LBL-21101

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

To be presented at the ASHRAE Winter Conference,
New York, NY, January 18-21, 1987

CLIMATE INDICATORS FOR ESTIMATING RESIDENTIAL HEATING AND COOLING LOADS

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November 1986

APPLIED SCIENCE
DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract Number DE-AC03-76SF-00098.

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ABSTRACT

An extensive data base of residential energy use generated with the DOE-2.1A simulation code provides us an opportunity for correlating building loads predicted by an hourly simulation model to commonly used climatic parameters such as heating and cooling degree-days, and to newer parameters such as insolation-days and latent enthalpy-days. We have emphasized the identification of reliable climatic parameters for estimating cooling loads and the incremental loads for individual building components, such as changing ceiling and wall R-values, infiltration rates or window areas.

We find the single parameter correlating best to total heating loads to be *daily* heating degree-days at base temperatures ranging from 56 F to 65 F depending on the thermal integrity of the house. However, higher correlations are obtained using two parameters *daily* heating degree-days and heating insolation-hours at base 65 F. For cooling, degree-day correlations alone are not accurate because of the presence of latent loads. We find that sensible cooling loads correlate best to *hourly* cooling degree-days at base temperatures ranging from 65 F to 71 F modified to omit vented hours, while latent cooling loads correlate to latent enthalpy-days at base 78 F and 0.0116 humidity ratio. The incremental savings in loads for added insulation correlate to base 65 F *daily* degree-days in heating, but to base 75 F *hourly* degree-days in cooling for ceiling and wall measures, and to base 65 F *vented hourly* degree-days in cooling for foundations measures. The incremental changes in window loads due to increased window size correlate to combinations of heating and cooling degree-days with insolation-days.

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† This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract Number DE-AC03-76SF-00098.

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INTRODUCTION

The influence of various energy conservation options on residential energy use in typical houses in the United States has been extensively analyzed. Over the past five years, the Energy Analysis Program at Lawrence Berkeley Laboratory has compiled a comprehensive residential energy data base using the DOE-2.1A program for five prototype houses (one-story, two-story, split-level, and two townhouses) with three types of foundations in 45 U.S. locations. The data base was originally created as the technical basis for the Department of Energy funded *Affordable Housing through Energy Conservation* project (Dept. of Energy 1986.1). The data has since been used in the PEAR simplified residential energy analysis computer program (Ritschard 1985), for the proposed energy standards for new federal residential buildings (Dept. of Energy 1986.2), and for the 1986 update of ASHRAE-90.2 residential energy standards. DOE-2.1A is a dynamic building energy analysis simulation program that calculates on an hour-by-hour basis the energy performance of a building for any climate (Dept. of Commerce 1980).

For each building and foundation type in the 45 locations, the data base contains roughly 20 simulations showing the energy impact of typical conservation measures such as ceiling, wall, and foundation insulation, different window glazings and areas, and varying infiltration rates. Sensitivity analyses was also done in a smaller number of base locations for optional conservation measures such as added south windows, reflective and heat-absorbing glazings, night insulation, whole house fans, attached sunspaces and night setbacks. The research effort in creating the data base is documented in the technical support document for the *Affordable Housing through Energy Conservation* project (Huang 1986).

The original purpose in correlating the data base to climatic parameters was to develop a simple extrapolation procedure for extending the data base to locations outside the 45 base cities. That effort is documented in Chapter 5 of the technical support document. This paper summarizes the results of the analysis, together with substantial extentions of the work.

Although analysis has been performed on data for all five prototype houses, in the interest of space this paper describes fully the results only for the one-story prototype. The analytical approach is valid for all five prototypes, and differences in those results from the one-story prototype will be noted. A sketch of the one-story prototype building is shown in Figure 1. Brief descriptions of the prototype houses and the assumed operating conditions are given in Table 1. The thermostat setpoints, ventilation schedule, and internal loads should be noted in particular because of their effects on the calculated building energy use.

In this paper we confine the discussion to observed correlations between the data base and various climatic parameters. We use the following energy use characteristics from the data base in the regression analysis: (1) total heating and cooling loads and (2) incremental heating and cooling loads (Δ loads) for incremental changes in conservation, i.e., added ceiling insulation or increased window area. We then calculate the correlations between these loads and the following climatic parameters: (1) temperature (daily and hourly heating and cooling degree-days at various base temperatures), (2) humidity (latent enthalpy-days), and (3) solar (winter, heating, and cooling insolation-days to various bases). Based on the regression results, we identify certain climatic parameters or combinations of parameters as the most reliable for estimating energy use in residential buildings. We also discuss the application of the results for simplified calculations or to extend the DOE-2 data base to other locations.

BUILDING LOADS DATA

The DOE-2.1A data base for each prototype house consists of more than 1,000 runs covering 45 locations (Table 2). For each location and foundation type, there is a set of from 18 to 20 simulations. These parametric sets differ somewhat depending on the foundation type chosen for the base location. We simulated higher insulation levels for the basement and crawl space configurations because of their prevalence in the colder locations. The parametric options chosen represent typical combinations of standard conservation measures and range from no insulation and single-pane windows to R-60 ceilings, R-27 walls, and triple-pane windows.

We have taken the data points for total heating and cooling loads from the systems loads in the DOE-2 data base. For the correlation analysis against climatic parameters, we selected four general levels of thermal integrity, identified throughout this paper for simplicity as uninsulated, loose, medium, and tight houses (Table 3).

We base the incremental changes in heating and cooling loads, or Δ loads, on analysis that converted the data base to matrix tables giving Δ loads from worst case conservation measures (see Table 4). We derive the individual Δ loads by comparing successive simulations in the data base where only that conservation measure has been changed. The cumulative Δ loads are composite values that assume all building components are tightened simultaneously. For example, the Δ load for R-0 to R-38 ceiling is the sum of the Δ load from R-0 to R-19 ceiling on an uninsulated house, plus the Δ load from R-19 to R-38 ceilings on a moderately insulated house. This procedure produces Δ loads representative of typical construction practices, and includes implicitly interactions between building components under typical conditions.

Further analysis showed that the component Δ loads are basically linear with respect to the following changes in building parameters: effective conductance for ceiling wall, and foundation insulation measures, window areas for window measures, and air change rates for infiltration measures (for a complete description of the data base analysis, see Huang 1985). Therefore, for each component, regression analysis needs to be done for only a single Δ load. We use the following data points from the one-story data base for the regression analysis of Δ heating and cooling loads: R-11 to R-38 ceilings, R-11 to R-27 walls, R-0 to R-5 4 feet edge insulation in slab foundations, R-0 to R-10 8 feet wall insulation in basement foundations, 10% to 20% window area for single-, double- and triple-pane windows, and 0.4 to 0.7 ach infiltration.

CLIMATIC DATA

The climatic parameters used in the regression analysis have been generated from the same hourly weather tapes as used to build the DOE-2 data base. For 42 of the 45 locations, the DOE-2.1A simulations have been done using "Test Reference Year" (TRY) weather tapes. For the three remaining locations, "Typical Meteorological Year" (TMY) tapes were used (see Table 2).†

Although most of the climatic parameters were tabulated on an hourly basis, we have converted all to daily equivalents to maintain consistency with well-known terms such as heating and cooling degree-days. To distinguish hourly values from climatic data based on daily values, we call them either *daily* or *hourly* degree-days. We have investigated the following climate parameters:

1. *Daily Heating Degree-Days (HDD)* at base temperatures from 46 F to 65 F, using maximum and minimum (max-min) daily temperatures.

$$\sum_{i=1}^{i=365} [T_{base} - [(T_{max} - T_{min})/2]]_{+} \qquad \begin{matrix} + = 1 \text{ if } \geq 0 \\ + = 0 \text{ if } < 0 \end{matrix} \qquad (1)$$

   This is the closest approximation to the traditional heating degree-days such as the 30-year long-term averages published by the National Oceanic and Atmospheric Administration (NOAA).

2. *Hourly Heating Degree-Days (HDHR)* at different base temperatures from 46 F to 65 F.

$$1/24 \sum_{i=1}^{i=365} \sum_{j=1}^{j=24} [T_{base} - T]_{+} \qquad \begin{matrix} + = 1 \text{ if } \geq 0 \\ + = 0 \text{ if } < 0 \end{matrix} \qquad (2)$$

   This term is actually heating degree-hours divided by 24. It is gaining usage with the increasing availability of hourly weather data and is the degree-day value often cited in hourly weather tape summaries.

3. *Daily Cooling Degree-Days (CDD)* at base temperatures from 60 F to 79 F, using maximum and minimum daily average temperatures.

   Cooling degree-days equivalent to Equation 1.

4. *Hourly Cooling Degree-Days (CDHR)* at base temperatures from 60 F to 79 F.

   Cooling degree-days equivalent to Equation 2.

5. *Vented Hourly Cooling Degree-Days (CDHRV),* $T \geq 78$ *F or* $T \geq T_{base}$ *and humidity ratio* ≥ 0.0116, at base temperatures from 60 F to 78 F.

   We modified hourly cooling degree-days to account for the enthalpy dependent ventilation assumption used in the DOE-2 simulations. Cooling degree-days are not counted when both the ambient temperature is below 78 F *and* humidity ratio is

† TRY weather tapes were selected as the largest set of hourly climate data available when the data base was created in 1981. The use of other climate data such as TMY or ASHRAE WYEC ("Weather Year for Energy Calculations") weather tapes will of course change the values for individual climatic parameters, such as the number of degree-days or the amount of insolation, but it needs to be investigated how much they will affect the functional relationship between those climatic parameters and loads.

below 0.0116 (Figure 2). This humidity ratio (lbs. of water per lb. of air) corresponds to the upper limit of the human comfort zone (ASHRAE 1985).

6. *Latent Enthalpy-Days (LED)* at base temperature of 78 F and base humidity ratio of 0.0116

$$1/24 \sum_{i=1}^{i=365} \sum_{j=1}^{j=24} [E - E_o]_+ \qquad \begin{array}{l} E_o = \textit{enthalpy at } T \text{ and } \textit{humidity ratio}_{base} \\ + = 1 \text{ if } T \geq 78\ F \\ + = 0 \text{ if } T < 78\ F,\ or\ E - E_o < 1 \end{array} \tag{3}$$

We use the enthalpy equivalent of degree-days for correlating latent cooling loads. Latent enthalpy-days (actually latent enthalpy-hours divided by 24) defines the amount of energy that must be removed from the air each hour to lower it to the ASHRAE comfort zone humidity ratio of 0.0116 without changing the drybulb temperature. To discount those hours when the air conditioner is not operating, we count only those hours when the drybulb is above the cooling thermostat setpoint of 78 F.

7. *Heating Insolation-Days (HID)* at 57 F, 60 F and 65 F base temperatures.

$$1/24 \sum_{i=1}^{i=365} \sum_{j=1}^{j=24} [\frac{1}{4}(S_n + S_s + S_e + S_w)]_+ \qquad \begin{array}{l} S = \textit{hourly insolation on vertical surface} \\ + = 1 \text{ if } T < T_{base} \\ + = 0 \text{ if } T \geq T_{base} \end{array} \tag{4}$$

This term is the total insolation hitting an average one-square-foot vertical surface during hours when temperatures are below a designated value (Bowen 1982). We devise this parameter for correlating useful solar heat gain. The threshold temperature omits those hours when there are no heating loads.

8. *Cooling Insolation-Days (CID, CIDV)* at 60 F, 65 F and 70 F base temperatures.

$$1/24 \sum_{i=1}^{i=365} \sum_{j=1}^{j=24} [\frac{1}{4}(S_n + S_s + S_e + S_w)]_+ \qquad \begin{array}{l} S = \textit{hourly insolation on vertical surface} \\ + = 1 \text{ if } T > T_{base} \\ + = 0 \text{ if } T \leq T_{base} \end{array} \tag{5}$$

This term is the total insolation hitting an average one-square-foot vertical surface when temperatures are above a designated value. We use this parameter for correlating cooling load penalties due to unwanted solar gain. The threshold temperature omits those hours when there are no cooling loads. As for hourly cooling degree-days, cooling insolation-days have been counted both including and omitting those hours when T < 78 F and humidity ratio < 0.0116.

9. *Winter Insolation-Days (WID).*

$$1/24 \sum_{i=1}^{i=month} [\sum_{j=1}^{j=days} \sum_{k=1}^{k=24} \frac{1}{4}(S_n + S_s + S_e + S_w)]_+ \qquad \begin{array}{l} S = \textit{hourly insolation on vertical surface} \\ + = 1 \text{ if } HDD_{month} \geq 200 \\ + = 0 \text{ if } HDD_{month} < 200 \end{array} \tag{6}$$

This term is the total insolation hitting an average one-square-foot vertical surface during winter months, defined as those with more than 200 heating degree-days calculated at a base temperature of 59 F. The threshold degree-day limit omits those months with minimal heating loads.

Appendices 2 through 7 list the values of these climatic parameters for the 45 base locations covered in the DOE-2 data base.

ANALYSIS

Climatic Correlations for Total Heating Loads

The traditional heating degree-days method for estimating building heating requirements was first developed more than 50 years ago using average daily temperatures and a base temperature of 65 F. In recent years, several suggestions have been made to improve the accuracy of this well-known method. For degree-day values to correlate with actual building loads, the base temperature should correspond to the average balance point temperature of the house, defined as the outside temperature below or above which the house will require mechanical heating or cooling to maintain the set indoor condition. The house balance point temperature depends on its thermal integrity, internal and solar gains, and thermostat settings. One study noted that 65 F may no longer be applicable to current houses due to their improved thermal integrity and suggested that a lower base temperature be used (Arens 1978). Others have proposed a variable-base method taking into account differing balance point temperatures (Kusuda 1981). In addition, with the increasing availability of hourly weather data, researchers have been moving toward calculating degree-days using hourly rather than average daily temperatures.

As an preliminary step, we compared *daily* and *hourly* heating degree-day values from the same weather tapes for different base temperatures (Appendix 1). Compared to the traditional max-min daily value, the *hourly* heating degree-day values are always higher. This discrepancy is most pronounced both in relative and absolute terms in temperate climates with long swing seasons. For example, the difference in base 65 °F heating degree-days is only 177 or 2% in Minneapolis, but 466 or 13% in San Francisco. The greatest differences are found in mild arid climates with large day-night temperatures swings. In Phoenix, the difference is 482 degree-days or 25% between daily and hourly values.

This comparison shows that when using heating degree-days values, attention must be paid to how they were calculated. For example, the 30-year long-term heating degree-day tables available from the National Climatic Center for over 3,000 locations are *daily* heating degree-days based on max-min temperatures. When compared to *hourly* heating degree-days from the TRY weather tapes for the 45 locations in the data base, there is an apparent 5% offset (Figure 3). However, when compared to the more equivalent *daily* heating degree-days, there is no bias in the scatter (Figure 4), indicating that in general the temperatures on the TRY data are close to long-term averages.

We use the SPSS statistical package to regress total annual heating loads from the DOE-2 data base to both *hourly* and *daily* heating degree-days at base temperatures from 53 F to 65 F. Table 5 summarizes the results. In general, all the correlations are quite good, with correlation coefficients (R) in the range from .9848 to .9952. Despite their greater precision, the correlations using *hourly* degree-days are in many cases poorer than those with *daily* values. This is due to several reasons, among them that geographical and seasonal variations in solar gain are not accounted for in the degree-day calculations. For both sets of regressions, we have used degree-days calculated at the same base temperatures for all locations, whereas the actual balance point temperatures can be expected to vary by location and time of year.

As expected from balance point principles, the regressions indicate that the base temperatures showing the best linearity between heating loads and degree-days shift downwards with improved thermal integrity. These base temperatures are identifiable by having the highest correlation coefficients and the smallest y-intercepts and are indicated in bold in Table 5. The relationship between base temperatures and linearity is illustrated by Figures 5 through 7. Although *daily* heating degree-days at base 65 F correlates linearly with loads for the uninsulated one-story house (Figure 5), they produce increased scatter and a substantial y-intercept when correlated to loads for the medium house (Figure 6). The best correlation for the medium house occurs using base 60 F *daily* heating degree-days (Figure 7). If *hourly* degree-days are used, the best fit is found at 57 F (Figure 8).

For *daily* heating degree-days, the base temperatures vary from 64 F for the uninsulated to 59 F for the tight option in the one-story prototype. For *hourly* heating degree-days, they are lower by a few degrees, ranging from 61 F to 56 F. Compared to the one-story buildings, base temperatures are esentially identical for the other two detached house prototypes (two-story and split-level), but roughly two degrees lower for the two townhouse prototypes. With a few caveats, these temperatures can be interpreted as national average balance point temperatures for the five prototype houses (see Table 6, columns 2 and 6).

These imputed balance point temperatures are highly dependent on the house characteristics and assumed operating conditions. For example, we have observed that if the night setback assumption is removed, the base temperatures rise by 2 to 3 degrees.

The results from the heating loads to degree-days correlations for all five prototypes are summarized in Table 6. At the imputed balance point temperatures, a basic linear relationship exists between heating loads and heating degree-days as indicated by the high correlation coefficients and minimal intercepts. Therefore, the heating loads in the residential DOE-2 data base can be approximated using the simple degree-day equation:

$$HL\ (MBtu) = (House\ K\!-\!value\ *\ 24)\,(A\ *\ HDD_{base})\ x\ 10^{-6} \qquad (7)$$

where HL = building heating load

HDD_{base} = *daily* heating degree-days at base temperatures given in column 1 in Table 6

and A = .87 for detached houses, .85 for townhouses

The 0.87 or 0.85 slopes are based on the regression results indicating that although the relationship of *daily* heating degree-days to DOE-2 heating loads is very linear, steady-state calculations generally give 12%-15% higher loads than the DOE-2 data base. This discrepancy is evident in Figure 7, where the slope according to the steady-state UA approximation is indicated by the dashed line. One can ignore this difference if *daily* degree-days are used only to extrapolate or adjust DOE-2 heating loads for degree-day differences, but it should be included when estimating heating loads directly from degree-day values.

For the *hourly* degree-day correlations, the slopes are within 5% of the steady-state value for the detached houses and within 10% for the townhouses, indicating good correspondence with the approximation:

$$HL\ (MBtu) = (House\ K{-}value\ *\ 24)\ (HDHR_{base})\ x\ 10^{-6} \tag{8}$$

where HL = building heating load

and $HDHR_{base}$ = *hourly* heating degree-days at base temperatures given in column 6 of Table 6.

A more literal usage of the regression results from Table 6 is :

$$HL\ (MBtu) = (House\ K{-}value\ *\ 24)\ (A\ *\ Heating\ Degree{-}days_{base})\ x\ 10^{-6} + B \tag{9}$$

where $Heating\ Degree\text{-}days_{base}$ = *daily* or *hourly* heating degree-days at base temperatures from columns 1 and 6 in Table 6

A = slopes from columns 3 or 8 in Table 6

B = intercepts from columns 4 or 9 in Table 6

We attribute most of the scatter on the heating degree-day correlations to geographical variations in solar gain. To account for this effect, we have done two-parameter regressions combining heating insolation-days with *daily* and *hourly* heating degree-days at various base temperatures. We find the best correlations for all levels of thermal integrity occur using base 65 F heating insolation-days with standard base 65 F *daily* heating degree-days:

$$HL\ (MBtu) = [(House\ k{-}value\ *\ 24)\ (A\ *\ HDD_{65}) + (Window\ area\ *\ Trans\ *\ 24)\ (B\ *\ HID_{65})]\ x\ 10^{-6} + C \tag{10}$$

where $Trans$ = Window glass transmission

A = slopes from column 2 of Table 7

B = slopes from column 3 of Table 7

and C = intercept from column 4 of Table 7

Our assumption in this formulation is that for the two-parameter regressions solar gain should be accounted for, not as a balance point reduction, but as an offsetting heat gain source.

Results of the two-parameter regressions for all five prototype houses are given in Table 7, and representative plots for the one-story prototype shown in Figures 9 and 10. In contrast to the variable-base degree-day regressions, the correlations do not deteriorate for the higher thermal integrities but remain above .994. Compared to the heating degree-day only regressions, the standard errors are marginally improved for the uninsulated house, but from 30% to 40% smaller for the medium and tight houses.

Climatic Correlations for Sensible, Latent, and Total Cooling Loads

Correlations of cooling loads to standard degree-day data are less straightforward than for heating loads due to the added presence of latent loads and window venting. However, once these effects have been accounted for in the selection of climatic variables, we find the resulting correlations show linearities comparable to those for heating loads.

The differences between *daily* and *hourly* cooling degree-days show a similar trend to that found for heating as described in a previous section (compare columns 8 and 9 of Appendix 1). The discrepancies are largest in arid locations with large temperature swings, such as Phoenix (446 degree-days or 13%), but insignificant in humid locations with small temperature swings such as Miami (47 degree-days or 1%).

Using regression analyses we first compared cooling loads for the four levels of thermal integrity against *daily* and *hourly* cooling degree-days at base temperatures ranging from 60 F to 72 F. The results of the cooling degree-day regressions are shown in Table 8. In contrast to the heating regressions, we find it difficult to impute a simple balance point temperature for all parameters because of the divergence between base temperatures with the highest correlations and those with the smallest intercepts. As true for heating, *hourly* degree-days do not produce higher correlations than *daily* degree-days and are noticeably poorer for the tighter thermal integrities (compare Figures 11 and 12). For both types of cooling degree-days, the large scatter and slopes indicate there are significant cooling loads not accounted for by the degree-day approximations.

Since degree-days measure only temperature differences, they should correlate to sensible, but not to latent cooling loads. To investigate this hypothesis, we separated the one-story cooling loads into sensible and latent components and then correlated sensible loads separately to cooling degree-days. We find the resulting correlations somewhat improved for *daily* cooling degree-days, with coefficients ranging from .9671 to .9942, and significantly improved for *hourly* cooling degree-days, with coefficients from .9917 to .9938 (Table 9 and Figures 13 and 14). In both cases, the correlations are significantly improved for the tighter thermal integrities. For *daily* cooling degree-days, the best correlations occur at a base temperature of 68 F, except for the uninsulated house, where 72 F works better. For *hourly* cooling degree-days, the best correlations occur at base temperatures ranging from 65 F for the tight to 71 F for the uninsulated house.

However, there remain significant negative intercepts in these *hourly* cooling degree-day regressions which we attribute to the cooling load reductions due to venting. To account for this effect, we make a further modification in the tabulation of *hourly* cooling degree-days by omitting those hours when venting takes place (Kusuda 1981). The DOE-2 data base was generated with an enthalpic venting schedule that assumed open windows only when the enthalpy of outside air is lower than that indoors. Therefore, we calculate modified *hourly* cooling degree-day by omitting those hours when temperatures are less than 78 F *and* humidity ratios are less than 0.0116. For simplicity we term this modification *vented hourly* cooling degree-days.* We have not attempted to modify *daily*

* If the DOE-2 data base had been generated using a temperature rather than enthalpy dependent venting schedule, the appropriate *hourly* cooling degree-day modification would have been to omit *all* hours with temperatures less than 78 F

cooling degree-days because of the imprecision of the daily time step.

There are strong regional variations in the differences between *hourly* and *vented hourly* values (compare columns 9 and 10 of Appendix 1). We find milder locations with long swing seasons show the largest reductions in absolute as well as relative terms (439 degree-days at base 65 F or 29% in Albuquerque). For comparison, in hot arid Phoenix the reductions are 409 degree-days or 11%, and in hot humid Brownsville, 182 or 5%. The percent reductions in cooling degree-days correlate moderately well with the vented loads in the DOE-2 data base, indicating that they approximate the effects of the enthalpic venting schedule (Figure 15). †

Correlations of sensible cooling loads to *vented hourly* cooling degree-days produced further improvements for all but the uninsulated house, with coefficents for the insulated thermal integrities ranging from .9940 to .9959, and reduced intercepts (Table 10 and Figure 16).

The results of the sensible cooling loads correlations to various types of cooling degree-days for the one-story prototype are summarized in Table 11. The generalized regression equation is:

$$SCL\ (MBtu) = (House\ K{-}value\ *\ 24)\ (A\ *\ Cooling\ degree{-}days_{base})\ x\ 10^{-6} + B \qquad (11)$$

where $Cooling\ degree\text{-}days_{base}$ = either *daily, hourly,* or *vented hourly* cooling degree-days at base temperatures listed on columns 1,5,9 of Table 11

A = slopes on columns 3,7,11 of Table 11

B = intercept on columns 4,8,12 of Table 11

To account for latent cooling loads, we determined that *latent enthalpy-days* is a useful climatic indicator. This parameter measures the amount of energy that must be removed from the air at a constant dry-bulb temperature in order to bring it to a reference humidity ratio of 0.0116 defined earlier. We also calculated but did not use sensible enthalpy-days, since they are essentially proportional to cooling degree-days.

The latent cooling loads in the DOE-2 data base vary only slightly for the different thermal integrity levels because internal conditions and infiltration rates have not been changed, and because DOE-2 does not treat the absorption and desorption of moisture by building materials and furniture. Since the sensible cooling load varies with house thermal integrity, the latent fraction ranges from 25% to 35% in humid Miami and from 5% to 11% in arid Phoenix, depending on the house thermal integrity. The regression analysis indicates a good correlation between latent cooling loads and latent enthalpy-days (Table 12 and Figure 17). Due to the small variation in latent loads, the regression results are similar for all four thermal integrities, with coefficients averaging 0.965. There is a striking anomaly in one location (Honolulu) where the DOE-2 latent loads are more than 200% of the predicted loads using latent enthalpy-days.

† The cooling load reductions shown by the DOE-2 data base for natural venting are less than optimum because the summer ventilation schedule (up to 78 F) is assumed to be from May 15 through September 30 for all 45 locations, with a winter ventilation schedule (up to 72 F) assumed for the rest of the year. This fixed operating condition lowers the benefit of natural venting in warm locations with lengthy cooling seasons.

The following equation can be used to estimate latent loads for the four thermal integrity levels :

$$LCL\ (MBtu) = A * LED_{78} * Air\ Change * 24 + B \tag{12}$$

where LCL = latent cooling load in MBtu
LED_{78} = latent enthalpy-days at 78 F and .0116 humidity ratio in Btu-days/lb of air
$Air\ Change$ = air changes per hour in lbs of air
A = slope from column 2 of Table 12
B = intercept from column 3 of Table 12

Separate analyses for sensible and latent cooling loads indicate that correlations for total cooling loads should be done using two parameters: cooling degree-days for the sensible portion and latent enthalpy-days for the latent portion. Such two-variable regressions have been done for all five prototype houses using latent enthalpy-days in combination with either *daily* cooling degree-days or *vented hourly* degree-days at various base temperatures. The highest correlations occur at base temperatures ranging from 64 F to 70 F for *daily* cooling degree-days and from 60 F to 69 F for *vented hourly* cooling degree-days (Table 13). At these base temperatures, the regressions are quite linear, with coefficients around .995 for all but the uninsulated house using *daily* cooling degree-days, and even higher using *vented hourly* degree-days. (Figures 18 and 19).

Similar to the case in heating, we also have done correlations adding another climatic parameter, cooling insolation-days, to account for the effects of solar gain. Based on the climatic correlations for Δ loads described later in this paper, we have chosen 70 F base cooling insolation-days and 75 F base *hourly* cooling degree-days, in addition to 78 F and 0.0116 humidity ratio latent enthalpy-days. Results of the three parameter regressions for all five prototype houses are summarized in Table 14. There are good correlations for all four thermal integrity levels, with coefficients generally above .994 and standard errors of roughly 2 MBtu (Figure 20).

$$CL\ (MBtu) = [\ (House\ k\!-\!value * 24)\ (A * CDHR_{75}) + (Window\ area * Trans * 24)\ (B * CIDV_{65}) + (Air\ change * 24)\ (C * LED_{78})]\ x\ 10^{-6} + D \tag{13}$$

where $Trans$ = Window glass transmission
A = slopes from column 2 of Table 14
B = slopes from column 3 of Table 14
C = slopes from column 4 of Table 14
and D = intercept from column 5 of Table 14

Climatic Correlations for Δ Loads

In this part of the paper, we describe those climatic parameters found to correlate well to Δ heating and cooling loads due to individual conservation measures. Although the previous regressions are adequate for estimating total house loads, we find that they may be significantly in error when applied to individual conservation measures for specific house components. For example, although cooling degree-days is the predominant climatic determinant for sensible cooling loads, we find cooling insolation-days to be far more important for determining Δ loads due to increased window size. Conversely, a component-by-component regression analysis clarifies the climatic determinants affecting individual component loads and can lead to more accurate ways for correlating total house loads. The results of the Δ loads regression analysis are summarized in Tables 15 through 18 and described below.

