Annual Heating and Cooling Requirements and Design Day Performance for a Residential Model in Six Climates: A Comparison of NBSLD, BLAST 2, and DOE-2.1*

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ABSTRACT

A comparison has been made of heating and cooling load predictions made by three public domain building energy analysis computer programs: NBSLD, BLAST 2, and DOE-2.1. DOE-2.1 analyses were made using both ASHRAE standard weighting factors (SWF's), and custom weighting factors (CWF's) calculated by the program for the specific thermal model. The thermal model used for the comparison is based on a typical, current practice single-family detached residence. Assumptions used in the comparison are described in detail. Three different kinds of comparisons were made: First, monthly and annual load calculations were compared for six locations spanning the range of climates in the continental United States, using ASHRAE Test Reference Year weather data. Second, predicted changes in annual heating and cooling loads (BLAST 2 and DOE-2.1 (CWF) only) from a baseline case, due to selected variations in the input model, were compared for a single climate (Washington, D. C.). Third, hourly heating and cooling load predictions were compared for design days that are representative of summer, winter, and transitional season weather conditions for a temperate climate. Annual heating load predictions show generally good agreement for all climates and consistent predicted changes from one climate to another, with the exception of the DOE-2.1 (SWF) predictions, which show marked underestimates for mild heating climates. Both DOE-2.1 (SWF) and (CWF) annual cooling load predictions are significantly higher (25% to 35%) than the (almost alike) BLAST 2 and NBSLD predictions for all climates but one (the exception is believed to be coincidental). The quality of agreement between the BLAST 2 and DOE-2.1 (CWF) predictions for the load changes from the respective baselines was quite good for essentially all of the input variations examined. Design day analyses for three typical days show acceptable agreement, with the greatest differences occurring in the predicted loads for the transitional season design day, when heating and cooling loads are smallest. The differences observed are due to differences in the way DOE-2.1 calculates the ratio of direct to diffuse solar radiation, and from the inability of SWF's to accurately represent the thermal mass characteristics of the very light structure examined.

KEYWORDS

Building energy analysis, Comparison, Computer programs, Thermal modeling.

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INTRODUCTION

This report compares and discusses the relative capabilities of three computer programs currently used for predicting the energy performance of buildings. The three programs are NBSLD (developed by the U. S. National Bureau of Standards), BLAST 2 (developed by the U. S. Army Construction Engineering Research Laboratory), and DOE-2.1 (developed by the University of California's Lawrence Berkeley Laboratory). For this effort, only load prediction capabilities were compared. The comparison is based on one building model, the Hastings Ranch Model, a 1,200 ft^2, single-story, detached residence designed according to typical current practices, using reasonable assumptions for the effects of occupant behavior.

Annual cumulative heating and cooling load predictions are compared for six climates for the basic house design. Weather data used for the annual analyses were ASHRAE TRY data for Minneapolis, Chicago, Washington, D. C., San Francisco, Phoenix, and Tampa, and were obtained from standard NOAA weather tapes. Monthly and annual cumulative heating and cooling load predictions are also compared for a limited number of model design variations for a single climate, Washington, D. C. Hourly load predictions for three design days typical of winter, summer, and transitional season weather are also compared.

Care was taken to insure that equivalent thermal interpretations of the building model were analyzed by each of the programs. The overall goal was to remove as many judgmental differences (the "human factor") as possible in developing the thermal interpretation of the building model for each of the programs. Judgmental differences can stem from ambiguities in the building model, or program input, or hidden assumptions in the programs. Thus, specifications for the building model were developed in considerable detail and included thermophysical properties of building materials, construction details and geometry, and internal loads. In some cases, limitations in one of the programs dictated design choices. For example, limitations in NBSLD necessitated a flat roof design. The thermal interpretation was input this way into all three programs even though the other two do not have such a limitation. However, when modeling the dynamic performance of the envelope components, the capabilities of each program were utilized as fully as possible, even if this led to differences in the inputs. For example, the dynamic heat-storage characteristics of the slab floor were modeled in BLAST 2 and NBSLD, but had to be treated as a pure thermal resistance in DOE-2.1. The general rule was to accommodate geometrical limitations, but not those related to thermal modeling.

Although the building model and related assumptions are meant to be reasonably realistic, the results should not be interpreted as definitive for each location analyzed. For example, the same ground temperatures (Section 3.3) were used for all six locations in order to save time and to decrease the chances of inadvertent input error. While this assumption does not affect the validity of the results for comparative purposes, it should be understood that, in actuality, ground temperature variations would be expected from one location to another, and that these variations could have a significant effect on the heating and cooling load predictions.

Subsequent sections of this report contain descriptions of the actual versions of the programs that were used, details of the building model, and results and comments.

COMPUTER PROGRAMS

All three programs are in the public domain and were developed with federal (and in the case of DOE-2.1, some state) support. They are all based on engineering algorithms described in references [1] and [2]. NBSLD calculates heating and cooling loads only whereas BLAST 2 and DOE-2.1 also simulate HVAC systems and plant equipment.

NBSLD

The standard version of NBSLD as documented in [3] was used for this comparison. The specific version used was a reference version resident on the NBS computer system, as maintained by the Thermal Analysis Group of the Center for Building Technology, NBS.

BLAST 2

The BLAST version used for this comparison is referred to as BLAST 2. The specific version used was the standard production version resident on the Lawrence Berkeley Laboratory computer system at the time the analyses used in this effort were completed. Documentation for this program is mostly internal to the actual code. A user's manual, which also gives a general description of program capabilities and use, is cited in reference [4].

DOE-2.1

The program version used for this comparison is referred to as DOE-2.1. The specific version used was the development production version resident on the Lawrence Berkeley Laboratory computer system. The present version was released in March, 1980. Documentation for DOE-2.1 is contained in the reports cited as [5,6].

INPUT ASSUMPTIONS

The Building Design: The Hastings Ranch Model

The specific house design chosen for this study was that developed by S. R. Hastings of the U. S. National Bureau of Standards (NBS), as described in [7]. Familiarly called the Hastings Ranch Model, the design typifies the characteristics of single-family, one-story, ranch-style housing currently being built in the U. S. Details of the construction and geometry are shown in the plan and elevation views of Figure 3.1.

Because of program limitations mentioned above, there are some differences between the Hastings Ranch Model and the actual interpretation of this design for development of program inputs. The specific geometrical and thermal interpretation of the Hastings Ranch Model actually used to develop inputs for the analyses is presented in Figure 3.2. Among the more significant differences are:

1) There is no shading of windows by overhangs or other external objects.

2) The use of a flat roof.

3) The physical separation of stud-wall and cavity-wall sections for each external wall. The aggregation of the stud portions of the wall into a single element is convenient and, because of the one-dimensional treatment of heat conduction by all of the programs, does not introduce error into the thermophysical interpretation.

4) The horizontal collection of windows (preserving height relationships) on each external wall.

Subsequent tables of this section describe the pertinent details of building materials, construction, internal loads, and temperature control schedules that were assumed.

The building was modeled as two zones: an unconditioned attic and a single conditioned zone representing the occupied part of the house. All three programs have the capability of estimating the conductive heat flow through the ceiling between these two zones. No internal partitions were used in the conditioned zone.

The building materials used in the model, and their thermophysical properties, are given in Table 3.1. The values chosen came from various sources and, although typical for the materials, should not be considered definitive. For this effort, the more important consideration was that the properties be uniform for each program.

The building materials noted in Table 3.1 were subsequently used to form the different envelope sections, which are usually referred to in the program inputs as "constructions". Details of the constructions used are given in Table 3.2.

Both BLAST 2 and NBSLD treat all envelope constructions of the occupied space dynamically. DOE-2.1 does not do this for the slab floor, which could cause significant differences in hourly load predictions, particularly during periods of moderate outside temperature. (The way each program treats these constructions is shown in Table 3.2.) Wherever the calculated response factors could be checked for consistency among the three programs, they were found to agree.

While NBSLD and BLAST 2 use the detailed heat-balance approach [1] for load calculations, DOE-2.1 uses the ASHRAE weighting-factor method [1] in either one of two approaches. In the first approach, DOE-2.1 employs standard weighting factors (SWF's) built into the program for three different building weights, and interpolates or extrapolates actual weighting-factor values to be used for the simulation based on the building weight specified by the user in the input. For this effort, the building weight was based on the weight of the slab floor without any furnishings or other contents. In the second approach, which is a more exact technique, "custom" weighting factors (CWF's) are calculated based on the the actual constructions of the building model. DOE-2.1 load predictions based on both approaches are compared and discussed in Sections 4.1 and 4.5. The parametric variations examined in Section 4.2 are based on CWF analyses only.

Temperature Schedules and Internal Loads.

The attic temperature was allowed to float totally unconstrained. Schedules were specified for the occupied space which maintained an interior temperature in the range of 68 °F to 78 °F. Heating loads occurred when the lower limit had to be maintained and cooling loads occurred to maintain the upper limit. If in any hour the temperature was between those limits, neither a heating nor a cooling load occurred. Heating and cooling loads could occur at any time of the year -- whenever temperatures were sufficiently low or high. No night setback was incorporated in the baseline case, but was examined as one of several variations to the baseline case, which are discussed in Section 4.2.

Internal loads and infiltration loads were determined based on the following assumed maximum values and the schedules shown in Table 3.3.

(a) Occupants: Three people, each generating 250 Btu/hr sensible and 150 Btu/hr latent loads. Based on the hourly schedule values in Table 3.3, the annual occupant heat loads are about 5.25×10^6 Btu/yr.

(b) Lighting: 0.52 W/ft^2, incandescent type, with 33% in the form of radiant energy incident on the inside surfaces of the space, and the remainder released directly to the air. (The standard weighting factors used in DOE-2.1 force the radiant fraction to be 50%.) With the schedule values in Table 3.3, this amounts to about 3.9 Kwh/day, or 4.86×10^6 Btu/yr.

(c) Equipment: 1.03 W/ft^2, with 33% in the form of radiant energy incident on the inside surfaces of the space, and the remainder released directly to the air. Using schedule values in Table 3.3, this amounts to about 16.25 Kwh/day, or 20.26×10^6 Btu/yr.

(d) Infiltration: For the conditioned space, an air exchange rate of 88 cfm (0.55 air changes per hour (ach)) at standard wind (15 mph) and inside-outside temperature difference (40 °F) conditions. (The NBSLD input assumes a summer value of 0.5 ach and a winter value of .6 ach.) For the attic, an air exchange rate of 75 cfm (2 ach) at design conditions. In all three programs, the air exchange rate due to infiltration is calculated each hour and varies with changing wind and temperature conditions. The dependence of the air exchange rate on wind and temperature difference is specified by the Achenbach-Coblentz equation [8]. NBSLD incorporates this relation directly into the program code. The coefficients of the terms in the infiltration equation are controllable by the user in BLAST 2 and DOE-2.1, and were set to correspond to those used internally in NBSLD.

Environmental Data

Weather data used for calculating annual cumulative heating and cooling loads consisted of the ASHRAE Test Reference Year (TRY) for the six cities shown in Table 3.4. DOE-2.1 and BLAST 2 both have separate weather processors which read NOAA-produced TRY tapes. Monthly average temperatures and degree days produced as output from both of these weather-processing programs were verified for correspondence. NBSLD reads the NOAA-produced tapes directly. Clearness Number values of 1.0 were used as inputs in DOE-2.1 and BLAST 2. The same values are assigned intrinsically in NBSLD for all twelve months. Ground temperatures used in each of the programs and for all climates were 68 °F for June through September, and 60 °F for October through May. Results of the annual analyses are presented and discussed in the next section.

