energy Center (FSEC) for data on latent cooling loads in single-family residences The only measured data which they have analyzed are from an unoccupied townhouse in Florida.* In this building, latent loads ranged from 25 to 37% of the total cooling equipment loads, with an average of 30%. For the data base simulations in Miami, the latent fraction ranges from 25% in the A house to 30% in the D house, which is slightly on the low side of the measured data. In comparison, data from the GRI research house suggests that latent loads are even smaller. For a cooling system operating at high speed and outdoor conditions of 78 to 85 °F and 75 to 87% relative humidity, the latent fraction is only 13 to 15%. †

The two sources of latent loads are infiltration and internal gains. The DOE-2 "Loads" output for the Miami D house shows that infiltration dominates, accounting for 87% of the latent load. However, we re-ran the data base D prototypes with increased latent internal gains to study the effects of our internal gains inputs. FSEC provided latent gains assumptions they used in a previous GRI report ‡ which indicate our latent internal gains assumptions may be on the low side. They assumed higher latent gains from occupants (4490 Btu/day vs. 2290 Btu/day) and included latent gains from plants and other household activities using water (3000 Btu/day). Thus, for the sensitivity runs we increased the latent internal gains from approximately 11,000 to 20,000 Btu/day. The results for Miami and Phoenix are presented below. In Miami, the total cooling load and the latent load increased by only 0.9 MMBtu/yr. The latent fraction thus increases from 30.1% to 32.0%. In Phoenix, an arid climate, the effect on total cooling load was also very small, yet the latent fraction increased from 8.7% to 10.8% (see Table 4).

b. Effect of different window venting criteria on latent loads. The DOE-2 program allows the user to specify one of three choices of window operations: temperature-control, enthalpic-control, or no venting at all (i.e., windows always closed). Temperature venting is done when outside conditions are cooler than indoor, whereas enthalpic venting is done when

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* Danny Parker, Florida Solar Energy Center, personal communication.

† William Bassett, Gas Research Institute, personal communication. For information on the GRI Research House, see "GRI's Research House Utilization Plan," Topical Report GRI-91/0035, Chicago, IL.

‡ "Latent and Sensible Load Distributions in Conventional and Energy Efficient Residences", GRI Contract No. 5082-243-0727.

Table 4. Effect of Increased Latent Internal Gains on DOE-2 Calculated Heating and Cooling Loads

City	Latent Gains(Btu/day)	Total Cooling Load(MMBtu)	Latent Cooling Load(MMBtu)	Latent Fraction
Miami	11,011	35.2	10.6	30.1%
	20,000	36.1	11.5	32.0%
Phoenix	11,011	30.0	2.6	8.7%
	20,000	30.7	3.3	10.8%

outside conditions are both cooler and less humid. Table 5 demonstrates the effect of this variable on building heating and cooling loads. The peak loads are not affected at all by this variable.

Table 5. Effect of Different Types of Window Ventilation of DOE-2 Calculated Heating and Cooling Loads

City	Venting Type	Heating Load(MMBtu)	Total Cooling Load(MMBtu)	Latent Cooling Load(MMBtu)
Miami	No Venting	1.3	36.6	10.9
	Enthalpic Venting	1.6	35.2	10.6
	Temperature Venting	1.6	31.3	9.5
Phoenix	No Venting	6.2	32.2	2.6
	Enthalpic Venting	6.6	30.0	2.6
	Temperature Venting	6.6	29.7	2.5