Ceiling, Wall, and Foundation Δ Loads. Since these Δ loads are due to changes in conduction, we have done regressions using degree-days as the predominant and insolation-days as the secondary climatic parameter. For heating, we find the best correlations with standard base 65 F *daily* heating degree-days (*HDD*) with standard errors of roughly .30 MBtu for both ceiling and wall Δ loads (Table 15 and Figures 21 through 24):

$$\Delta HL_{ceiling} = .949 * \Delta UA * 24 * HDD_{65} + .01\ MBtu \tag{14}$$

$$\Delta HL_{wall} = .909 * \Delta UA * 24 * HDD_{65} - .09\ MBtu \tag{15}$$

$$\Delta HL_{slab\ foundation} = .770 * \Delta UA * 24 * HDD_{65} - .32\ MBtu \tag{16}$$

$$\Delta HL_{basement\ foundation} = .925 * \Delta UA * 24 * HDD_{65} - .36\ MBtu \tag{17}$$

The addition of heating insolation-days as a second parameter does not improve the correlation, and the use of *hourly* values or different base temperatures for heating degree-days makes it worse (Table 15). This indicates that differences in sol-air effects have minimal impact on the Δ heating loads, and that Δ loads for each component should be calculated using a temperature close to the indoor thermostat setpoint rather than the balance point of the house.

For cooling, we find the best correlations using *hourly* cooling degree-days (*CDHR*) at base 75 F for ceiling and wall Δ loads, and *vented hourly* cooling degree-days at base 65 F for foundation Δ loads (Figures 25 through 28):

$$\Delta CL_{ceiling} = 1.64 * \Delta UA * 24 * CDHR_{75} + .34\ MBtu \tag{18}$$

$$\Delta CL_{wall} = 1.10 * \Delta UA * 24 * CDHR_{75} - .01\ MBtu \tag{19}$$

$$\Delta CL_{slab\ foundation} = .558 * \Delta UA * 24 * CDHRV_{65} - .27\ MBtu \tag{20}$$

$$\Delta CL_{basement\ foundation} = .760 * \Delta UA * 24 * CDHRV_{65} + .35\ MBtu \tag{21}$$

The correlation coefficients are noticeable poorer than those for heating, but because Δ loads are smaller, the standard errors are similar for ceilings and basement foundations (approximately 0.3 MBtu), smaller for walls (0.1 MBtu), but significantly larger for slab foundations (1.3 MBtu). The high base temperature indicates that Δ cooling loads for ceilings and walls should also be calculated using a base temperature closer to the indoor setpoint rather than the balance point temperature of the house. As in heating, two parameter regressions with an additional solar term (cooling insolation-days at base 70 F) do not significantly improve the correlation (Table 16).

Infiltration Δ Loads. Infiltration Δ loads are due to changes in convective heat flow. For heating, the Δ loads are sensible and correlate to heating degree-days. As for the insulation measures, we find the best correlation using standard base 65 F *daily* heating degree-days (Figure 29 and Table 17), with a standard error of 0.60 MBtu.

$$\Delta HL_{infiltration} = .946 * \Delta UA_{equivalent} * 24 * HDD_{65} + .67\ MBtu \tag{22}$$

For cooling, the Δ loads have a latent as well as a sensible term; therefore, they should correlate to latent enthalpy-days (LED_{78}) together with cooling degree-days. This is confirmed by the regression results (Table 17), where the addition of the latent parameter reduces the standard error by nearly a half from 0.83 to 0.42 MBtu. We find the best regression using cooling degree-days (either *hourly* or *daily*) at base 75 F with latent enthalpy-days at 78 F and 0.0116 humidity ratio (Figure 30).

$$\Delta CL_{infiltration} = (.905 * \Delta UA_{equivalent} * 24 * CDHR_{75}) + (.472 * Ach_{lbs\ air} * 24 * LED_{78}) - .50\ MBtu \tag{23}$$

Window Δ Loads. Window Δ loads result from changes in conduction as well as solar gain. Consequently, we have done two parameter regressions using heating or cooling degree-days in conjunction with insolation-days. For heating, we also have done regressions substituting winter insolation-days for heating insolation-days. Separate regressions are done for single-, double-, and triple-pane windows (Table 18).

In heating, for single pane windows the primary climatic parameter is *daily* heating degree-days at base 65 F, indicating the dominance of conductive heat losses over solar gain. The addition of heating insolation-days somewhat improves the regression, reducing the standard error from 1.58 to 1.14 MBtu (Figures 31 and 32). For double- and triple-pane windows, regressions using degree-days alone are very poor (Figure 33). The addition of heating insolation-days improves the correlations significantly, but the correlation coefficients remain relatively low (Figure 34 and Table 18).

$$\Delta HL_{1-pane} = .774 * \Delta UA * 24 * HDD_{65} - .258 * \Delta Area * Trans * 24 * HID_{65} + .26\ MBtu \tag{24}$$

$$\Delta HL_{2-pane} = .715 * \Delta UA * 24 * HDD_{65} - .257 * \Delta Area * Trans * 24 * HID_{65} - .04\ MBtu \tag{25}$$

$$\Delta HL_{3-pane} = .665 * \Delta UA * 24 * HDD_{65} - .236 * \Delta Area * Trans * 24 * HID_{65} - .11\ MBtu \tag{26}$$

However, because the Δ loads for multipane windows are small, the standard errors are less than 0.8 MBtu. These are smaller than those for single-pane windows, but still more than double those for ceiling and walls. The relatively large scatter indicates that heating insolation-days can be regarded as only approximate indicators of load reductions due to solar gain. Table 18 shows the use of winter insolation-days is even less reliable.

In cooling, we find a strong correlation between window cooling Δ loads and cooling insolation-days (CID_{70}) at base 70 F (Figure 35), with standard errors from .92 to .99 MBtu. These can be further reduced by a third (standard errors from .68 to .80 MBtu) if vented hours are omitted ($CIDV_{70}$, Table 18).

$$\Delta CL_{1-pane} = .567 * \Delta Area * Trans * 24 * CIDV_{70} + .52\ MBtu \tag{27}$$

$$\Delta CL_{2-pane} = .589 * \Delta Area * Trans * 24 * CIDV_{70} + .46\ MBtu \tag{28}$$

$$\Delta CL_{3-pane} = .612 * \Delta Area * Trans * 24 * CIDV_{70} + .37\ MBtu \tag{29}$$

The linearities are so high that adding cooling degree-days improves the correlation only marginally (Figure 36).

Applications of Results

The regression analysis has shown that the geographical variations of loads characteristics in a large DOE-2 residential data base can be converted into linear equations using some common and some not so common climatic parameters as the independent variables. In most instances these relationships can be interpreted as steady-state equations with modified slopes. The errors in this simplification are relatively small (less than 2 MBtu for total loads of an average house, less than 1 MBtu for Δ loads in windows and less than 0.5 MBtu for Δ loads in ceilings and walls) and within the uncertainty band associated with computer models. †

Although the climatic regression results can be used to simplify the data base, the original intent of the work is to develop extrapolation procedures for extending the DOE-2 results to other locations not covered in the data base. The choice of an appropriate extrapolation technique depends on the intended use of the data base, the availability of climatic data, and the complexity of the calculations. For the *Affordable Housing Through Energy Conservation* project, the simplified format of the Energy Sliderules dictated that the climatic extrapolation be reduced to a single multiplicative term. For heating, we chose base 60 F *daily* heating degree-days since they give the best correlations for an average house of medium thermal integrity. For cooling, we chose base 65 F *daily* cooling degree-days primarily because they are available from NOAA for a large number of locations. To reduce extrapolation errors, we grouped secondary locations with base cities having similar heating degree-day ratios (HDD_{65}/HDD_{57}) for heating, or similar latent enthalpy-days to cooling degree-days ratios for cooling (for a description of this extrapolation procedure, see chapter 5 of Huang 1986).

For more detailed extrapolation procedures, climatic data on variable-base degree-days, insolation-days and latent enthalpy-days would be required. If a project is concerned mainly with energy savings rather than total energy use, such is the case for many building energy standards, separate extrapolations can be done for each building component, using, for example, base 75 F cooling degree-days to estimate cooling energy savings due to added insulation, but cooling insolation-days to estimate those due to window shading.

At present, there may be practical problems in using some of the regression results because the needed climatic data may not be available. Parameters such as 65 F *daily* heating and cooling degree-days are well understood and available from NOAA for over 3,000 locations. Other such as latent enthalpy-days or heating insolation-days are not widely available, and would probably have to be calculated by individual users from hourly weather tapes. It is our hope that if the newer climatic parameters indeed prove to be useful and gain acceptance, efforts can then be made to process weather tapes in a systematic fashion and the resulting climatic parameters made available to the public.

Another question that needs to be addressed is how much the relationships we have found between residential loads and different climatic parameters are a function of the weather tapes and modeling strategies that we have used. We hope to answer this

† Validation studies have shown that DOE-2.1 is within 10% for predicting energy use in typical residential buildings over periods of several days or longer (Judkoff, 1983; A.D. Little 1982).

question in the near future by performing similar kinds of climate analysis with results for simulations done using DOE-2.1C with WYEC and TMY weather tapes.

CONCLUSIONS

We find that total heating loads can be estimated with moderate accuracy using the single parameter of variable base *daily* heating degree-days. However, adding a second parameter for heating insolation-hours not only improves the correlation but makes it possible to use standard base 65 F heating degree-days. Once the effects of solar gain have been separated out, the balance point temperatures for the prototypes and thermal integrities investigated are similar enough to permit the use of standard heating degree-days.

For total cooling loads, reliable estimates require at least two climatic parameters. We find good correlations using latent enthalpy hours either with variable-base *hourly* cooling degree-days modified to omit vented hours, or with base 75 F *hourly* cooling degree-days and base 70 F cooling insolation-hours.

In the analysis of Δ loads, we identify the following six climatic parameters as the most useful for correlating load changes in different building components:

	Climatic Parameters	
Component	Heating	Cooling
Ceiling, Walls, and Foundations	HDD_{65}	$CDHR_{75}$, $CDHRV_{65}$
Infiltration	HDD_{65}	$CDHR_{75}$, LED_{78}
Windows	HDD_{65} , HID_{65}	$CIDV_{70}$

HDD_{65} = *daily* heating degree-days at base 65 F.

$CDHR_{75}$ = *hourly* cooling degree-days at base 75 F.

$CDHRV_{65}$ = *vented hourly* cooling degree-days at base 65 F.

HID_{65} = heating insolation-days at base 65 F.

$CIDV_{70}$ = cooling insolation-days at base 70 F, hours below 78 F and .0116 humidity ratio omitted.

LED_{78} = latent enthalpy-days at base 78 F and humidity ratio .0116.

These six parameters cover the major climate-driven heat flows that affect a building's heating and cooling loads: conductive and convective heat losses and solar heat gains during the heating season, and sensible, latent, and solar heat gains during the cooling season. The correlations for Δ heating loads are very good for the conductive and convective effects and adequate for solar gain. The correlations for Δ cooling loads are good for solar gain, adequate for above-ground conductive effects (i.e., ceilings and walls) and infiltration, but in need of improvement for below- ground conductive effects (i.e., foundations).

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Table 1
Description of Prototype Houses and Operating Conditions

Prototype house geometries	One-story ranch	Two-story	Split-level	Middle-unit Townhouse	End-unit Townhouse
Dimensions (ft.) :	28x55x8	28x40x16	28x28x8, 28x20x16	20x30x16	20x30x16
Ceiling area (ft^2) :	1540	2240	1904	1200	1200
Wall area (ft^2) :	1154	1932	1596	476	956
Window area (ft^2) :	154	224	210	144	144
Perimeter length (ft.) :	166	136	160	100	100
Overhangs :	2 ft overhangs assumed over south windows				

Foundation condition	Dependent on prevalent construction type for each location; generally slab in warm locations, heated basement in colder locations, and crawl space in intermediate locations.
Heating setpoint :	70 F, with a 6 hour night setback to 60 F between 12 and 6 a.m.
Cooling setpoint :	78 F all hours
Natural ventilation :	Assumed for those hours when ventilation can satisfy entire cooling load, and enthalpy of outside air is less than that of indoor air, and if temperatures are less than 78° for the summer months (May 15 through September 30) or less than 72° for the rest of the year.
Internal Loads :	(3.2 persons occupancy assumed)
Sensible	43,145 Btu/day , plus lighting at 1 KWh/ft^2 per year.
Latent	12,156 Btu/day.
Window shading :	Shading coefficient of 0.6316 is assumed all year around to account for the effects of sash and drapes.
Heating System †:	Gas furnace with a net seasonal efficiency of 70% and capacities of 75,000 Btu for the uninsulated house and 50,000 Btu for the other thermal integrity levels.
Cooling System :†	Air conditioner with an SEER of 9.2 and a rated capacity of 33,000 Btu.

† The DOE-2 residential data base was generated with the described space conditioning system. However, the climatic regressions described in this paper were done only for only building loads, not energies.

Table 2
Foundation Types and Locations in DOE-2 Residential Data Base

City	Weather data	Slab	Basement	Ventilated crawl
Albuquerque NM	TRY	X		
Atlanta GA	TRY	X	X	X
Birmingham AL	TRY	X	X	
Bismarck ND	TRY		X	
Boise ID	TRY		X	X
Boston MA	TRY		X	
Brownsville TX	TRY	X		
Buffalo NY	TRY		X	
Burlington VT	TRY		X	
Charleston SC	TRY	X		X
Cheyenne WY	TRY		X	
Chicago IL	TRY	X	X	
Cincinnati OH	TRY	X	X	X
Denver CO	TRY		X	
El Paso TX	TRY	X		
Fort Worth TX	TRY	X		
Fresno CA	TRY	X		X
Great Falls MO	TRY		X	
Honolulu HA	TRY	X		
Jacksonville FL	TRY	X		
Juneau AK	TMY		X	
Kansas City MO	TRY		X	
Lake Charles LA	TRY	X		
Las Vegas NV	TMY	X		X
Los Angeles CA	TRY	X		X
Medford OR	TMY		X	X
Memphis TN	TRY	X	X	X
Miami FL	TRY	X		
Minneapolis MN	TRY		X	
Nashville TN	TRY	X	X	X
New York NY	TRY	X	X	
Oklahoma City OK	TRY	X		
Omaha NB	TRY		X	
Philadelphia PA	TRY		X	
Phoenix AZ	TRY	X		
Pittsburgh PA	TRY		X	
Portland ME	TRY		X	
Portland OR	TRY		X	X
Reno NV	TMY	X	X	
Salt Lake City UT	TRY		X	
San Antonio TX	TRY	X		X
San Diego CA	TRY	X		X
San Francisco CA	TRY	X		X
Seattle WA	TRY		X	X
Washington DC	TRY		X	

Table 3
Conservation Measures for Uninsulated, Loose, Medium, and Tight Constructions

Thermal integrity	Ceiling R-value (nominal)	Wall R-value (nominal)	Foundation R-value (nominal)	Infil-tration (ach)	Window glazing (panes)	Prototype house k-values (Btu/h·F) †				
						One-story	Two-story	Split-level	Mid-town	End-town
Uninsulated	R-0	R-0	R-0 slab	0.7	1	1199.9	1390.6	1286.7	669.9	775.0
			R-0 bsmt			1161.3	1351.8	1258.1	627.5	732.7
			R-0 crawl			1379.8	1503.4	1369.4	698.3	803.4
Loose	R-19	R-11	R-0	0.7	1	708.6	868.5	799.1	481.5	522.9
			R-0 bsmt			670.0	829.7	770.5	439.1	480.6
			R-0 crawl			888.5	981.3	881.9	509.9	551.3
Medium	R-30	R-19	R-5 2ft slab	0.7	2	423.1	547.0	479.4	290.6	317.5
			R-5 4ft bsmt			450.1	566.6	482.2	299.6	326.6
			R-11 crawl			466.8	572.8	498.7	293.7	320.6
Tight	R-38	R-27	R-10 2ft slab	0.7	3	347.6	452.0	391.3	241.6	260.6
			R-10 8ft bsmt			366.2	466.0	391.7	249.1	268.1
			R-19 crawl			373.5	466.6	405.1	241.8	260.8

† K-values shown are for prototype houses with exterior siding, which are assumed for all locations except Los Angeles and Fresno, where stucco walls are assumed. K-values for houses with stucco walls are slightly higher than those shown.

Table 4
Δ Loads for Washington, D.C.

WASHINGTON   1 STORY RANCH HOUSE   BASEMENT

HEATING

Base Load = 110.709 MBtu/Yr

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

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

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

Area Multipliers

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

COOLING

Base Load = 39.302 MBtu/Yr

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

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

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

Area Multipliers

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

Table 5
Regression Analysis of Heating Loads for One-story Prototype House against Heating Degree-Days

(Heating loads and intercepts in MBtu, **bold** indicates highest correlation or smallest intercept)

House integrity	*Daily* heating degree-days at various bases												
	53	54	55	56	57	58	59	60	61	62	63	64	65
Uninsulated													
Correlation (R)	.9776	.9810	.9840	.9866	.9888	.9907	.9923	.9936	.9945	.9951	**.9952**	.9950	.9944
Slope	1.2293	1.1861	1.1451	1.1063	1.0699	1.0361	1.0047	.9751	.9473	.9212	.8962	.8723	.8492
Intercept (MBtu)	26.90	24.54	22.16	19.79	17.37	14.90	12.34	9.76	7.13	4.44	1.73	**-.98**	-3.67
Loose													
Correlation (R)	.9755	.9790	.9821	.9848	.9871	.9890	.9904	.9915	.9922	**.9924**	.9922	.9916	.9905
Slope	1.1852	1.1435	1.1037	1.0660	1.0305	.9975	.9667	.9376	.9102	.8844	.8596	.8359	.8130
Intercept (MBtu)	11.84	10.51	9.17	7.84	6.49	5.11	3.70	2.28	.84	**-.63**	-2.11	-3.58	-5.03
Medium													
Correlation (R)	.9830	.9852	.9872	.9888	.9901	.9911	.9917	**.9920**	.9920	.9916	.9910	.9900	.9888
Slope	1.1651	1.1222	1.0816	1.0432	1.0072	.9736	.9423	.9128	.8850	.8589	.8340	.8103	.7876
Intercept (MBtu)	5.22	4.44	3.67	2.89	2.11	1.31	.50	**-.32**	-1.16	-2.01	-2.86	-3.72	-4.56
Tight													
Correlation (R)	.9831	.9851	.9867	.9880	.9890	.9897	**.9901**	.9901	.9898	.9892	.9883	.9871	.9857
Slope	1.1189	1.0776	1.0383	1.0013	.9665	.9342	.9040	.8756	.8489	.8238	.7998	.7771	.7552
Intercept (MBtu)	3.61	3.01	2.40	1.79	1.18	.56	**-.08**	-.73	-1.38	-2.05	-2.72	-3.39	-4.06

House integrity	*Hourly* heating degree-days at various bases												
	53	54	55	56	57	58	59	60	61	62	63	64	65
Uninsulated													
Correlation (R)	.9797	.9824	.9847	.9868	.9885	.9898	.9908	.9914	**.9917**	.9916	.9910	.9902	.9889
Slope	1.2241	1.1812	1.1408	1.1030	1.0672	1.0336	1.0019	.9719	.9433	.9160	.8902	.8654	.8418
Intercept (MBtu)	19.20	16.90	14.57	12.19	9.79	7.34	4.88	2.39	**-.11**	-2.60	-5.11	-7.60	-10.09
Loose													
Correlation (R)	.9762	.9790	.9814	.9834	.9850	.9861	.9869	**.9872**	.9871	.9866	.9857	.9844	.9827
Slope	1.1772	1.1356	1.0964	1.0595	1.0244	.9914	.9602	.9306	.9023	.8754	.8498	.8252	.8019
Intercept (MBtu)	7.59	6.30	5.01	3.70	2.38	1.04	**-.30**	-1.65	-3.00	-4.34	-5.68	-7.01	-8.34
Medium													
Correlation (R)	.9811	.9829	.9844	.9855	.9863	.9868	**.9870**	.9868	.9864	.9856	.9845	.9832	.9817
Slope	1.1534	1.1114	1.0718	1.0346	.9994	.9664	.9352	.9057	.8777	.8511	.8259	.8019	.7791
Intercept (MBtu)	2.74	1.98	1.23	.46	**-.31**	-1.09	-1.88	-2.67	-3.46	-4.25	-5.04	-5.83	-6.63
Tight													
Correlation (R)	.9803	.9818	.9831	.9840	.9846	**.9848**	.9847	.9843	.9836	.9826	.9814	.9799	.9781
Slope	1.1070	1.0665	1.0284	.9926	.9588	.9270	.8970	.8687	.8418	.8162	.7921	.7690	.7471
Intercept (MBtu)	1.67	1.08	.49	**-.11**	-.72	-1.33	-1.95	-2.57	-3.19	-3.81	-4.44	-5.06	-5.69

Table 6
Average Balance Point Temperatures and Regression Results for Heating Loads in Five Prototype Houses

(Heating loads, intercepts, and standard errors in MBtu)

	Daily Heating Degree-days (HDD_{base})					*Hourly* Heating Degree-days ($HDHR_{base}$)				
Prototype & House integrity	1. Base Temp (F)	2. Corr. coeff. (R)	3. UA Slope	4. Inter-cept	5. Stand error	6. Base Temp (F)	7. Corr. coeff. (R)	8. UA Slope	9. Inter-cept	10. Stand error
Ranch										
Uninsulated	64	.9950	.8723	-.98	5.84	61	.9917	.9433	-.11	7.50
Loose	62	.9924	.8844	-.63	3.99	59	.9869	.9602	-.30	5.25
Medium	60	.9920	.9128	-.32	2.72	57	.9863	.9994	-.31	3.54
Tight	59	.9901	.9040	-.08	2.38	56	.9840	.9926	-.11	3.02
Two-story										
Uninsulated	64	.9941	.8472	.43	7.18	62	.9910	.8906	-1.47	8.84
Loose	62	.9932	.8485	.48	4.48	59	.9888	.8945	-.82	5.82
Medium	60	.9924	.8690	.43	3.17	58	.9879	.9208	-.54	3.99
Tight	59	.9904	.8522	.51	2.82	57	.9855	.9045	-.28	3.45
Split-level										
Uninsulated	64	.9939	.8823	-.92	7.10	61	.9907	.9550	-.05	8.75
Loose	62	.9925	.8756	-.64	4.53	59	.9877	.9521	-.34	5.80
Medium	60	.9908	.8812	-.28	3.00	57	.9855	.9648	-.27	3.76
Tight	59	.9882	.8582	-.14	2.63	56	.9825	.9423	-.17	3.21
Middle-unit Townhouse										
Uninsulated	62	.9930	.8434	.01	3.39	59	.9888	.9172	.22	4.30
Loose	60	.9911	.8319	.13	2.50	58	.9856	.8804	-.62	3.17
Medium	57	.9896	.8643	-.06	1.76	55	.9836	.9196	-.57	2.21
Tight	56	.9869	.8411	-.16	1.56	53	.9799	.9305	-.24	1.93
End-unit Townhouse										
Uninsulated	62	.9932	.8610	1.00	4.00	60	.9894	.9086	-.22	4.98
Loose	61	.9917	.8255	-.40	2.71	58	.9866	.9002	-.31	3.43
Medium	58	.9906	.8580	-.22	1.88	55	.9848	.9452	-.29	2.38
Tight	56	.9882	.8608	.10	1.63	54	.9818	.9167	-.35	2.03

HDD_{base} = *Daily* heating degree-days at base temperatures; $HDHR_{base}$ = *Hourly* heating degree-days at base temperatures.

Table 7
Two-dimensional Analysis of Total Heating Loads for Five Prototype Houses

(Heating loads, intercepts, and standard errors are in MBtu)

House integrity	Correlation coefficient (R)	Slopes HDD_{65}	Slopes HID_{65}	Intercept	Standard error
Ranch					
Uninsulated	.9965	.9151	-1.0209	3.85	4.91
Loose	.9957	.9910	-.8794	1.39	3.03
Medium	.9969	.8987	-.9643	1.04	1.72
Tight	.9962	.8774	-1.0562	.97	1.50
Two-story					
Uninsulated	.9954	.8808	-.6983	5.04	6.42
Loose	.9958	.8670	-.6566	2.30	3.59
Medium	.9963	.8544	-.7700	1.65	2.22
Tight	.9953	.8266	-.8577	1.51	1.98
Split-level					
Uninsulated	.9955	.9244	-.8140	4.57	6.15
Loose	.9954	.9027	-.7367	1.89	3.58
Medium	.9957	.8838	-.8139	1.37	2.06
Tight	.9945	.8515	-.8896	1.25	1.81
Middle-unit Townhouse					
Uninsulated	.9954	.8686	-.8139	1.58	2.79
Loose	.9947	.8416	-.7368	.74	1.95
Medium	.9953	.8060	-.8168	.57	1.21
Tight	.9935	.7717	-.8879	.53	1.11
End-unit Townhouse					
Uninsulated	.9951	.8750	-.8474	2.08	3.43
Loose	.9950	.8514	-.7635	.85	2.11
Medium	.9958	.8206	-.8187	.62	1.27
Tight	.9944	.7829	-.9265	.57	1.14

Table 8
Regression Analysis of Cooling Loads for One-story Prototype House against Cooling Degree-Days

(Cooling loads and intercepts in MBtu, **bold** indicates smallest intercept or highest correlation)

House integrity	*Daily* Cooling degree-days at various bases												
	60	61	62	63	64	65	66	67	68	69	70	71	72
Uninsulated													
Correlation (R)	.9610	.9643	.9674	.9705	.9733	.9761	.9787	.9812	.9833	.9850	**.9857**	.9847	.9813
Slope	.5894	.6219	.6579	.6982	.7437	.7954	.8545	.9231	1.0035	1.0977	1.2086	1.3377	1.4888
Intercept (MBtu)	-5.04	-3.99	-2.93	-1.90	-.87	**.15**	1.16	2.14	3.08	4.01	4.94	5.95	7.03
Loose													
Correlation (R)	.9793	.9817	.9839	.9857	.9874	.9888	.9899	.9906	**.9908**	.9901	.9879	.9835	.9758
Slope	.7384	.7786	.8231	.8730	.9290	.9927	1.0652	1.1493	1.2474	1.3617	1.4955	1.6501	1.8292
Intercept (MBtu)	-6.62	-5.83	-5.04	-4.27	-3.49	-2.73	-1.96	-1.23	-.51	**.21**	.94	1.72	2.58
Medium													
Correlation (R)	.9804	.9823	.9839	.9851	.9860	.9866	**.9867**	.9863	.9852	.9828	.9787	.9718	.9612
Slope	1.0291	1.0826	1.1421	1.2086	1.2833	1.3682	1.4648	1.5766	1.7067	1.8576	2.0335	2.2350	2.4668
Intercept (MBtu)	-6.98	-6.25	-5.53	-4.82	-4.10	-3.40	-2.70	-2.03	-1.37	-.71	**-.04**	.68	1.46
Tight													
Correlation (R)	.9797	.9813	.9825	.9834	.9840	**.9842**	.9838	.9829	.9813	.9782	.9733	.9656	.9540
Slope	1.1565	1.2165	1.2832	1.3576	1.4411	1.5359	1.6438	1.7685	1.9135	2.0812	2.2765	2.4997	2.7557
Intercept (MBtu)	-6.67	-6.00	-5.32	-4.66	-4.00	-3.35	-2.70	-2.07	-1.45	-.83	**-.20**	.48	1.21

