Using Regression Equations to Determine the Relative Importance of Inputs to Energy Simulation Tools

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ABSTRAT

A set of statistical regression equations was developed to predict relative heating and cooling loads of external zones of commercial buildings. The equations were derived from the coil loads predicted by several thousand DOE-2 simulations. These equations formed the basis for the building envelope criteria in ASHRAE/IES Standard 90.1-1989, "Energy Efficient Design of New Commercial Buildings Except Low-Rise Residential Buildings." Because these equations predict relative loads, they can be used to determine the relative importance of a broad range of envelope parameters across a variety of climate types.

This paper presents the procedure used to develop the equations. The relative importance of all the major loads input variables are discussed for a sample office building, for a broad range of climates. A load sensitivity analysis is then performed, which permits direct comparison of key envelope parameters. The analysis results provide general guidance to DOE-2 users as to the relative importance of specific loads input variables.

INTRODUCTION

When developing input for energy simulation tools, users often do not know how sensitive the simulation tool is to specific inputs. This often leads them to spend a substantial amount of time defining specific inputs in detail when those data may be less significant compared to other data. Some variables affect predicted annual energy performance significantly with only small relative changes, while others have very little effect over the entire range of possible values. This problem becomes further complicated because energy performance is predicted as an overall response to the interactions of all the input variables over time, not just a single variable. Determining relative importance becomes more complex with interactions of the input variables with climate. For these reasons, there are no simple rules for determining which inputs are most important in specific situations.

In 1982, the U.S. Department of Energy (DOE) initiated a research project to develop recommended changes to then current ANSI/ASHRAE/IES Standard 90A-1980 (ASHRAE 1980). This was the predecessor to ASHRAE/IES Standard 90.1-1989. A major portion of the new research focused on dealing with the complex interactions between building envelopes and internal loads. The previous standard (90A-1980) treated building envelopes fairly simply, mostly a means of limiting heat flow. It ignored many phenomena important in commercial building design, such as beneficial solar gains through fenestration, daylighting, and other factors. These limitations, coupled with the desire to allow designers greater flexibility in complying with envelope criteria, prompted the development of a new approach to specifying building envelope requirements. In this approach, exterior zones (walls, fenestration, and internal loads) are treated as components of an interactive thermal system.

The researchers involved used predicted total heating and cooling coil loads from several thousand DOE-2.1B simulations (Lawrence Berkeley Laboratory 1984) to derive a set of regressions equations. These equations predict annual total heating and cooling coil loads based on envelope and internal load characteristics of perimeter zones. The researchers then developed criteria for the exterior envelope as a set of maximum annual thermal loads based on climate, envelope physical characteristics, and combined lighting and equipment internal loads (Jones 1983; Pacific Northwest Laboratory 1983).

ENVSTD COMPUTER PROGRAM

The regression equations formed the basis for a computer program known as ENVSTD (for ENVelope STanDard) (Crawley and Boulin 1990). The ENVSTD regression equations predict heating and cooling coil loads for a building's perimeter zones, defined as the 15-ft-wide (4.57-m) exterior thermal zones. The program can be used to determine envelope compliance for ASHRAE Standard 90.1 (ASHRAE 1989).

To calculate the heating and cooling loads, ENVSTD uses the following information about the building design exterior wall, by orientation:

- climate
- total exterior wall area (opaque and glazed)
- fenestration area, shading coefficient, visible light transmittance, and U-value
- projection factor (ratio of overhang depth to height above window sill) for horizontal shading overhangs
- opaque wall U-value, thermal capacitance (heat capacity), and position of insulation relative to wall mass
- lighting power density
- miscellaneous equipment power density
- fraction of exterior zone lighting controlled for daylight utilization.

Once this information has been entered, the program calculates the location-specific predicted annual total heating and cooling coil loads for the building design being considered.

ENVSTD's usefulness extends beyond determining total loads for a building envelope design. The regression equations can be used to compare the relative importance or impact of various envelope parameters on a building's total heating and cooling coil loads. Because the program also responds to variations in climate, it can be used to evaluate the load sensitivities of envelope parameters at different locations.

LOADS AS A FUNCTION OF INDIVIDUAL CHARACTERISTICS

To evaluate the effects of varying individual envelope characteristics, we used a model of an office building. The building we selected was a three-story, 48,664-ft^2 (4,521-m^2) suburban office building.