BINNED RESULTS

APPENDIX G: MONTHLY DOMESTIC HOT WATER LOADS BY CITY

	Monthly Hot Water Loads (MMBtu)												
REGION/City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
NORTHEAST													
Boston	1.75	1.57	1.67	1.50	1.43	1.28	1.27	1.29	1.31	1.47	1.55	1.70	17.81
New York	1.65	1.47	1.56	1.40	1.33	1.19	1.18	1.19	1.22	1.38	1.45	1.60	16.63
NORTH CENTRAL													
Chicago	1.74	1.55	1.63	1.45	1.36	1.21	1.20	1.22	1.26	1.44	1.52	1.68	17.27
Minneapolis	1.97	1.74	1.81	1.59	1.47	1.30	1.29	1.33	1.40	1.62	1.73	1.92	19.18
Kansas City	1.62	1.44	1.51	1.33	1.24	1.10	1.10	1.13	1.18	1.35	1.43	1.58	16.03
SOUTH													
Washington	1.58	1.41	1.48	1.33	1.25	1.13	1.12	1.14	1.18	1.33	1.40	1.54	15.90
Atlanta	1.33	1.18	1.25	1.13	1.08	0.99	0.99	1.02	1.04	1.16	1.20	1.30	13.68
Miami	0.91	0.82	0.89	0.83	0.83	0.78	0.79	0.80	0.79	0.84	0.84	0.90	10.03
Fort Worth	1.24	1.10	1.16	1.04	0.98	0.89	0.89	0.90	0.93	1.05	1.10	1.21	12.50
New Orleans	1.13	1.00	1.07	0.98	0.95	0.88	0.89	0.90	0.92	1.01	1.03	1.11	11.86
WEST													
Denver	1.79	1.59	1.67	1.50	1.43	1.29	1.29	1.32	1.36	1.53	1.60	1.75	18.12
Albuquerque	1.44	1.28	1.34	1.19	1.13	1.02	1.02	1.05	1.09	1.23	1.29	1.41	14.48
Phoenix	1.22	1.08	1.13	1.01	0.95	0.85	0.85	0.87	0.90	1.02	1.08	1.19	12.17
Seattle	1.58	1.42	1.53	1.42	1.40	1.30	1.32	1.33	1.33	1.43	1.45	1.56	17.10
San Francisco	1.36	1.23	1.35	1.28	1.29	1.22	1.25	1.24	1.22	1.29	1.27	1.35	15.36
Los Angeles	1.25	1.13	1.24	1.18	1.18	1.12	1.13	1.12	1.10	1.16	1.15	1.22	13.99

APPENDIX H: BINNED BUILDING LOADS

BUILDING LOADS BINNED BY TEMPERATURE AND HUMIDITY RATIO

These tables show the total heating, total cooling, and latent cooling loads in kBtu and the number of full-load hours for each building by 5 degree temperature bins for heating, and by 5 degree temperature and .002 humidity ratio bins for cooling. The midpoints of the bins are identified on the left of each table for the one-dimensional temperature bins for heating loads, or on the left (for temperatures) and across the top (for humidity ratios) of each table for the two-dimensional bins for cooling loads. For example, the temperature bin 62.5 includes all loads for temperatures between 60 and 65 F; likewise, the humidity bin 0.003 includes all loads when humidity ratios are between 0.002 and 0.004.

BUILDING LOADS BINNED BY TEMPERATURE AND HOUR OF DAY

These tables show the heating and cooling loads in kBtu for each building binned two-dimensionally by 5 degree temperatures and the hour of day. The midpoints of the temperature bins are identified on the left of the tables. For example, the temperature bin 62.5 includes loads when outdoor temperatures are between 60 and 65 F. The hour of day bins are identified across the top of the tables, with the 25th column indicating the total load for each temperature bin. Likewise, the bottom row on the tables indicates the total load for each hour of the day. Since the hour-of-day bins are too detailed for many applications, the same bin information has been combined into three 8-hour time-of-day periods, or two periods separating setback from no setback hours.

BUILDING LOADS BINNED BY TEMPERATURE AND TIME-OF-DAY PERIODS

These tables show the heating and cooling loads in kBtu for each building binned by 5 degree temperatures and by three eight-hour time-of-day periods (12 a.m. - 8 a.m., 8 a.m. - 4 p.m., and 4 p.m. - 12 a.m.), or by two periods separating setback from no setback hours of operation. Setback is assumed from 11 p.m. until 7 a.m. The midpoints of the temperature bins are identified on the left of the tables. For example, the temperature bin 62.5 F includes loads when outdoor temperatures are between 60 and 65 F. The time-of-day bins are identified across the top of the tables - the first three, for the eight-hour time periods; the next two, for no setback and setback hours; and the last, for the total load for all hours. The bottom row on each table gives the total load for each time-of-day period.