Design-day analyses were accomplished in order to compare hourly performance predictions for each of the programs. Three design days, intended to be typical winter, midseason, and summer days, were analyzed with each of the programs. Washington D. C. was the geographical location used in all of these analyses. Table 3.5 summarizes the input parameters used for the design-day runs. Results of the design-day analyses are given in Section 5.

MONTHLY AND ANNUAL HEATING AND COOLING REQUIREMENTS

In this section, each program's predictions of monthly and annual cumulative heating and cooling loads are compared. The basic house design was analyzed with all three programs using climate data for all six cities described in the preceding section. These results are described in Section 4.1. In addition, certain design and use parameters were varied, and the changes in cumulative heating and cooling loads predicted by BLAST 2 and DOE-2.1 were also compared for one climate only -- Washington, D.C. These results are described in Section 4.2.

Effect of Climate on Basic House Design

The results of the monthly and annual load prediction analyses for the six climates are presented in Table 4.1 (heating), and Table 4.2 (cooling). Figures 4.1 and 4.2 summarize the annual results for heating and cooling, respectively. (It is not possible to develop a quantitative correlation between predicted loads and climate based on analyses for only six climates. Heating and cooling degree-days are used in these figures only as a convenient parameter for the abscissae of the plots; i.e., in order to arrange the load results in an approximate way according to climate severity.) For DOE-2.1, both standard and custom weighting-factor results are presented. The heating or cooling loads as presented here consist of cumulative sums of the hourly heating or cooling loads for the respective time periods. The analyses do not contain any systems or equipment simulations, and thus the results cannot be interpreted as energy requirements for the building.

NBSLD and BLAST 2 load predictions agree well for both heating and cooling for all climates. DOE-2.1 predicts consistently lower heating loads for both standard and custom weighting-factor results, although the custom weighting-factor results show close agreement with both BLAST 2 and NBSLD. DOE-2.1 also predicts consistently higher cooling loads for both standard and custom weighting factors, again with the custom weighting-factor results being in closer agreement with NBSLD and BLAST 2. The agreement is best in a relative sense for the largest loads, such as Minneapolis heating or Tampa cooling. The <u>changes</u> predicted in both heating and cooling loads from one climate to another are, for the most part, consistent among all the programs.

For heating load, the maximum difference in results occurs for Minneapolis, the most severe climate, and is about 5.1×10^6 Btu, or about 12% of the mean of the three results. It is worth noting that, regardless of climate, the order of the value of the prediction is always the same: NBSLD highest, BLAST 2 next, DOE-2.1 (CWF) next, and finally DOE-2.1 (SWF) lowest. The possibility that systematic differences occurred in the treatment of internal loads or infiltration was explored and ruled out. The observed predictions for DOE-2.1 (SWF) and (CWF) show the greatest differences (both absolute and relative) when heating loads are small, i.e., in mild climates, and in spring and autumn months in more severe climates, when monthly loads are small. (What is actually important is not that the monthly or annual sums be small, but rather that there be many hours when the hourly load is small -- this occurs during mild weather, whether by virtue of climate or of season.) This effect is a clear sign that dynamic effects are different, very likely because of weighting factor differences; i.e., the use of standard weighting factors gives the building characteristics of greater thermal mass. The fact that the standard and custom weighting-factor differences converge with increasingly colder climates also supports this explanation, since thermal mass effects become less important as climate severity increases. Thus, the observed results are primarily due to differences in the dynamic treatment of conduction heat losses and heat storage in the building elements.

For cooling, a comparison of predicted loads shows a different situation. As for heating, NBSLD and BLAST 2 show very good agreement for both monthly and annual loads. Unlike the predictions for heating loads, however, neither program predicts consistently higher or lower for all the climates used in the analyses. Both the DOE-2.1 (SWF) and (CWF) cooling load predictions are significantly higher than those of NBSLD and BLAST 2. (SWF) predictions range up to a maximum difference from BLAST 2 and NBSLD results of about 14×10^6 Btu for Tampa. With one exception, DOE-2.1 (CWF) predictions show better agreement with the other two programs, but still range from about 3×10^6 Btu larger to a maximum of about 8×10^6 Btu larger. The DOE-

2.1 (CWF) results are expected to agree better with the predictions of BLAST 2 and NBSLD because of the more realistic treatment of dynamic thermal mass characteristics of the CWF method. However, this feature does not explain the large differences that still remain. The probable reason for this disparity stems from the DOE-2.1 approach to determining the ratios of direct and diffuse solar radiation, and the effect of clouds on each radiation component; however, studies outside of the scope of the current effort will be needed to develop definitive conclusions.

The exceptional case is for the San Francisco climate, where DOE-2.1 (SWF) predicts a lower annual cooling load than the DOE-2.1 (CWF) prediction and agrees well with the BLAST 2 and NBSLD predictions. Data from Table 4.2 indicate that almost all of the differences occur during months of small cooling requirements. For these months, the DOE-2.1 (SWF) cooling-load predictions are consistently lower than the DOE-2.1 (CWF) predictions. In the warmest months with the highest cooling loads, both (SWF) and (CWF) predictions agree closely. These observations suggest that the more thermally massive characteristic of the (SWF) model overcompensates for the higher direct solar radiation during the mild-climate months to produce a lower total cooling load than the (CWF) model. Thus, the better agreement of the (SWF) results with the BLAST 2 and NBSLD results is probably coincidental.

Effect of Selected Changes in Design and Use Parameters

Two goals were involved in comparing BLAST 2 and DOE-2.1 predictions of annual heating and cooling requirements when selected design and use parameters were modified. The first was to better understand, and perhaps isolate, the causes for the differences in the results reported in the previous section. In addition, in some applications of these computer programs, the desired goal is to predict heating and cooling load differences caused by changes to the building design. Parameters varied were: internal loads; infiltration; temperature settings (including effects of night setback); window shading, orientation, and glazing type; and insulation levels in floor, ceiling, and walls. These analyses were accomplished only for Washington, D.C., except for night setback effects which were also examined using Minneapolis weather data. The results of these analyses are presented in Tables 4.3 to 4.6, and corresponding Figures 4.3 to 4.6.

Table 4.3 and Figures 4.3a and 4.3b summarize the predicted annual heating and cooling requirements for a number of variations of internal loads and infiltration rates. The "variation summary" values shown in Table 4.3 are symbolic and represent changes relative to the standard internal loads and infiltration case (the baseline). Figures 4.3a and 4.3b show the results for heating and cooling, respectively, in bargraph form. These figures also show differences from the appropriate BLAST 2 or DOE-2.1 (CWF) baseline load for each of the variations. For heating, the baseline annual loads differ by only about 2%. The changes from the appropriate baseline predicted by BLAST 2 and DOE-2.1 are quite consistent. For variations in infiltration, the predicted changes are almost the same for both programs. For internal load variations, BLAST 2 predicts slightly larger annual load changes than DOE-2.1, and the difference in the predicted changes is larger for smaller internal loads -- a maximum of about 1×10^6 Btu when the internal loads are zero. This indicates that slight differences in the treatment of conduction heat losses by the two programs may underlie the differences observed in predicted load changes. The baseline annual cooling loads show a much greater difference: DOE-2.1 (CWF) predicts results about 25% greater than BLAST 2. However, the changes from the baseline predicted by each of the programs agree more closely for cooling than for heating. For the specific comparison performed for this effort, it was possible to specify internal loads and infiltration rates in the program inputs so that they predicted essentially the same component of the total annual loads from these two sources. All these observations lead to the conclusion that both programs can be made to predict similar results for the effects of internal loads and infiltration on heating and cooling loads if equivalent inputs to each of the programs are used.

Table 4.4 and Figures 4.4a and 4.4b show the effects of changing the interior temperature setting on predicted annual heating and cooling loads. In all cases where the temperature setting changes have a significant effect on annual heating loads, BLAST 2 predicts slightly larger changes (about 1×10^6 Btu out of a total change of about 10×10^6 Btu) from the baseline than does DOE-2.1 (CWF), and the agreement in predicted changes is quite good. The predicted changes for cooling agree even more closely with each other. DOE-2.1 (CWF) consistently predicts slightly larger changes. The difference in cooling load changes predicted for the anomalous 73 $^{\circ}$F - 73 $^{\circ}$F case are again the largest of this series of variations, but are considerably less than for heating loads.

These results are significant because, at a fixed interior temperature, the DOE-2.1 simulation does not require use of a special temperature-variation algorithm (which is not strictly a part of the loads calculation) and thus allows direct comparison of actual load simulation algorithms of the two programs. Table 4.4 presents annual heating and cooling results for the fixed 73 °F interior temperature case for three additional combinations of internal loads and infiltration rates, where each is zero, either individually or simultaneously. When compared with predictions for the same internal load and infiltration combinations with 68 ° - 78 ° interior temperature settings shown in Table 4.3, the predicted changes from the baseline are seen to be quite consistent. This observation seems to indicate that, at least within the range of conditions considered in these analyses, the variable-temperature algorithm does not strongly affect load-prediction changes caused by changes in internal loads or infiltration rates. Since the average inside-outside temperature difference is smaller during cooling periods than for heating periods over the course of the year for the Washington, D. C. climate, it is possible that the anomaly observed for the fixed 73 °F interior temperature case is related to the treatment of conduction heat losses and gains.

Table 4.5 and Figures 4.5a and 4.5b present results showing the effect of night setback on annual heating requirements for Washington, D.C., and Minneapolis. In both cases, the baseline cases assume standard internal loads and infiltration. DOE-2.1 (CWF) consistently predicts slightly smaller effects for a given amount of setback than BLAST 2, and the predicted difference increases both for the more severe Minneapolis climate and for increasing levels of setback. The differences in the predictions could be partly or entirely caused by differences in the treatment of conduction heat losses, which would be greater for the more severe Minneapolis climate. However, it is also possible that the DOE-2.1 (CWF) predictions are caused by the more rapid levelling-off trend at the greater setback levels than that predicted by BLAST 2.

Results from the last set of analyses in this section, presented in Table 4.6 and Figures 4.4a and 4.4b, show the comparative effect of selected design changes, e.g., eaves on the north and south to shade windows, double glazing, window redistribution (north to south), doubled insulation levels in walls, ceiling, and floor.

From the results shown here, BLAST 2 and DOE-2.1 (CWF) make almost the same predictions for all of the design options analyzed. This is true for both heating and cooling, even though the annual cooling load predictions by the two programs differ for the baseline cases by about 25%. Thus, the treatment of changes in conduction heat flow due to changes in insulation levels is quite consistent between the two programs. The exceptions occur for those design changes related to solar gains through windows (shading eaves and various window orientation and glazing options), for which DOE-2.1 (CWF) predicts lower annual heating loads and higher annual cooling loads. In the case of the design variation with no windows, there is close agreement between the predicted annual cooling loads (although there is not agreement between changes from the respective baseline cases). These observed differences are consistent with the algorithm differences in DOE-2.1 that determine the direct/diffuse solar radiation ratio.

DESIGN-DAY PERFORMANCE

Design day heating and cooling load predictions are presented in Figures 5.1 to 5.3 and Tables 5.1 to 5.3 for the baseline case. In addition, Tables 5.1 to 5.3 summarize the hourly peak and daily cumulative heating and cooling loads for cases assuming zero infiltration and zero internal loads, both individually and together.

Design-day inputs to the programs were chosen to match maximum and minimum temperatures and their time of occurrence. However, each of the programs constructs profiles that have slight variations in weather parameters at other hours. The resultant differences in the temperature profiles constructed by each of the programs are unavoidable without actual changes in the algorithms, but since these differences are small, they lead to only minor differences in the results.