To look at the relationships between individual characteristics and building loads, we selected six different geographic locations. These locations provide examples from the broad variation of climates in the United States: hot/cold (Washington, D.C.), hot/dry (El Paso, Texas), hot/humid (Houston, Texas), temperate/warm (Los Angeles, California), temperate/cool (Seattle, Washington), and cold (Minneapolis, Minnesota).

Figures 1 through 6 each contain graphs for the six envelope characteristics that we varied:

- opaque wall U-value
- opaque wall heat capacity
- fenestration U-value
- glazing (glass) shading coefficient
- window-to-wall ratio or WWR (percentage of glazing)
- internal load (lighting and equipment power density).

The vertical scale on each graph displays the relative heating and cooling loads (unitless) calculated by ENVSTD. The horizontal scale shows the range of a single envelope characteristic.

The two left-most components of each figure show opaque wall characteristic graphs--for U-value and heat capacity. The heat capacity varies from 1 to 21 Btu/(ft^2·°F) (20 to 430 kJ/(m^2·K)), and the opaque wall U-value varies from 0.0 to 0.40 Btu/(h·ft^2·°F) (0.0 to 2.3 W/(m^2·K)), depending on location.

In the center of each figure are two graphs for glazing characteristics--fenestration U-value and glazing shading coefficient. For fenestration U-value, values are shown for 0.0 to 1.4 Btu/(h·ft^2·°F) (0.0 to 7.9 W/(m^2·K)). For glazing shading coefficient, values range from 0.0 to 1.0.

The fifth graph within each figure illustrates the effects of varying the WWR from 0.0 to 1.0 (from 0 to 100% glazing). The last graph on each figure demonstrates the impact of varying the internal loads (miscellaneous equipment and lighting) from 0 to 6.0 W/ft^2 (0 to 65 W/m^2). Six watts is the maximum used by the regression equations (1.0 W/ft^2 (11 W/m^2) for miscellaneous equipment and 5.0 W/ft^2 (54 W/m^2) for lighting).

To maintain consistency in each of the curves shown in Figures 1 through 6, we chose values for the envelope characteristics other than the one varied from a set of baseline values for each location. We selected these values so that, as a whole, an envelope design using this set would comply with ASHRAE Standard 90.1 for the given location. In most cases, these are identical to the criterion values provided in ENVSTD for each location. All of the baseline buildings have a WWR of 0.284 (28.4% of total wall area is glazed) and an aspect ratio of 1.55 (ratio of length of east/west walls to length of north/south walls). Internal loads are 1.73 W/ft^2 (19 W/m^2) for lighting and 0.50 W/ft^2 (5.4 W/m^2) for miscellaneous office equipment.

Any of the envelope design characteristics included in the regression equations could have been selected for the comparisons of loads impacts. We chose these six to demonstrate a range of response as predicted by the regression equations. Variables not shown here but that could be evaluated with ENVSTD include projection factor of external shading overhangs, daylighting control factor and glazing visible light transmittance, and aspect ratio or orientation of the exterior walls.

It should be noted that ENVSTD does not automatically produce comparisons such as those shown in these figures. We generated these data by incrementally changing each characteristic and recording the calculated heating and cooling loads. While one component was varied, we held all the others constant.

By examining the load impact figures, the envelope components with the most impact on thermal loads become immediately obvious, for both the specific location and overall. In all locations, the WWR plays an important role in determining the relative magnitude of the overall loads, but other components can be as significant. However, as one might expect, the relative importance of the different parameters varies with location.

For example, in Minneapolis (Figure 6), the heating and cooling loads are sensitive to both the U-values but relatively insensitive to the glazing shading coefficient. However, in Los Angeles (Figure 4), the opposite trend is noticed. Here, the heating and cooling loads are sensitive to the glazing shading coefficient, yet insensitive to both the U-values.

In the following section, we look more closely at the sensitivity of heating and cooling loads to envelope parameters.

SENSITIVITY ANALYSIS

Although Figures 1 through 6 enable us to compare the relative impacts of various envelope parameters, they do not permit direct comparisons because of the varying ranges and units of the abscissa. In a given location, the slopes of the curves in any two plots cannot be directly compared to one another because they will have different units.