House integrity	*Hourly* Cooling degree-days at various bases												
	60	61	62	63	64	65	66	67	68	69	70	71	72
Uninsulated													
Correlation (R)	.9755	.9789	.9821	.9851	.9878	.9902	.9922	.9937	**.9945**	.9943	.9926	.9891	.9828
Slope	.6106	.6449	.6829	.7253	.7730	.8267	.8873	.9560	1.0336	1.1215	1.2212	1.3328	1.4567
Intercept (MBtu)	-9.38	-8.55	-7.74	-6.95	-6.18	-5.42	-4.68	-3.95	-3.21	-2.44	-1.62	**-.77**	.20
Loose													
Correlation (R)	.9822	.9841	.9857	.9868	.9875	**.9876**	.9871	.9856	.9830	.9789	.9728	.9641	.9521
Slope	.7554	.7969	.8429	.8940	.9514	1.0157	1.0879	1.1694	1.2608	1.3635	1.4789	1.6066	1.7466
Intercept (MBtu)	-9.43	-8.80	-8.19	-7.57	-6.98	-6.38	-5.80	-5.22	-4.61	-3.98	-3.30	-2.59	**-1.79**
Medium													
Correlation (R)	.9779	.9788	**.9792**	.9790	.9783	.9768	.9745	.9710	.9661	.9592	.9500	.9378	.9219
Slope	1.0528	1.1078	1.1688	1.2364	1.3122	1.3968	1.4916	1.5980	1.7169	1.8492	1.9966	2.1579	2.3321
Intercept (MBtu)	-9.42	-8.81	-8.22	-7.63	-7.05	-6.48	-5.92	-5.35	-4.76	-4.15	-3.49	-2.80	**-2.03**
Tight													
Correlation (R)	.9753	**.9757**	.9757	.9751	.9739	.9719	.9689	.9647	.9591	.9514	.9413	.9280	.9110
Slope	1.1802	1.2415	1.3094	1.3846	1.4688	1.5626	1.6678	1.7856	1.9169	2.0628	2.2249	2.4017	2.5921
Intercept (MBtu)	-8.87	-8.30	-7.74	-7.19	-6.65	-6.12	-5.59	-5.05	-4.50	-3.91	-3.30	-2.64	**-1.91**

Table 9
Regression Analysis of Sensible Cooling Loads for One-story Prototype House against Cooling Degree-Days

(Sensible cooling loads and intercepts in MBtu, **bold** indicates smallest intercept or highest correlation)

House integrity	*Daily* Cooling degree-days at various bases												
	63	64	65	66	67	68	69	70	71	72	73	74	75
Uninsulated													
Correlation (R)	.9381	.9420	.9460	.9500	.9539	.9578	.9615	.9648	.9669	**.9671**	.9646	.9580	.9474
Slope	.5674	.6050	.6480	.6972	.7545	.8216	.9008	.9945	1.1041	1.2335	1.3843	1.5569	1.7541
Intercept (MBtu)	**.14**	.95	1.75	2.53	3.29	4.01	4.73	5.43	6.19	7.01	7.93	8.99	10.21
Loose													
Correlation (R)	.9719	.9748	.9776	.9802	.9826	.9848	.9864	**.9871**	.9860	.9823	.9752	.9633	.9466
Slope	.6627	.7061	.7556	.8122	.8778	.9546	1.0446	1.1505	1.2737	1.4178	1.5843	1.7729	1.9855
Intercept (MBtu)	-2.26	-1.70	-1.14	-.58	**-.05**	.47	.98	1.49	2.05	2.65	3.33	4.11	4.99
Medium													
Correlation (R)	.9854	.9877	.9897	.9915	.9928	**.9937**	.9937	.9923	.9886	.9818	.9710	.9549	.9335
Slope	.8826	.9384	1.0019	1.0745	1.1585	1.2566	1.3710	1.5051	1.6597	1.8393	2.0448	2.2752	2.5318
Intercept (MBtu)	-2.74	-2.24	-1.75	-1.26	-.79	-.33	**.13**	.59	1.09	1.62	2.21	2.88	3.63
Tight													
Correlation (R)	.9884	.9902	.9919	.9931	.9940	**.9942**	.9934	.9912	.9865	.9786	.9664	.9489	.9258
Slope	.9783	1.0399	1.1099	1.1898	1.2823	1.3901	1.5155	1.6623	1.8312	2.0269	2.2502	2.4994	2.7761
Intercept (MBtu)	-2.68	-2.22	-1.77	-1.32	-.88	-.46	**-.03**	.39	.86	1.35	1.91	2.53	3.22

House integrity	*Hourly* Cooling degree-days at various bases												
	63	64	65	66	67	68	69	70	71	72	73	74	75
Uninsulated													
Correlation (R)	.9634	.9680	.9724	.9767	.9809	.9848	.9882	.9906	**.9917**	.9908	.9872	.9803	.9696
Slope	.5963	.6368	.6824	.7343	.7933	.8605	.9370	1.0245	1.1234	1.2345	1.3582	1.4932	1.6369
Intercept (MBtu)	-4.32	-3.75	-3.19	-2.66	-2.14	-1.61	-1.07	-.50	**.09**	.76	1.52	2.41	3.48
Loose													
Correlation (R)	.9847	.9873	.9897	.9916	.9931	**.9938**	.9936	.9918	.9881	.9818	.9721	.9586	.9410
Slope	.6869	.7324	.7836	.8415	.9072	.9815	1.0655	1.1610	1.2678	1.3866	1.5172	1.6577	1.8048
Intercept (MBtu)	-5.02	-4.61	-4.20	-3.80	-3.40	-3.00	-2.58	-2.14	-1.67	-1.14	-.55	**.14**	.95
Medium													
Correlation (R)	.9907	.9920	.9929	**.9931**	.9925	.9909	.9878	.9829	.9755	.9650	.9507	.9322	.9093
Slope	.9133	.9713	1.0364	1.1097	1.1924	1.2855	1.3902	1.5079	1.6385	1.7821	1.9377	2.1026	2.2719
Intercept (MBtu)	-4.99	-4.60	-4.22	-3.84	-3.47	-3.09	-2.69	-2.26	-1.82	-1.32	-.77	**-.14**	.58
Tight													
Correlation (R)	.9911	.9919	**.9921**	.9916	.9903	.9878	.9838	.9778	.9692	.9574	.9417	.9217	.8972
Slope	1.0091	1.0726	1.1438	1.2239	1.3142	1.4157	1.5295	1.6573	1.7986	1.9534	2.1206	2.2971	2.4774
Intercept (MBtu)	-4.68	-4.32	-3.96	-3.61	-3.26	-2.90	-2.52	-2.12	-1.71	-1.24	-.72	**-.13**	.53

Table 10
Regression Analysis of Sensible Cooling Loads for One-story Prototype House against Vented Hourly Cooling Degree-Days

(Cooling loads and intercepts in MBtu, **bold** indicates smallest intercept or highest correlation)

	Vented hourly cooling degree-days at various bases *												
integrity	63	64	65	66	67	68	69	70	71	72	73	74	75
Uninsulated													
Correlation (R)	.9509	.9565	.9623	.9681	.9738	.9791	.9838	.9874	**.9895**	.9894	.9864	.9799	.9694
Slope	.5994	.6420	.6899	.7440	.8053	.8744	.9527	1.0409	1.1399	1.2500	1.3715	1.5034	1.6434
Intercept (MBtu)	1.61	1.52	1.44	1.37	1.32	**1.30**	1.32	1.41	1.57	1.87	2.29	2.90	3.73
Loose													
Correlation (R)	.9815	.9846	.9876	.9902	.9924	.9937	**.9940**	.9926	.9891	.9829	.9732	.9594	.9415
Slope	.6978	.7456	.7993	.8594	.9272	1.0031	1.0886	1.1841	1.2905	1.4074	1.5347	1.6710	1.8132
Intercept (MBtu)	-1.21	-1.23	-1.24	-1.24	-1.22	-1.17	-1.08	-.94	-.74	-.46	**-.07**	.44	1.10
Medium													
Correlation (R)	.9926	.9941	.9952	**.9957**	.9954	.9940	.9910	.9861	.9785	.9676	.9529	.9337	.9102
Slope	.9255	.9870	1.0556	1.1322	1.2180	1.3135	1.4202	1.5382	1.6683	1.8093	1.9607	2.1199	2.2828
Intercept (MBtu)	-1.81	-1.79	-1.77	-1.73	-1.67	-1.58	-1.46	-1.29	-1.07	-.77	-.39	**.10**	.70
Tight													
Correlation (R)	.9947	.9955	**.9959**	.9955	.9943	.9919	.9879	.9816	.9727	.9604	.9441	.9234	.8983
Slope	1.0254	1.0926	1.1676	1.2512	1.3448	1.4487	1.5645	1.6922	1.8326	1.9844	2.1467	2.3166	2.4896
Intercept (MBtu)	-1.82	-1.80	-1.76	-1.72	-1.65	-1.56	-1.43	-1.26	-1.04	-.75	-.38	**.08**	.64

* *vented* means that hours when $T \leq 78$ F, and humidity ratio ≤ 0.0116 are not counted.

Table 11
Regression Results for Sensible Cooling Loads in One-story Prototype House

(Cooling loads and intercepts in MBtu)

	Daily Cooling Degree-Days (CDD_{base})				*Hourly* Cooling Degree-Days ($CDHR_{base}$)				*Vented Hourly* Cooling Degree-Days ($CDHRV_{base}$)			
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
House integrity	Base temp (F)	R	UA Slope	Inter-cept	Base temp (F)	R	UA Slope	Inter-cept	Base Temp (F)	R	UA Slope	Inter-cept
Uninsulated	72	.9671	1.2335	7.01	71	.9917	1.1234	.09	71	.9895	1.1399	1.57
Loose	70	.9871	1.1505	1.49	68	.9938	.9815	-3.00	69	.9940	1.0886	-1.08
Medium	68	.9937	1.2566	-.33	66	.9931	1.1097	-3.84	66	.9957	1.1322	-1.73
Tight	68	.9942	1.3901	-.46	65	.9921	1.1438	-3.96	65	.9959	1.1676	-1.76

CDD_{65} = *Daily* Cooling degree-days at 65F; $CDHR_{base}$ = *Hourly* Cooling degree-days at base temperature; $CDHRV_{base}$ = *Vented Hourly* Cooling degree-days at base temperature.

Table 12

Regression Results for Latent Cooling Loads in One-story Prototype House

(Latent cooling loads and intercepts in MBtu)

House integrity	Latent Enthalpy-Days *(LED)* at T ≥ 78°, Humidity Ratio ≥ 0.0116 Correlation coefficient (R)	Slope	Intercept (MBtu)	Standard error (MBtu)
Uninsulated	.9675	1.2313	.699	1.41
Loose	.9639	1.1624	.583	1.41
Medium	.9649	1.0599	.497	1.27
Tight	.9645	1.0245	.463	1.23

Table 13
Two-Parameter Regression Results for Total Cooling Loads in Five Prototype Houses

(Cooling loads, intercepts, and standard errors in MBtu)

Prototype	House integrity	Correlation coefficient (R)	Base temp (F)	Slopes CDD_{base}	Slopes *LED*	Intercept	Standard error
Ranch	Uninsulated	.9860	70	1.2402	-.2061	4.83	4.46
	Loose	.9935	68	1.1399	.4917	-.12	2.23
	Medium	.9948	67	1.3307	.7171	-1.27	1.61
	Tight	.9945	66	1.3550	.7518	-1.81	1.55
Two-Story	Uninsulated	.9894	70	1.1977	.0569	4.69	4.48
	Loose	.9955	68	1.1007	.4897	-.38	2.23
	Medium	.9955	66	1.1730	.6186	-2.37	1.85
	Tight	.9950	66	1.2666	.6500	-2.37	1.83
Split-Level	Uninsulated	.9888	70	1.3013	-.0910	5.19	4.52
	Loose	.9958	68	1.1941	.4706	-.02	2.10
	Medium	.9958	66	1.3120	.6359	-1.64	1.72
	Tight	.9953	65	1.3425	.6703	-2.28	1.69
Middle-unit Townhouse	Uninsulated	.9932	68	1.2030	.2289	1.85	2.14
	Loose	.9957	66	1.1246	.6263	-.36	1.45
	Medium	.9548	65	1.4012	.8290	-1.15	1.36
	Tight	.9943	64	1.4508	.8671	-1.60	1.36
End-unit Townhouse	Uninsulated	.9916	68	1.1440	.0663	2.13	2.55
	Loose	.9958	67	1.1650	.6007	.20	1.49
	Medium	.9953	65	1.3285	.8068	-1.19	1.33
	Tight	.9947	64	1.3760	.8495	-1.63	1.33

Table 13 (continued)

Two-Parameter Regression Results for Total Cooling Loads in Five Prototype Houses

Prototype	House integrity	Correlation coefficient (R)	Base temp (F)	Slopes $CDHRV_{base}$	Slopes LED	Intercept	Standard error
Ranch	Uninsulated	.9954	69	1.1348	.0852	.33	2.57
	Loose	.9965	65	.9750	.3837	-2.31	1.64
	Medium	.9966	63	1.1135	.5463	-2.73	1.30
	Tight	.9965	61	1.1076	.5300	-2.78	1.23
Two-Story	Uninsulated	.9968	68	1.0352	.1294	-.70	2.46
	Loose	.9976	66	.9936	.4690	-2.75	1.64
	Medium	.9968	63	1.0512	.4890	-3.39	1.58
	Tight	.9962	61	1.0321	.4690	-3.50	1.58
Split-Level	Uninsulated	.9967	68	1.1255	-.0072	-.25	2.45
	Loose	.9980	65	1.0223	.3655	-2.61	1.44
	Medium	.9976	62	1.1211	.4408	-2.75	1.30
	Tight	.9972	61	1.1697	.4694	-2.75	1.30
Middle-unit Townhouse	Uninsulated	.9980	66	1.0926	.1691	-.18	1.16
	Loose	.9984	63	1.0082	.4140	-1.16	.89
	Medium	.9979	60	1.1722	.5353	-1.62	.87
	Tight	.9974	60	1.2915	.6043	-1.58	.91
End-unit Townhouse	Uninsulated	.9976	67	1.1013	.1224	.05	1.36
	Loose	.9984	64	1.0227	.4271	-1.10	.91
	Medium	.9980	61	1.1614	.5444	-1.59	.86
	Tight	.9978	60	1.2243	.5807	-1.61	.87

Table 14

Three-dimensional Analysis of Total Cooling Loads for Five Prototype Houses

(Cooling loads, intercepts, and standard errors are in MBtu)

Prototype	House integrity	Correlation coefficient (R)	Slopes $CDHR_{75}$	Slopes $CIDV_{70}$	Slopes LED_{78}	Intercept	Standard error
Ranch	Uninsulated	.9947	1.1087	1.2710	.7394	-2.09	2.79
	Loose	.9935	.9225	1.1079	1.0552	-4.00	2.25
	Medium	.9943	.8380	1.4056	1.0542	-3.78	1.71
	Tight	.9940	.7943	1.6500	1.0477	-3.73	1.64
Two-story	Uninsulated	.9960	1.0397	1.0220	.7598	-3.23	2.77
	Loose	.9946	.8779	.9074	.9461	-4.95	2.47
	Medium	.9936	.8064	1.1676	.9286	-4.80	2.24
	Tight	.9930	.7571	1.3666	.9096	-4.74	2.17
Split-Level	Uninsulated	.9962	1.1236	1.1084	.7253	-2.84	2.67
	Loose	.9954	.9286	.9902	.9871	-4.67	2.23
	Medium	.9948	.8600	1.2595	.9766	-4.28	1.95
	Tight	.9944	.8098	1.4687	.9653	-4.21	1.88
Middle-unit Townhouse	Uninsulated	.9967	1.0171	1.1547	.9281	-2.13	1.51
	Loose	.9958	.8386	1.0951	1.1212	-2.91	1.45
	Medium	.9960	.7290	1.4237	1.1472	-2.67	1.22
	Tight	.9958	.6780	1.6672	1.1491	-2.62	1.18
End-unit Townhouse	Uninsulated	.9966	1.0443	1.1762	.8865	-1.98	1.63
	Loose	.9960	.8620	1.1026	1.1218	-2.91	1.47
	Medium	.9960	.7626	1.4289	1.1546	-2.70	1.25
	Tight	.9958	.7091	1.6725	1.1524	-2.65	1.20

Table 15
Regression Analysis of Δ Ceiling, Wall, and Foundation Heating Loads against Climatic Variables

(intercepts and standard errors are in MBtu for Δ R11→R38 ceilings, R11→R27 wall loads, R0→R5 4' slab loads, and R0→R10 8' basement loads)

	Heating									
	Heating degree-days						65° Heating insolation-days *(HID)* + Heating degree-days			
	Daily (HDD)			*Hourly (HDHR)*			*Daily (HDD)*		*Hourly(HDHR)*	
House component	65	60	57	65	57	55	65	60	65	57
Δ Ceiling Loads										
Correlation (R)	**.9968**	.9934	.9876	.9936	.9885	.9840	.9974	.9943	.9960	.9899
Slope(s)	**.9488**	1.0880	1.1935	.9440	1.1918	1.2731	-.0028, .9876	.0032, 1.0412	-.0058, 1.0257	.0038, 1.1301
Intercept (MBtu)	**.014**	.876	1.361	-.417	.875	1.182	.294	.503	.099	.426
Std Error (MBtu)	**.305**	.435	.595	.429	.574	.675	.273	.402	.337	.538
Δ Wall Loads										
Correlation (R)	**.9961**	.9926	.9866	.9924	.9870	.9824	.9968	.9935	.9951	.9883
Slope(s)	**.9093**	1.0427	1.1435	.9043	1.1413	1.2190	-.0030, .9492	.0030, 1.0002	-.0058, .9851	.0036, 1.0840
Intercept (MBtu)	**-.094**	.542	.900	-.409	.544	.772	.128	.281	-.017	.0224
Std Error (MBtu)	**.248**	.339	.456	.343	.450	.523	.223	.319	.277	.426
Δ Slab Foundation Loads										
Correlation (R)	**.9798**	.9734	.9581	.9730	.9615	.9499	.9842	.9760	.9805	.9684
Slope(s)	**.7704**	.9611	1.1080	.7118	1.000	1.0955	-.0732, .8853	.0456, .8811	-.1018, .8636	.0713, .8727
Intercept (MBtu)	**-.322**	.749	1.384	-.649	.892	1.2787	-.012	.405	-.325	.322
Std Error (MBtu)	**.776**	.889	1.112	.896	1.067	1214	.688	.845	.762	.968
Δ Basement Foundation Loads										
Correlation (R)	**.9811**	.9764	.9676	.9680	.9563	.9490	.9878	.9780	.9824	.9596
Slope(s)	**.9251**	1.0089	1.0623	.9246	1.0709	1.1118	-.0700, .9779	-.0333, 1.0333	-.1054, 1.0144	-.0481, 1.1119
Intercept (MBtu)	**-.365**	.813	1.543	-.758	1.081	1.555	.920	1.481	1.040	2.027
Std Error (MBtu)	**.447**	.498	.582	.579	.674	.727	.359	.481	.431	.649

0

Table 16
Regression Analysis of Δ Ceiling, Wall, and Foundation Cooling Loads against Climatic Variables

(intercepts and standard errors are in MBtu for Δ R11→R38 ceilings, R11→R27 wall loads, R0→R5 4' slab loads, and R0→R10 8' basement loads)

	Cooling									
	Cooling degree-days					70° Cooling insolation-days *(CID)* + Cooling degree-days				
	Daily (CDD)		*Hourly (CDHR)*		*Vented hourly (CDHRV)*	*Daily (CDD)*		*Hourly (CDHR)*		*Vented hourly (CDHRV)*
House component	65	75	65	75	65	65	75	65	75	65
Δ Ceiling Loads										
Correlation (R)	.8348	.8973	.8849	**.9641**	.8589	.8349	.9090	.9016	.9655	.8600
Slope(s)	.5743	1.6603	.6251	**1.6369**	.6189	.0005, .5440	.0028, 1.3034	-.0074, 1.0560	.0010, 1.5167	-.0017, .7160
Intercept (MBtu)	.411	.780	.109	**.345**	.379	.371	.411	.501	.237	.504
Std Error (MBtu)	.684	.548	.579	**.330**	.636	.684	.518	.537	.323	.634
Δ Wall Loads										
Correlation (R)	.8700	.9573	.9070	**.9866**	.8932	.8844	.9581	.9567	.9866	.9150
Slope(s)	.3932	1.1636	.4209	**1.100**	.4229	-.0044, .6367	.0005, 1.0976	-.0088, .9202	-.0001, 1.1032	-.0051, .7147
Intercept (MBtu)	.009	.193	-.135	**-.012**	-.005	.255	.140	.214	-.010	.284
Std Error (MBtu)	.309	.181	.264	**.102**	.282	.293	.180	.183	.102	.253
Δ Slab Foundation Loads										
Correlation (R)	.8356	.8473	.8512	.8393	**.8564**	.8473	.8733	.8664	.8732	.8672
Slope(s)	.5259	1.3316	.5544	1.2189	**.5576**	-.0999, .7952	.0666, .9971	-.1088, .8558	.0733, .8904	-.0841 .7877
Intercept (MBtu)	.296	1.397	-.254	.829	**.272**	1.166	.188	.448	.-.369	1.065
Std Error (MBtu)	1.443	1.395	1.379	1.428	**1.356**	1.395	1.280	1.312	1.280	1.308
Δ Basement Foundation Loads										
Correlation (R)	.8118	.6305	.7679	.5988	**.8162**	.8130	.7527	.7680	.7268	.8175
Slope(s)	.6693	2.0197	.6680	1.4538	**.7600**	.0085 .6064	.0551, .8487	-.0037, .6984	.0773, -.1304	-.0116, .8589
Intercept (MBtu)	-.283	.132	-.484	-.118	**.352**	-.347	-.515	-.471	-.660	-.281
Std Error (MBtu)	.315	.419	.346	.432	**.312**	.314	.355	.345	.371	.311

Table 17
Regression Analysis of Δ Infiltration Loads against Climatic Variables

(intercepts and standard errors are in MBtu
for Δ infiltration from 0.7 to 0.4ach)

Heating						
	Heating degree-days					
	Daily (HDD)			*Hourly (HDHR)*		
House component	65	60	57	65	57	55
Δ Infiltration Loads						
Correlation (R)	**.9868**	.9810	.9735	.9839	.9750	.9693
Slope	**.9464**	1.0825	1.1852	.9418	1.1843	1.2635
Intercept (MBtu)	**.671**	1.517	1.994	.253	1.522	1.825
Std Error (MBtu)	**.597**	.717	.845	.660	.821	.908

Cooling										
	Cooling degree-days					Latent enthalpy-days *(LED_{78})* + Cooling degree-days				
	Daily (CDD)		*Hourly (CDHR)*		*Vented hourly (CDHRV)*	*Daily (CDD)*		*Hourly (CDHR)*		*Vented hourly (CDHRV)*
House component	65	75	65	75	65	65	75	65	75	65
Δ Infiltration Loads										
Correlation (R)	.8060	.8714	.8079	.8035	.8288	.9003	.9558	.9093	**.9547**	.9083
Slope(s)	.6458	1.878	.6647	1.5888	.6955	.4751, .2612	.4022, 1.1128	.4652, .2959	**.4716, .9055**	.4434, .3178
Intercept (MBtu)	-.604	-.208	-.837	-.473	-.637	-.348	-.288	-.496	**-.501**	-.398
Std Error (MBtu)	.828	.686	.825	.833	.783	.609	.411	.582	**.416**	.585

Table 18
Regression Analysis of Δ Window Loads against Climatic Variables
(intercepts and standard errors are in MBtu for a 154 ft^2 increase in window area)

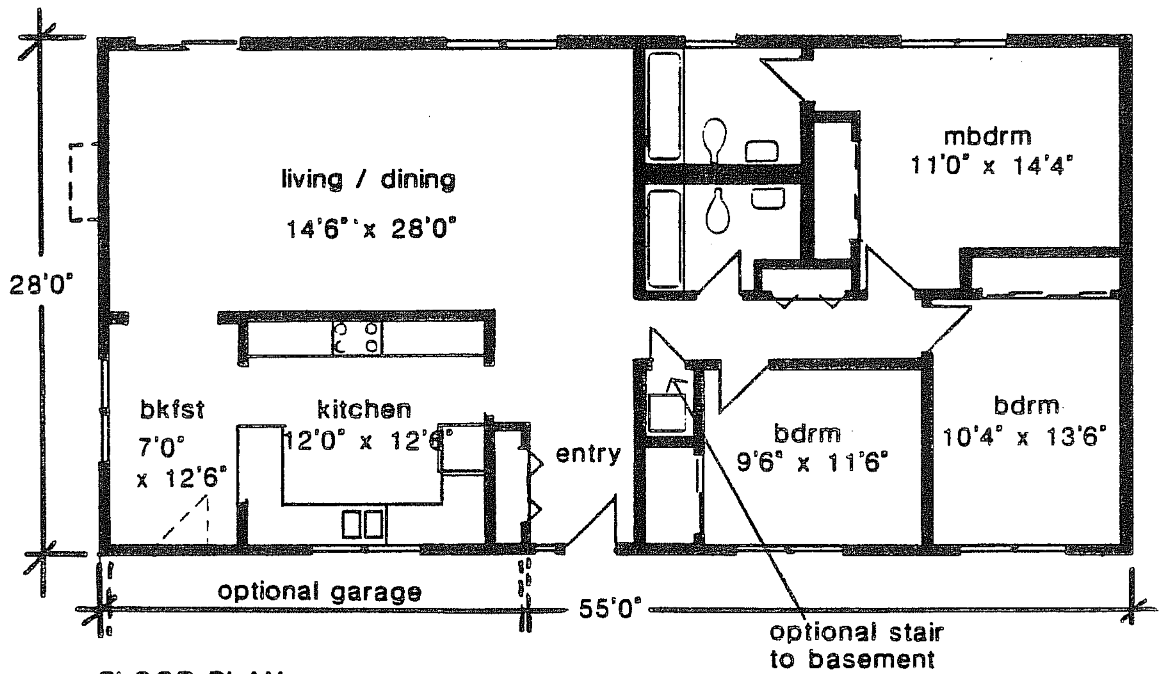
Heating

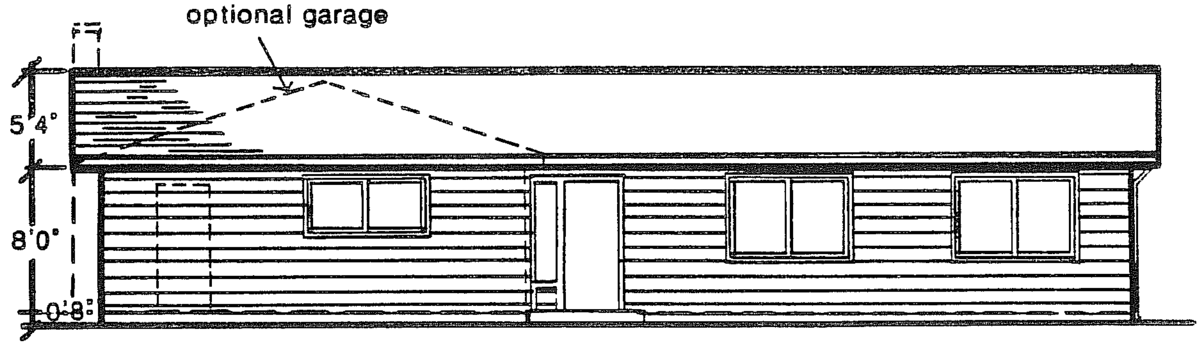
House component	65° Heating insolation days (HID_{65})	Heating degree days Daily 65	Heating degree days Hourly 65	65° Heating insolation-days *(HID)* + Heating deg.-days Daily 65	Daily 60	Hourly 65	Hourly 57	Total winter insolation *(TWI)* + Heating deg.-days Daily 65	Daily 60	Hourly 65	Hourly 57
Single-pane											
Correlation (R)	.6183	.9703	.9594	**.9847**	.9785	.9795	.9678	.9772	.9800	.9683	.9715
Slope(s)	.6285	.6468	.6383	**-.2579, .7738**	-.1236, .8127	-.3169, .7990	-.1032, .8743	-.2492, .7706	-.2149, .8691	-.2956, .7875	-.2425, .9678
Intercept (MBtu)	-1.629	-1.998	-2.626	**.259**	.653	-.127	.487	-.887	.582	-1.529	.749
Std Error (MBtu)	5.138	1.581	1.843	**1.140**	1.348	1.317	1.646	1.388	1.300	1.632	1.550
Double-pane											
Correlation (R)	.4130	.8738	.8547	**.9484**	.9357	.9410	.9181	.9248	.9398	.9093	.9308
Slope(s)	.1900	.5044	.4925	**-.2571, .7147**	-.1869, .7793	-.2853, .7702	-.1748, .8340	-.2947, .7854	-.2884, .9028	-.3173, .7989	-.3075, 1.0121
Intercept (MBtu)	-.850	-1.956	-2.129	**-038**	.124	-.205	.049	-.833	-.142	-1.125	-.056
Std Error (MBtu)	2.297	1.227	1.310	**.800**	.890	.854	1.000	.960	.862	1.050	.922
Triple-pane											
Correlation (R)	.1452	.6642	.6370	**.8534**	.8328	.8419	.8058	.8303	.8571	.8068	.8456
Slope(s)	.0422	.3467	.3319	**-.2356, .6650**	-.1900, .6881	-.2526, .6830	-.1803, .7289	-.3068, .7646	-.3059, .8877	-.3196, .7740	-.3191, .9956
Intercept (MBtu)	-.568	-1.704	-1.745	**-.111**	-.023	-.206	-.071	-.648	-.215	-.829	-.160
Std Error (MBtu)	1.428	1.079	1.112	**.752**	.799	.779	.854	.804	.743	.852	.770