Figure 5.1 and Table 5.1 show load predictions for the summer design day. Peak-load values are in good agreement for NBSLD and DOE-2.1 (SWF and CWF); BLAST 2 is about 6% less for the standard internal load case. The DOE-2.1 (SWF) peak load lags one to two hours behind for cases with and without internal loads. NBSLD shows a different time of discontinuity because it does not account for daylight savings time. For intermediate loads, Figure 5.1 clearly shows that the DOE-2.1 (CWF) predictions agree better with NBSLD and BLAST 2 results than those of DOE-2.1 (SWF). Table 5.1 shows that the daily total loads agree very well for NBSLD and BLAST 2. The DOE-2.1 (SWF) daily total is about 25% higher than BLAST 2 and NBSLD; the DOE-2.1 (CWF) results agree better (about 7% higher). Consistent with the monthly and annual results, the hourly loads predicted by DOE-2.1 (SWF) are characteristic of a more thermally massive building. Table 5.1 also shows results for various assumptions for internal loads and infiltration. Like the monthly and annual results for these same variations, described in Section 4.2, the differences in load predictions between the baseline case and each of these variations is almost the same for each of the programs. Hourly data for these variations are not shown graphically.

The winter design-day results are presented in Figure 5.2 and Table 5.2. For the standard internal loads case, the peak heating loads predicted by BLAST 2, DOE-2.1 (SWF) and DOE-2.1 (CWF) agree quite well, both in value and time of occurrence. The NBSLD peak load is about 12% higher than the peak load predicted by the other two programs. For daily total loads (standard internal loads case), NBSLD is highest, DOE-2.1 (SWF) is lowest (about 25%), and DOE-2.1 (CWF) and BLAST 2 are intermediate. Figure 5.2 shows that this is also the ranking for most hours of the day, with the exception of the period from about 7 a.m. to noon, where NBSLD and DOE-2.1 (SWF) exchange highest and lowest ranking. The DOE-2.1 (SWF) time lag is present, as it was in the summer data. Differences in the thermal mass characteristics clearly show up in the data, and are consistent with the summer analyses. Data shown in Table 5.2 for the same combinations of zero internal loads and infiltration discussed above support the previous conclusion that each program treats these load components the same.

Table 5.3 and Figure 5.3 present results for the midseason design day. For the standard internal loads case, each of the programs predicts both heating and cooling loads during the day, except for DOE-2.1 (SWF), which predicts no nighttime heating load. Like the results for the other design days, NBSLD predicts the largest peak heating load and corresponding daily total, and the second lowest peak cooling load and lowest daily total. DOE-2.1 (SWF) does the opposite, and the predictions from these first two programs generally bracket the results from BLAST 2 and DOE-2.1 (CWF). Data presented in Table 5.3 for other combinations of internal loads and infiltration support conclusions discussed above about the similarity with which each program treats these load components.

A general conclusion that can be made on the basis of the design-day load predictions is that each of the programs produces results that are representative of buildings with different thermal mass characteristics. NBSLD results represent a building with the smallest thermal mass, DOE-2.1 (SWF) the largest, while BLAST 2 and DOE-2.1 (CWF) results are intermediate and show the best agreement for peak loads, shape of hourly profiles, and daily totals. These results are consistent with the annual predictions discussed in Section 4.1. It is also significant to note that the cooling load differences seen in the design-day results are consistent with the annual results, but the sizes of the differences are significantly smaller. A probable reason is that the design-day specifications included cloudless days, and thus represented a situation where program differences related to the calculation of direct and diffuse components of solar radiation were minimized.

CONCLUSIONS

The results presented and discussed above form the basis for a number of specific conclusions:

1. NBSLD, BLAST 2, and DOE-2.1 (CWF) annual load predictions agree very well for all six climates examined. DOE-2.1 (SWF) predictions are consistently lower than the other three, and exhibit the greatest discrepancy for mild climate conditions. The reason for this discrepancy is related to differences in the treatment of thermal mass effects (discussed in greater detail below). Each program exhibits consistent changes in annual heating load from one climate to the next, with a small divergence which increases slowly with climate severity. There are probably slight differences in the way each program calculates heat conduction losses and gains, most likely in their treatment of convective film coefficients.

2. NBSLD and BLAST 2 annual cooling load predictions agree closely for all six climates. Both DOE 2.1 (SWF) and (CWF) predictions are significantly (about 25% to 35%) higher, although the (CWF) predictions show better agreement. The reason for these differences is probably due to the way DOE-2.1 determines the direct/diffuse solar radiation ratio from weather data. The predicted changes in annual cooling load from one climate to another are essentially as consistent as the predicted changes in annual heating load.

3. Trends in monthly loads are consistent programs although there are greater relative variations from one program to another, particularly for months when the the loads are small because of mild climate conditions. The greatest discrepancies in monthly trends were exhibited by the DOE-2.1 (SWF) load predictions.

4. The changes in heating and cooling loads predicted by BLAST 2 and DOE-2.1 (CWF) for all the parametric variations in the building design and use assumptions that were performed for this effort agree very well, even though the DOE-2.1 (CWF) baseline annual cooling load was 25% higher than that of BLAST 2. The differences that were observed could be traced, again, to differences in the direct/diffuse solar radiation ratio. Variations involving internal loads and infiltration assumptions show that all of the programs treat these elements of the total heating or cooling load in the same way.

5. The results of the design-day calculations for each program show good agreement in predicting peak heating and cooling loads, their times of occurrence, and the overall shapes of the hourly load curves. The biggest discrepancies, exhibited by DOE-2.1 (SWF), are characteristic of a more thermally massive building; use of custom weighting factors in DOE-2.1 removed most of these differences. The shapes of the hourly load curves support the conclusion that each program treats the hourly internal load profiles the same.

Several general conclusions are evident. First, there is a high quality of agreement and consistency among the programs in their load predictions and the similarities are much more significant than the differences that do exist. Further, all of the differences can be explained in a straightforward manner. Whether or not the absolute values of load predictions agree, the programs (at least, BLAST 2 and DOE-2.1 (CWF)) predict almost the same changes in these loads as the result of a wide range of changes in design and occupant behavior. Secondly, the level of agreement shows that, with care and attention to detail, the same thermal model can be input into each of the programs. Finally, the building design chosen for this effort had very little thermal mass attributable to the structure, and it is clear that even the lightest standard ASHRAE weighting factors attribute too much thermal mass to performance of this particular design. The CWF's calculated by DOE-2.1 lead to heating and cooling load predictions that clearly are in better agreement with the other two programs than the load predictions based on SWF's.

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TABLE 3.1 MULTIPROGRAM COMPARISON - THERMOPHYSICAL PROPERTIES OF MATERIALS

Building Material	Thermal Resistance[a]	Thermal Conductivity[a]	Density[a]	Specific Heat[a]	Solar Absorptivity	Thermal Absorptivity	Surface Roughness[b]
Shingles	0.5				0.9	0.9	3
Plywood		0.07	34	0.29			
Wood Siding		0.0497	37	0.29	0.9	0.9	4
Sheathing		0.0317	20	0.31			
Insulation		0.0265	2	0.2			
Gypsum Board		0.0938	50	0.2	0.9	0.9	5
2X4 Studs		0.07	32	0.33			
Carpeting	1.5				0.9	0.9	2
Concrete		1.0	140	0.2			
Polystyrene		0.0167	2.2	0.29			
Earth		0.75	100	0.2			
Glazing[c]	0.038				0[d]	0.9	6

(a) Physical units: Thermal resistance: $ft^2 \cdot hr \cdot {}^oF/Btu$; Thermal conductivity: $Btu/hr \cdot ft \cdot {}^oF$; Density: lb/ft^3; Specific Heat: $Btu/lb \cdot {}^oF$.
(b) The roughness parameter can take six values ranging from very rough (1) to very smooth (6). The values are input as part of the materials specification in BLAST 2, and as part of the construction specification in DOE-2.1.
(c) Optical transmittance is .87, which is equivalent to an ASHRAE shading coefficient of 1.00 for single-pane glass. The thermal resistance is equivalent to a U-value of 1.13 when film coefficients are included. This value is equivalent to the DOE-2.1 parameter GLASS-CONDUCTANCE = 1.39, when the inside film resistance is included.
(d) In BLAST 2, this value is used only to compute the reabsorption of optical radiation reflected from other inside surfaces of the space.

TABLE 3.2 MULTIPROGRAM COMPARISON - CONSTRUCTION SPECIFICATIONS

Constructions	Surface Type[a]			Layers[b]	Thick-ness	U Value[c]	Thermal Resistance[c]
	NBSLD	BLAST 2	DOE-2.1				
Insulated Wall	D	D	D	Wood Siding	.03125		
				Sheathing	.0417		
				Insulation	.292		
				Gypsum Board	.0417		
				I-F-R[d]			.68
Stud Wall	D	D	D	Wood Siding	.03125		
				Sheathing	.0417		
				2X4 Stud	.292		
				Gypsum Board	.0417		
				I-F-R			.68
Attic Wall	F	F	F			.4	
Roof	D	D	D	Shingles			.5
				Plywood	.0417		
				I-F-R			.68
Ceiling	F	F	F			.0498[e]	
Floor Slab	D	D	F	Earth	.5		
				Polystyrene	.0833		
				Concrete	.333	.102[f]	
				Carpet			1.5
Door	F	F	F			.49	

(a) F = fast (thermal mass effects are not considered); D = delayed (thermal mass effects are considered).
(b) From outside to inside. DOE-2.1 and BLAST 2 use this convention while NBSLD uses the reverse order.
(c) Physical units: Thermal resistance: $hr \cdot {}^{o}F \cdot ft^2/Btu$; U-Value has reciprocal units.
(d) The inside film resistance (I-F-R) must be explicitly specified in DOE-2.1. Except for the inside surface of roofs, these values are intrinsically provided by BLAST 2 and NBSLD, and depend on the surface orientation and direction of heat flow in the current hour. DOE-2.1 values were chosen to match those used in BLAST 2 and NBSLD on the basis of orientation for only the convective portion of heat transfer.
(e) Equivalent to R-19.
(f) Overall U, representing all four layers shown (DOE-2.1 uses this value in load calculations).

TABLE 3.3 MULTIPROGRAM COMPARISON - HOURLY INTERNAL LOAD PROFILES

Hour	Occupants	Lighting	Equipment
1	1.00	0.00	0.17
2	1.00	0.00	0.17
3	1.00	0.00	0.17
4	1.00	0.00	0.17
5	1.00	0.00	0.17
6	1.00	0.00	0.48
7	1.00	1.00	0.71
8	1.00	1.00	0.95
9	0.40	0.023	0.57
10	0.40	0.023	0.61
11	0.40	0.023	0.57
12	0.40	0.023	0.88
13	0.40	0.023	0.62
14	0.40	0.023	0.48
15	0.40	0.023	0.48
16	0.69	0.023	0.51
17	0.69	0.023	0.48
18	1.00	0.023	0.65
19	1.00	0.023	0.70
20	1.00	0.50	0.81
21	1.00	0.50	1.00
22	1.00	1.00	0.62
23	1.00	1.00	0.70
24	1.00	1.00	0.48

TABLE 3.4 MULTIPROGRAM COMPARISON - WEATHER DATA SUMMARY (TRY)

City	Year	Heating Degree Days (Base 65 ^{o}F)	Cooling Degree Days (Base 65 ^{o}F)
Minneapolis	1970	8405	894
Chicago	1974	6191	713
Washington	1957	4164	1491
San Francisco	1974	3394	98
Phoenix	1951	1516	3334
Tampa	1953	473	3152