This difficulty can be avoided by normalizing the envelope parameter during the calculation of the slope. This produces a sensitivity coefficient, S_i, for parameter i, as shown by

$$S_i = \frac{\delta \mathrm{Load}}{\dfrac{\delta P_i}{P_{i,n}}}$$

where δLoad is the change in load, δP_i is the change in envelope parameter i, and $P_{i,n}$ is the nominal value of the envelope parameter.

For a selected set of nominal envelope parameters, using this definition of sensitivity coefficient lets us make a direct comparison of the heating or cooling load's sensitivity to those parameters. Provided that similar nominal envelope parameters are selected, this definition will also allow the designer to make sensitivity comparisons between different geographic locations.

Figures 7 and 8 show the heating and cooling load sensitivities for the six locations. The nominal values of the envelope parameters are the baseline values described in the previous section. Bars extending above the horizontal axis indicate positive parameter sensitivities (that is, increasing the parameter results in a corresponding increase in load). Negative sensitivities occur when the envelope parameters and loads are inversely related.

These figures permit comparisons of load sensitivities, both within a single location and between different locations. For example, consider Figure 8, which shows the cooling load sensitivity to the six envelope parameters. In El Paso, the cooling load is most sensitive to shading coefficient, window-to-wall ratio, and internal loads.

However, if the cooling load sensitivities in El Paso are compared to those in Seattle, it is obvious that these same parameters have a much smaller impact. Of course, this is largely because of the lower total cooling load in Seattle. However, this comparison indicates that decreasing the shading coefficient will have an approximately three-fold larger impact on cooling load in El Paso than in Seattle.

SUMMARY

Although ENVSTD was developed and is intended primarily for demonstrating compliance with Standard 90.1, it is also a valuable tool for evaluating the relative impact of various envelope parameters. This permits the designer to immediately identify those parameters that will dominate the thermal performance of the building.

The sensitivity analysis presented above permits a direct comparison of the load impacts of different envelope parameters in ENVSTD. However, the methodology presented is applicable to other simulation tools such as DOE-2 or BLAST. Using one of these simulation tools, a complete sensitivity analysis could include other issues such as system types and lighting.

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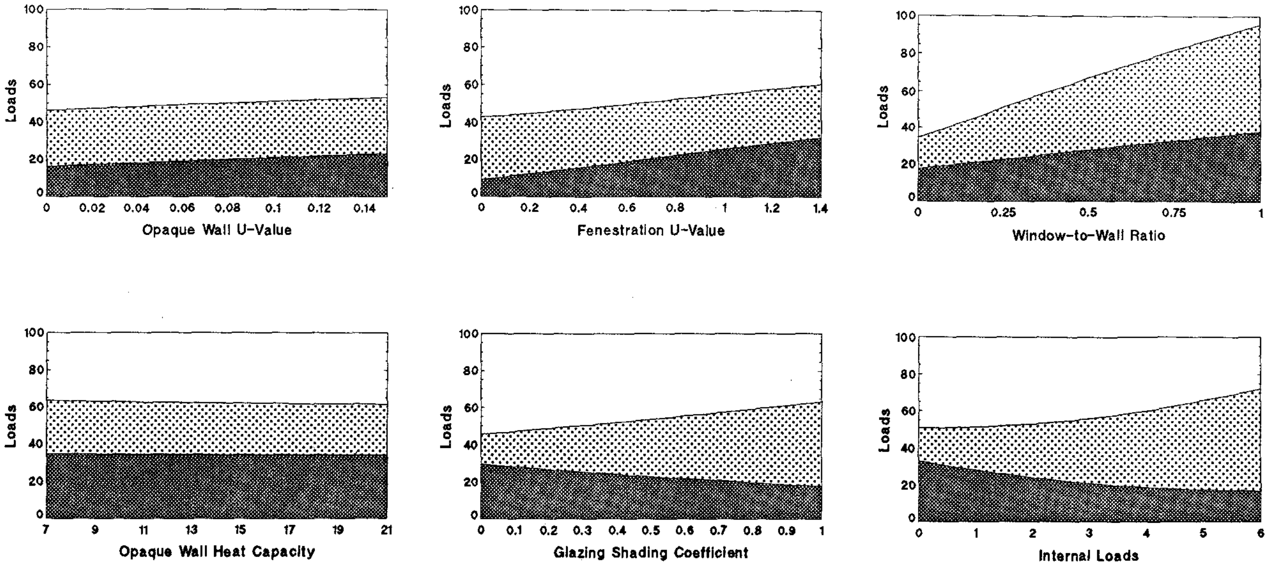