Cooling

House component	70° Cooling insolation-days *(CID)* *Unvented*	*(CID)* *Vented*	Cooling Degree-days Daily 65	Daily 75	Hourly 65	Hourly 75	*Vented* 70° Cooling insolation-days $(CIDV_{70})$ + Cooling degree-days Daily 65	Daily 75	Hourly 65	Hourly 75	*Vented hourly* 65
Single-pane											
Correlation (R)	.9830	**.9889**	.9747	.8259	.9740	.8152	.9909	.9900	.9922	.9905	.9914
Slope(s)	.5683	**.5667**	1.1833	2.6966	1.2143	2.443	.4225, .3148	.5300, .2589	.4017, .3728	.5253, .2741	.4186, .3404
Intercept (MBtu)	-1.746	**.523**	1.744	4.609	.677	3.311	.758	.672	.448	.532	.764
Std Error (MBtu)	.993	**.801**	1.207	3.044	1.222	3.126	.725	.760	.672	.741	.708
Double-pane											
Correlation (R)	.9813	**.9900**	.9629	.7879	.9571	.7724	.9900	.9902	.9901	.9901	.9900
Slope(s)	.5899	**.5899**	2.3253	5.1173	2.3733	4.6036	.5659 .1000	.6120 -.2085	.5601 .1283	.6013 -.1457	.5745 .0672
Intercept (MBtu)	-1.530	**.458**	1.616	4.235	.719	3.167	.491	.404	.446	.456	.479
Std Error (MBtu)	.921	**.675**	1.291	2.946	1.387	3.038	.674	.669	.672	.672	.675
Triple-pane											
Correlation (R)	.9774	**.9884**	.9577	.7746	.9494	.7559	.9884	.9892	.9884	.9892	.9884
Slope(s)	.6107	**.6121**	3.4451	7.4938	3.5072	6.7111	.6248, -.0760	.6454, -.6454	.6310, -.1174	.6438, -.5759	.6366, -.1545
Intercept (MBtu)	-1.484	**.367**	1.477	3.966	.652	2.994	.351	.262	.373	.362	.336
Std Error (MBtu)	.954	**.685**	1.298	2.852	1.415	2.951	.685	.662	.684	.661	.683