TABLE 3.5 MULTIPROGRAM COMPARISON - DESIGN-DAY PARAMETERS

Parameter	Design Day		
	Winter	Summer	Midseason
Month/Day	1/21	8/21	4/21
Day Type	Weekday	Weekday	Weekday
Precipitation	Clear	Clear	Clear
Cloud Amount	0	0	0
Wind Speed (mph)	7.5	7.5	7.5
Clearness Number	1.0	1.0	1.0
Max. Drybulb Temp. (^{o}F)	25	95	75
Time of Occurrence (hr)	15	15	15
Max. Wetbulb Temp. (^{o}F)	19	65	55
Time of Occurrence (hr)	15	15	15
Max. Dewpoint Temp. (^{o}F)	0	43.5	36.5
Time of Occurrence (^{o}F)	15	15	15
Min. Drybulb Temp. (^{o}F)	14	75	50
Time of Occurrence (hr)	5	5	5
Min. Wetbulb Temp. (^{o}F)	11	57.7	43.8
Time of Occurrence (^{o}F)	5	5	5
Min. Dewpoint Temp. (^{o}F)	0	43.5	36.5
Time of Occurrence (hr)	5	5	5

TABLE 4.1 MULTIPROGRAM COMPARISON - MONTHLY AND ANNUAL HEATING REQUIREMENTS[1] FOR HASTINGS RANCH MODEL[2]

City	Monthly Heating (10^6 Btu)												Annual Total
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
MINNEAPOLIS													
NBSLD	12.84	8.63	6.37	2.51	.73	.01	0.	0.	.23	1.58	5.43	9.64	47.96
BLAST	12.29	8.14	5.61	2.22	.55	0.	0.	0.	.19	1.55	5.50	9.19	45.23
DOE-2 (SWF)[3]	12.24	7.98	5.32	1.58	.08	0.	0.	0.	0.	.95	5.37	9.32	42.84
DOE-2 (CWF)[3]	11.77	7.84	5.48	1.97	.48	0.	0.	0.	.16	1.46	5.31	8.98	43.45
CHICAGO													
NBSLD	6.74	5.83	3.90	1.49	.65	.03	0.	0.	.18	1.01	3.13	5.53	28.51
BLAST	6.66	5.54	3.67	1.29	.46	.01	0.	0.	.12	.94	3.28	5.68	27.65
DOE-2 (SWF)[3]	6.61	5.36	3.04	.62	.10	0.	0.	0.	0.	.41	2.92	5.63	24.69
DOE-2 (CWF)[3]	6.48	5.38	3.36	1.16	.39	.01	0.	0.	.11	.90	3.15	5.53	26.48
WASHINGTON D.C.													
NBSLD	5.15	2.82	2.23	.84	.13	.01	0.	0.	.03	.68	1.41	3.24	16.54
BLAST	4.92	2.59	1.87	.63	.08	0.	0.	0.	.02	.57	1.32	3.22	15.21
DOE-2 (SWF)[3]	4.71	2.32	1.27	.20	0.	0.	0.	0.	0.	.21	.75	2.79	12.26
DOE-2 (CWF)[3]	4.79	2.62	1.84	.59	.08	0.	0.	0.	.02	.54	1.28	3.11	14.87
SAN FRANCISCO													
NBSLD	1.37	.91	.75	.67	.70	.17	.05	.02	.04	.17	.57	1.21	6.62
BLAST	1.51	.88	.66	.50	.51	.07	.01	0.	.01	.11	.55	1.34	6.14
DOE-2 (SWF)[3]	.96	.26	.16	0.	.01	0.	0.	0.	0.	0.	.05	.73	2.16
DOE-2 (CWF)[3]	1.44	.84	.63	.49	.52	.08	.01	0.	.01	.10	.52	1.26	5.89
PHOENIX													
NBSLD	1.13	.76	.37	.07	.04	0.	0.	0.	0.	.03	.43	.99	3.64
BLAST	1.10	.50	.26	.04	.01	0.	0.	0.	0.	.01	.29	.85	3.06
DOE-2 (SWF)[3]	.26	.03	.01	0.	0.	0.	0.	0.	0.	0.	.01	.11	.43
DOE-2 (CWF)[3]	1.05	.47	.27	.04	.01	0.	0.	0.	0.	.01	.32	.85	3.00
TAMPA													
NBSLD	.31	.15	.03	.03	0.	0.	0.	0.	0.	.02	.09	.31	.94
BLAST	.25	.10	.02	.02	0.	0.	0.	0.	0.	.01	.05	.29	.73
DOE-2 (SWF)[3]	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	.04	.04
DOE-2 (CWF)[3]	.25	.10	.02	.01	0.	0.	0.	0.	0.	.01	.05	.27	.71

(1) Cumulative heating and cooling loads only. No equipment simulations are included.
(2) Standard internal loads for lights and equipment (see Section 3.2).
(3) SWF: ASHRAE Standard Weighting Factors; CWF: Custom Weighting Factors.

TABLE 4.2 MULTIPROGRAM COMPARISON - MONTHLY AND ANNUAL COOLING REQUIREMENTS[1] FOR HASTINGS RANCH MODEL[2]

City	Monthly Cooling (10^6 Btu)												Annual Total
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
MINNEAPOLIS													
NBSLD	0.	0.	0.	.26	.54	2.66	3.77	2.95	1.52	.29	0.	0.	11.98
BLAST	0.	0.	0.	.25	.62	2.69	3.63	2.94	1.26	.27	0.	0.	11.64
DOE-2 (SWF)[3]	0.	0.	0.	.36	1.11	4.21	5.30	4.26	1.81	.20	0.	0.	17.25
DOE-2 (CWF)[3]	0.	0.	0.	.44	1.24	3.62	4.53	3.64	1.71	.38	0.	0.	15.56
CHICAGO													
NBSLD	0.	0.	.02	.21	.26	1.55	3.59	2.66	1.33	.33	.10	0.	10.04
BLAST	0.	0.	0.	.22	.31	1.76	3.58	2.70	1.27	.18	.07	0.	10.10
DOE-2 (SWF)[3]	0.	0.	0.	.34	.88	3.06	5.19	4.49	1.86	.10	.11	0.	16.02
DOE-2 (CWF)[3]	0.	.01	.04	.60	1.06	2.68	4.43	3.80	1.80	.42	.15	0.	14.98
WASHINGTON D.C.													
NBSLD	0.	0.	.08	.63	1.19	3.24	3.81	3.06	2.49	.28	.04	.03	14.86
BLAST	0.	0.	.06	.81	1.58	3.40	4.01	3.35	2.45	.26	.03	.01	15.97
DOE-2 (SWF)[3]	0.	0.	.04	1.15	2.35	4.84	5.88	4.85	3.48	.30	0.	0.	22.91
DOE-2 (CWF)[3]	0.	.03	.24	1.23	2.21	4.18	5.04	4.13	2.95	.54	.12	.06	20.74
SAN FRANCISCO													
NBSLD	.12	.21	.15	.22	.11	.34	.58	.87	1.14	.97	.30	.08	5.09
BLAST	.07	.16	.12	.28	.18	.55	.80	1.08	1.15	.90	.22	.05	5.56
DOE-2 (SWF)[3]	.01	.06	.05	.23	.07	.61	1.04	1.27	1.35	1.13	.07	0.	5.90
DOE-2 (CWF)[3]	.20	.37	.43	.69	.42	.86	1.16	1.36	1.45	1.29	.44	.16	8.82
PHOENIX													
NBSLD	.78	.57	1.32	1.73	3.36	5.03	7.15	6.15	5.55	3.03	1.17	.47	36.51
BLAST	.59	.58	1.41	1.91	3.71	5.33	7.11	6.14	5.64	3.06	1.25	.40	37.12
DOE-2 (SWF)[3]	.50	.72	1.99	3.13	5.02	6.66	9.07	7.70	6.95	4.15	1.42	.19	47.50
DOE-2 (CWF)[3]	1.12	1.18	2.13	2.93	4.51	5.84	7.99	6.71	5.98	3.73	1.70	.79	44.60
TAMPA													
NBSLD	.67	.94	1.71	1.59	3.22	4.12	4.57	4.28	4.02	2.31	.91	.74	29.09
BLAST	.71	.97	1.92	1.77	3.31	3.88	4.20	3.94	3.48	2.27	.95	.62	28.02
DOE-2 (SWF)[3]	.85	1.40	2.86	2.76	4.62	6.09	6.44	6.10	5.25	3.33	1.52	.95	42.18
DOE-2 (CWF)[3]	1.10	1.44	2.55	2.48	4.00	5.18	5.50	5.18	4.43	2.88	1.48	1.04	37.26

(1) Cumulative heating and cooling loads only. No equipment simulations are included.
(2) Standard internal loads for lights and equipment (see Section 3.2).
(3) SWF: ASHRAE Standard Weighting Factors; CWF: Custom Weighting Factors.

TABLE 4.3 MULTIPROGRAM COMPARISON - EFFECT OF CHANGES IN INTERNAL LOADS AND INFILTRATION (WASHINGTON, D.C.)

Variation Summary				Annual Heating (10^6 Btu)		Annual Cooling (10^6 Btu)	
Occupants	Lighting	Equipment	Infiltration	BLAST 2	DOE-2.1 (CWF)	BLAST 2	DOE-2.1 (CWF)
1[a]	1[a]	1[a]	1[a]	15.21	14.87	15.97	20.74
1	1	1	0	9.69	9.17	16.63	21.79
0	0	0	1	29.08	27.02	6.84	11.06
0	0	0	0	22.71	20.37	6.80	11.25
.5	.5	.5	1	21.57	20.46	10.82	15.41
2	2	2	1	6.69	6.92	29.41	34.39
1	1	1	.5	12.41	11.99	16.22	21.12
1[b]	1[b]	1[b]	1	15.17	14.90	15.79	20.73
1[c]	1[c]	1[c]	1	21.42	19.92	21.44	26.06
1[d]	1[d]	1[d]	1	16.19	14.69	16.44	20.47

(a) Baseline case.
(b) The total daily contribution from occupants, lights, and equipment remains the same, but is evenly distributed over all hours of the day.
(c) Similar to b above, except that the total daily contribution is evenly distributed over the hours 8 a.m. to 4 p.m., and is zero at all other times.
(d) Similar to c above, except the contribution appears evenly distributed over the hours 8 p.m. to 4 a.m.

TABLE 4.4 MULTIPROGRAM COMPARISON - EFFECT OF INTERIOR TEMPERATURE (WASHINGTON, D.C.)

Temperature Conditions (°F)	Annual Heating (10^6 Btu)		Annual Cooling (10^6 Btu)	
	BLAST 2	DOE-2.1 (CWF)	BLAST 2	DOE-2.1 (CWF)
Cooling - Heating				
73 - 73[a]	25.02	23.76	25.33	30.21
73 - 73[b]	17.43	16.45	25.95	31.19
73 - 73[c]	41.12	38.12	13.16	18.22
73 - 73[d]	32.76	29.99	12.97	18.36
75.5 - 70.5[a]	19.66	19.08	20.18	25.23
78 - 68[a,e]	15.21	14.87	15.97	20.74
75.5 - 73[a]	24.64	23.65	20.44	25.70
78 - 73[a]	24.40	23.22	16.21	21.25
73 - 70.5[a]	19.91	19.53	24.94	30.12
73 - 68[a]	15.44	15.34	24.65	29.65

(a) Std. Int. Loads., Infil., (b) Std. Int. Loads, Zero Infil., (c) Zero Int. Lds., Std. Infil., (d) Zero Int. Lds., Infil.
(e) Baseline case.

TABLE 4.5 MULTIPROGRAM COMPARISON - EFFECT OF NIGHT SETBACK

Temperature Conditions (°F)	Annual Heating (10^6 Btu)			
	Washington, D.C.		Minneapolis	
	BLAST 2	DOE-2.1 (CWF)	BLAST 2	DOE-2.1 (CWF)
78 - 73 - 73[a]	24.40	23.22	57.76	54.52
78 - 73 - 68	20.40	19.38	52.87	50.08
78 - 68 - 68[b]	15.21	14.87	45.23	43.45
78 - 68 - 64	12.51	12.27	41.76	40.28
78 - 68 - 60	10.56	10.41	38.79	37.56
78 - 68 - 56	9.31	9.27	36.27	35.26

(a) Cooling-Heating-Setback temperatures. Night setback is from 11 p.m. to 7 a.m.
(b) Baseline.