BUILDING LOADS BINNED BY TEMPERATURE AND HUMIDITY RATIO

ChiC- c Bsmt   Chicago IL

Heating Loads   Binned vs. Temperature

72.5	3
67.5	69
62.5	462
57.5	1080
52.5	2012
47.5	2868
42.5	5389
37.5	9605
32.5	11649
27.5	10204
22.5	6221
17.5	5956
12.5	4430
7.5	2805
2.5	1831
-2.5	568
-7.5	309
-12.5	0
-17.5	0
-22.5	0
Htg Ld	65461

Total Cooling Loads   Binned vs. Temperature and Humidity

T/H.R.	.001	.003	.005	.007	.009	.011	.013	.015	.017	.019	.021	All
117.5	0	0	0	0	0	0	0	0	0	0	0	0
112.5	0	0	0	0	0	0	0	0	0	0	0	0
107.5	0	0	0	0	0	0	0	0	0	0	0	0
102.5	0	0	0	0	0	0	0	0	0	0	0	0
97.5	0	0	0	0	0	0	158	52	0	0	0	210
92.5	0	0	0	0	69	19	425	565	240	41	0	1359
87.5	0	0	0	164	184	484	543	1278	655	50	0	3357
82.5	0	0	38	186	502	448	580	825	504	75	0	3157
77.5	0	0	42	46	350	479	346	254	161	0	0	1677
72.5	0	0	0	6	40	97	101	44	9	0	0	297
67.5	0	0	0	0	0	2	12	14	0	0	0	28
62.5	0	0	0	0	0	0	0	0	0	0	0	0
57.5	0	0	0	0	0	0	0	0	0	0	0	0
52.5	0	0	0	0	0	0	0	0	0	0	0	0
Cl Lds	0	0	80	401	1144	1528	2165	3032	1569	166	0	10085

Latent Cooling Loads   Binned vs. Temperature and Humidity

T/H.R.	.001	.003	.005	.007	.009	.011	.013	.015	.017	.019	.021	All
117.5	0	0	0	0	0	0	0	0	0	0	0	0
112.5	0	0	0	0	0	0	0	0	0	0	0	0
107.5	0	0	0	0	0	0	0	0	0	0	0	0
102.5	0	0	0	0	0	0	0	0	0	0	0	0
97.5	0	0	0	0	0	0	25	10	0	0	0	35
92.5	0	0	0	0	5	2	79	131	72	14	0	303
87.5	0	0	0	5	18	71	106	326	201	20	0	746
82.5	0	0	0	5	49	74	124	230	175	31	0	688
77.5	0	0	0	1	41	80	78	71	50	0	0	322
72.5	0	0	0	0	6	16	24	13	3	0	0	62
67.5	0	0	0	0	0	0	4	5	0	0	0	8
62.5	0	0	0	0	0	0	0	0	0	0	0	0
57.5	0	0	0	0	0	0	0	0	0	0	0	0
52.5	0	0	0	0	0	0	0	0	0	0	0	0
Cl Lds	0	0	0	10	118	244	440	784	501	65	0	2163