Figure 1. Floor Plan and Elevation of 1-Story Ranch House





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

Total floor area 1540 sq ft

Figure 2. Calculation of Vented Hourly Cooling Degree Days

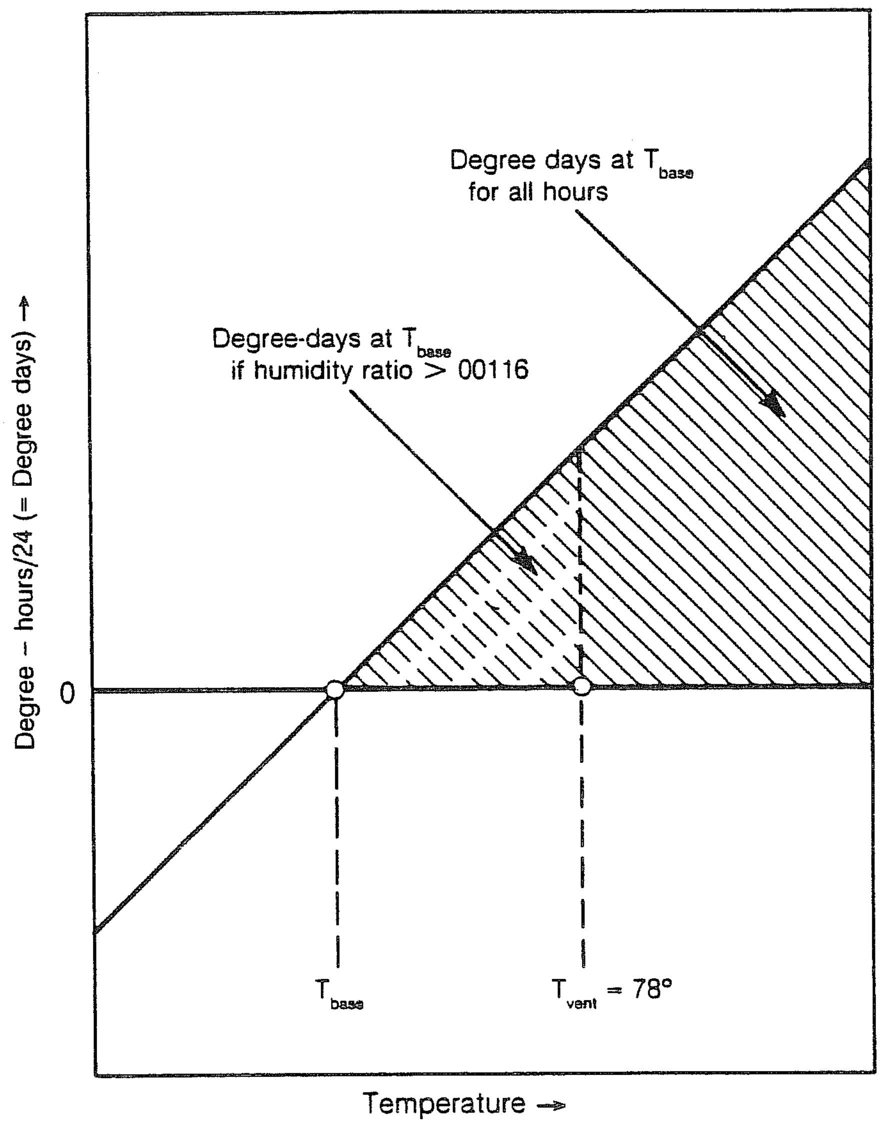


Figure 3. NOAA Long–Term HDD Compared to Weather Tape HDHR

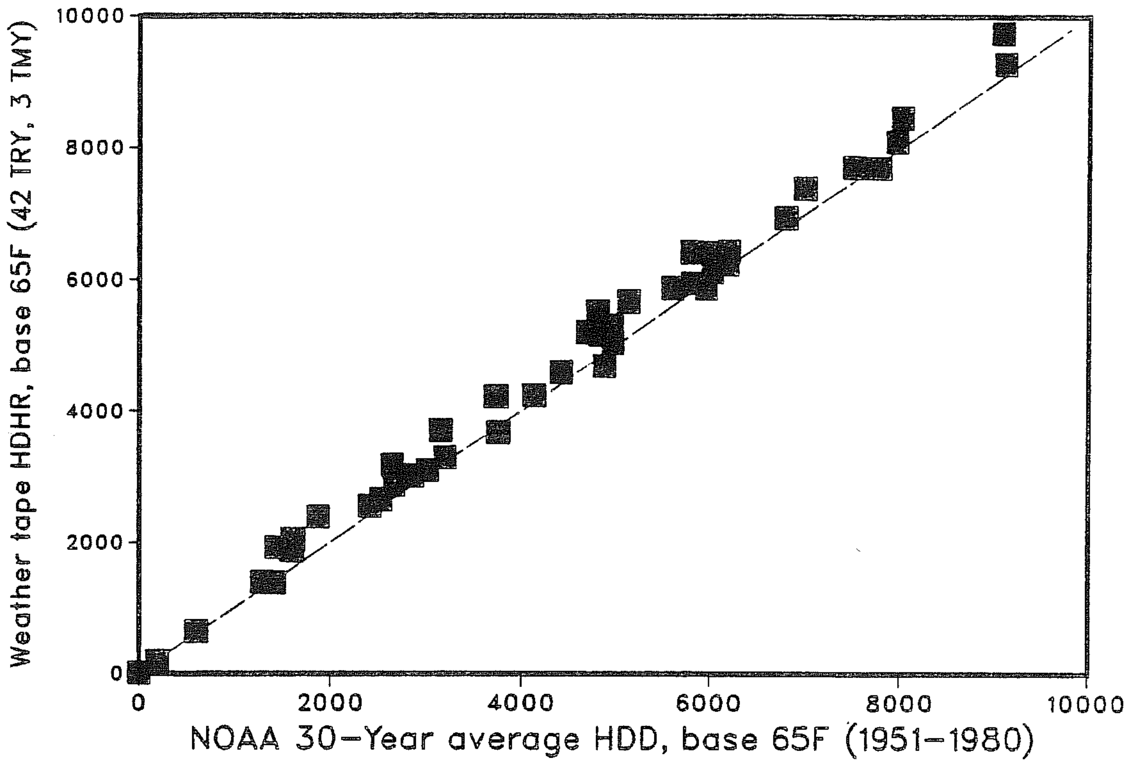


Figure 4. NOAA Long–Term HDD Compared to Weather Tape HDD

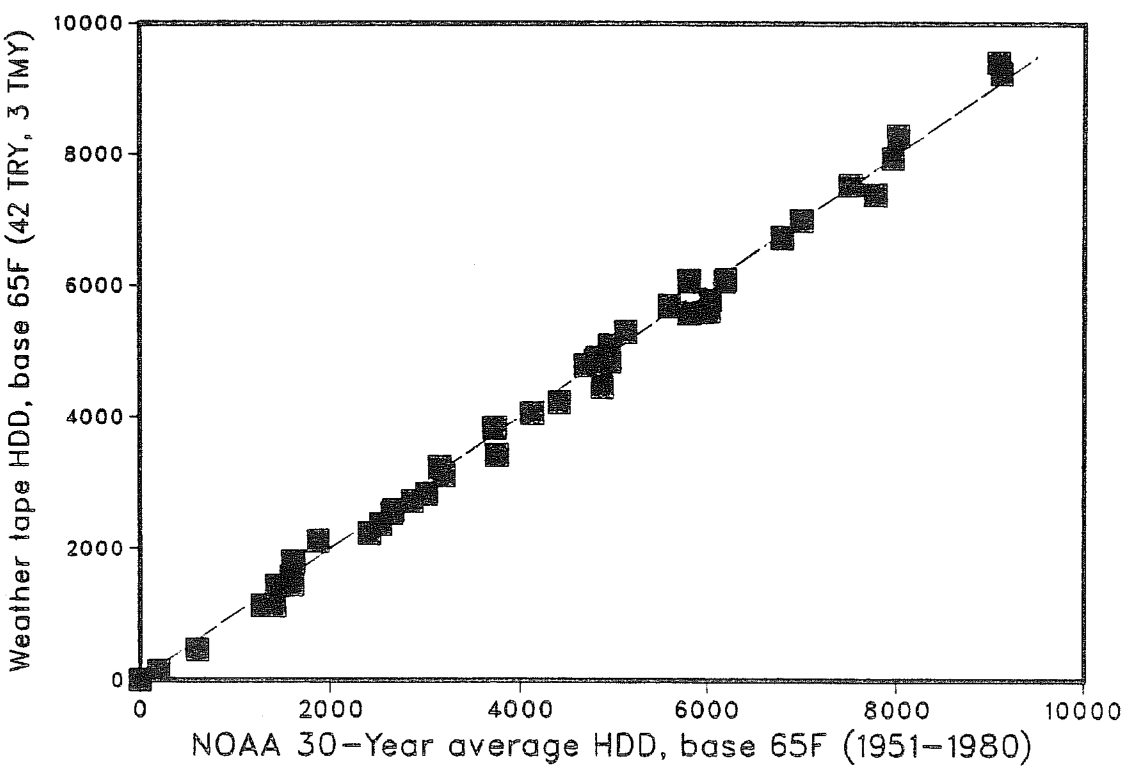


Figure 5

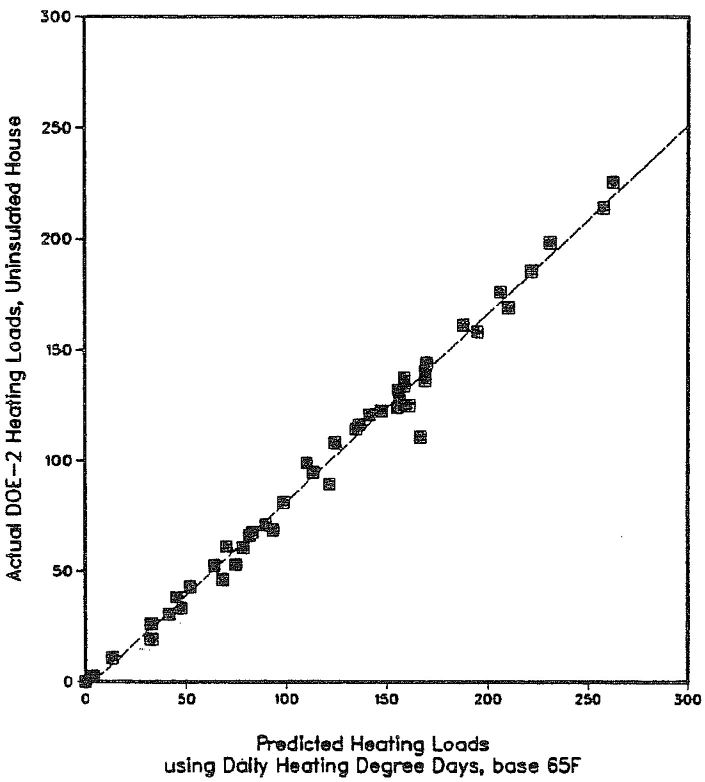


Figure 6

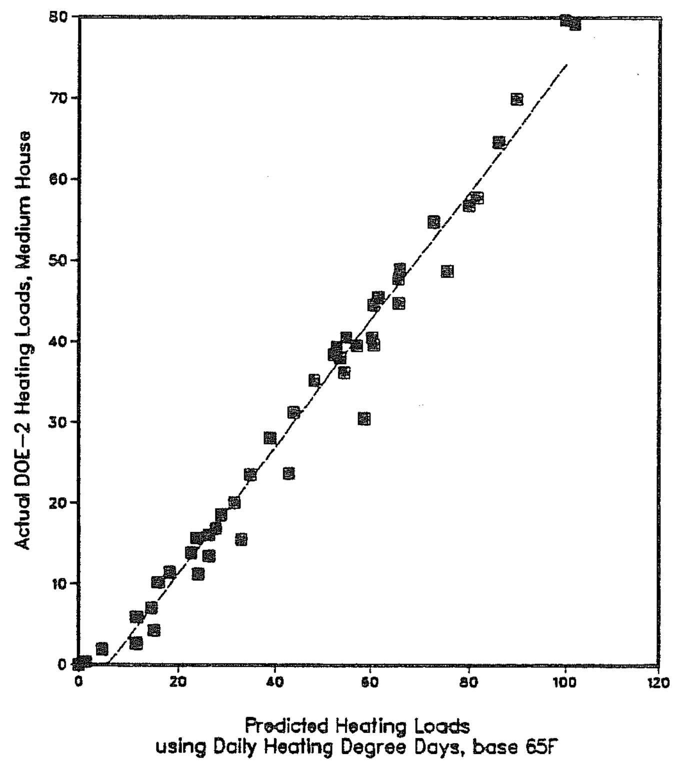


Figure 7

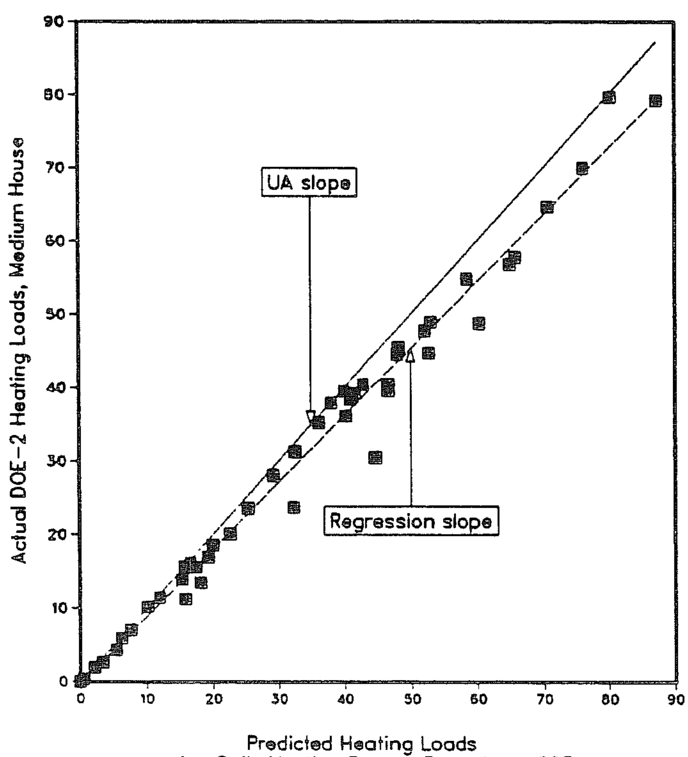


Figure 8

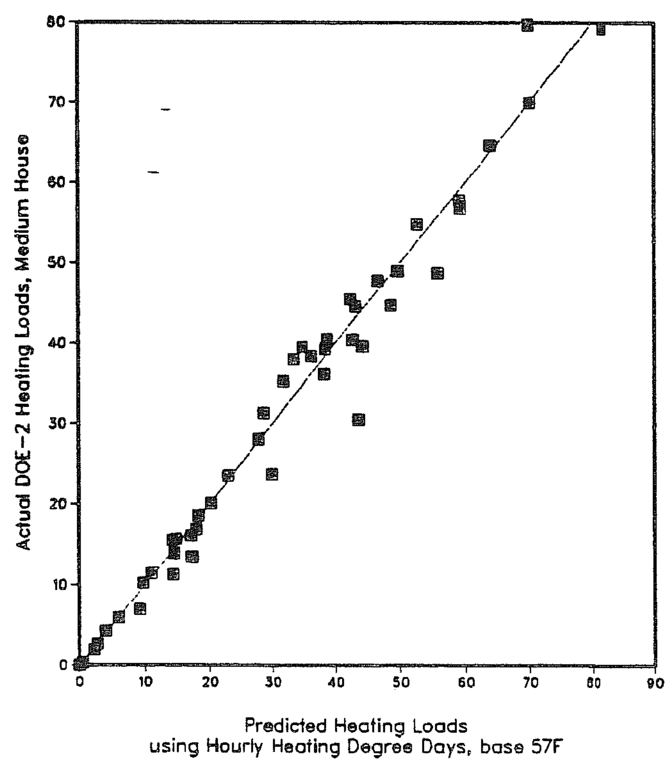


Figure 9

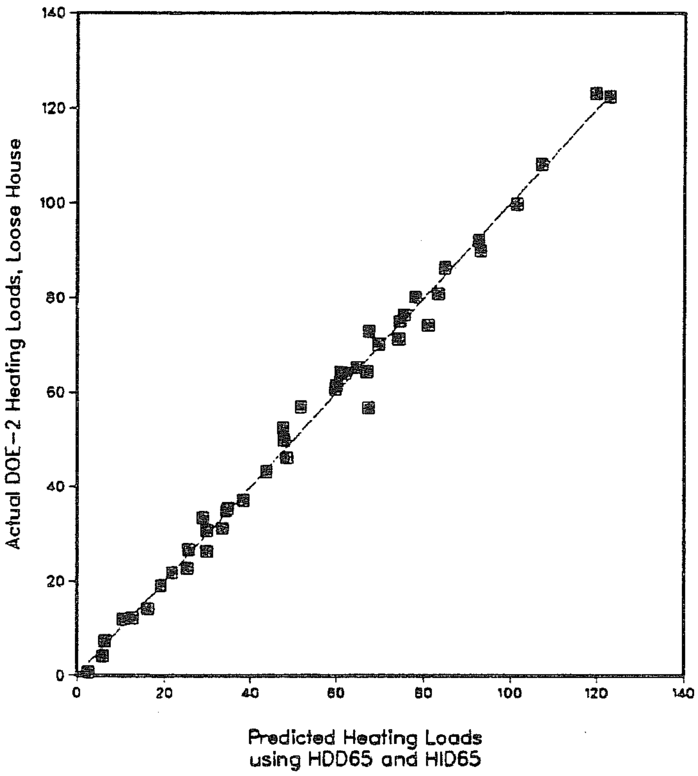


Figure 10

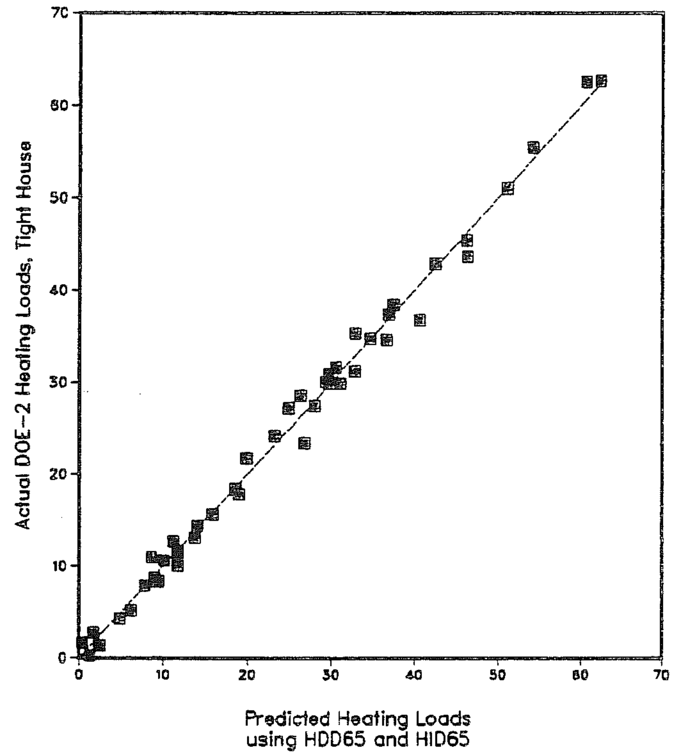


Figure 11

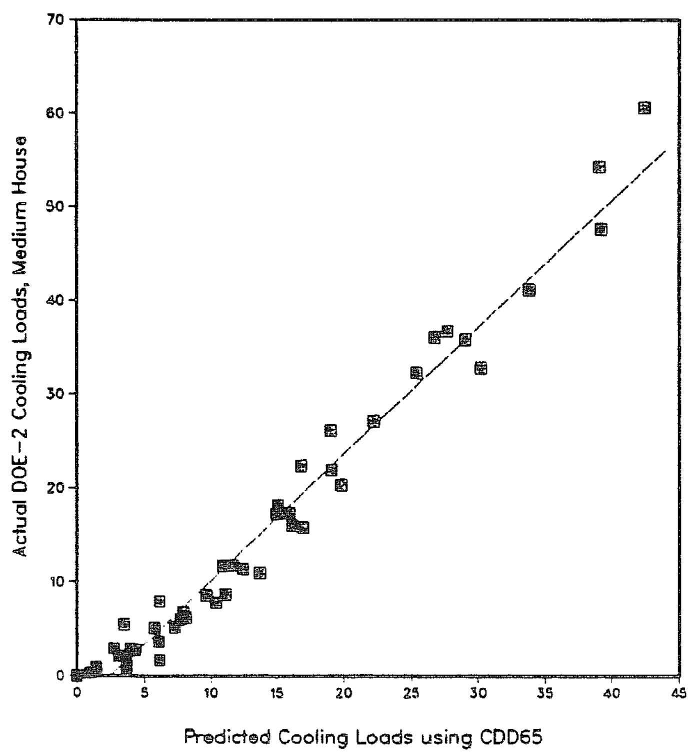


Figure 12

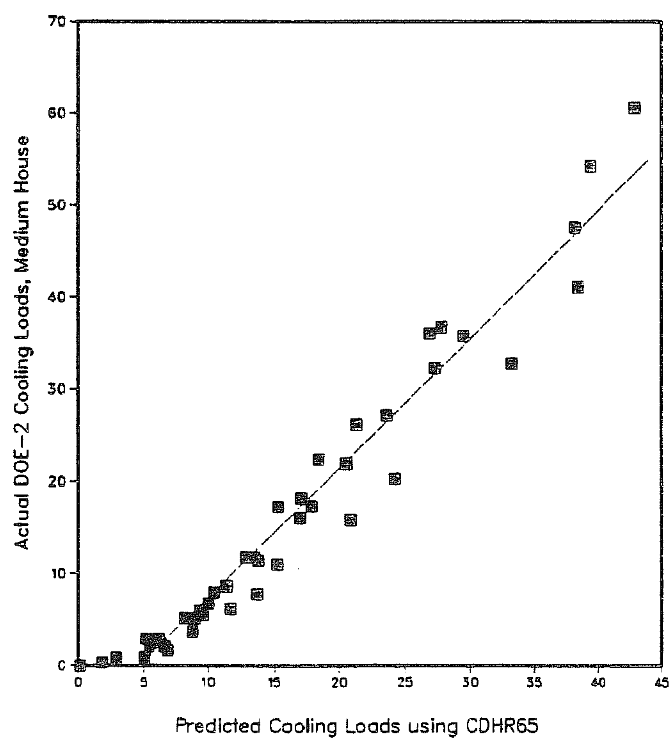


Figure 13

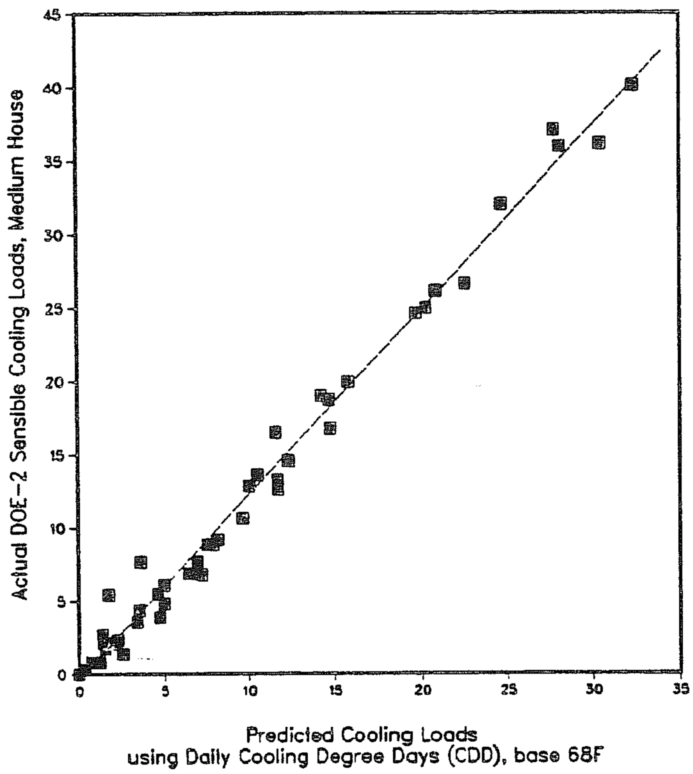


Figure 14

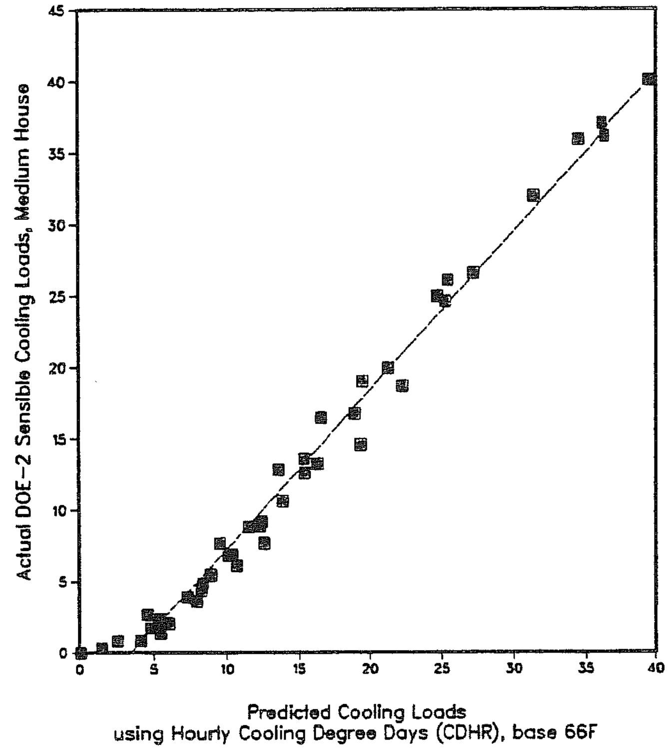


Figure 15

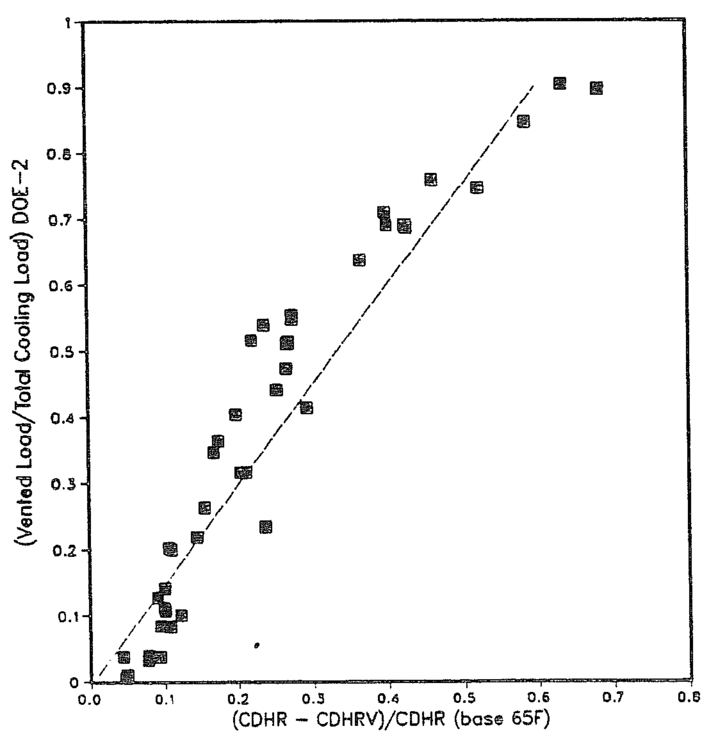


Figure 16

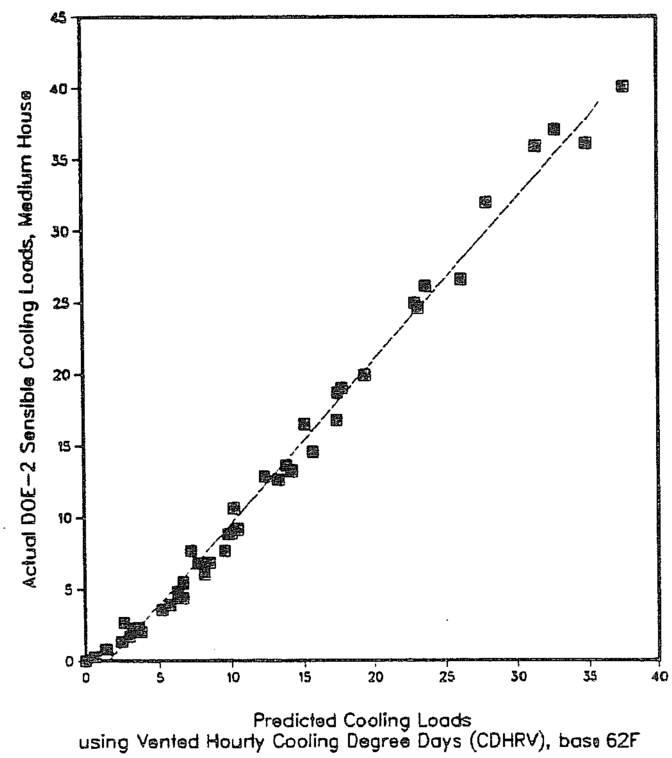


Figure 17

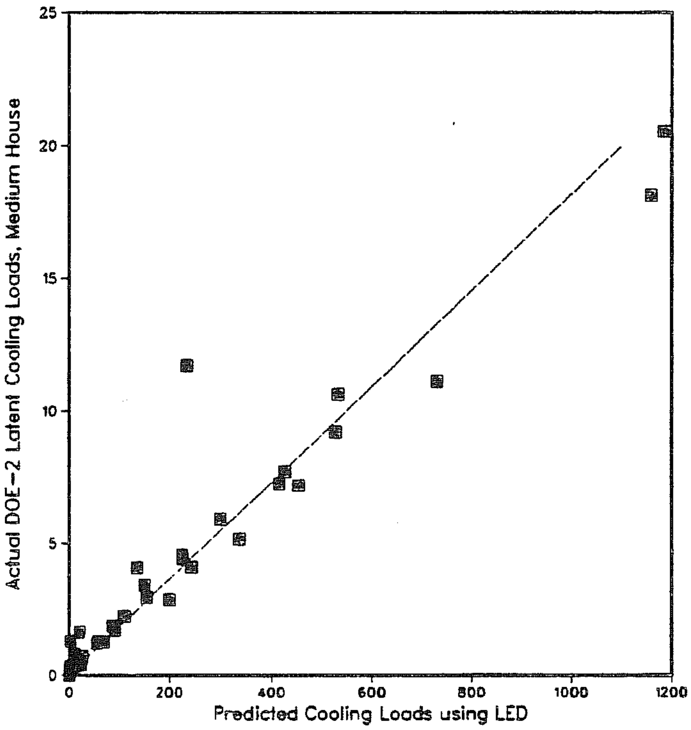


Figure 18

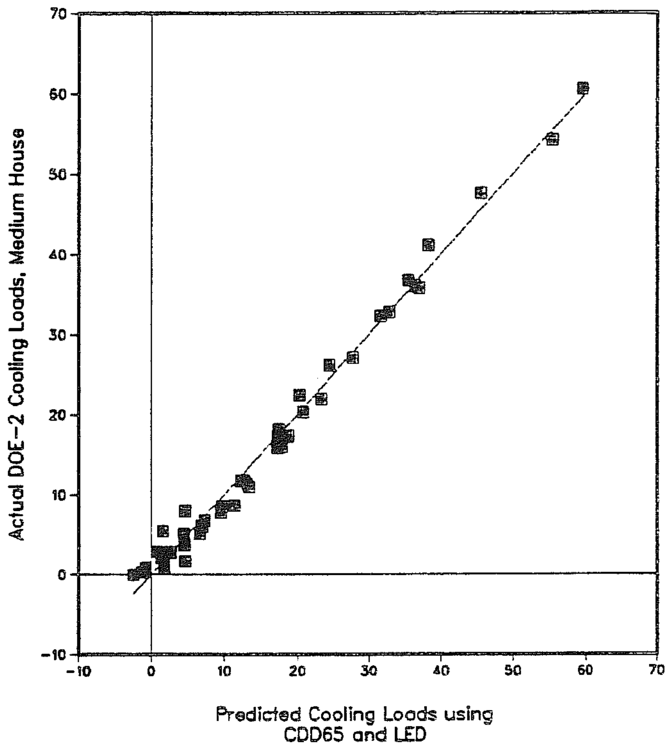


Figure 19

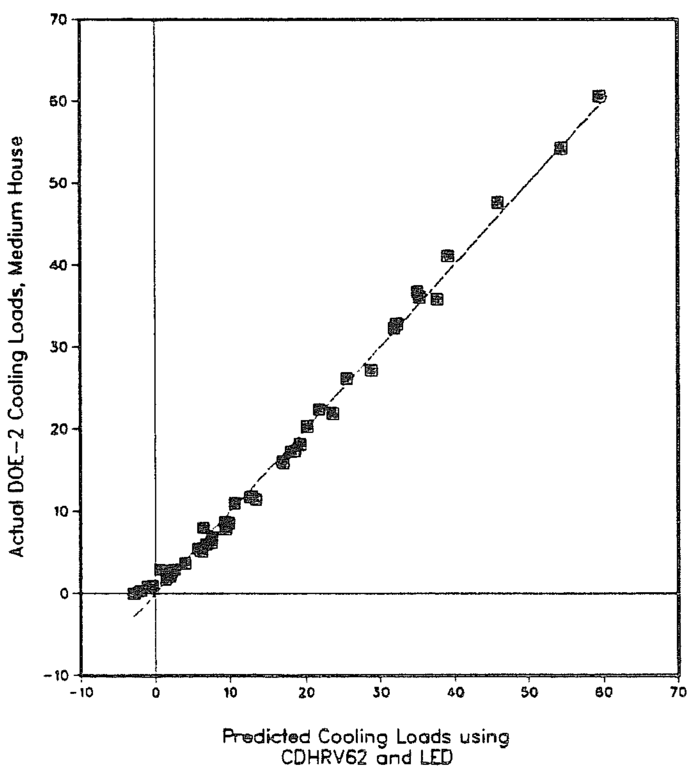


Figure 20

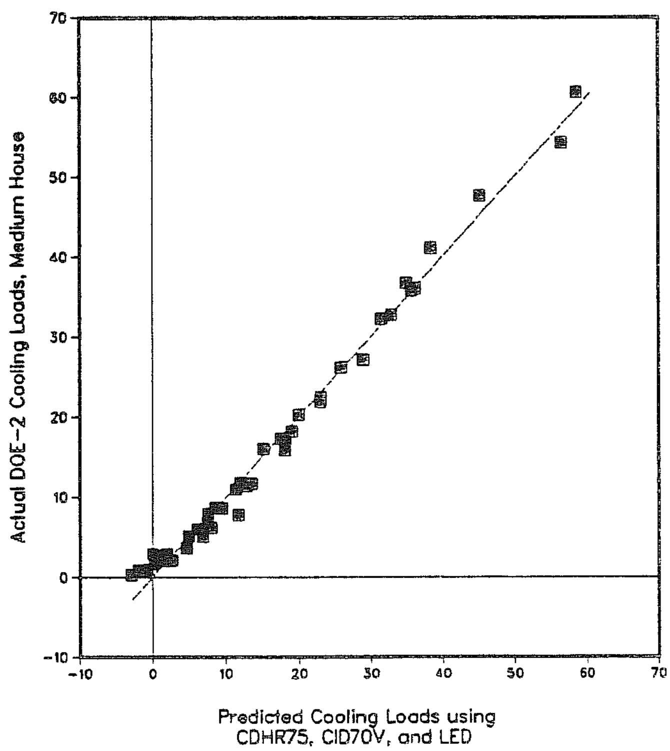


Figure 21: Δ Ceiling Heating Loads Compared to HDD65

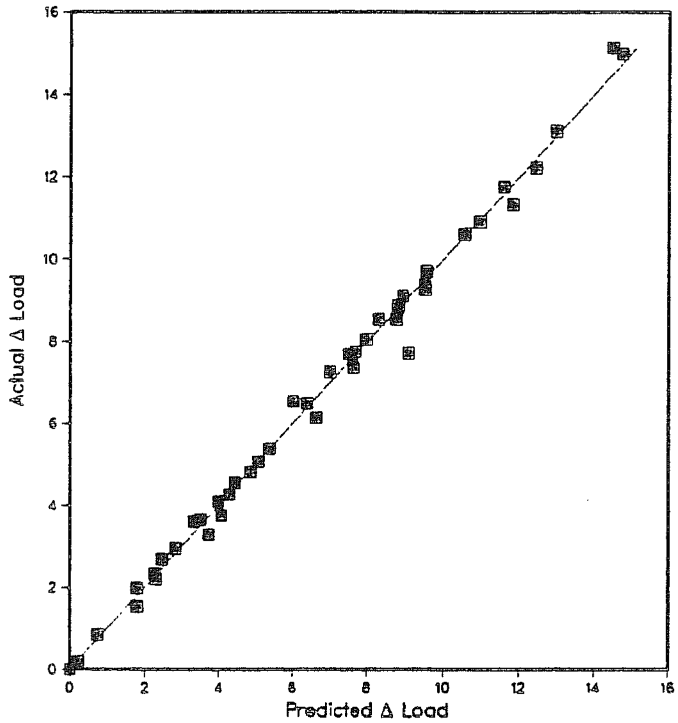


Figure 22: Δ Wall Heating Loads Compared to HDD65

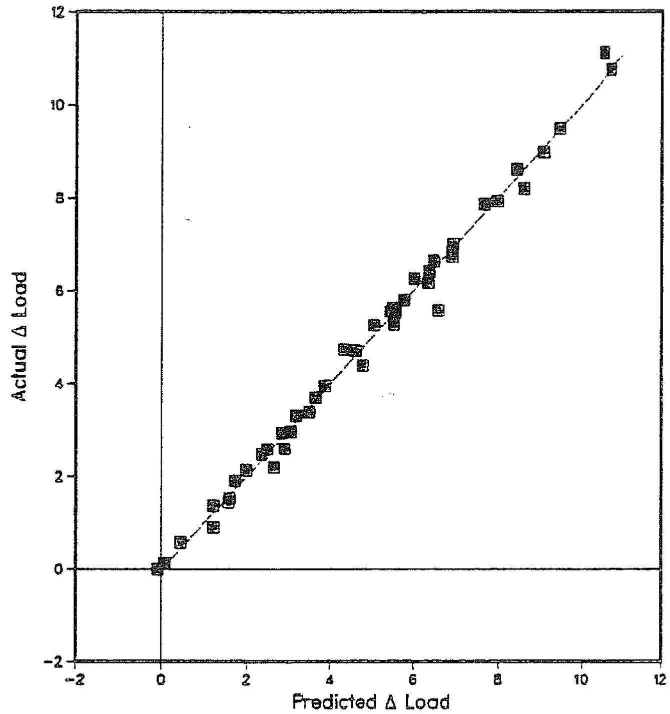


Figure 23: Δ Slab Foundation Heating Loads, Compared to HDD65

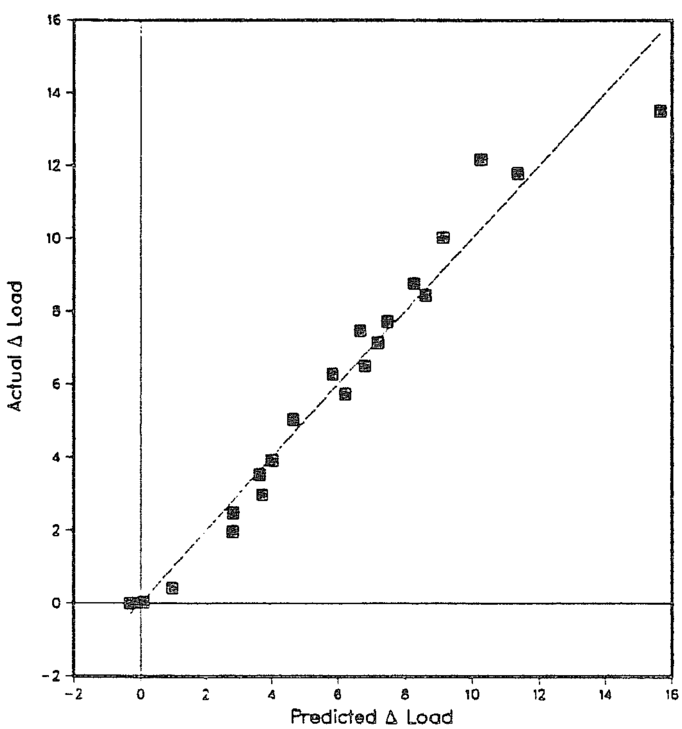


Figure 24: Δ Basement Foundation Heating Loads, Compared to HDD65

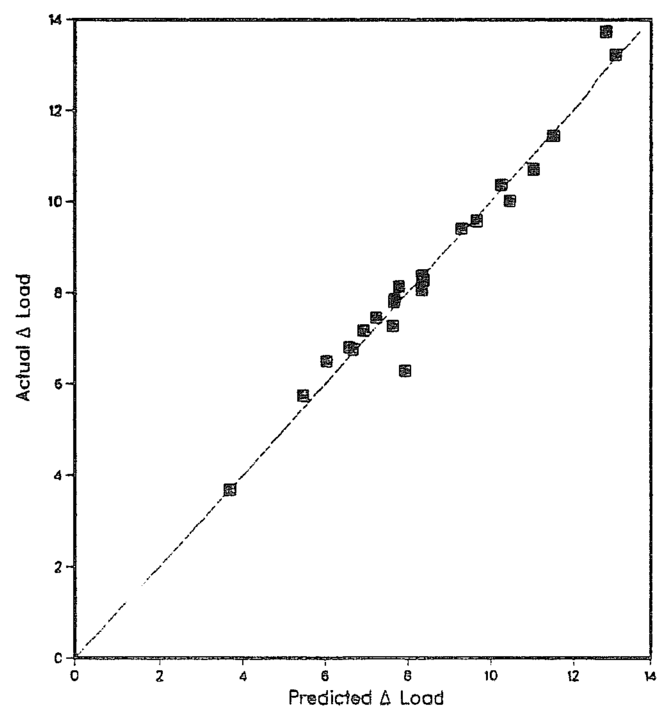


Figure 25: Δ Ceiling Cooling Loads
Compared to CDHR75

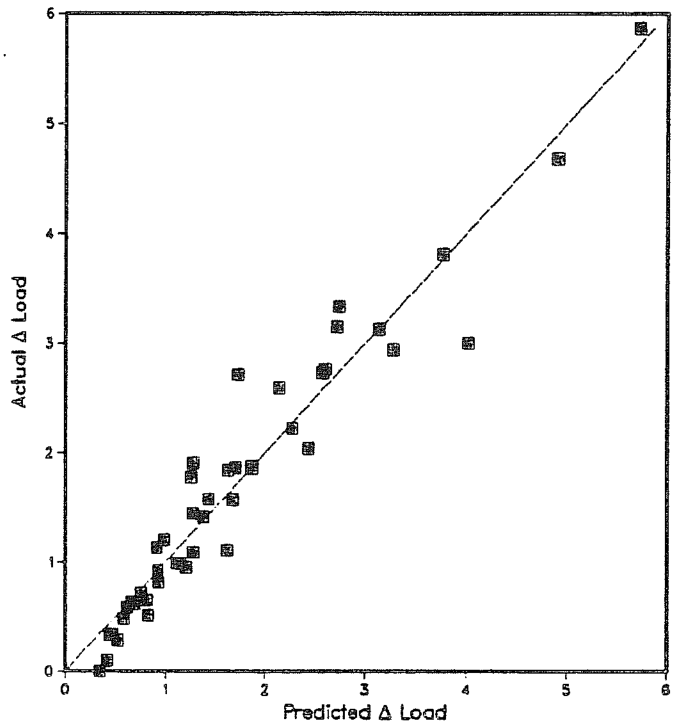


Figure 26: Δ Wall Cooling Loads
Compared to CDHR75

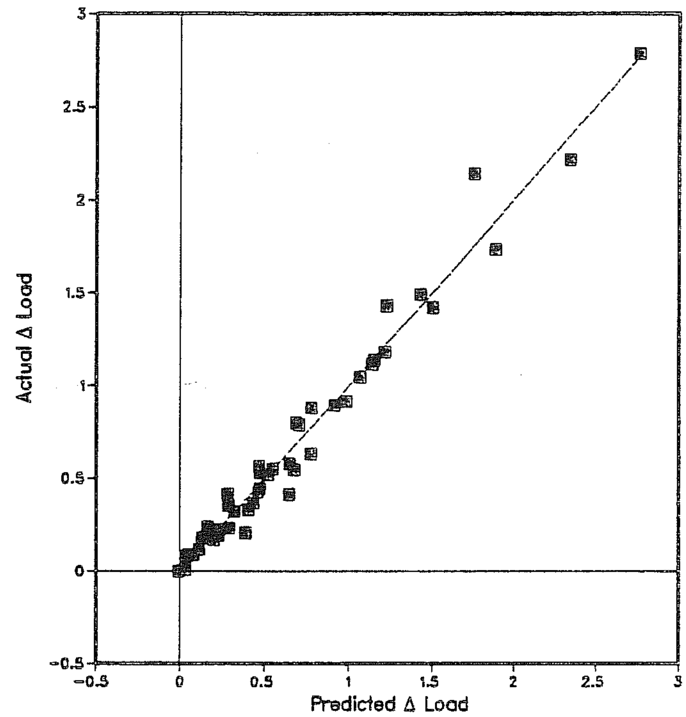


Figure 27: Δ Slab Foundation Cooling Loads
Compared to CDHRV65

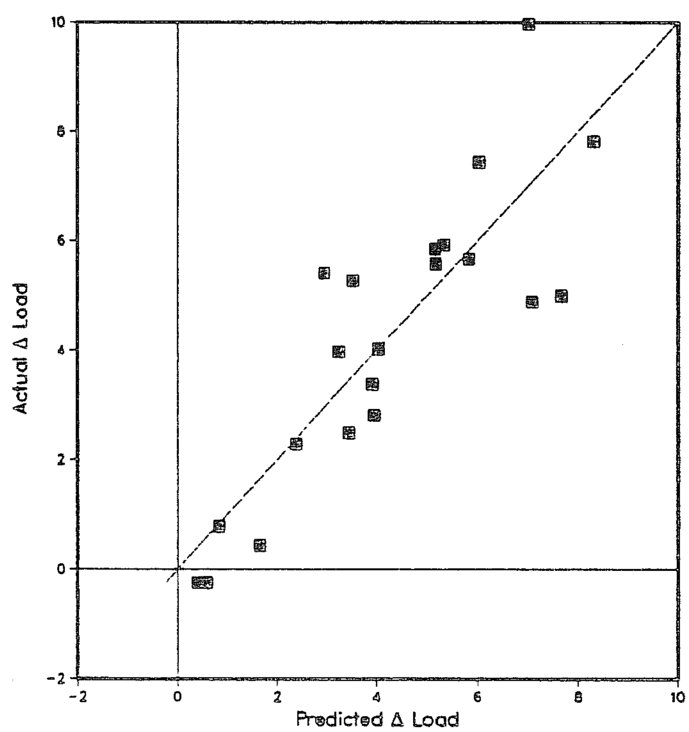


Figure 28: Δ Basement Foundation Cooling Loads
Compared to CDHRV65

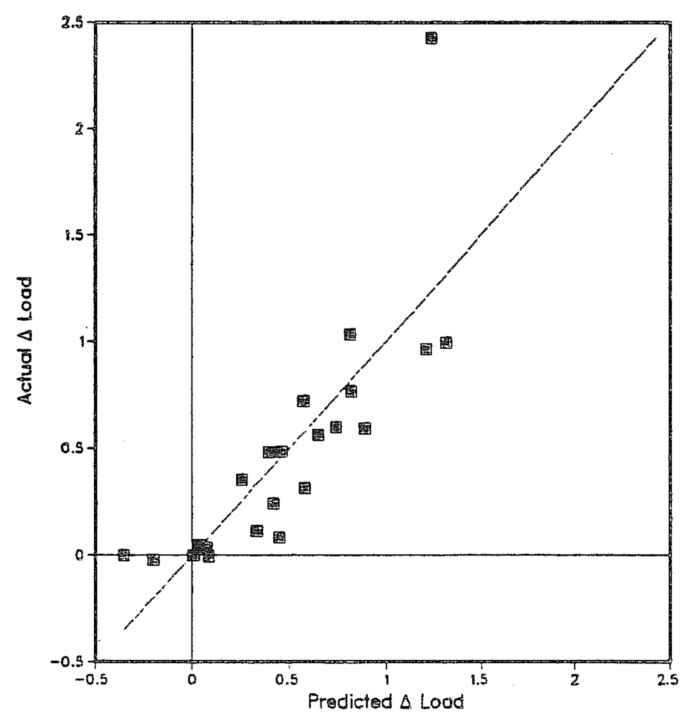


Figure 29: Δ Infiltration Heating Loads Compared to HDD65

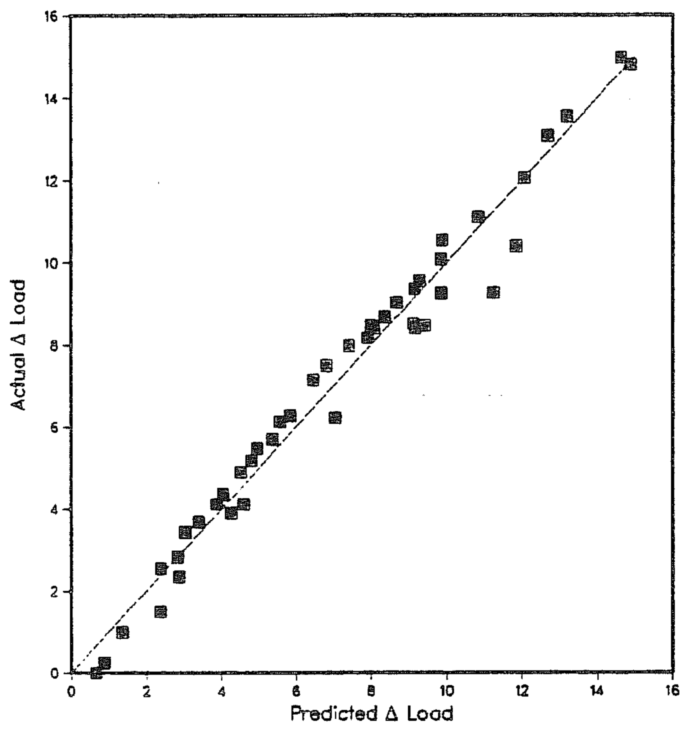


Figure 30: Δ Infiltration Cooling Loads Compared to CDHR75 and LED

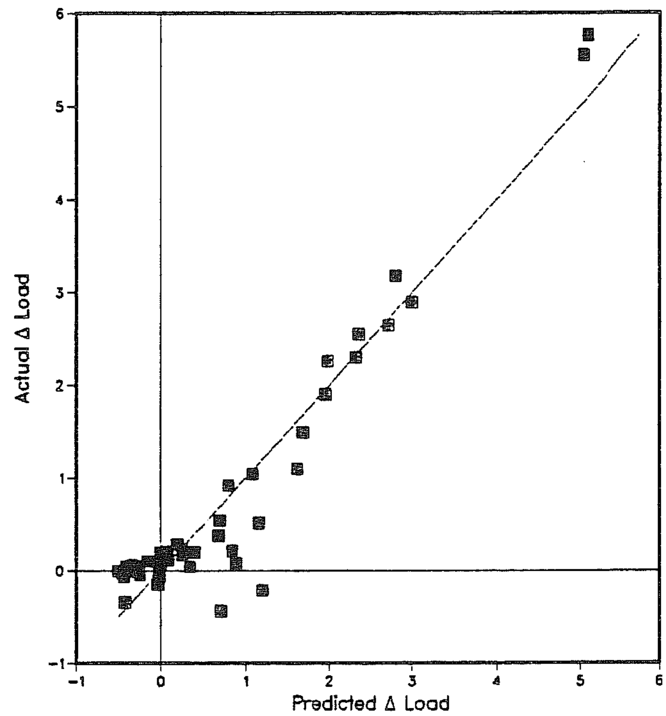


Figure 31: Δ Heating Loads, Single-Glazing Windows, Compared to HDD65

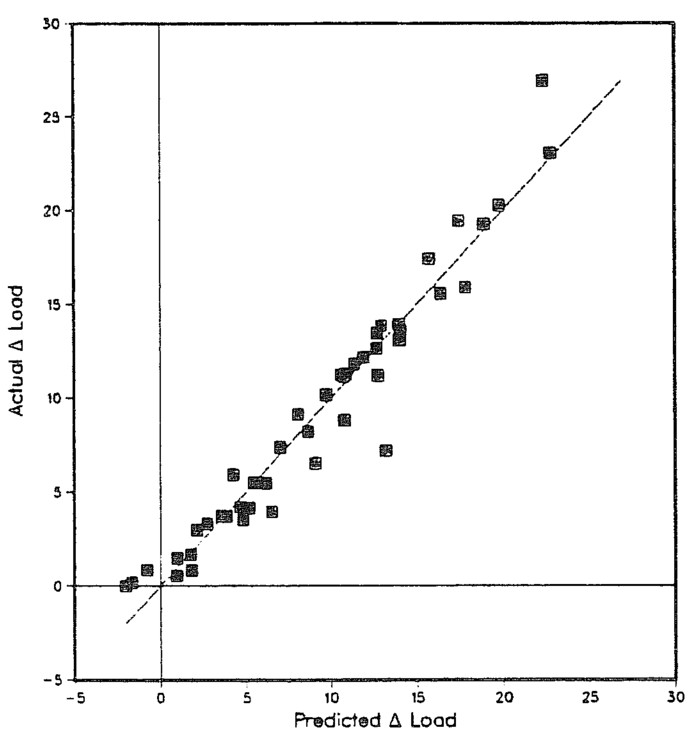


Figure 32: Δ Heating Loads, Single-Glazing Windows, Compared to HDD65 and HID65

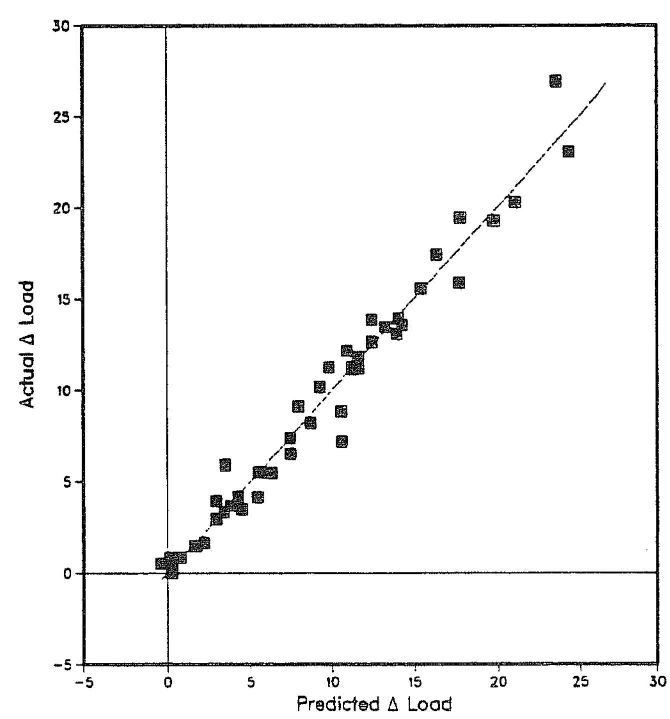


Figure 33: Δ Heating Loads, Double-Glazing Windows, Compared to HDD65

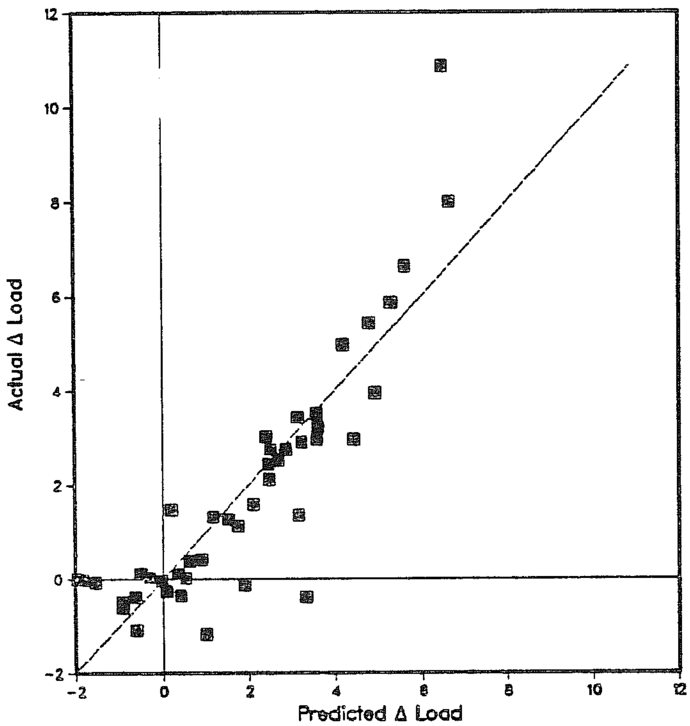


Figure 34: Δ Heating Loads, Double-Glazing Windows, Compared to HDD65 and HID65

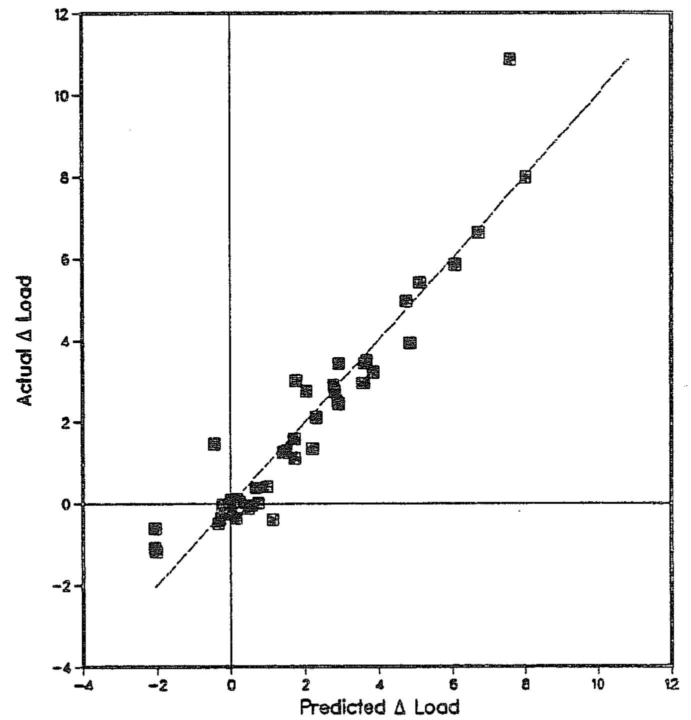


Figure 35: Δ Cooling Loads, Single-Glazing Windows, Compared to CIDV70.

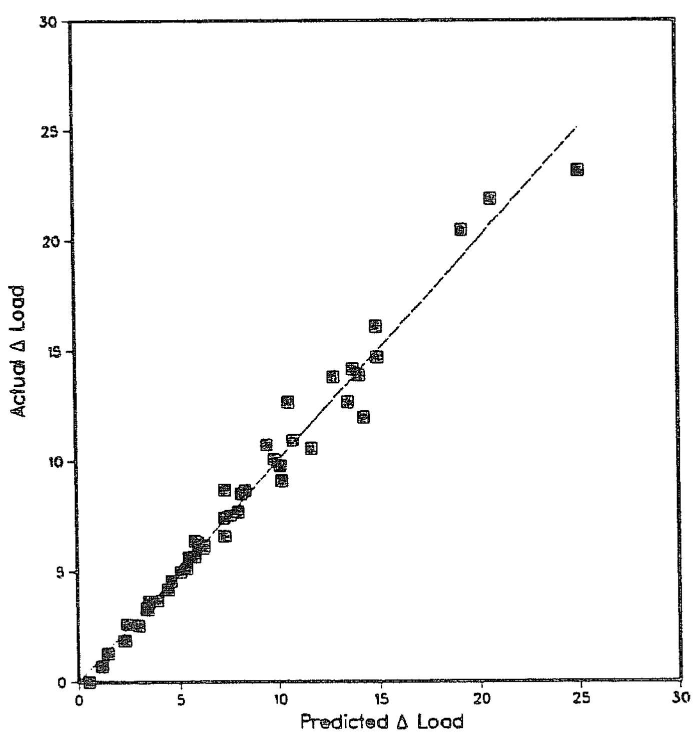
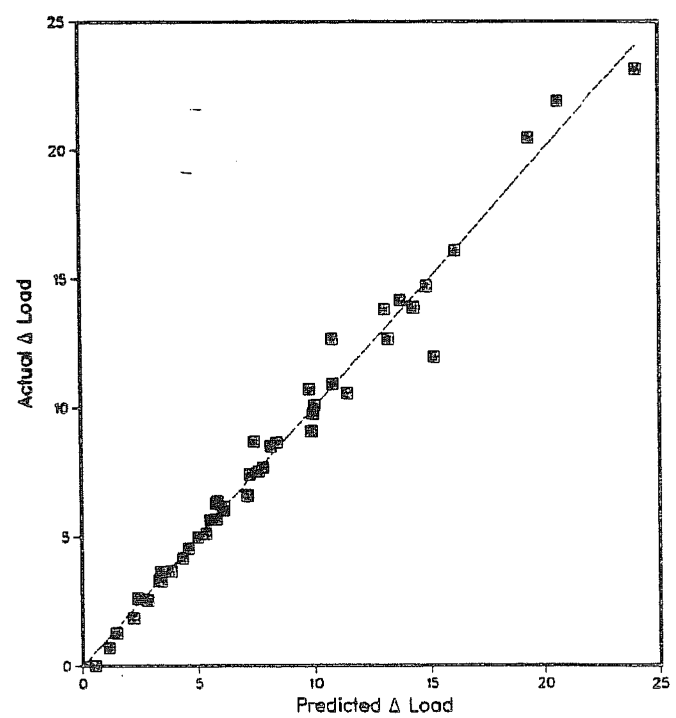


Figure 36: Δ Cooling Loads, Single-Glazing Windows, Compared to CDHR75 and CIDV70



Appendix 1. Comparision of degree-days from NOAA long-term averages to hourly weather tapes †

Location	NOAA *HDD* 57°	Weather tape *HDD* 57°	Weather tape *HDHR* 57°	NOAA *HDD* 65°	Weather tape *HDD* 65°	Weather tape *HDHR* 65°	NOAA *CDD* 65°	Weather tape *CDD* 65°	Weather tape *CDHR* 65°	Weather tape *CDHRV* 65°
Albuquerque NM	2755	2625	2945	4414	4220	4597	1254	1345	1498	1059
Atlanta GA	1673	1542	1794	3021	2828	3105	1670	1469	1504	1345
Birmingham AL	1563	1494	1766	2863	2724	3020	1881	1654	1809	1628
Bismarck ND	6904	7337	7566	9075	9411	9747	473	528	836	652
Boise ID	3786	3631	3960	5802	5577	5945	742	749	1080	789
Boston MA	3720	3804	3927	5593	5690	5874	699	674	760	580
Brownsville TX	176	115	230	609	464	646	3772	3851	3877	3695
Buffalo NY	4771	4706	4869	6798	6731	6943	476	400	572	329
Burlington VT	5811	5781	5903	7953	7943	8102	379	368	569	361
Charleston SC	873	1054	1319	1868	2115	2389	2304	1983	2104	1895
Cheyenne WY	5086	4804	5168	7000	6988	7385	309	308	612	351
Chicago IL	4356	4153	4318	6177	6065	6238	955	713	865	634
Cincinnati OH	3269	3200	3353	4950	4843	5042	1159	1147	1275	1053
Denver CO	4034	3610	4097	6014	5612	6123	680	559	814	513
El Paso TX	1394	1390	1701	2664	2587	2880	2096	1951	2386	1821
Fort Worth TX	1307	1150	1425	2407	2229	2555	2809	2500	2689	2436
Fresno CA	1262	1164	1653	2647	2535	3177	1769	1639	2014	1590
Great Falls MT	5595	5264	5478	7766	7392	7700	391	343	618	370
Honolulu HA	0	0	0	0	0	9	4389	3862	3755	3406
Jacksonville	607	402	593	1402	1138	1384	2520	2731	2738	2526
Juneau AK *	6273	6349	6460	9105	9245	9277	1	0	12	0
Kansas City MO	3243	3319	3557	4812	4904	5160	1681	1475	1648	1410
Lake Charles	708	725	957	1579	1570	1895	2682	2633	2651	2445
Las Vegas NV *	1277	1144	1408	2532	2370	2657	3029	2975	3276	2876
Los Angeles CA	383	197	387	1595	1459	1872	728	357	490	155
Medford OR *	2816	2902	3416	4798	4864	5516	645	544	928	674
Memphis TN	1878	1789	1993	3207	3106	3296	2067	1872	2096	1885
Miami FL	23	27	52	199	142	185	4095	4180	4227	4019
Minneapolis MN	6024	6345	6479	8007	8282	8459	662	894	1058	848
Nashville TN	2300	2021	2255	3756	3425	3677	1661	1483	1674	1490
New York NY	3130	2757	2941	4868	4461	4689	1089	1027	1049	784
Oklahoma City	2308	2364	2743	3735	3829	4225	1914	1882	2021	1839
Omaha NE	4435	4272	4597	6194	6092	6433	1166	1007	1251	996
Philadelphia	3216	3393	3586	4947	5085	5300	1075	1081	1190	990
Phoenix AZ	552	482	906	1442	1436	1918	3746	3334	3780	3371
Pittsburgh PA	4047	3796	4002	5950	5598	5870	645	732	928	678
Portland ME	5256	5296	5476	7501	7537	7714	254	292	504	303
Portland OR	2559	2691	2981	4691	4789	5201	332	248	462	249
Reno NV *	3867	3671	4300	6030	5781	6415	357	345	949	689
Salt Lake City	3888	4223	4498	5802	6070	6420	981	958	1265	928
San Antonio TX	711	878	1086	1606	1800	2044	2983	2860	2903	2775
San Diego CA	237	115	277	1284	1132	1396	842	600	677	280
San Francisco	1102	1070	1401	3161	3239	3705	115	98	181	66
Seattle WA	2815	2874	3223	5121	5291	5669	184	134	270	129
Washington DC	2541	2458	2645	4122	4061	4247	1430	1491	1566	1323

† *HDD* = *daily* heating degree days, *HDHR* = *hourly* heating degree days, *CDD* = *daily* cooling degree days, *CDHR* = *hourly* cooling degree days, *CDHRV* = *vented hourly* cooling degree days.

* TMY weather tape; rest are TRY weather tapes

Appendix 2. Daily Heating degree-days at various bases

Location	Degree-days base temperatures (°F)															
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
Albuquerque NM	1481	1628	1779	1937	2099	2268	2445	2625	2808	2997	3187	3382	3583	3789	4002	4220
Atlanta GA	755	851	951	1057	1170	1289	1414	1542	1676	1820	1969	2131	2298	2470	2646	2828
Birmingham AL	745	834	929	1030	1138	1252	1368	1494	1625	1763	1905	2053	2208	2372	2547	2724
Bismarck ND	5724	5944	6167	6395	6625	6860	7097	7337	7581	7828	8079	8333	8591	8856	9129	9411
Boise ID	2260	2437	2617	2805	3000	3202	3413	3631	3852	4083	4318	4562	4809	5061	5316	5577
Boston MA	2495	2663	2836	3018	3206	3402	3601	3804	4015	4236	4463	4694	4932	5175	5427	5690
Brownsville TX	16	23	33	44	57	74	91	115	146	178	213	253	298	347	402	464
Buffalo NY	3232	3426	3628	3831	4041	4259	4482	4706	4934	5169	5413	5663	5920	6185	6454	6731
Burlington VT	4171	4386	4604	4825	5055	5293	5534	5781	6033	6287	6544	6806	7075	7357	7648	7943
Charleston SC	450	517	593	674	761	852	951	1054	1166	1283	1405	1533	1669	1813	1962	2115
Cheyenne WY	3211	3417	3633	3854	4083	4317	4556	4804	5058	5318	5583	5852	6127	6410	6695	6988
Chicago IL	2817	2989	3169	3353	3542	3739	3942	4153	4371	4593	4823	5061	5302	5548	5803	6065
Cincinnati OH	1992	2147	2307	2473	2647	2826	3009	3200	3394	3592	3791	3994	4200	4410	4623	4843
Denver CO	2171	2356	2548	2747	2953	3167	3387	3610	3840	4073	4316	4564	4818	5078	5342	5612
El Paso TX	659	749	845	944	1049	1159	1270	1390	1516	1649	1789	1937	2091	2250	2415	2587
Fort Worth TX	480	559	643	733	833	936	1041	1150	1263	1384	1511	1641	1777	1921	2072	2229
Fresno CA	431	516	605	702	805	917	1035	1164	1303	1453	1610	1777	1953	2142	2335	2535
Great Falls MT	3724	3927	4137	4350	4569	4796	5028	5264	5506	5757	6012	6272	6541	6818	7102	7392
Honolulu HA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jacksonville	98	122	149	187	231	282	340	402	469	543	621	707	806	911	1023	1138
Juneau AK *	4147	4425	4711	5018	5330	5655	5998	6349	6706	7065	7425	7786	8150	8515	8880	9245
Kansas City MO	2222	2362	2510	2663	2820	2982	3147	3319	3495	3676	3862	4057	4259	4467	4683	4904
Lake Charles	280	325	375	432	496	568	643	725	813	904	999	1097	1202	1316	1438	1570
Las Vegas NV *	433	512	600	696	797	907	1023	1144	1273	1410	1557	1710	1870	2032	2199	2370
Los Angeles CA	6	11	18	30	51	86	134	197	284	401	533	682	846	1030	1233	1459
Medford OR *	1517	1693	1878	2069	2267	2470	2682	2902	3128	3359	3595	3839	4087	4341	4598	4864
Memphis TN	987	1082	1182	1288	1405	1526	1654	1789	1931	2078	2231	2393	2562	2736	2918	3106
Miami FL	6	8	10	12	15	18	21	27	36	45	54	67	82	98	119	142
Minneapolis MN	4844	5041	5247	5459	5674	5893	6117	6345	6575	6807	7044	7284	7526	7773	8025	8282
Nashville TN	1121	1232	1351	1478	1609	1742	1879	2021	2173	2333	2500	2674	2853	3039	3230	3425
New York NY	1617	1754	1901	2056	2220	2392	2572	2757	2950	3148	3351	3562	3779	4003	4230	4461
Oklahoma City	1394	1514	1638	1771	1910	2053	2203	2364	2530	2703	2878	3057	3241	3430	3625	3829
Omaha NE	2968	3142	3320	3500	3684	3875	4071	4272	4479	4692	4907	5132	5362	5599	5842	6092
Philadelphia	2199	2355	2514	2681	2852	3027	3208	3393	3584	3780	3979	4185	4398	4620	4850	5085