TABLE 4.6 MULTIPROGRAM COMPARISON - EFFECT OF SELECTED DESIGN CHANGES (WASHINGTON, D.C.)

Design Change	Annual Heating (10^6 Btu)		Annual Cooling (10^6 Btu)	
	BLAST 2	DOE-2.1 (CWF)	BLAST 2	DOE-2.1 (CWF)
Baseline	15.21	14.87	15.97	20.74
2 ft. Eaves (N & S)	15.30	14.95	14.70	19.46
4 ft. Eaves (N & S)	15.74	15.36	13.85	18.44
No Windows	9.43	10.69	9.15	9.98
Double-Glazed Windows (2G)	10.48	10.48	15.85	20.25
Windows N → S, 1G	14.03	13.03	18.26	25.09
Windows N → S, 2G	9.51	8.97	18.10	24.43
2 x Wall Insulation	13.31	13.04	15.61	20.33
2 x Ceiling Insulation	13.59	12.56	15.48	20.06
2 x Floor Insulation	13.59	12.91	19.00	23.84
2 x All Insulation, 1G	10.09	10.68	18.39	23.33
2 x All Insulation, 2G	5.57	6.51	18.92	23.36

TABLE 5.1 MULTIPROGRAM COMPARISON - SUMMER DESIGN-DAY SUMMARY

Design Day	Heating (10^3 Btu)				Cooling (10^3 Btu)			
	NBSLD	BLAST 2	DOE-2.1 (SWF)	DOE-2.1 (CWF)	NBSLD	BLAST 2	DOE-2.1 (SWF)	DOE-2.1 (CWF)
(Baseline) Std. Int. Lds.[a]								
Daily Total	0	0	0	0	182.8	183.6	229.3	198.7
Peak Load	0	C	0	0	16.3	15.10	16.30	16.38
Hour of Peak					12	14	15	14
Zero Infil.								
Daily Total	----	0	0	0	----	179.2	222.3	192.1
Peak Load		0	0	0		14.55	15.33	15.74
Hour of Peak						14	15	14
Zero O-L-E[b]								
Daily Total	0	0	0	0	111.7	110.6	146.5	128.3
Peak Load	0	0	0	0	13.33	12.85	13.44	14.13
Hour of Peak					13	14	15	14
Zero O-L-E-I[b]								
Daily Total	0	0	0	0	100.5	105.8	139.5	121.5
Peak Load	0	0	0	0	12.27	12.30	12.66	13.50
Hour of Peak					13	14	15	14

(a) Standard internal loads for lights and equipment (see Section 3.2).
(b) O - Occupants, L - Lights, E - Equipment, I - Infiltration.

TABLE 5.2 MULTIPROGRAM COMPARISON - WINTER DESIGN-DAY SUMMARY								
Design Day	Heating (10^3 Btu)				Cooling (10^3 Btu)			
	NBSLD	BLAST 2	DOE-2.1 (SWF)	DOE-2.1 (CWF)	NBSLD	BLAST 2	DOE-2.1 (SWF)	DOE-2.1 (CWF)
(Baseline) Std. Int. Lds.[a]								
Daily Total	244.7	211.4	183.2	193.7	0	0	0	0
Peak Load	17.4	15.51	15.45	15.35	0	0	0	0
Hour of Peak	5	5	5	5				
Zero Infil.								
Daily Total	----	136.9	104.8	121.7	----	0	0	0
Peak Load		11.42	10.62	11.14		0	0	0
Hour of Peak		5	6	5				
Zero O-L-E[b]								
Daily Total	330.1	289.8	265.3	261.5	0	0	0	0
Peak Load	19.3	17.18	17.83	17.00	0	0	0	0
Hour of Peak	6	6	7	6				
Zero O-L-E-I[b]								
Daily Total	211.1	209.3	183.8	185.1	0	0	0	0
Peak Load	13.8	13.22	13.94	12.95	0	0	0	0
Hour of Peak	6	6	8	7				

(a) Standard internal loads for lights and equipment (see Section 3.2).
(b) O - Occupants, L - Lights, E - Equipment, I - Infiltration.

TABLE 5.3 MULTIPROGRAM COMPARISON - MIDSEASON DESIGN-DAY SUMMARY								
Design Day	Heating (10^3 Btu)				Cooling (10^3 Btu)			
	NBSLD	BLAST 2	DOE-2.1 (SWF)	DOE-2.1 (CWF)	NBSLD	BLAST 2	DOE-2.1 (SWF)	DOE-2.1 (CWF)
(Baseline) Std. Int. Lds.[a]								
Daily Total	13.1	5.9	0	5.7	36.4	46.6	52.3	58.84
Peak Load	3.28	2.09	0	2.06	7.26	7.76	6.86	8.79
Hour of Peak	5	5		5	13	13	16	13
Zero Infil.								
Daily Total	----	2.0	0	1.7	----	53.5	64.8	65.5
Peak Load		1.10	0	.96		8.21	7.66	9.24
Hour of Peak		5		5		13	16	13
Zero O-L-E[b]								
Daily Total	41.2	29.9	0	26.1	13.5	18.9	0	27.6
Peak Load	5.43	4.30	0	4.39	3.80	4.71	0	5.91
Hour of Peak	5	6		6	14	14		14
Zero O-L-E-I[b]								
Daily Total	25.6	22.3	0	18.71	18.8	20.7	.23	30.3
Peak Load	3.83	3.49	0	3.48	4.62	4.87	.23	6.21
Hour of Peak	5	6		6	13	14	17	14

(a) Standard internal loads for lights and equipment (see Section 3.2).
(b) O - Occupants, L - Lights, E - Equipment, I - Infiltration.

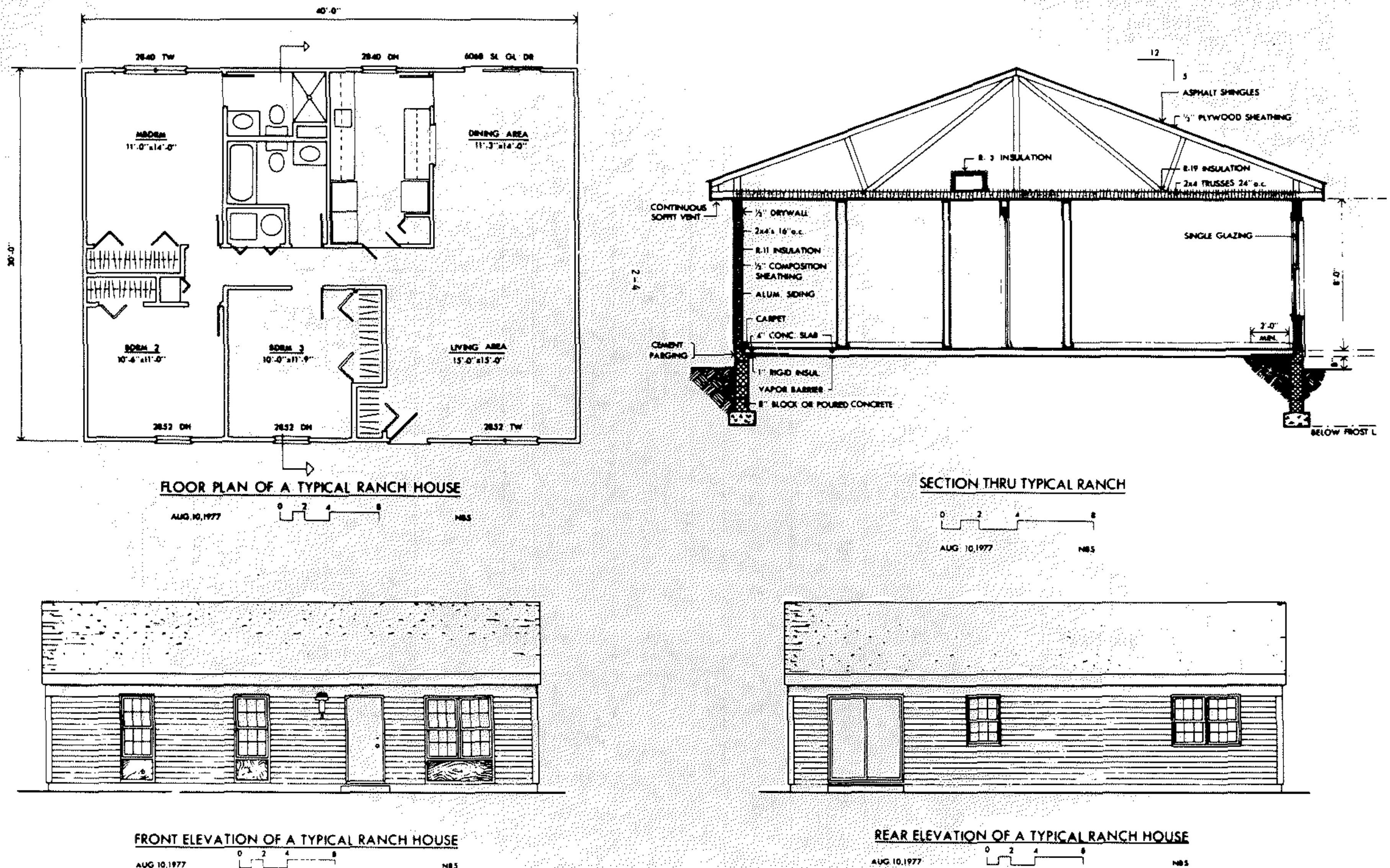

Fig. 3.1 Plan view, section, and elevation for the Hastings Ranch Model

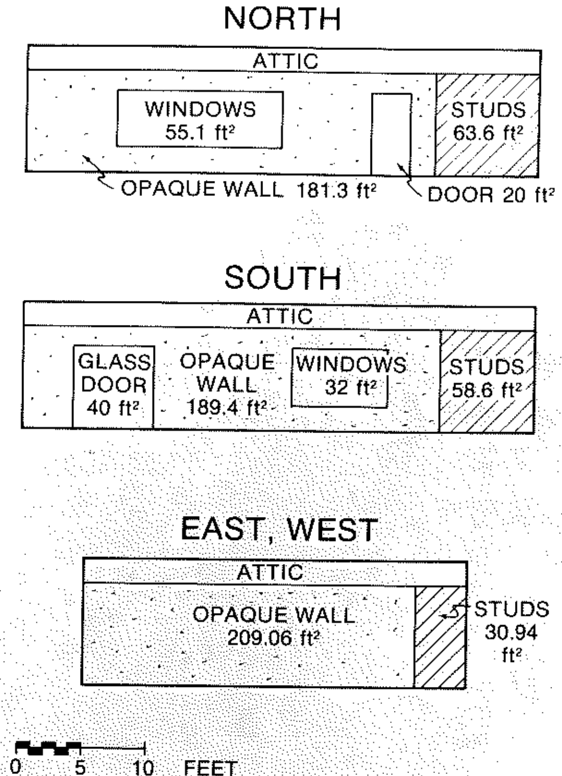

Fig. 3.2 Details of geometry for the thermal interpretation of the Hastings Ranch Model