BUILDING LOADS BINNED BY TEMPERATURE AND HOUR OF DAY

ChiC- c Bsmt   Chicago IL

Heating Loads   Binned vs. Hour and Temperature

T/Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
72.5	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
67.5	0	0	0	0	0	27	26	10	2	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	69
62.5	0	0	0	2	2	144	150	53	41	13	3	5	6	6	2	6	6	5	6	1	5	3	1	0	462
57.5	0	0	2	0	0	227	188	170	86	53	55	33	29	22	33	28	24	18	21	26	27	29	10	0	1080
52.5	0	0	4	15	20	333	420	240	144	100	73	87	93	64	52	45	39	49	40	41	43	64	46	0	2012
47.5	2	12	37	69	101	356	346	306	304	210	114	110	50	41	62	51	72	84	120	104	115	130	73	0	2868
42.5	26	82	146	181	210	368	597	485	223	228	215	192	190	201	196	215	223	227	236	223	233	264	227	2	5389
37.5	171	290	335	355	396	433	919	588	549	492	414	406	402	353	284	290	285	359	361	433	476	489	512	12	9605
32.5	189	276	372	417	394	465	862	772	650	554	539	513	454	429	464	482	556	527	525	531	594	535	513	39	11649
27.5	341	422	487	535	525	452	987	716	615	464	287	222	261	246	205	249	250	388	409	410	438	532	622	141	10204
22.5	163	255	242	289	335	405	738	426	324	227	300	269	187	157	216	135	159	167	232	240	229	178	239	108	6221
17.5	212	236	261	242	198	278	411	387	297	260	221	135	226	227	141	190	214	226	198	307	291	325	339	132	5956
12.5	116	160	223	260	364	256	517	472	256	196	95	125	65	19	64	75	101	161	182	159	200	202	109	55	4430
7.5	127	146	125	129	132	221	274	118	207	205	109	53	24	45	22	25	65	78	115	106	140	57	191	89	2805
2.5	47	53	118	149	154	96	190	295	140	0	29	25	0	0	0	22	25	30	60	100	73	134	62	31	1831
-2.5	61	66	32	0	0	65	95	0	46	34	0	0	0	0	0	0	0	0	0	0	0	37	82	50	568
-7.5	0	0	35	71	72	36	47	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	309
-12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-17.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-22.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat	1455	1999	2418	2712	2903	4167	6767	5085	3884	3036	2454	2176	1985	1811	1741	1813	2019	2320	2507	2681	2864	2983	3026	657	65461

BUILDING LOADS BINNED BY TEMPERATURE AND HOUR OF DAY (CONT.)

ChiC- c Bsmt   Chicago IL

Total Cooling Loads   Binned vs. Hour and Temperature

T/Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
117.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97.5	0	0	0	0	0	0	0	0	0	0	16	18	32	38	42	21	43	0	0	0	0	0	0	0	210
92.5	0	0	0	0	0	0	0	0	11	17	36	110	208	279	273	238	149	38	0	0	0	0	0	0	1359
87.5	0	0	0	0	0	0	0	6	34	163	284	307	339	362	421	455	380	375	182	39	10	0	0	0	3357
82.5	3	0	0	0	0	0	3	39	112	145	136	171	174	275	324	365	393	320	261	209	119	66	34	10	3157
77.5	3	0	0	0	0	0	2	10	2	26	33	31	61	92	142	192	230	225	188	150	117	93	67	14	1677
72.5	0	0	0	0	0	0	0	0	0	0	0	0	3	3	6	29	46	45	42	53	48	17	5	0	297
67.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	13	5	2	0	0	0	0	28
62.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cool	5	0	0	0	0	0	5	55	159	351	506	636	817	1049	1207	1300	1250	1017	678	452	294	175	105	24	10085

ChiC- c Bsmt   Chicago IL

Latent Cooling Loads   Binned vs. Hour and Temperature

T/Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
117.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97.5	0	0	0	0	0	0	0	0	0	0	3	3	6	7	7	3	6	0	0	0	0	0	0	0	35
92.5	0	0	0	0	0	0	0	0	2	4	9	32	46	61	59	50	33	7	0	0	0	0	0	0	303
87.5	0	0	0	0	0	0	0	2	8	43	68	70	75	77	88	93	78	80	52	10	3	0	0	0	746
82.5	1	0	0	0	0	0	1	11	33	37	32	38	35	51	52	58	68	69	62	61	41	23	12	3	688
77.5	1	0	0	0	0	0	1	3	0	6	8	6	12	15	26	27	39	35	40	31	27	24	17	4	322
72.5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	5	11	9	10	11	10	3	1	0	62
67.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	1	1	0	0	0	0	8
62.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cool	2	0	0	0	0	0	1	16	43	89	119	148	175	212	232	237	238	204	165	113	81	51	30	7	2163