Phoenix AZ	111	147	187	231	283	341	404	482	565	658	760	874	1000	1136	1283	1436
Pittsburgh PA	2483	2654	2830	3009	3197	3393	3592	3796	4005	4220	4438	4660	4886	5116	5354	5598
Portland ME	3660	3870	4090	4317	4551	4790	5040	5296	5557	5821	6090	6368	6652	6939	7235	7537
Portland OR	1339	1504	1681	1864	2056	2257	2470	2691	2918	3153	3400	3655	3922	4202	4492	4789
Reno NV *	2140	2344	2553	2767	2987	3211	3439	3671	3909	4157	4409	4668	4933	5210	5493	5781
Salt Lake City	2826	3014	3206	3399	3597	3801	4009	4223	4439	4658	4879	5103	5335	5574	5820	6070
San Antonio TX	352	414	481	552	627	706	788	878	973	1075	1181	1289	1408	1532	1662	1800
San Diego CA	1	2	7	15	26	41	73	115	169	241	328	434	572	737	926	1132
San Francisco	192	256	338	446	575	725	892	1070	1268	1483	1724	1994	2282	2588	2906	3239
Seattle WA	1383	1564	1752	1951	2163	2387	2621	2874	3141	3415	3706	4011	4322	4640	4963	5291
Washington DC	1366	1500	1641	1788	1943	2108	2280	2458	2640	2827	3020	3217	3418	3625	3840	4061

* TMY weather data, all others TRY weather data.

Appendix 3. Hourly Heating degree-days at various bases

Location	Degree-days base temperatures (°F) 50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
Albuquerque NM	1783	1933	2088	2249	2415	2586	2764	2945	3133	3325	3523	3726	3934	4149	4370	4597
Atlanta GA	985	1084	1189	1298	1413	1533	1661	1794	1934	2080	2232	2392	2559	2734	2915	3105
Birmingham AL	1015	1106	1203	1304	1411	1524	1642	1766	1897	2035	2180	2334	2494	2662	2837	3020
Bismarck ND	5868	6099	6334	6573	6816	7062	7311	7566	7824	8087	8354	8625	8899	9177	9459	9747
Boise ID	2539	2725	2917	3114	3317	3525	3740	3960	4186	4418	4657	4902	5154	5412	5676	5945
Boston MA	2574	2750	2932	3120	3314	3513	3717	3927	4143	4367	4600	4841	5087	5341	5603	5874
Brownsville TX	66	81	99	119	142	169	198	230	266	305	348	397	451	511	575	646
Buffalo NY	3369	3568	3772	3981	4195	4414	4638	4869	5106	5349	5598	5854	6116	6385	6661	6943
Burlington VT	4299	4509	4726	4948	5177	5413	5655	5903	6157	6417	6683	6955	7233	7517	7807	8102
Charleston SC	678	754	836	921	1013	1109	1211	1319	1432	1552	1676	1805	1939	2081	2232	2389
Cheyenne WY	3546	3759	3978	4205	4436	4673	4917	5168	5424	5687	5955	6231	6511	6796	7088	7385
Chicago IL	2943	3124	3309	3499	3695	3897	4105	4318	4537	4760	4989	5224	5466	5715	5974	6238
Cincinnati OH	2156	2311	2471	2636	2807	2983	3166	3353	3546	3743	3946	4154	4367	4586	4811	5042
Denver CO	2693	2873	3060	3253	3454	3661	3875	4097	4327	4562	4804	5054	5311	5575	5845	6123
El Paso TX	964	1054	1148	1248	1353	1463	1580	1701	1828	1961	2098	2242	2392	2549	2711	2880
Fort Worth TX	722	805	893	988	1088	1194	1307	1425	1547	1675	1808	1946	2090	2238	2393	2555
Fresno CA	725	832	948	1072	1205	1346	1496	1653	1818	1990	2169	2355	2549	2750	2960	3177
Great Falls MT	3880	4088	4303	4524	4752	4986	5229	5478	5734	5998	6266	6543	6825	7111	7403	7700
Honolulu HA	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	9
Jacksonville	230	266	305	351	403	460	524	593	670	752	840	935	1036	1144	1259	1384
Juneau AK *	4267	4552	4847	5153	5467	5791	6122	6460	6801	7146	7494	7847	8201	8558	8917	9277
Kansas City MO	2444	2591	2741	2895	3053	3215	3382	3557	3737	3924	4115	4313	4516	4725	4939	5160
Lake Charles	441	500	564	632	705	783	867	957	1053	1154	1262	1375	1494	1621	1755	1895
Las Vegas NV *	664	750	843	942	1048	1161	1281	1408	1543	1683	1830	1982	2142	2308	2480	2657
Los Angeles CA	46	65	90	123	165	220	294	387	501	636	791	967	1161	1379	1616	1872
Medford OR *	1933	2122	2318	2523	2734	2953	3181	3416	3658	3905	4159	4419	4686	4957	5234	5516
Memphis TN	1159	1261	1369	1483	1602	1726	1856	1993	2136	2284	2438	2598	2764	2936	3113	3296
Miami FL	14	17	20	25	31	37	44	52	62	74	87	101	118	137	160	185
Minneapolis MN	4968	5173	5382	5595	5810	6028	6251	6479	6711	6948	7188	7434	7684	7938	8197	8459
Nashville TN	1333	1448	1569	1695	1827	1965	2107	2255	2410	2571	2739	2914	3095	3283	3476	3677
New York NY	1776	1924	2077	2238	2404	2575	2755	2941	3134	3335	3543	3760	3982	4212	4447	4689
Oklahoma City	1751	1877	2007	2143	2285	2432	2585	2743	2907	3076	3252	3435	3623	3818	4019	4225
Omaha NE	3267	3441	3619	3804	3993	4189	4390	4597	4808	5025	5247	5474	5706	5943	6186	6433
Philadelphia	2360	2522	2688	2858	3033	3213	3397	3586	3781	3980	4185	4398	4615	4839	5066	5300
Phoenix AZ	371	429	491	560	636	718	809	906	1009	1120	1237	1361	1491	1627	1769	1918
Pittsburgh PA	2668	2841	3020	3205	3397	3593	3795	4002	4215	4433	4657	4886	5122	5365	5615	5870
Portland ME	3821	4039	4263	4493	4730	4972	5221	5476	5737	6004	6275	6553	6836	7124	7417	7714
Portland OR	1554	1728	1912	2104	2306	2520	2745	2981	3227	3482	3747	4021	4305	4596	4896	5201
Reno NV *	2770	2969	3176	3388	3607	3831	4062	4300	4544	4795	5051	5313	5581	5854	6132	6415
Salt Lake City	3065	3255	3450	3651	3855	4065	4279	4498	4721	4949	5181	5419	5661	5909	6162	6420
San Antonio TX	521	588	659	735	815	900	990	1086	1187	1293	1404	1521	1644	1772	1905	2044
San Diego CA	32	48	68	94	127	166	216	277	350	441	552	684	833	1002	1188	1396
San Francisco	341	435	546	674	823	992	1186	1401	1638	1894	2168	2456	2755	3063	3380	3705
Seattle WA	1597	1790	1996	2217	2450	2696	2954	3223	3501	3789	4086	4390	4701	5018	5341	5669
Washington DC	1543	1684	1830	1982	2140	2303	2471	2645	2826	3011	3202	3399	3602	3810	4025	4247

* TMY weather data, all others TRY weather data.

Appendix 4. Daily Cooling degree-days at various bases

Location	Latent enthalpy days†	Degree-days base temperatures (°F)																
		62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
Albuquerque NM	2.4	1791	1636	1487	1345	1210	1079	950	832	718	609	512	420	336	259	185	123	72
Atlanta GA	226.5	2024	1833	1647	1469	1299	1141	988	842	706	578	458	348	251	171	108	64	28
Birmingham AL	300.3	2217	2025	1836	1654	1473	1302	1142	988	841	702	573	453	340	240	158	94	49
Bismarck ND	26.8	792	697	608	528	453	386	328	275	227	181	139	104	75	52	32	16	8
Boise ID	0.2	1073	960	853	749	648	552	462	385	317	256	199	148	108	79	57	39	23
Boston MA	68.5	997	880	772	674	587	507	439	374	317	268	223	182	148	117	89	66	47
Brownsville TX	1158.6	4767	4455	4151	3851	3560	3276	2999	2727	2463	2207	1961	1725	1497	1278	1073	882	701
Buffalo NY	18.1	675	576	484	400	323	257	203	157	119	87	60	38	22	10	4	2	1
Burlington VT	25.6	584	506	435	368	312	260	211	171	138	106	78	57	41	29	22	15	10
Charleston SC	415.3	2622	2404	2191	1983	1786	1596	1411	1231	1064	905	754	618	494	388	296	212	140
Cheyenne WY	0.0	537	456	379	308	242	185	135	93	57	29	14	6	3	1	0	0	0
Chicago IL	55.6	1030	919	815	713	620	539	461	385	315	253	208	169	136	107	82	59	41
Cincinnati OH	110.0	1593	1440	1290	1147	1011	882	757	640	536	437	348	273	215	163	119	81	52
Denver CO	0.5	852	749	652	559	471	390	316	249	193	148	109	82	57	38	25	16	10
El Paso TX	21.7	2540	2337	2141	1951	1776	1608	1448	1292	1143	1000	867	740	625	521	423	338	264
Fort Worth TX	426.0	3135	2917	2705	2500	2304	2118	1938	1766	1602	1446	1297	1155	1020	894	771	655	542
Fresno CA	3.0	2143	1968	1798	1639	1487	1338	1193	1051	919	792	678	572	471	384	307	242	182
Great Falls MT	0.0	577	490	411	343	284	233	190	151	119	92	69	50	32	19	10	3	1
Honolulu HA	235.6	4957	4592	4227	3862	3497	3132	2768	2405	2047	1697	1364	1053	776	540	334	171	63
Jacksonville	531.8	3483	3228	2976	2731	2494	2270	2051	1837	1633	1438	1249	1070	905	750	604	473	359
Juneau AK *	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kansas City MO	243.8	1917	1764	1616	1475	1339	1208	1084	968	858	757	662	576	495	417	346	282	223
Lake Charles	730.2	3346	3099	2862	2633	2413	2199	1996	1802	1613	1435	1262	1099	945	794	654	523	404
Las Vegas NV *	12.2	3560	3361	3166	2975	2787	2605	2431	2264	2105	1946	1792	1642	1499	1362	1233	1108	991
Los Angeles CA	1.8	815	639	484	357	251	175	120	87	65	48	36	25	18	12	8	4	2
Medford OR *	1.9	853	743	638	544	458	385	323	264	211	163	122	89	61	42	26	14	5
Memphis TN	453.1	2412	2225	2045	1872	1708	1552	1403	1259	1124	997	874	755	646	545	450	362	285
Miami FL	1183.2	5209	4862	4519	4180	3844	3511	3184	2864	2551	2245	1949	1664	1396	1151	929	736	568
Minneapolis MN	91.9	1224	1108	999	894	790	690	601	522	446	374	311	251	199	153	115	87	61
Nashville TN	225.6	2001	1824	1650	1483	1324	1175	1034	902	775	651	535	436	345	263	189	129	81
New York NY	87.1	1431	1293	1157	1027	902	782	670	563	464	385	313	248	190	141	100	67	40
Oklahoma City	337.3	2376	2204	2039	1882	1734	1591	1455	1322	1194	1072	959	851	749	653	563	478	397
Omaha NE	199.8	1360	1237	1119	1007	901	797	702	612	528	452	382	317	261	210	163	125	96
Philadelphia	154.2	1481	1341	1208	1081	957	841	731	630	533	444	363	292	230	172	121	78	43
Phoenix AZ	134.9	3977	3755	3542	3334	3131	2931	2735	2551	2369	2198	2031	1869	1716	1566	1425	1288	1158
Pittsburgh PA	58.3	1104	974	850	732	618	518	428	348	281	219	168	123	89	60	39	23	12
Portland ME	24.3	495	420	353	292	235	185	146	112	84	61	44	30	19	11	6	3	1
Portland OR	0.2	458	377	308	248	199	158	125	97	75	58	43	31	23	16	10	7	4
Reno NV *	0.8	583	498	417	345	281	223	173	133	106	80	57	38	25	14	9	5	2
Salt Lake City	0.7	1310	1189	1070	958	849	745	644	549	461	382	314	256	200	148	105	65	41
San Antonio TX	527.5	3548	3311	3081	2860	2641	2428	2220	2021	1829	1647	1468	1297	1133	976	832	695	568
San Diego CA	7.0	1104	921	755	600	466	348	251	171	115	74	47	28	18	12	7	3	1
San Francisco	0.0	221	167	127	98	74	52	33	21	13	7	4	2	1	0	0	0	0
Seattle WA	0.0	248	205	167	134	108	88	72	59	47	35	27	20	15	11	8	6	4
Washington DC	149.6	1937	1782	1634	1491	1351	1214	1084	959	841	731	629	532	441	360	285	217	162

† latent enthalpy-days are in units of Btu-day/lb of air.