Figure 1. Loads vs. Envelope Parameters for Washington, DC

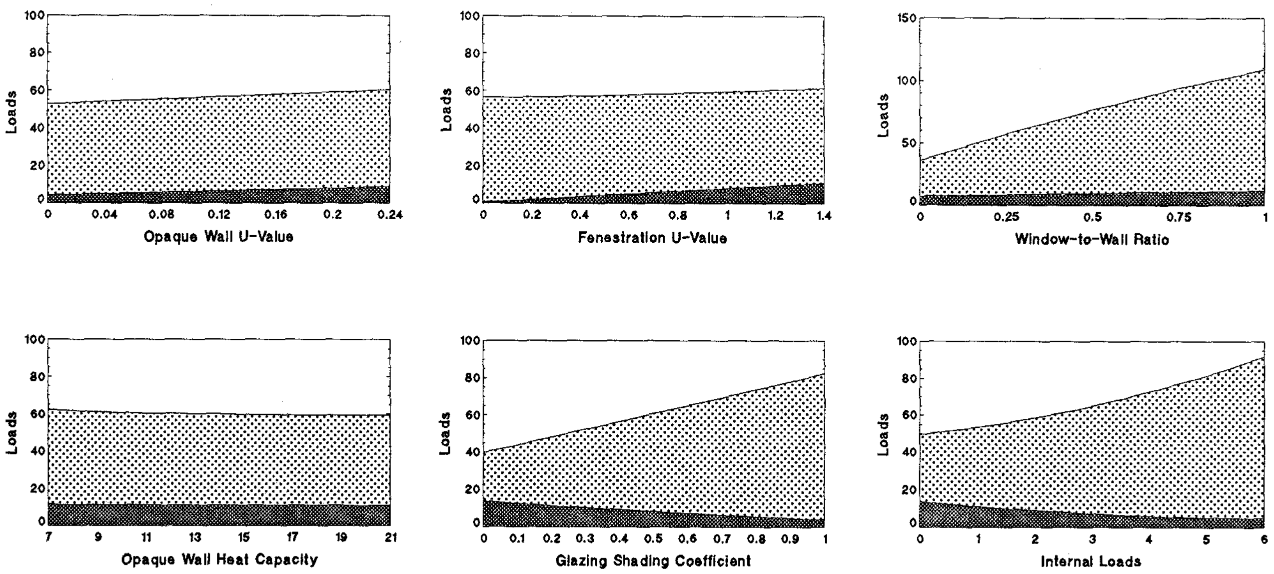

Figure 2. Loads vs. Envelope Parameters for El Paso, Texas

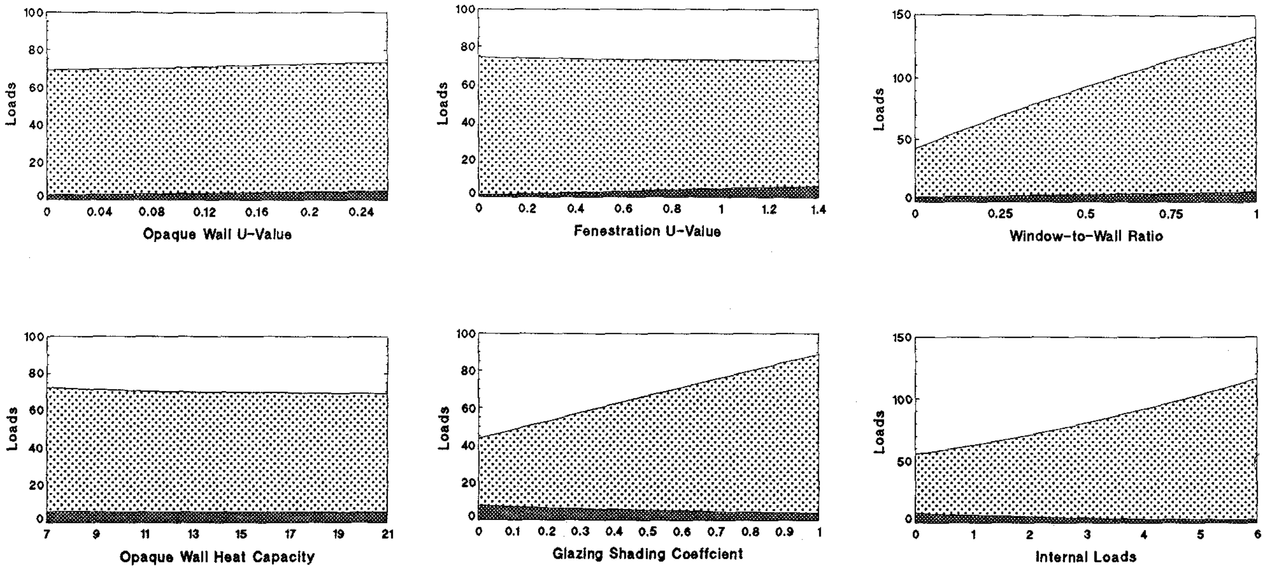