BUILDING LOADS BINNED BY TEMPERATURE AND TIME OF DAY PERIODS

ChiC- c Bsmt   Chicago IL

Heating Loads   Binned vs. Time of Day and Temperature

	12am-8am	8am-4pm	4pm-12am	No setback Hours	Setback Hours	All Hours
72.5	3	0	0	0	3	3
67.5	63	4	1	15	53	69
62.5	351	82	27	162	298	462
57.5	587	339	155	664	417	1080
52.5	1032	658	322	1220	792	2012
47.5	1229	942	698	1946	923	2868
42.5	2095	1660	1635	3778	1612	5389
37.5	3487	3190	2927	6693	2911	9605
32.5	3747	4085	3820	8638	3014	11649
27.5	4465	2549	3190	6314	3890	10204
22.5	2853	1815	1552	3685	2535	6221
17.5	2225	1697	2032	3984	1970	5956
12.5	2368	895	1169	2481	1951	4430
7.5	1272	690	841	1560	1243	2805
2.5	1102	216	515	995	838	1831
-2.5	319	80	169	199	369	568
-7.5	308	0	0	47	261	309
-12.5	0	0	0	0	0	0
-17.5	0	0	0	0	0	0
-22.5	0	0	0	0	0	0
Heat	27506	18900	19057	42385	23078	65461

Total Cooling Loads   Binned vs. Time of Day and Temperature

	12am-8am	8am-4pm	4pm-12am	No setback Hours	Setback Hours	All Hours
117.5	0	0	0	0	0	0
112.5	0	0	0	0	0	0
107.5	0	0	0	0	0	0
102.5	0	0	0	0	0	0
97.5	0	167	43	210	0	210
92.5	0	1172	187	1359	0	1359
87.5	6	2365	986	3357	0	3357
82.5	45	1702	1412	3143	16	3157
77.5	15	579	1084	1659	19	1677
72.5	0	41	256	297	0	297
67.5	0	0	29	29	0	28
62.5	0	0	0	0	0	0
57.5	0	0	0	0	0	0
52.5	0	0	0	0	0	0
Cool	65	6025	3995	10051	34	10085

Latent Cooling Loads   Binned vs. Time of Day and Temperature

	12am-8am	8am-4pm	4pm-12am	No setback Hours	Setback Hours	All Hours
117.5	0	0	0	0	0	0
112.5	0	0	0	0	0	0
107.5	0	0	0	0	0	0
102.5	0	0	0	0	0	0
97.5	0	29	6	35	0	35
92.5	0	263	40	303	0	303
87.5	2	522	223	747	0	746
82.5	13	336	339	683	5	688
77.5	5	100	217	316	6	322
72.5	0	7	55	62	0	62
67.5	0	0	8	8	0	8
62.5	0	0	0	0	0	0
57.5	0	0	0	0	0	0
52.5	0	0	0	0	0	0
Cool	19	1255	889	2153	10	2163

APPENDIX I: BINNED CLIMATE DATA

The bins are identified on the left and across the top of each table, with the identifier denoting the midpoint of each bin. For example, the temperature bin 62.5 F indicates the number of hours when outside temperatures are between 60 and 65 F; likewise, the humidity bin 0.003 indicates the number of hours when humidity ratios are between 0.002 and 0.004.