* TMY weather data, all others TRY.

Appendix 5. Hourly Cooling degree-days at various bases

Location	Latent enthalpy days†	Degree-days base temperatures (°F) 62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
Albuquerque NM	2.4	1931	1781	1636	1498	1368	1246	1130	1021	920	827	738	657	581	511	447	388	335
Atlanta GA	226.5	2053	1863	1679	1504	1339	1183	1036	900	777	669	572	487	411	344	286	234	188
Birmingham AL	300.3	2378	2181	1991	1809	1635	1468	1310	1160	1019	891	775	671	576	491	415	347	286
Bismarck ND	26.8	1083	996	913	836	763	695	631	572	517	465	418	375	334	296	261	229	199
Boise ID	0.2	1384	1277	1176	1080	990	906	827	753	683	619	558	502	449	401	355	312	273
Boston MA	68.5	1069	958	855	760	673	593	520	454	393	339	290	247	208	175	147	123	102
Brownsville TX	1158.6	4777	4472	4171	3877	3589	3308	3034	2768	2509	2260	2020	1788	1567	1358	1165	989	832
Buffalo NY	18.1	840	744	654	572	496	427	364	306	255	211	171	138	111	87	68	52	39
Burlington VT	25.6	795	714	639	569	504	443	388	336	289	248	211	178	149	124	103	83	67
Charleston SC	415.3	2748	2526	2311	2104	1904	1715	1535	1364	1202	1049	905	777	662	560	469	389	319
Cheyenne WY	0.0	833	753	680	612	548	488	432	380	332	289	249	213	180	150	123	99	78
Chicago IL	55.6	1188	1073	966	865	771	683	601	526	459	399	344	295	251	213	179	149	124
Cincinnati OH	110.0	1695	1549	1409	1275	1148	1028	916	811	713	623	541	468	402	343	290	244	202
Denver CO	0.5	1097	996	901	814	733	659	589	526	466	412	362	317	276	238	203	172	145
El Paso TX	21.7	2993	2785	2582	2386	2199	2018	1845	1682	1526	1378	1240	1111	990	878	774	678	589
Fort Worth TX	426.0	3319	3102	2892	2689	2492	2303	2118	1940	1767	1604	1448	1300	1161	1031	913	805	706
Fresno CA	3.0	2482	2318	2162	2014	1873	1738	1610	1488	1372	1264	1161	1064	972	886	804	727	656
Great Falls MT	0.0	838	760	687	618	555	497	443	393	347	306	267	233	201	172	146	123	103
Honolulu HA	235.6	4841	4478	4115	3755	3398	3045	2698	2357	2023	1704	1403	1126	878	663	497	361	253
Jacksonville	531.8	3484	3227	2978	2738	2508	2286	2072	1866	1668	1479	1298	1127	968	825	699	589	492
Juneau AK *	0.0	31	23	17	12	9	6	4	3	2	1	1	0	0	0	0	0	0
Kansas City MO	243.8	2099	1942	1792	1648	1509	1378	1253	1135	1024	919	821	729	643	564	492	426	365
Lake Charles	730.2	3346	3108	2876	2651	2432	2219	2015	1819	1632	1454	1284	1123	974	835	712	604	510
Las Vegas NV *	12.2	3855	3656	3463	3276	3094	2918	2746	2579	2417	2261	2110	1965	1825	1689	1560	1436	1318
Los Angeles CA	1.8	874	727	599	490	398	321	254	198	151	113	86	67	54	44	36	30	25
Medford OR *	1.9	1193	1099	1011	928	850	777	708	644	583	527	475	426	381	338	299	262	229
Memphis TN	453.1	2659	2466	2278	2096	1923	1757	1600	1451	1308	1173	1045	926	816	714	623	540	466
Miami FL	1183.2	5255	4909	4566	4227	3892	3562	3238	2922	2613	2317	2032	1760	1502	1264	1049	857	689
Minneapolis MN	91.9	1377	1266	1160	1058	959	865	774	690	613	543	479	420	367	318	275	236	201
Nashville TN	225.6	2187	2009	1838	1674	1516	1365	1220	1082	953	836	729	632	546	470	403	342	289
New York NY	87.1	1438	1302	1172	1049	934	824	721	625	536	457	384	320	264	215	174	138	108
Oklahoma City	337.3	2514	2344	2180	2021	1869	1722	1582	1447	1318	1196	1080	971	869	774	688	609	537
Omaha NE	199.8	1619	1491	1368	1251	1138	1030	927	830	739	656	579	507	442	382	328	280	237
Philadelphia	154.2	1600	1458	1321	1190	1066	949	838	734	637	548	469	399	338	284	237	197	160
Phoenix AZ	134.9	4448	4220	3997	3780	3570	3366	3169	2980	2797	2622	2454	2292	2137	1989	1846	1710	1579
Pittsburgh PA	58.3	1275	1153	1038	928	825	728	638	554	479	412	352	298	251	209	172	140	113
Portland ME	24.3	721	644	572	504	443	386	335	288	246	210	177	148	123	99	80	63	49
Portland OR	0.2	660	587	522	462	408	360	316	277	242	211	183	158	136	116	99	84	70
Reno NV *	0.8	1210	1118	1031	949	871	798	729	664	602	544	489	438	390	345	303	265	229
Salt Lake City	0.7	1601	1484	1372	1265	1164	1068	977	891	810	734	662	596	533	474	420	370	324
San Antonio TX	527.5	3598	3361	3129	2903	2684	2470	2265	2067	1878	1700	1530	1370	1220	1082	956	841	738
San Diego CA	7.0	1210	1013	835	677	540	423	323	243	178	131	94	69	51	37	28	20	15
San Francisco	0.0	326	269	221	181	149	124	102	84	69	57	48	40	34	28	23	19	15
Seattle WA	0.0	397	348	306	270	237	208	183	160	139	120	104	89	76	65	55	47	40
Washington DC	149.6	2015	1859	1709	1566	1428	1298	1175	1057	947	843	745	656	574	501	434	374	319

† latent enthalpy-days are in units of Btu-day/lb of air.

* TMY weather data, all others TRY.

Appendix 6. Vented hourly cooling degree-days at various bases ‡

Location	Latent enthalpy days†	Degree-days base temperatures (°F)																
		62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
Albuquerque NM	2.4	1245	1182	1120	1059	1000	942	884	827	771	715	659	604	550	495	441	388	335
Atlanta GA	226.5	1773	1628	1485	1345	1211	1080	955	838	731	635	549	472	403	340	284	234	188
Birmingham AL	300.3	2068	1919	1772	1628	1487	1348	1214	1086	964	850	747	652	565	485	413	347	286
Bismarck ND	26.8	783	738	695	652	611	571	532	495	458	423	388	355	322	290	259	229	199
Boise ID	0.2	908	869	829	789	749	709	669	629	589	550	510	470	430	391	352	312	273
Boston MA	68.5	737	684	631	580	530	481	434	389	346	305	267	232	200	172	146	123	102
Brownsville TX	1158.6	4476	4214	3953	3695	3440	3187	2938	2693	2453	2219	1992	1770	1556	1353	1163	989	832
Buffalo NY	18.1	434	398	363	329	297	266	237	209	182	158	136	116	98	81	66	52	39
Burlington VT	25.6	457	425	392	361	331	303	275	249	224	201	179	157	138	119	101	83	67
Charleston SC	415.3	2395	2226	2060	1895	1735	1579	1428	1282	1140	1004	874	757	651	554	467	389	319
Cheyenne WY	0.0	414	393	372	351	330	309	288	267	246	225	204	183	162	141	120	99	78
Chicago IL	55.6	805	747	690	634	580	528	479	431	386	345	305	269	236	205	176	149	124
Cincinnati OH	110.0	1340	1243	1147	1053	963	876	792	713	637	567	501	441	386	335	288	244	202
Denver CO	0.5	603	572	542	513	483	454	425	397	368	340	311	283	255	227	200	172	145
El Paso TX	21.7	2120	2020	1920	1821	1722	1622	1524	1426	1328	1232	1137	1043	950	858	767	678	589
Fort Worth TX	426.0	2911	2752	2593	2436	2282	2129	1978	1829	1683	1541	1404	1271	1144	1023	911	805	706
Fresno CA	3.0	1806	1734	1662	1590	1518	1446	1374	1302	1230	1158	1086	1015	943	871	799	727	656
Great Falls MT	0.0	432	412	391	370	350	329	309	288	267	247	226	206	185	165	144	123	103
Honolulu HA	235.6	4352	4037	3721	3406	3093	2783	2478	2178	1884	1601	1331	1079	850	650	492	361	253
Jacksonville	531.8	3123	2922	2723	2526	2334	2145	1961	1780	1603	1432	1266	1107	956	819	697	589	492
Juneau AK *	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kansas City MO	243.8	1698	1601	1505	1410	1315	1222	1131	1041	953	868	785	706	630	558	490	426	365
Lake Charles	730.2	3007	2818	2631	2445	2261	2081	1904	1732	1566	1406	1250	1102	961	829	710	604	510
Las Vegas NV *	12.2	3238	3117	2997	2876	2756	2635	2515	2394	2274	2154	2033	1913	1793	1674	1555	1436	1318
Los Angeles CA	1.8	219	196	174	155	137	122	109	96	84	73	63	54	47	40	35	30	25
Medford OR *	1.9	781	745	710	674	639	604	568	534	499	464	430	396	363	329	296	262	229
Memphis TN	453.1	2303	2162	2023	1885	1750	1617	1488	1363	1242	1124	1012	905	804	709	621	540	466
Miami FL	1183.2	4933	4627	4322	4019	3717	3417	3121	2829	2543	2266	1997	1737	1489	1258	1047	857	689
Minneapolis MN	91.9	1045	979	913	848	783	720	658	598	542	491	442	396	352	311	273	236	201
Nashville TN	225.6	1884	1751	1619	1490	1364	1240	1120	1004	894	793	698	612	534	464	401	342	289
New York NY	87.1	998	926	854	784	714	645	579	514	453	396	341	292	248	207	171	138	108
Oklahoma City	337.3	2212	2086	1962	1839	1718	1600	1484	1371	1261	1154	1051	952	858	769	686	609	537
Omaha NE	199.8	1214	1141	1068	996	925	855	786	720	656	594	535	479	425	374	326	280	237
Philadelphia	154.2	1264	1171	1080	990	902	817	734	654	577	506	440	381	328	280	236	197	160
Phoenix AZ	134.9	3802	3659	3515	3371	3228	3085	2943	2801	2661	2521	2383	2246	2110	1975	1842	1710	1579
Pittsburgh PA	58.3	875	808	742	678	616	555	498	444	394	349	308	269	233	200	169	140	113
Portland ME	24.3	395	363	332	303	275	249	224	202	181	162	143	126	109	93	78	63	49
Portland OR	0.2	290	277	263	249	235	222	208	194	180	167	153	139	125	112	98	84	70
Reno NV *	0.8	797	761	725	689	654	618	582	547	511	476	441	405	370	335	300	265	229
Salt Lake City	0.7	1070	1023	975	928	881	834	788	741	694	648	601	555	508	462	416	370	324
San Antonio TX	527.5	3378	3175	2974	2775	2579	2386	2199	2016	1841	1673	1512	1358	1214	1079	954	841	738
San Diego CA	7.0	394	356	318	280	243	206	172	140	113	92	74	58	46	35	27	20	15
San Francisco	0.0	78	74	70	66	62	58	54	50	46	42	38	35	31	27	23	19	15
Seattle WA	0.0	149	142	136	129	122	115	108	101	95	88	81	74	67	60	54	47	40
Washington DC	149.6	1616	1517	1419	1323	1228	1135	1044	956	870	787	708	632	560	494	432	374	319

† latent enthalpy-days are in units of Btu-day/lb of air.

‡ hours when T < 78°F and humidity ratio < .0116 not counted.

* TMY weather data, all others TRY.

Appendix 7. Winter, Heating, and Cooling insolation-days

(Btu-day/sq.ft. on average vertical surface)

Location	Winter insolation-days‡		Heating insolation-days†			Cooling insolation-days†			*Vented* Cooling insolation-days†		
			T<57°	T<60°	T<65°	T>60°	T>65°	T>70°	T>60°	T>65°	T>70°
Albuquerque NM	4962	(5)	5499	6145	7274	8091	6891	5495	3824	3783	3691
Atlanta GA	3774	(5)	2874	3345	4354	8520	7458	6058	5995	5849	5245
Birmingham AL	3108	(4)	2624	3166	4074	8841	7895	6870	6541	6420	6062
Bismarck ND	7008	(9)	5349	5774	6529	5529	4695	3641	2887	2799	2633
Boise ID	5116	(7)	4570	5158	6429	6812	5499	4291	2862	2862	2862
Boston MA	4329	(6)	4929	5595	6849	5633	4358	2958	2441	2341	2116
Brownsville TX	774	(1)	466	649	1166	12104	11537	10845	10466	10354	10137
Buffalo NY	5574	(8)	4512	5020	6058	5316	4241	2979	1895	1829	1616
Burlington VT	5579	(8)	5033	5562	6483	4549	3658	2629	1749	1695	1520
Charleston SC	3108	(4)	2049	2441	3162	10379	9570	8179	7474	7374	7049
Cheyenne WY	8654	(9)	6333	6991	8137	5583	4520	3395	1841	1841	1841
Chicago IL	4866	(7)	4549	5099	6283	6016	4845	3579	2783	2741	2474
Cincinnati OH	5049	(7)	3887	4308	5029	6949	6199	5120	4545	4429	4037
Denver CO	6237	(7)	5408	6108	7499	6279	4895	3733	2279	2258	2216
El Paso TX	3733	(4)	3083	3591	4658	10220	9108	7808	5495	5491	5429
Fort Worth TX	3433	(4)	2791	3262	4116	9620	8762	7745	7037	6958	6662
Fresno CA	3945	(5)	2779	3429	4754	9495	8187	6766	4841	4841	4841
Great Falls MT	5983	(8)	5141	5699	6795	5108	4062	2891	1570	1570	1570
Honolulu HA	1029	(1)	0	0	8	14691	14674	14495	13470	13466	13337
Jacksonville	841	(1)	1312	1774	2583	10674	9791	8774	8283	8154	7845
Juneau AK *	4354	(10)	5204	5899	6837	1104	312	66	0	0	0
Kansas City MO	3495	(5)	3812	4270	5299	7674	6595	5258	4541	4470	4241
Lake Charles	1933	(3)	1545	1949	2687	10183	9399	8258	7679	7562	7179
Las Vegas NV *	3433	(4)	2879	3674	5058	11524	10170	9116	7474	7474	7470
Los Angeles CA	812	(1)	1233	2579	5599	9429	6308	3116	1108	1066	937
Medford OR *	4962	(8)	4212	4854	5941	6566	5470	4274	2870	2866	2858
Memphis TN	3941	(5)	3170	3633	4487	8579	7720	6566	5991	5883	5549
Miami FL	695	(1)	149	237	499	12537	12229	11666	11279	11191	10954
Minneapolis MN	4979	(7)	5112	5554	6241	5762	5045	4104	3408	3374	3070
Nashville TN	3387	(5)	2974	3491	4324	8120	7241	6154	5808	5662	5208
New York NY	4562	(6)	4158	4833	6004	6520	5483	4333	3466	3420	3116
Oklahoma City	3995	(5)	3687	4249	5233	7974	7008	5954	5441	5329	5041
Omaha NE	5658	(7)	4566	5137	6095	6912	6054	5008	3904	3849	3666
Philadelphia	4283	(6)	4187	4579	5541	7045	6049	4787	4141	4041	3674
Phoenix AZ	1712	(2)	1495	2016	3049	11870	10808	9466	7879	7874	7820
Pittsburgh PA	4854	(7)	4224	4670	5483	6620	5762	4433	3379	3299	2945
Portland ME	5258	(7)	5879	6516	7441	5112	4183	2966	1858	1820	1591
Portland OR	4512	(7)	3979	4916	6558	4970	3354	2116	1016	1016	1016
Reno NV *	6358	(8)	7029	7866	9337	6904	5437	4174	2716	2716	2699
Salt Lake City	5712	(7)	5070	5579	6445	7233	6383	5524	3841	3841	3833
San Antonio TX	3195	(4)	1870	2204	3016	9762	8929	7866	7908	7812	7354
San Diego CA	854	(1)	874	1824	4974	10145	6816	3466	1466	1458	1312
San Francisco	3129	(4)	4083	5995	8937	5520	2616	1024	337	337	337
Seattle WA	4808	(8)	4649	5620	7124	3466	2029	1295	499	499	499
Washington DC	3320	(5)	3783	4266	5229	7149	6199	5149	4479	4366	4133

‡ Winter insolation-days for months with more than 200 heating degree days at base 59° (number of months shown in parenthesis).
† Heating insolation-days = insolation when $T<T_{base}$; Cooling insolation-days = insolation when $T>T_{base}$; Vented cooling insolation-days = insolation when $T>T_{base}$ if humidity ratio >.0116, otherwise T>78°.
* TMY weather data, otherwise all TRY weather data

Appendix 1
Comparision of Degree-Days from NOAA Long-term Averages to Hourly Weather Tapes †

	NOAA	Weather tape		NOAA	Weather tape		NOAA	Weather tape		
	HDD	*HDD*	*HDHR*	*HDD*	*HDD*	*HDHR*	*CDD*	*CDD*	*CDHR*	*CDHRV*
Location	57	57	57	65	65	65	65	65	65	65
Albuquerque NM	2755	2625	2945	4414	4220	4597	1254	1345	1498	1059
Atlanta GA	1673	1542	1794	3021	2828	3105	1670	1469	1504	1345
Birmingham AL	1563	1494	1766	2863	2724	3020	1881	1654	1809	1628
Bismarck ND	6904	7337	7566	9075	9411	9747	473	528	836	652
Boise ID	3786	3631	3960	5802	5577	5945	742	749	1080	789
Boston MA	3720	3804	3927	5593	5690	5874	699	674	760	580
Brownsville TX	176	115	230	609	464	646	3772	3851	3877	3695
Buffalo NY	4771	4706	4869	6798	6731	6943	476	400	572	329
Burlington VT	5811	5781	5903	7953	7943	8102	379	368	569	361
Charleston SC	873	1054	1319	1868	2115	2389	2304	1983	2104	1895
Cheyenne WY	5086	4804	5168	7000	6988	7385	309	308	612	351
Chicago IL	4356	4153	4318	6177	6065	6238	955	713	865	634
Cincinnati OH	3269	3200	3353	4950	4843	5042	1159	1147	1275	1053
Denver CO	4034	3610	4097	6014	5612	6123	680	559	814	513
El Paso TX	1394	1390	1701	2664	2587	2880	2096	1951	2386	1821
Fort Worth TX	1307	1150	1425	2407	2229	2555	2809	2500	2689	2436
Fresno CA	1262	1164	1653	2647	2535	3177	1769	1639	2014	1590
Great Falls MT	5595	5264	5478	7766	7392	7700	391	343	618	370
Honolulu HA	0	0	0	0	0	9	4389	3862	3755	3406
Jacksonville	607	402	593	1402	1138	1384	2520	2731	2738	2526
Juneau AK *	6273	6349	6460	9105	9245	9277	1	0	12	0
Kansas City MO	3243	3319	3557	4812	4904	5160	1681	1475	1648	1410
Lake Charles	708	725	957	1579	1570	1895	2682	2633	2651	2445
Las Vegas NV *	1277	1144	1408	2532	2370	2657	3029	2975	3276	2876
Los Angeles CA	383	197	387	1595	1459	1872	728	357	490	155
Medford OR *	2816	2902	3416	4798	4864	5516	645	544	928	674
Memphis TN	1878	1789	1993	3207	3106	3296	2067	1872	2096	1885
Miami FL	23	27	52	199	142	185	4095	4180	4227	4019
Minneapolis MN	6024	6345	6479	8007	8282	8459	662	894	1058	848
Nashville TN	2300	2021	2255	3756	3425	3677	1661	1483	1674	1490
New York NY	3130	2757	2941	4868	4461	4689	1089	1027	1049	784
Oklahoma City	2308	2364	2743	3735	3829	4225	1914	1882	2021	1839
Omaha NE	4435	4272	4597	6194	6092	6433	1166	1007	1251	996
Philadelphia	3216	3393	3586	4947	5085	5300	1075	1081	1190	990
Phoenix AZ	552	482	906	1442	1436	1918	3746	3334	3780	3371
Pittsburgh PA	4047	3796	4002	5950	5598	5870	645	732	928	678
Portland ME	5256	5296	5476	7501	7537	7714	254	292	504	303
Portland OR	2559	2691	2981	4691	4789	5201	332	248	462	249
Reno NV *	3867	3671	4300	6030	5781	6415	357	345	949	689
Salt Lake City	3888	4223	4498	5802	6070	6420	981	958	1265	928
San Antonio TX	711	878	1086	1606	1800	2044	2983	2860	2903	2775
San Diego CA	237	115	277	1284	1132	1396	842	600	677	280
San Francisco	1102	1070	1401	3161	3239	3705	115	98	181	66
Seattle WA	2815	2874	3223	5121	5291	5669	184	134	270	129
Washington DC	2541	2458	2645	4122	4061	4247	1430	1491	1566	1323

† *HDD* = ***daily*** heating degree days, *HDHR* = ***hourly*** heating degree days, *CDD* = ***daily*** cooling degree days, *CDHR* = ***hourly*** cooling degree days, *CDHRV* = ***vented hourly*** cooling degree days.

* TMY weather tape; rest are TRY weather tapes

Appendix 2
Daily Heating Degree-Days at Various Bases

Location	Degree-days base temperatures (F)															
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
Albuquerque NM	1481	1628	1779	1937	2099	2268	2445	2625	2808	2997	3187	3382	3583	3789	4002	4220
Atlanta GA	755	851	951	1057	1170	1289	1414	1542	1676	1820	1969	2131	2298	2470	2646	2828
Birmingham AL	745	834	929	1030	1138	1252	1368	1494	1625	1763	1905	2053	2208	2372	2547	2724
Bismarck ND	5724	5944	6167	6395	6625	6860	7097	7337	7581	7828	8079	8333	8591	8856	9129	9411
Boise ID	2260	2437	2617	2805	3000	3202	3413	3631	3852	4083	4318	4562	4809	5061	5316	5577
Boston MA	2495	2663	2836	3018	3206	3402	3601	3804	4015	4236	4463	4694	4932	5175	5427	5690
Brownsville TX	16	23	33	44	57	74	91	115	146	178	213	253	298	347	402	464
Buffalo NY	3232	3426	3628	3831	4041	4259	4482	4706	4934	5169	5413	5663	5920	6185	6454	6731
Burlington VT	4171	4386	4604	4825	5055	5293	5534	5781	6033	6287	6544	6806	7075	7357	7648	7943
Charleston SC	450	517	593	674	761	852	951	1054	1166	1283	1405	1533	1669	1813	1962	2115
Cheyenne WY	3211	3417	3633	3854	4083	4317	4556	4804	5058	5318	5583	5852	6127	6410	6695	6988
Chicago IL	2817	2989	3169	3353	3542	3739	3942	4153	4371	4593	4823	5061	5302	5548	5803	6065
Cincinnati OH	1992	2147	2307	2473	2647	2826	3009	3200	3394	3592	3791	3994	4200	4410	4623	4843
Denver CO	2171	2356	2548	2747	2953	3167	3387	3610	3840	4073	4316	4564	4818	5078	5342	5612
El Paso TX	659	749	845	944	1049	1159	1270	1390	1516	1649	1789	1937	2091	2250	2415	2587
Fort Worth TX	480	559	643	733	833	936	1041	1150	1263	1384	1511	1641	1777	1921	2072	2229
Fresno CA	431	516	605	702	805	917	1035	1164	1303	1453	1610	1777	1953	2142	2335	2535
Great Falls MT	3724	3927	4137	4350	4569	4796	5028	5264	5506	5757	6012	6272	6541	6818	7102	7392
Honolulu HA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jacksonville	98	122	149	187	231	282	340	402	469	543	621	707	806	911	1023	1138
Juneau AK *	4147	4425	4711	5018	5330	5655	5998	6349	6706	7065	7425	7786	8150	8515	8880	9245
Kansas City MO	2222	2362	2510	2663	2820	2982	3147	3319	3495	3676	3862	4057	4259	4467	4683	4904
Lake Charles	280	325	375	432	496	568	643	725	813	904	999	1097	1202	1316	1438	1570
Las Vegas NV *	433	512	600	696	797	907	1023	1144	1273	1410	1557	1710	1870	2032	2199	2370
Los Angeles CA	6	11	18	30	51	86	134	197	284	401	533	682	846	1030	1233	1459
Medford OR *	1517	1693	1878	2069	2267	2470	2682	2902	3128	3359	3595	3839	4087	4341	4598	4864
Memphis TN	987	1082	1182	1288	1405	1526	1654	1789	1931	2078	2231	2393	2562	2736	2918	3106
Miami FL	6	8	10	12	15	18	21	27	36	45	54	67	82	98	119	142
Minneapolis MN	4844	5041	5247	5459	5674	5893	6117	6345	6575	6807	7044	7284	7526	7773	8025	8282
Nashville TN	1121	1232	1351	1478	1609	1742	1879	2021	2173	2333	2500	2674	2853	3039	3230	3425
New York NY	1617	1754	1901	2056	2220	2392	2572	2757	2950	3148	3351	3562	3779	4003	4230	4461
Oklahoma City	1394	1514	1638	1771	1910	2053	2203	2364	2530	2703	2878	3057	3241	3430	3625	3829
Omaha NE	2968	3142	3320	3500	3684	3875	4071	4272	4479	4692	4907	5132	5362	5599	5842	6092
Philadelphia	2199	2355	2514	2681	2852	3027	3208	3393	3584	3780	3979	4185	4398	4620	4850	5085
Phoenix AZ	111	147	187	231	283	341	404	482	565	658	760	874	1000	1136	1283	1436
Pittsburgh PA	2483	2654	2830	3009	3197	3393	3592	3796	4005	4220	4438	4660	4886	5116	5354	5598
Portland ME	3660	3870	4090	4317	4551	4790	5040	5296	5557	5821	6090	6368	6652	6939	7235	7537
Portland OR	1339	1504	1681	1864	2056	2257	2470	2691	2918	3153	3400	3655	3922	4202	4492	4789
Reno NV *	2140	2344	2553	2767	2987	3211	3439	3671	3909	4157	4409	4668	4933	5210	5493	5781
Salt Lake City	2826	3014	3206	3399	3597	3801	4009	4223	4439	4658	4879	5103	5335	5574	5820	6070
San Antonio TX	352	414	481	552	627	706	788	878	973	1075	1181	1289	1408	1532	1662	1800
San Diego CA	1	2	7	15	26	41	73	115	169	241	328	434	572	737	926	1132
San Francisco	192	256	338	446	575	725	892	1070	1268	1483	1724	1994	2282	2588	2906	3239
Seattle WA	1383	1564	1752	1951	2163	2387	2621	2874	3141	3415	3706	4011	4322	4640	4963	5291
Washington DC	1366	1500	1641	1788	1943	2108	2280	2458	2640	2827	3020	3217	3418	3625	3840	4061

* TMY weather data, all others TRY weather data.