Figure 3. Loads vs. Envelope Parameters for Houston, Texas

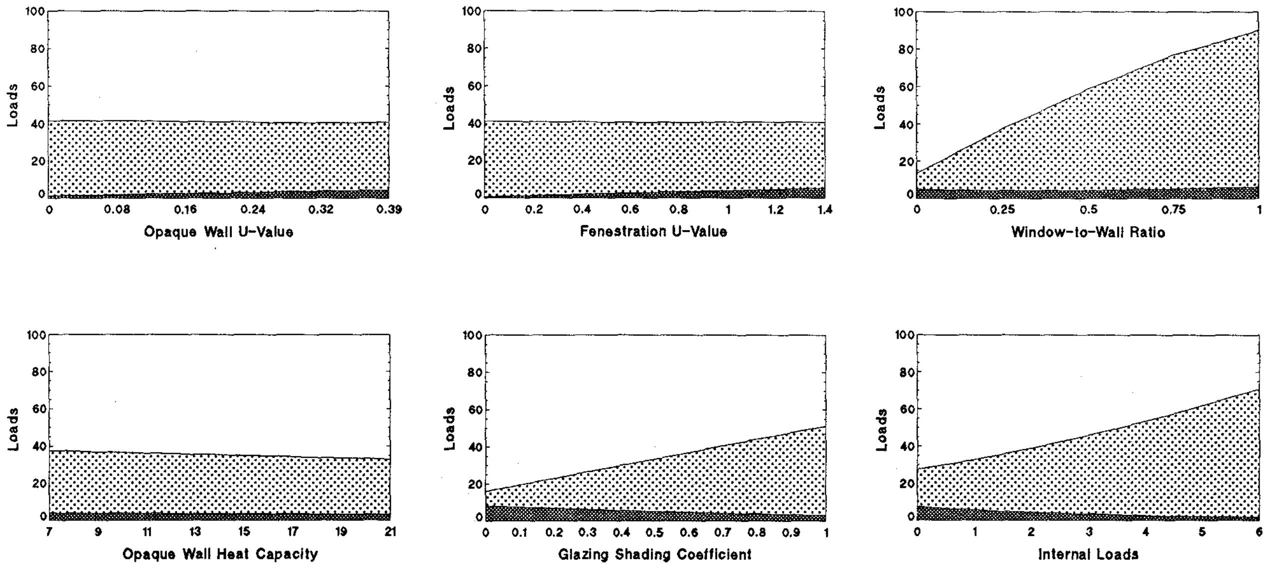

Figure 4. Loads vs. Envelope Parameters for Los Angeles, California