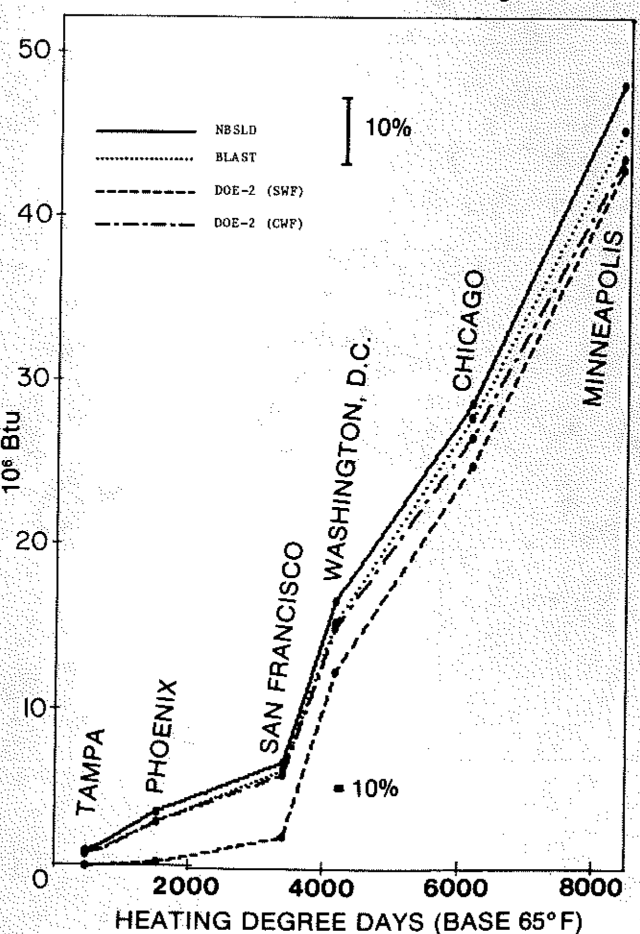

Fig. 4.1 Annual heating requirements vs climate

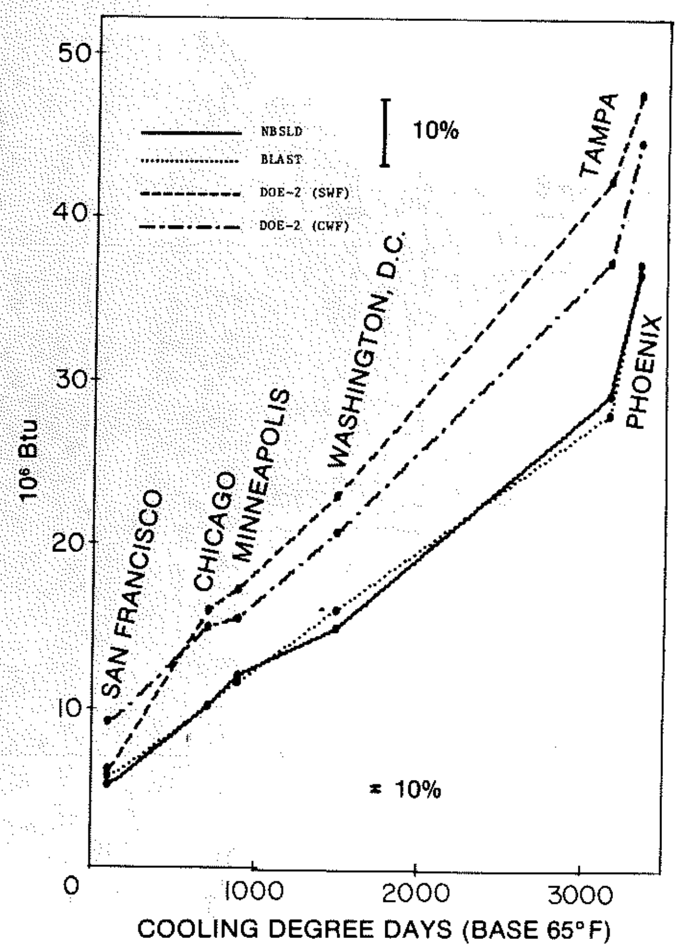

Fig. 4.2 Annual cooling requirements vs climate

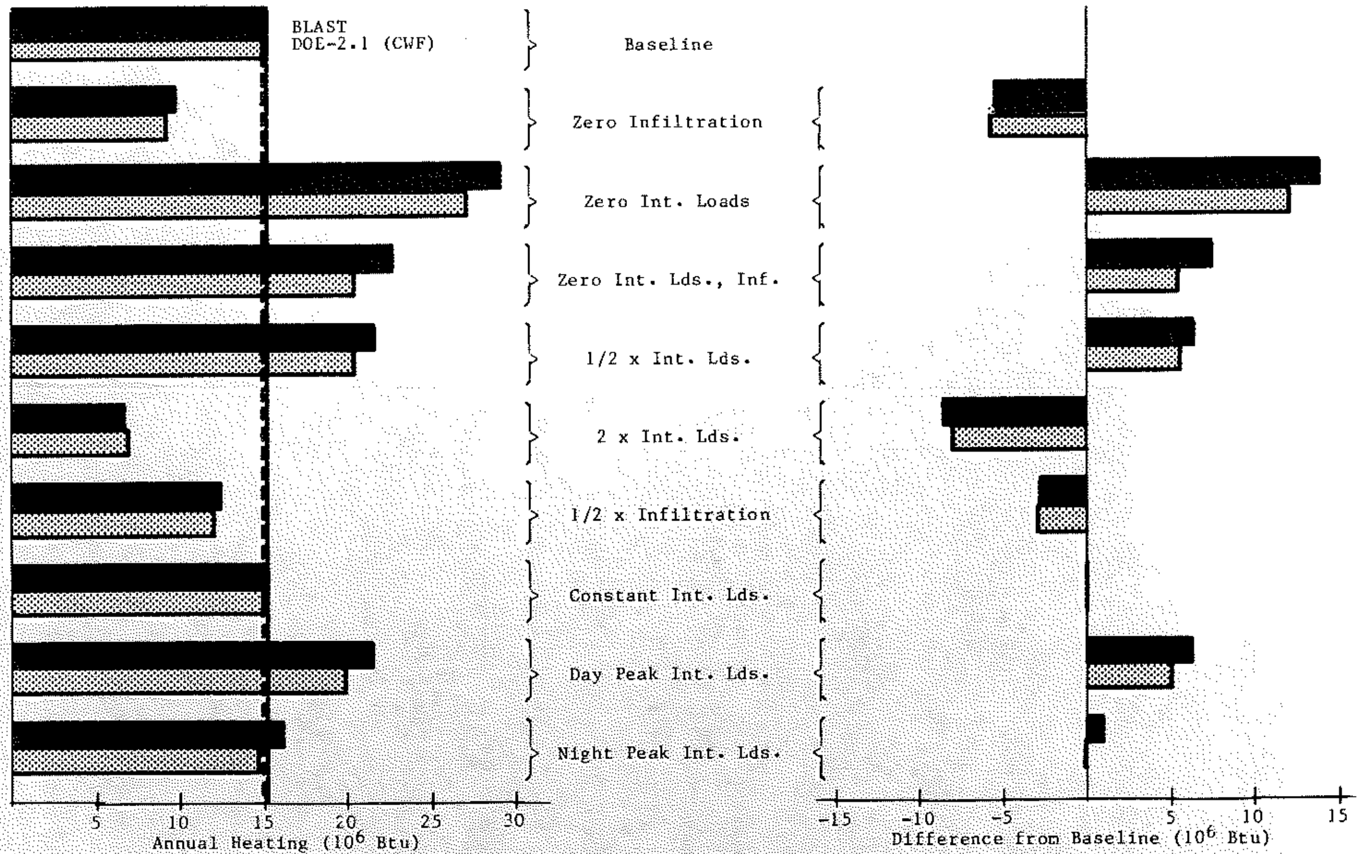

Fig. 4.3a Effect of changes in internal loads and infiltration on annual heating loads (Washington, D.C.)

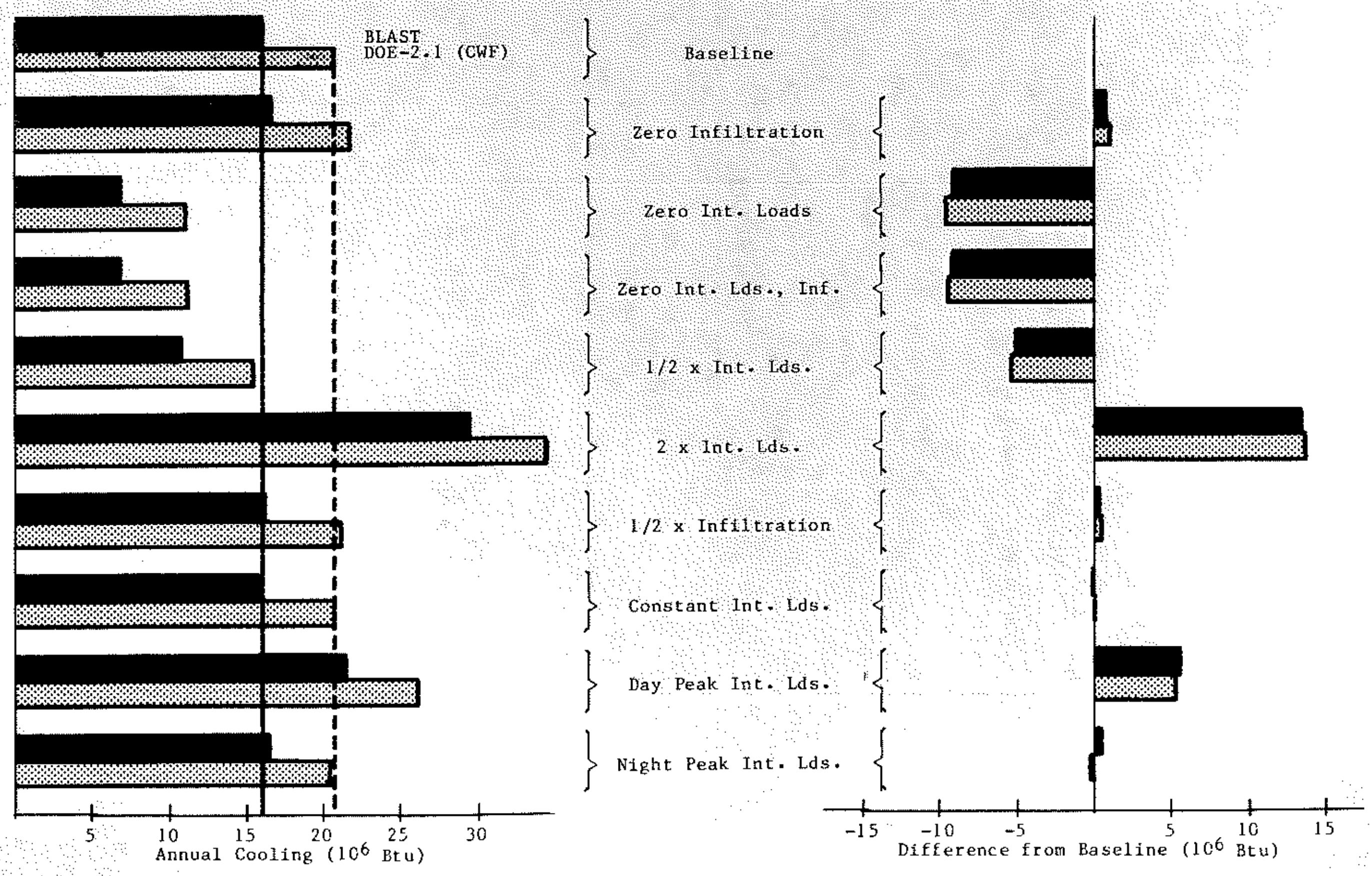

Fig. 4.3b Effect of changes in internal loads and infiltration on annual cooling loads (Washington, D.C.)