BINNED CLIMATE DATA

ChiC- c Bsmt   Chicago IL

Ambient Hours   Binned vs. Hour and Temperature

T/Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
122.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
117.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97.5	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	1	2	0	0	0	0	0	0	0	11
92.5	0	0	0	0	0	0	0	0	1	1	3	7	12	15	13	11	7	2	0	0	0	0	0	0	72
87.5	0	0	0	0	0	0	0	1	4	15	25	25	28	26	26	27	22	23	12	3	1	0	0	0	238
82.5	1	0	0	0	0	0	1	9	23	29	27	33	27	31	32	31	30	25	25	23	14	9	6	3	379
77.5	18	16	9	6	6	9	20	35	33	34	30	24	32	26	29	28	28	28	28	27	28	28	27	19	568
72.5	30	25	32	31	24	30	35	35	31	26	26	29	23	23	24	26	28	28	27	34	33	35	35	37	707
67.5	38	41	37	38	44	40	38	29	30	27	29	30	26	27	23	23	20	28	37	33	32	30	33	38	771
62.5	32	33	34	31	35	35	32	25	29	29	24	20	25	23	28	29	27	28	21	23	33	34	33	32	695
57.5	33	36	40	40	36	26	22	28	25	19	23	24	23	24	23	19	26	19	27	31	28	29	29	30	660
52.5	27	22	18	21	20	30	31	24	21	24	23	25	23	24	18	20	20	24	19	18	19	20	21	22	534
47.5	20	21	22	24	25	24	19	23	29	26	19	18	16	14	19	17	17	18	25	22	24	23	21	20	506
42.5	26	28	29	28	28	26	25	27	14	19	23	23	25	31	29	31	30	28	25	24	23	26	25	28	621
37.5	39	39	35	34	35	32	33	26	30	32	32	32	34	32	29	30	30	31	31	35	36	36	37	34	794
32.5	27	27	31	31	29	31	27	30	30	28	32	33	29	27	31	32	35	34	34	34	36	33	31	31	743
27.5	32	32	32	33	31	26	28	25	25	22	15	12	15	17	15	16	15	21	21	21	22	27	30	30	563
22.5	12	15	13	14	16	20	19	13	11	9	14	14	10	8	12	9	9	8	11	11	10	8	10	13	289
17.5	13	12	12	11	9	12	10	11	10	10	10	6	11	12	8	9	11	10	9	13	12	13	13	13	260
12.5	7	8	10	11	15	10	12	13	8	7	4	6	3	1	3	4	4	6	7	6	7	7	4	5	168
7.5	6	6	5	5	5	8	6	3	6	7	4	2	1	2	1	1	3	3	4	4	5	2	6	6	101
2.5	2	2	4	5	5	3	4	7	4	0	1	1	0	0	0	1	1	1	2	3	2	4	2	2	56
-2.5	2	2	1	0	0	2	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	2	16
-7.5	0	0	1	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
-12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-17.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-22.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

BINNED CLIMATE DATA (CONT.)

ChiC- c Bsmt   Chicago IL

Ambient Hours   Binned vs. Humidity and Temperature

T/H.R.	.001	.003	.005	.007	.009	.011	.013	.015	.017	.019	.021	All
122.5	0	0	0	0	0	0	0	0	0	0	0	0
117.5	0	0	0	0	0	0	0	0	0	0	0	0
112.5	0	0	0	0	0	0	0	0	0	0	0	0
107.5	0	0	0	0	0	0	0	0	0	0	0	0
102.5	0	0	0	0	0	0	0	0	0	0	0	0
97.5	0	0	0	0	0	0	8	3	0	0	0	11
92.5	0	0	0	0	4	1	23	30	12	2	0	72
87.5	0	0	0	14	13	37	38	88	44	4	0	238
82.5	0	0	4	25	47	62	73	97	61	10	0	379
77.5	0	1	20	31	101	116	106	116	75	2	0	568
72.5	0	13	48	85	143	119	169	110	20	0	0	707
67.5	0	20	75	122	166	192	162	34	0	0	0	771
62.5	1	52	88	251	189	111	3	0	0	0	0	695
57.5	0	65	172	262	155	6	0	0	0	0	0	660
52.5	2	105	210	206	11	0	0	0	0	0	0	534
47.5	9	157	247	93	0	0	0	0	0	0	0	506
42.5	26	327	266	2	0	0	0	0	0	0	0	621
37.5	33	613	148	0	0	0	0	0	0	0	0	794
32.5	136	603	4	0	0	0	0	0	0	0	0	743
27.5	283	280	0	0	0	0	0	0	0	0	0	563
22.5	264	25	0	0	0	0	0	0	0	0	0	289
17.5	260	0	0	0	0	0	0	0	0	0	0	260
12.5	168	0	0	0	0	0	0	0	0	0	0	168
7.5	101	0	0	0	0	0	0	0	0	0	0	101
2.5	56	0	0	0	0	0	0	0	0	0	0	56
-2.5	16	0	0	0	0	0	0	0	0	0	0	16
-7.5	8	0	0	0	0	0	0	0	0	0	0	8
-12.5	0	0	0	0	0	0	0	0	0	0	0	0
-17.5	0	0	0	0	0	0	0	0	0	0	0	0
-22.5	0	0	0	0	0	0	0	0	0	0	0	0