Appendix 3
Hourly Heating Degree-Days at Various Bases

Location	Degree-days base temperatures (F)															
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
Albuquerque NM	1783	1933	2088	2249	2415	2586	2764	2945	3133	3325	3523	3726	3934	4149	4370	4597
Atlanta GA	985	1084	1189	1298	1413	1533	1661	1794	1934	2080	2232	2392	2559	2734	2915	3105
Birmingham AL	1015	1106	1203	1304	1411	1524	1642	1766	1897	2035	2180	2334	2494	2662	2837	3020
Bismarck ND	5868	6099	6334	6573	6816	7062	7311	7566	7824	8087	8354	8625	8899	9177	9459	9747
Boise ID	2539	2725	2917	3114	3317	3525	3740	3960	4186	4418	4657	4902	5154	5412	5676	5945
Boston MA	2574	2750	2932	3120	3314	3513	3717	3927	4143	4367	4600	4841	5087	5341	5603	5874
Brownsville TX	66	81	99	119	142	169	198	230	266	305	348	397	451	511	575	646
Buffalo NY	3369	3568	3772	3981	4195	4414	4638	4869	5106	5349	5598	5854	6116	6385	6661	6943
Burlington VT	4299	4509	4726	4948	5177	5413	5655	5903	6157	6417	6683	6955	7233	7517	7807	8102
Charleston SC	678	754	836	921	1013	1109	1211	1319	1432	1552	1676	1805	1939	2081	2232	2389
Cheyenne WY	3546	3759	3978	4205	4436	4673	4917	5168	5424	5687	5955	6231	6511	6796	7088	7385
Chicago IL	2943	3124	3309	3499	3695	3897	4105	4318	4537	4760	4989	5224	5466	5715	5974	6238
Cincinnati OH	2156	2311	2471	2636	2807	2983	3166	3353	3546	3743	3946	4154	4367	4586	4811	5042
Denver CO	2693	2873	3060	3253	3454	3661	3875	4097	4327	4562	4804	5054	5311	5575	5845	6123
El Paso TX	964	1054	1148	1248	1353	1463	1580	1701	1828	1961	2098	2242	2392	2549	2711	2880
Fort Worth TX	722	805	893	988	1088	1194	1307	1425	1547	1675	1808	1946	2090	2238	2393	2555
Fresno CA	725	832	948	1072	1205	1346	1496	1653	1818	1990	2169	2355	2549	2750	2960	3177
Great Falls MT	3880	4088	4303	4524	4752	4986	5229	5478	5734	5998	6266	6543	6825	7111	7403	7700
Honolulu HA	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	9
Jacksonville	230	266	305	351	403	460	524	593	670	752	840	935	1036	1144	1259	1384
Juneau AK *	4267	4552	4847	5153	5467	5791	6122	6460	6801	7146	7494	7847	8201	8558	8917	9277
Kansas City MO	2444	2591	2741	2895	3053	3215	3382	3557	3737	3924	4115	4313	4516	4725	4939	5160
Lake Charles	441	500	564	632	705	783	867	957	1053	1154	1262	1375	1494	1621	1755	1895
Las Vegas NV *	664	750	843	942	1048	1161	1281	1408	1543	1683	1830	1982	2142	2308	2480	2657
Los Angeles CA	46	65	90	123	165	220	294	387	501	636	791	967	1161	1379	1616	1872
Medford OR *	1933	2122	2318	2523	2734	2953	3181	3416	3658	3905	4159	4419	4686	4957	5234	5516
Memphis TN	1159	1261	1369	1483	1602	1726	1856	1993	2136	2284	2438	2598	2764	2936	3113	3296
Miami FL	14	17	20	25	31	37	44	52	62	74	87	101	118	137	160	185
Minneapolis MN	4968	5173	5382	5595	5810	6028	6251	6479	6711	6948	7188	7434	7684	7938	8197	8459
Nashville TN	1333	1448	1569	1695	1827	1965	2107	2255	2410	2571	2739	2914	3095	3283	3476	3677
New York NY	1776	1924	2077	2238	2404	2575	2755	2941	3134	3335	3543	3760	3982	4212	4447	4689
Oklahoma City	1751	1877	2007	2143	2285	2432	2585	2743	2907	3076	3252	3435	3623	3818	4019	4225
Omaha NE	3267	3441	3619	3804	3993	4189	4390	4597	4808	5025	5247	5474	5706	5943	6186	6433
Philadelphia	2360	2522	2688	2858	3033	3213	3397	3586	3781	3980	4185	4398	4615	4839	5066	5300
Phoenix AZ	371	429	491	560	636	718	809	906	1009	1120	1237	1361	1491	1627	1769	1918
Pittsburgh PA	2668	2841	3020	3205	3397	3593	3795	4002	4215	4433	4657	4886	5122	5365	5615	5870
Portland ME	3821	4039	4263	4493	4730	4972	5221	5476	5737	6004	6275	6553	6836	7124	7417	7714
Portland OR	1554	1728	1912	2104	2306	2520	2745	2981	3227	3482	3747	4021	4305	4596	4896	5201
Reno NV *	2770	2969	3176	3388	3607	3831	4062	4300	4544	4795	5051	5313	5581	5854	6132	6415
Salt Lake City	3065	3255	3450	3651	3855	4065	4279	4498	4721	4949	5181	5419	5661	5909	6162	6420
San Antonio TX	521	588	659	735	815	900	990	1086	1187	1293	1404	1521	1644	1772	1905	2044
San Diego CA	32	48	68	94	127	166	216	277	350	441	552	684	833	1002	1188	1396
San Francisco	341	435	546	674	823	992	1186	1401	1638	1894	2168	2456	2755	3063	3380	3705
Seattle WA	1597	1790	1996	2217	2450	2696	2954	3223	3501	3789	4086	4390	4701	5018	5341	5669
Washington DC	1543	1684	1830	1982	2140	2303	2471	2645	2826	3011	3202	3399	3602	3810	4025	4247

* TMY weather data, all others TRY weather data.

Appendix 4
Daily Cooling Degree-Days at Various Bases

Location	Latent enthalpy days†	Degree-days base temperatures (F)																
		62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
Albuquerque NM	2.4	1791	1636	1487	1345	1210	1079	950	832	718	609	512	420	336	259	185	123	72
Atlanta GA	226.5	2024	1833	1647	1469	1299	1141	988	842	706	578	458	348	251	171	108	64	28
Birmingham AL	300.3	2217	2025	1836	1654	1473	1302	1142	988	841	702	573	453	340	240	158	94	49
Bismarck ND	26.8	792	697	608	528	453	386	328	275	227	181	139	104	75	52	32	16	8
Boise ID	0.2	1073	960	853	749	648	552	462	385	317	256	199	148	108	79	57	39	23
Boston MA	68.5	997	880	772	674	587	507	439	374	317	268	223	182	148	117	89	66	47
Brownsville TX	1158.6	4767	4455	4151	3851	3560	3276	2999	2727	2463	2207	1961	1725	1497	1278	1073	882	701
Buffalo NY	18.1	675	576	484	400	323	257	203	157	119	87	60	38	22	10	4	2	1
Burlington VT	25.6	584	506	435	368	312	260	211	171	138	106	78	57	41	29	22	15	10
Charleston SC	415.3	2622	2404	2191	1983	1786	1596	1411	1231	1064	905	754	618	494	388	296	212	140
Cheyenne WY	0.0	537	456	379	308	242	185	135	93	57	29	14	6	3	1	0	0	0
Chicago IL	55.6	1030	919	815	713	620	539	461	385	315	253	208	169	136	107	82	59	41
Cincinnati OH	110.0	1593	1440	1290	1147	1011	882	757	640	536	437	348	273	215	163	119	81	52
Denver CO	0.5	852	749	652	559	471	390	316	249	193	148	109	82	57	38	25	16	10
El Paso TX	21.7	2540	2337	2141	1951	1776	1608	1448	1292	1143	1000	867	740	625	521	423	338	264
Fort Worth TX	426.0	3135	2917	2705	2500	2304	2118	1938	1766	1602	1446	1297	1155	1020	894	771	655	542
Fresno CA	3.0	2143	1968	1798	1639	1487	1338	1193	1051	919	792	678	572	471	384	307	242	182
Great Falls MT	0.0	577	490	411	343	284	233	190	151	119	92	69	50	32	19	10	3	1
Honolulu HA	235.6	4957	4592	4227	3862	3497	3132	2768	2405	2047	1697	1364	1053	776	540	334	171	63
Jacksonville	531.8	3483	3228	2976	2731	2494	2270	2051	1837	1633	1438	1249	1070	905	750	604	473	359
Juneau AK *	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kansas City MO	243.8	1917	1764	1616	1475	1339	1208	1084	968	858	757	662	576	495	417	346	282	223
Lake Charles	730.2	3346	3099	2862	2633	2413	2199	1996	1802	1613	1435	1262	1099	945	794	654	523	404
Las Vegas NV *	12.2	3560	3361	3166	2975	2787	2605	2431	2264	2105	1946	1792	1642	1499	1362	1233	1108	991
Los Angeles CA	1.8	815	639	484	357	251	175	120	87	65	48	36	25	18	12	8	4	2
Medford OR *	1.9	853	743	638	544	458	385	323	264	211	163	122	89	61	42	26	14	5
Memphis TN	453.1	2412	2225	2045	1872	1708	1552	1403	1259	1124	997	874	755	646	545	450	362	285
Miami FL	1183.2	5209	4862	4519	4180	3844	3511	3184	2864	2551	2245	1949	1664	1396	1151	929	736	568
Minneapolis MN	91.9	1224	1108	999	894	790	690	601	522	446	374	311	251	199	153	115	87	61
Nashville TN	225.6	2001	1824	1650	1483	1324	1175	1034	902	775	651	535	436	345	263	189	129	81
New York NY	87.1	1431	1293	1157	1027	902	782	670	563	464	385	313	248	190	141	100	67	40
Oklahoma City	337.3	2376	2204	2039	1882	1734	1591	1455	1322	1194	1072	959	851	749	653	563	478	397
Omaha NE	199.8	1360	1237	1119	1007	901	797	702	612	528	452	382	317	261	210	163	125	96
Philadelphia	154.2	1481	1341	1208	1081	957	841	731	630	533	444	363	292	230	172	121	78	43
Phoenix AZ	134.9	3977	3755	3542	3334	3131	2931	2735	2551	2369	2198	2031	1869	1716	1566	1425	1288	1158
Pittsburgh PA	58.3	1104	974	850	732	618	518	428	348	281	219	168	123	89	60	39	23	12
Portland ME	24.3	495	420	353	292	235	185	146	112	84	61	44	30	19	11	6	3	1
Portland OR	0.2	458	377	308	248	199	158	125	97	75	58	43	31	23	16	10	7	4
Reno NV *	0.8	583	498	417	345	281	223	173	133	106	80	57	38	25	14	9	5	2
Salt Lake City	0.7	1310	1189	1070	958	849	745	644	549	461	382	314	256	200	148	105	65	41
San Antonio TX	527.5	3548	3311	3081	2860	2641	2428	2220	2021	1829	1647	1468	1297	1133	976	832	695	568
San Diego CA	7.0	1104	921	755	600	466	348	251	171	115	74	47	28	18	12	7	3	1
San Francisco	0.0	221	167	127	98	74	52	33	21	13	7	4	2	1	0	0	0	0
Seattle WA	0.0	248	205	167	134	108	88	72	59	47	35	27	20	15	11	8	6	4
Washington DC	149.6	1937	1782	1634	1491	1351	1214	1084	959	841	731	629	532	441	360	285	217	162

† latent enthalpy-days are in units of Btu-day/lb of air.

* TMY weather data, all others TRY.

Appendix 5
Hourly Cooling Degree-Days at Various Bases

Location	Latent enthalpy days†	Degree-days base temperatures (F)																
		62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
Albuquerque NM	2.4	1931	1781	1636	1498	1368	1246	1130	1021	920	827	738	657	581	511	447	388	335
Atlanta GA	226.5	2053	1863	1679	1504	1339	1183	1036	900	777	669	572	487	411	344	286	234	188
Birmingham AL	300.3	2378	2181	1991	1809	1635	1468	1310	1160	1019	891	775	671	576	491	415	347	286
Bismarck ND	26.8	1083	996	913	836	763	695	631	572	517	465	418	375	334	296	261	229	199
Boise ID	0.2	1384	1277	1176	1080	990	906	827	753	683	619	558	502	449	401	355	312	273
Boston MA	68.5	1069	958	855	760	673	593	520	454	393	339	290	247	208	175	147	123	102
Brownsville TX	1158.6	4777	4472	4171	3877	3589	3308	3034	2768	2509	2260	2020	1788	1567	1358	1165	989	832
Buffalo NY	18.1	840	744	654	572	496	427	364	306	255	211	171	138	111	87	68	52	39
Burlington VT	25.6	795	714	639	569	504	443	388	336	289	248	211	178	149	124	103	83	67
Charleston SC	415.3	2748	2526	2311	2104	1904	1715	1535	1364	1202	1049	905	777	662	560	469	389	319
Cheyenne WY	0.0	833	753	680	612	548	488	432	380	332	289	249	213	180	150	123	99	78
Chicago IL	55.6	1188	1073	966	865	771	683	601	526	459	399	344	295	251	213	179	149	124
Cincinnati OH	110.0	1695	1549	1409	1275	1148	1028	916	811	713	623	541	468	402	343	290	244	202
Denver CO	0.5	1097	996	901	814	733	659	589	526	466	412	362	317	276	238	203	172	145
El Paso TX	21.7	2993	2785	2582	2386	2199	2018	1845	1682	1526	1378	1240	1111	990	878	774	678	589
Fort Worth TX	426.0	3319	3102	2892	2689	2492	2303	2118	1940	1767	1604	1448	1300	1161	1031	913	805	706
Fresno CA	3.0	2482	2318	2162	2014	1873	1738	1610	1488	1372	1264	1161	1064	972	886	804	727	656
Great Falls MT	0.0	838	760	687	618	555	497	443	393	347	306	267	233	201	172	146	123	103
Honolulu HA	235.6	4841	4478	4115	3755	3398	3045	2698	2357	2023	1704	1403	1126	878	663	497	361	253
Jacksonville	531.8	3484	3227	2978	2738	2508	2286	2072	1866	1668	1479	1298	1127	968	825	699	589	492
Juneau AK *	0.0	31	23	17	12	9	6	4	3	2	1	1	0	0	0	0	0	0
Kansas City MO	243.8	2099	1942	1792	1648	1509	1378	1253	1135	1024	919	821	729	643	564	492	426	365
Lake Charles	730.2	3346	3108	2876	2651	2432	2219	2015	1819	1632	1454	1284	1123	974	835	712	604	510
Las Vegas NV *	12.2	3855	3656	3463	3276	3094	2918	2746	2579	2417	2261	2110	1965	1825	1689	1560	1436	1318
Los Angeles CA	1.8	874	727	599	490	398	321	254	198	151	113	86	67	54	44	36	30	25
Medford OR *	1.9	1193	1099	1011	928	850	777	708	644	583	527	475	426	381	338	299	262	229
Memphis TN	453.1	2659	2466	2278	2096	1923	1757	1600	1451	1308	1173	1045	926	816	714	623	540	466
Miami FL	1183.2	5255	4909	4566	4227	3892	3562	3238	2922	2613	2317	2032	1760	1502	1264	1049	857	689
Minneapolis MN	91.9	1377	1266	1160	1058	959	865	774	690	613	543	479	420	367	318	275	236	201
Nashville TN	225.6	2187	2009	1838	1674	1516	1365	1220	1082	953	836	729	632	546	470	403	342	289
New York NY	87.1	1438	1302	1172	1049	934	824	721	625	536	457	384	320	264	215	174	138	108
Oklahoma City	337.3	2514	2344	2180	2021	1869	1722	1582	1447	1318	1196	1080	971	869	774	688	609	537
Omaha NE	199.8	1619	1491	1368	1251	1138	1030	927	830	739	656	579	507	442	382	328	280	237
Philadelphia	154.2	1600	1458	1321	1190	1066	949	838	734	637	548	469	399	338	284	237	197	160
Phoenix AZ	134.9	4448	4220	3997	3780	3570	3366	3169	2980	2797	2622	2454	2292	2137	1989	1846	1710	1579
Pittsburgh PA	58.3	1275	1153	1038	928	825	728	638	554	479	412	352	298	251	209	172	140	113
Portland ME	24.3	721	644	572	504	443	386	335	288	246	210	177	148	123	99	80	63	49
Portland OR	0.2	660	587	522	462	408	360	316	277	242	211	183	158	136	116	99	84	70
Reno NV *	0.8	1210	1118	1031	949	871	798	729	664	602	544	489	438	390	345	303	265	229
Salt Lake City	0.7	1601	1484	1372	1265	1164	1068	977	891	810	734	662	596	533	474	420	370	324
San Antonio TX	527.5	3598	3361	3129	2903	2684	2470	2265	2067	1878	1700	1530	1370	1220	1082	956	841	738
San Diego CA	7.0	1210	1013	835	677	540	423	323	243	178	131	94	69	51	37	28	20	15
San Francisco	0.0	326	269	221	181	149	124	102	84	69	57	48	40	34	28	23	19	15
Seattle WA	0.0	397	348	306	270	237	208	183	160	139	120	104	89	76	65	55	47	40
Washington DC	149.6	2015	1859	1709	1566	1428	1298	1175	1057	947	843	745	656	574	501	434	374	319

† latent enthalpy-days are in units of Btu-day/lb of air.

* TMY weather data, all others TRY.

Appendix 6
Vented hourly cooling Degree-Days at Various Bases ‡

Location	Latent enthalpy days†	Degree-days base temperatures (F)																
		62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
Albuquerque NM	2.4	1245	1182	1120	1059	1000	942	884	827	771	715	659	604	550	495	441	388	335
Atlanta GA	226.5	1773	1628	1485	1345	1211	1080	955	838	731	635	549	472	403	340	284	234	188
Birmingham AL	300.3	2068	1919	1772	1628	1487	1348	1214	1086	964	850	747	652	565	485	413	347	286
Bismarck ND	26.8	783	738	695	652	611	571	532	495	458	423	388	355	322	290	259	229	199
Boise ID	0.2	908	869	829	789	749	709	669	629	589	550	510	470	430	391	352	312	273
Boston MA	68.5	737	684	631	580	530	481	434	389	346	305	267	232	200	172	146	123	102
Brownsville TX	1158.6	4476	4214	3953	3695	3440	3187	2938	2693	2453	2219	1992	1770	1556	1353	1163	989	832
Buffalo NY	18.1	434	398	363	329	297	266	237	209	182	158	136	116	98	81	66	52	39
Burlington VT	25.6	457	425	392	361	331	303	275	249	224	201	179	157	138	119	101	83	67
Charleston SC	415.3	2395	2226	2060	1895	1735	1579	1428	1282	1140	1004	874	757	651	554	467	389	319
Cheyenne WY	0.0	414	393	372	351	330	309	288	267	246	225	204	183	162	141	120	99	78
Chicago IL	55.6	805	747	690	634	580	528	479	431	386	345	305	269	236	205	176	149	124
Cincinnati OH	110.0	1340	1243	1147	1053	963	876	792	713	637	567	501	441	386	335	288	244	202
Denver CO	0.5	603	572	542	513	483	454	425	397	368	340	311	283	255	227	200	172	145
El Paso TX	21.7	2120	2020	1920	1821	1722	1622	1524	1426	1328	1232	1137	1043	950	858	767	678	589
Fort Worth TX	426.0	2911	2752	2593	2436	2282	2129	1978	1829	1683	1541	1404	1271	1144	1023	911	805	706
Fresno CA	3.0	1806	1734	1662	1590	1518	1446	1374	1302	1230	1158	1086	1015	943	871	799	727	656
Great Falls MT	0.0	432	412	391	370	350	329	309	288	267	247	226	206	185	165	144	123	103
Honolulu HA	235.6	4352	4037	3721	3406	3093	2783	2478	2178	1884	1601	1331	1079	850	650	492	361	253
Jacksonville	531.8	3123	2922	2723	2526	2334	2145	1961	1780	1603	1432	1266	1107	956	819	697	589	492
Juneau AK *	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kansas City MO	243.8	1698	1601	1505	1410	1315	1222	1131	1041	953	868	785	706	630	558	490	426	365
Lake Charles	730.2	3007	2818	2631	2445	2261	2081	1904	1732	1566	1406	1250	1102	961	829	710	604	510
Las Vegas NV *	12.2	3238	3117	2997	2876	2756	2635	2515	2394	2274	2154	2033	1913	1793	1674	1555	1436	1318
Los Angeles CA	1.8	219	196	174	155	137	122	109	96	84	73	63	54	47	40	35	30	25
Medford OR *	1.9	781	745	710	674	639	604	568	534	499	464	430	396	363	329	296	262	229
Memphis TN	453.1	2303	2162	2023	1885	1750	1617	1488	1363	1242	1124	1012	905	804	709	621	540	466
Miami FL	1183.2	4933	4627	4322	4019	3717	3417	3121	2829	2543	2266	1997	1737	1489	1258	1047	857	689
Minneapolis MN	91.9	1045	979	913	848	783	720	658	598	542	491	442	396	352	311	273	236	201
Nashville TN	225.6	1884	1751	1619	1490	1364	1240	1120	1004	894	793	698	612	534	464	401	342	289
New York NY	87.1	998	926	854	784	714	645	579	514	453	396	341	292	248	207	171	138	108
Oklahoma City	337.3	2212	2086	1962	1839	1718	1600	1484	1371	1261	1154	1051	952	858	769	686	609	537
Omaha NE	199.8	1214	1141	1068	996	925	855	786	720	656	594	535	479	425	374	326	280	237
Philadelphia	154.2	1264	1171	1080	990	902	817	734	654	577	506	440	381	328	280	236	197	160
Phoenix AZ	134.9	3802	3659	3515	3371	3228	3085	2943	2801	2661	2521	2383	2246	2110	1975	1842	1710	1579
Pittsburgh PA	58.3	875	808	742	678	616	555	498	444	394	349	308	269	233	200	169	140	113
Portland ME	24.3	395	363	332	303	275	249	224	202	181	162	143	126	109	93	78	63	49
Portland OR	0.2	290	277	263	249	235	222	208	194	180	167	153	139	125	112	98	84	70
Reno NV *	0.8	797	761	725	689	654	618	582	547	511	476	441	405	370	335	300	265	229
Salt Lake City	0.7	1070	1023	975	928	881	834	788	741	694	648	601	555	508	462	416	370	324
San Antonio TX	527.5	3378	3175	2974	2775	2579	2386	2199	2016	1841	1673	1512	1358	1214	1079	954	841	738
San Diego CA	7.0	394	356	318	280	243	206	172	140	113	92	74	58	46	35	27	20	15
San Francisco	0.0	78	74	70	66	62	58	54	50	46	42	38	35	31	27	23	19	15
Seattle WA	0.0	149	142	136	129	122	115	108	101	95	88	81	74	67	60	54	47	40
Washington DC	149.6	1616	1517	1419	1323	1228	1135	1044	956	870	787	708	632	560	494	432	374	319

† latent enthalpy-days are in units of Btu-day/lb of air.

‡ hours when T < 78F and humidity ratio < .0116 not counted.

* TMY weather data, all others TRY.

Appendix 7
Winter, Heating, and Cooling Insolation-Days
(Btu-day/sq.ft. on average vertical surface)

Location	Winter insolation-days‡		Heating insolation-days† T<57	T<60	T<65	Cooling insolation-days† T>60	T>65	T>70	*Vented* Cooling insolation-days† T>60	T>65	T>70
Albuquerque NM	4962	(5)	5499	6145	7274	8091	6891	5495	3824	3783	3691
Atlanta GA	3774	(5)	2874	3345	4354	8520	7458	6058	5995	5849	5245
Birmingham AL	3108	(4)	2624	3166	4074	8841	7895	6870	6541	6420	6062
Bismarck ND	7008	(9)	5349	5774	6529	5529	4695	3641	2887	2799	2633
Boise ID	5116	(7)	4570	5158	6429	6812	5499	4291	2862	2862	2862
Boston MA	4329	(6)	4929	5595	6849	5633	4358	2958	2441	2341	2116
Brownsville TX	774	(1)	466	649	1166	12104	11537	10845	10466	10354	10137
Buffalo NY	5574	(8)	4512	5020	6058	5316	4241	2979	1895	1829	1616
Burlington VT	5579	(8)	5033	5562	6483	4549	3658	2629	1749	1695	1520
Charleston SC	3108	(4)	2049	2441	3162	10379	9570	8179	7474	7374	7049
Cheyenne WY	8654	(9)	6333	6991	8137	5583	4520	3395	1841	1841	1841
Chicago IL	4866	(7)	4549	5099	6283	6016	4845	3579	2783	2741	2474
Cincinnati OH	5049	(7)	3887	4308	5029	6949	6199	5120	4545	4429	4037
Denver CO	6237	(7)	5408	6108	7499	6279	4895	3733	2279	2258	2216
El Paso TX	3733	(4)	3083	3591	4658	10220	9108	7808	5495	5491	5429
Fort Worth TX	3433	(4)	2791	3262	4116	9620	8762	7745	7037	6958	6662
Fresno CA	3945	(5)	2779	3429	4754	9495	8187	6766	4841	4841	4841
Great Falls MT	5983	(8)	5141	5699	6795	5108	4062	2891	1570	1570	1570
Honolulu HA	1029	(1)	0	0	8	14691	14674	14495	13470	13466	13337
Jacksonville	841	(1)	1312	1774	2583	10674	9791	8774	8283	8154	7845
Juneau AK *	4354	(10)	5204	5899	6837	1104	312	66	0	0	0
Kansas City MO	3495	(5)	3812	4270	5299	7674	6595	5258	4541	4470	4241
Lake Charles	1933	(3)	1545	1949	2687	10183	9399	8258	7679	7562	7179
Las Vegas NV *	3433	(4)	2879	3674	5058	11524	10170	9116	7474	7474	7470
Los Angeles CA	812	(1)	1233	2579	5599	9429	6308	3116	1108	1066	937
Medford OR *	4962	(8)	4212	4854	5941	6566	5470	4274	2870	2866	2858
Memphis TN	3941	(5)	3170	3633	4487	8579	7720	6566	5991	5883	5549
Miami FL	695	(1)	149	237	499	12537	12229	11666	11279	11191	10954
Minneapolis MN	4979	(7)	5112	5554	6241	5762	5045	4104	3408	3374	3070
Nashville TN	3387	(5)	2974	3491	4324	8120	7241	6154	5808	5662	5208
New York NY	4562	(6)	4158	4833	6004	6520	5483	4333	3466	3420	3116
Oklahoma City	3995	(5)	3687	4249	5233	7974	7008	5954	5441	5329	5041
Omaha NE	5658	(7)	4566	5137	6095	6912	6054	5008	3904	3849	3666
Philadelphia	4283	(6)	4187	4579	5541	7045	6049	4787	4141	4041	3674
Phoenix AZ	1712	(2)	1495	2016	3049	11870	10808	9466	7879	7874	7820
Pittsburgh PA	4854	(7)	4224	4670	5483	6620	5762	4433	3379	3299	2945
Portland ME	5258	(7)	5879	6516	7441	5112	4183	2966	1858	1820	1591
Portland OR	4512	(7)	3979	4916	6558	4970	3354	2116	1016	1016	1016
Reno NV *	6358	(8)	7029	7866	9337	6904	5437	4174	2716	2716	2699
Salt Lake City	5712	(7)	5070	5579	6445	7233	6383	5524	3841	3841	3833
San Antonio TX	3195	(4)	1870	2204	3016	9762	8929	7866	7908	7812	7354
San Diego CA	854	(1)	874	1824	4974	10145	6816	3466	1466	1458	1312
San Francisco	3129	(4)	4083	5995	8937	5520	2616	1024	337	337	337
Seattle WA	4808	(8)	4649	5620	7124	3466	2029	1295	499	499	499
Washington DC	3320	(5)	3783	4266	5229	7149	6199	5149	4479	4366	4133

‡ Winter insolation-days for months with more than 200 heating degree days at base 59 (number of months shown in parenthesis).

† Heating insolation-days = insolation when $T<T_{base}$; Cooling insolation-days = insolation when $T>T_{base}$; Vented cooling insolation-days = insolation when $T>T_{base}$ if humidity ratio >.0116, otherwise T>78.

* TMY weather data, otherwise all TRY weather data