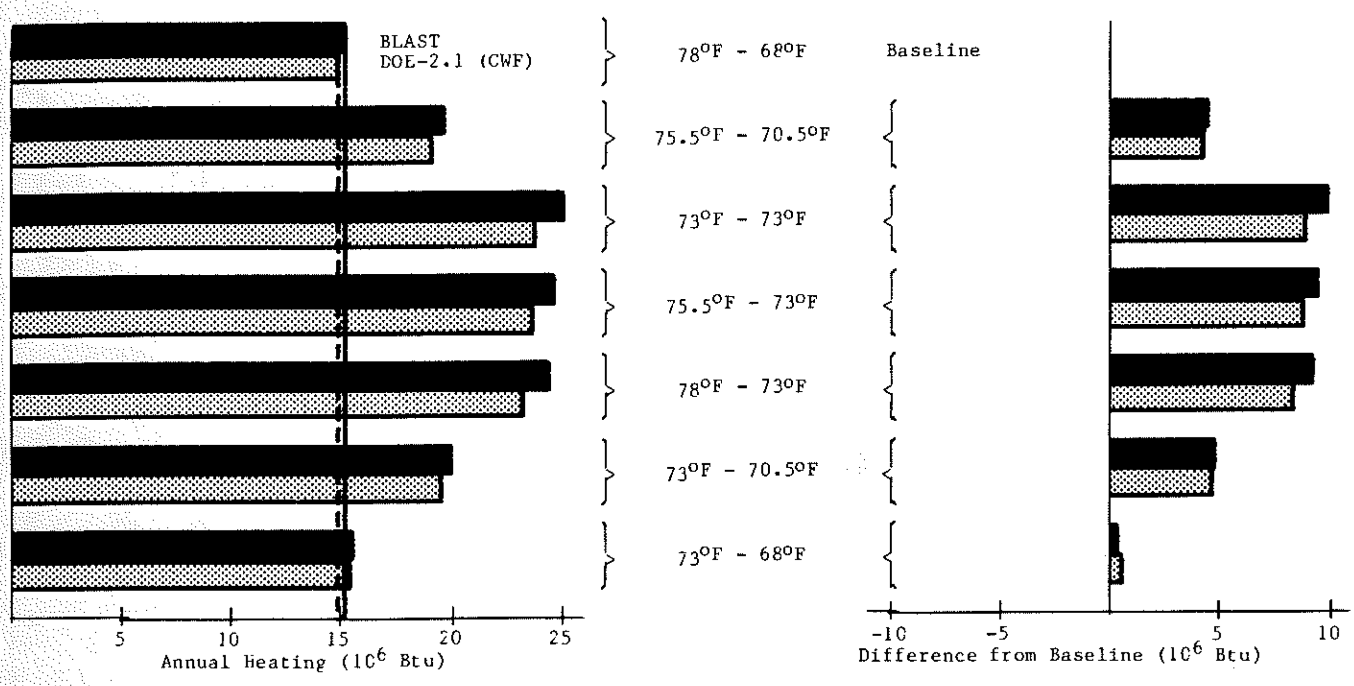

Fig. 4.4a Effect of interior temperature setting on annual heating loads (Washington, D.C.)

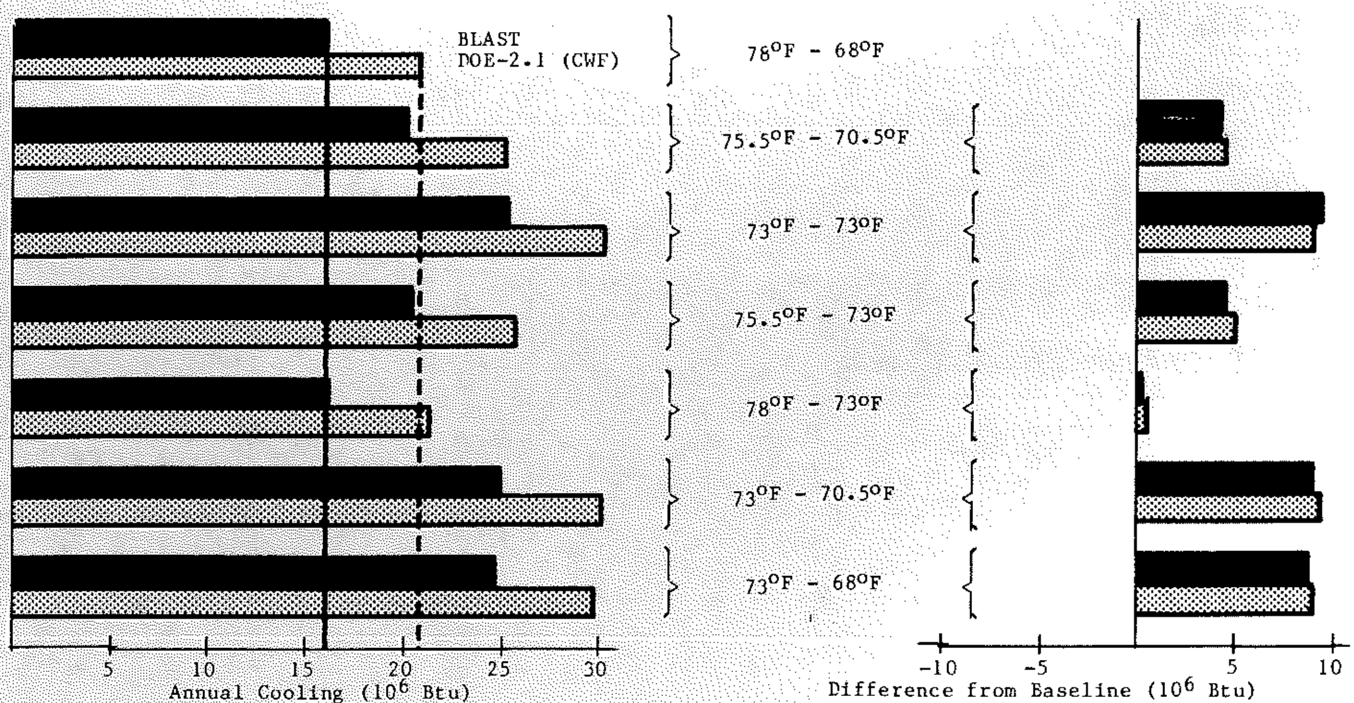

Fig. 4.4b Effect of interior temperature setting on annual cooling loads (Washington, D.C.)

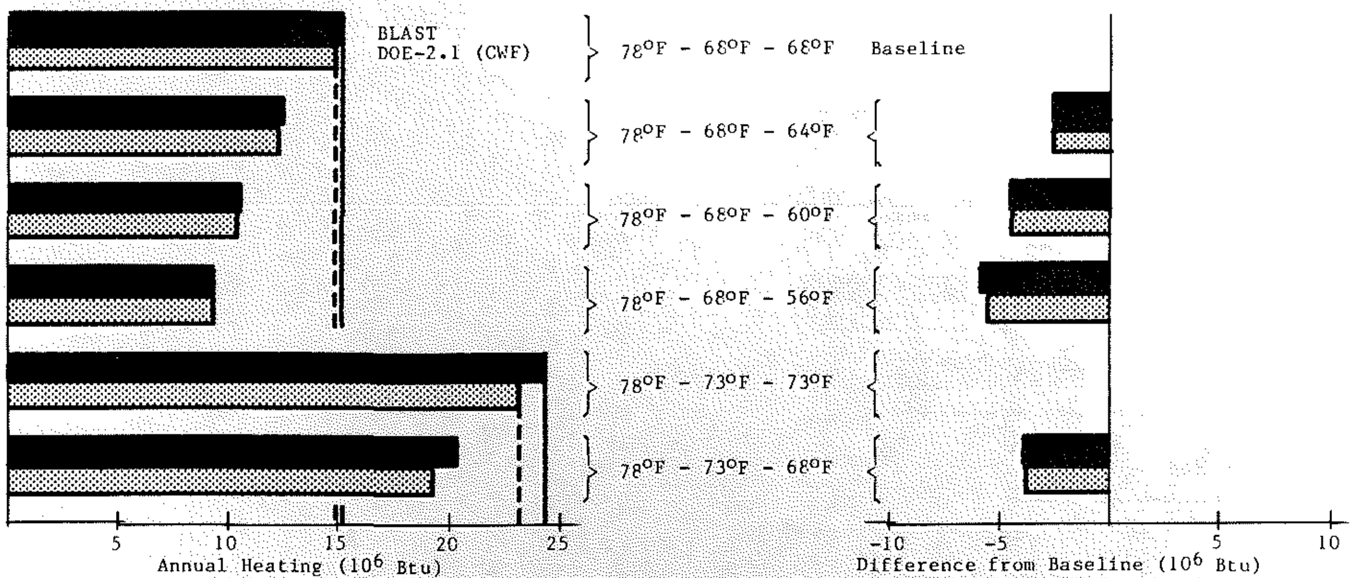

Fig. 4.5a Effect of night setback on annual heating loads (Washington, D.C.)

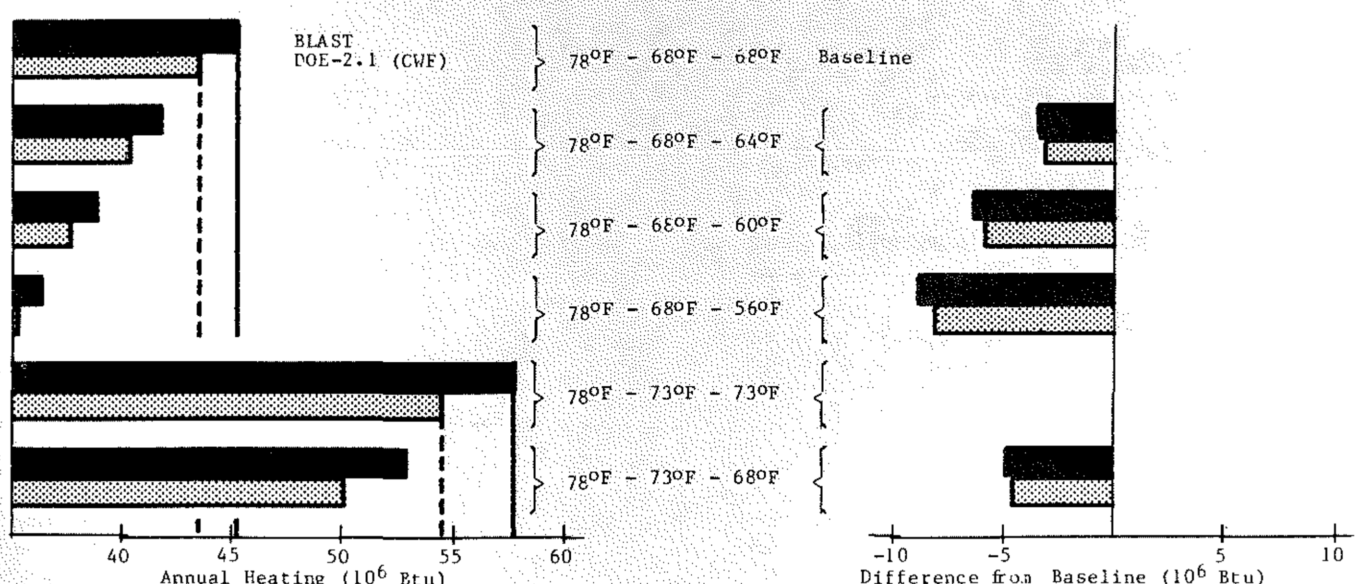

Fig. 4.5b Effect of night setback on annual heating loads (Minneapolis)

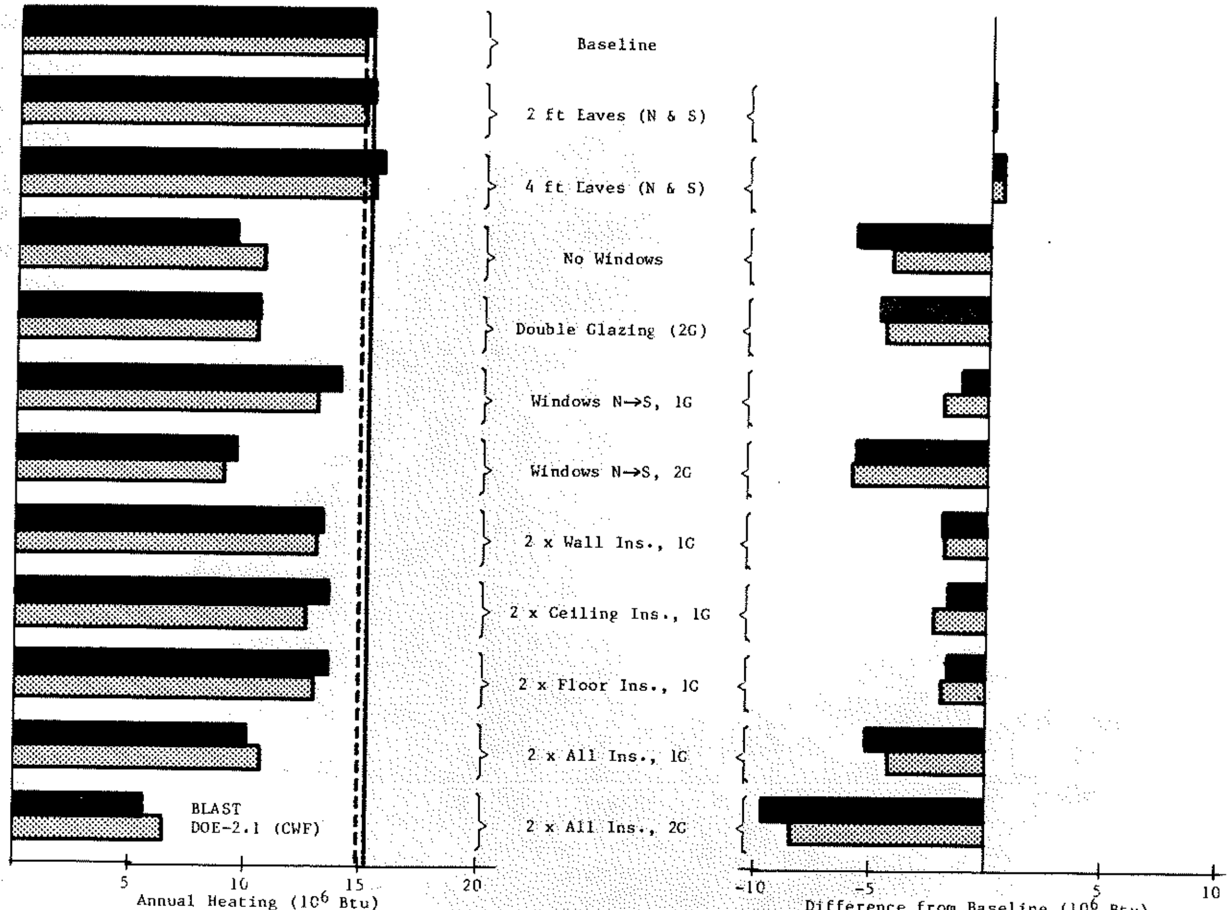

Fig. 4.6a Effect of selected design changes on annual heating loads (Washington, D.C.)

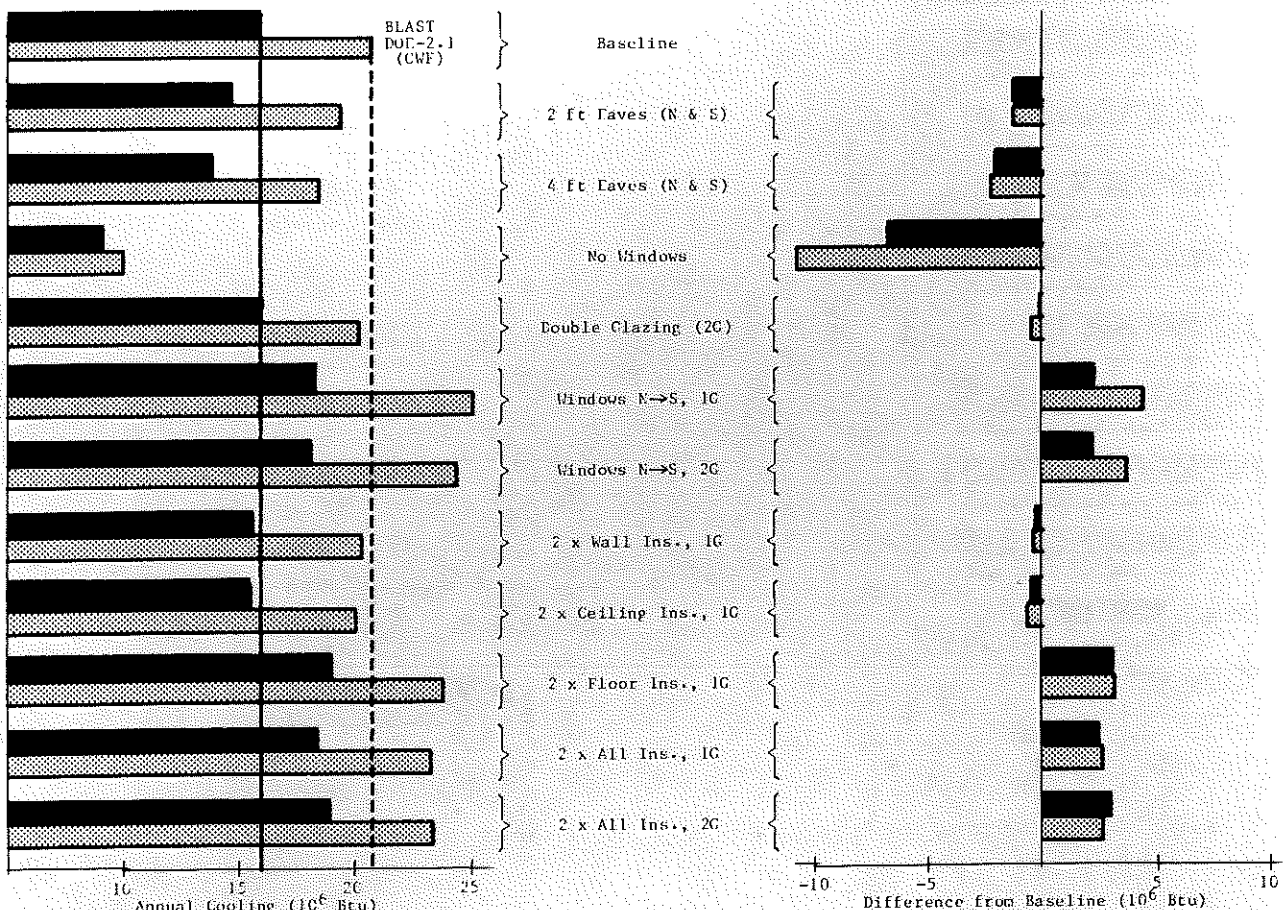

Fig. 4.6b Effect of selected design changes on annual cooling loads (Washington, D.C.)

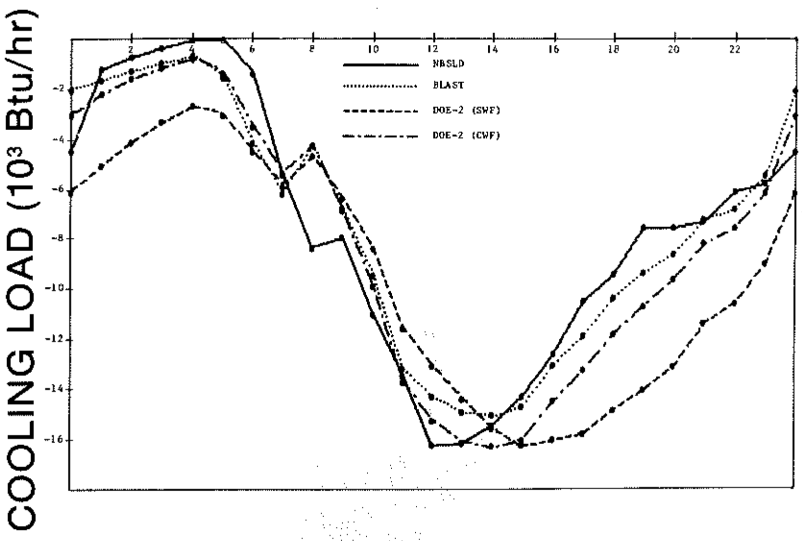

Fig. 5.1 Hourly loads for summer design day

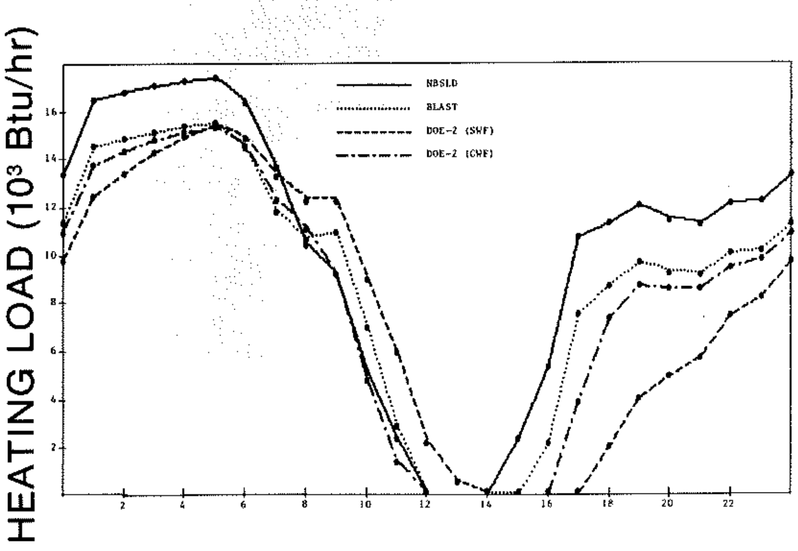

Fig. 5.2 Hourly loads for winter design day

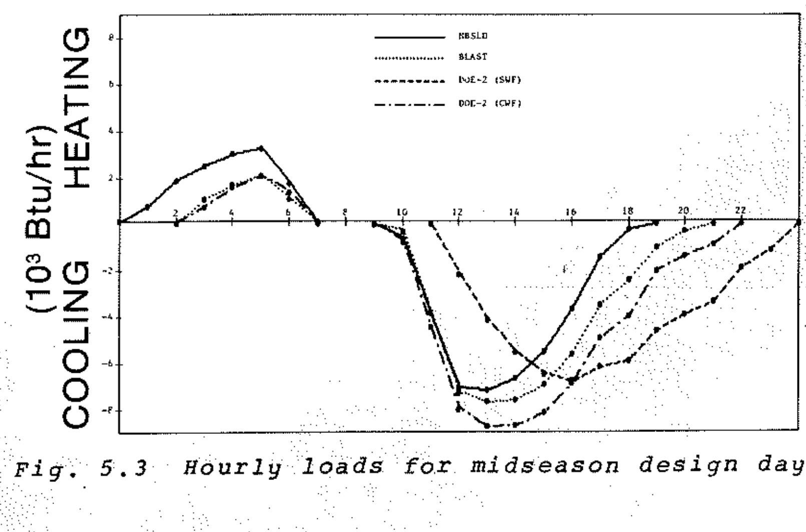

Fig. 5.3 Hourly loads for midseason design day