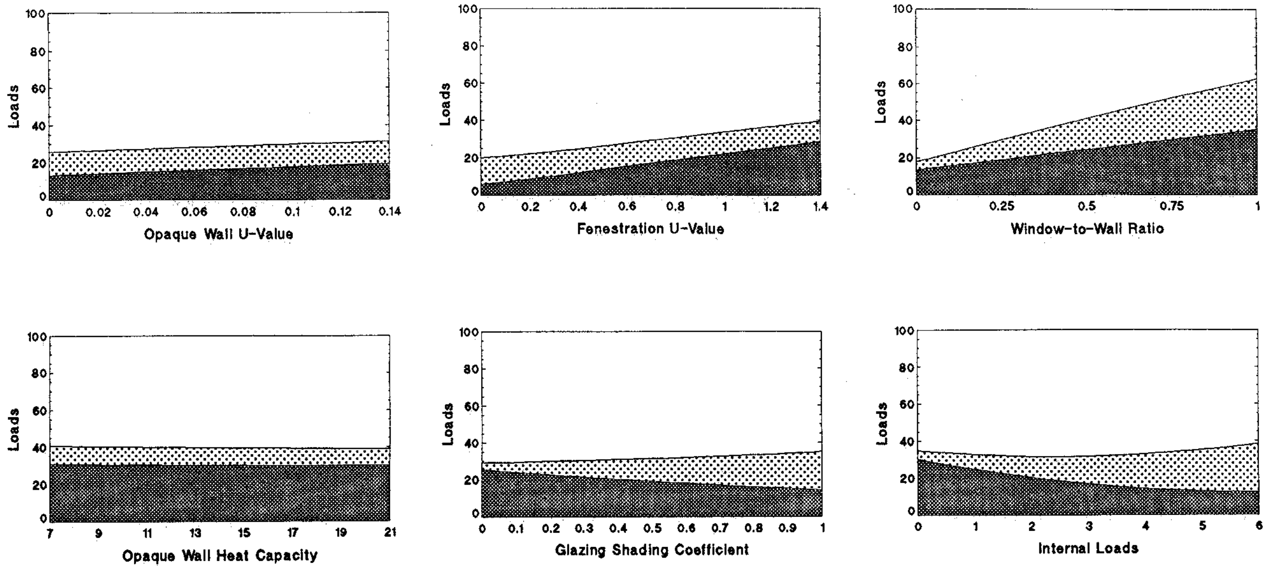

Figure 5. Loads vs. Envelope Parameters for Seattle, Washington

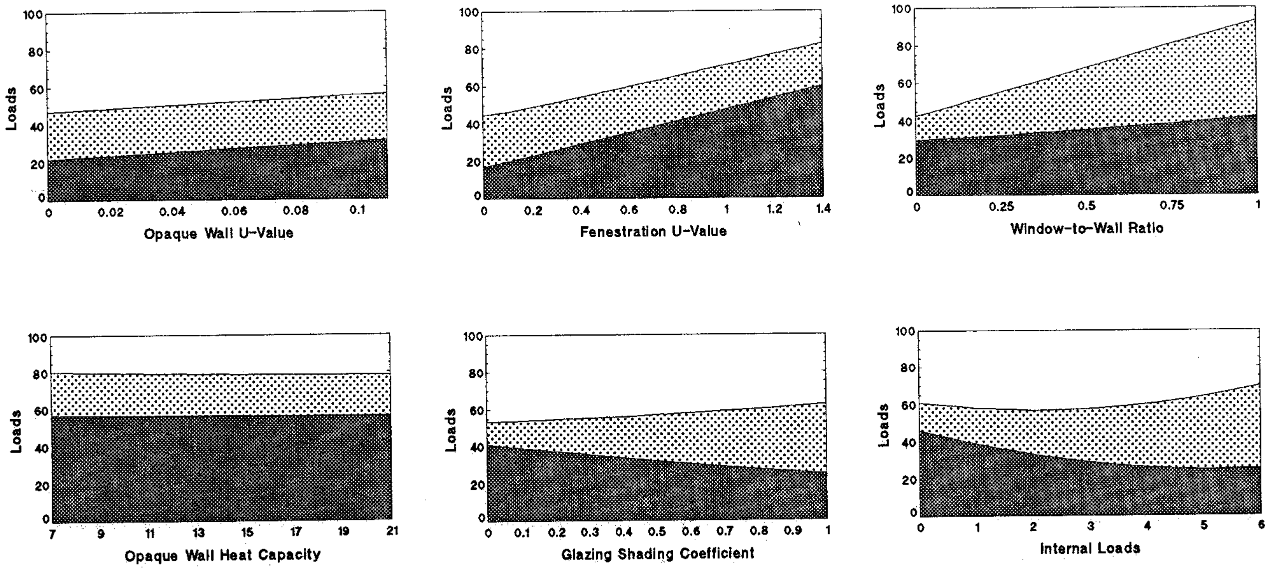

Figure 6. Loads vs. Envelope Parameters for Minneapolis, Minnesota

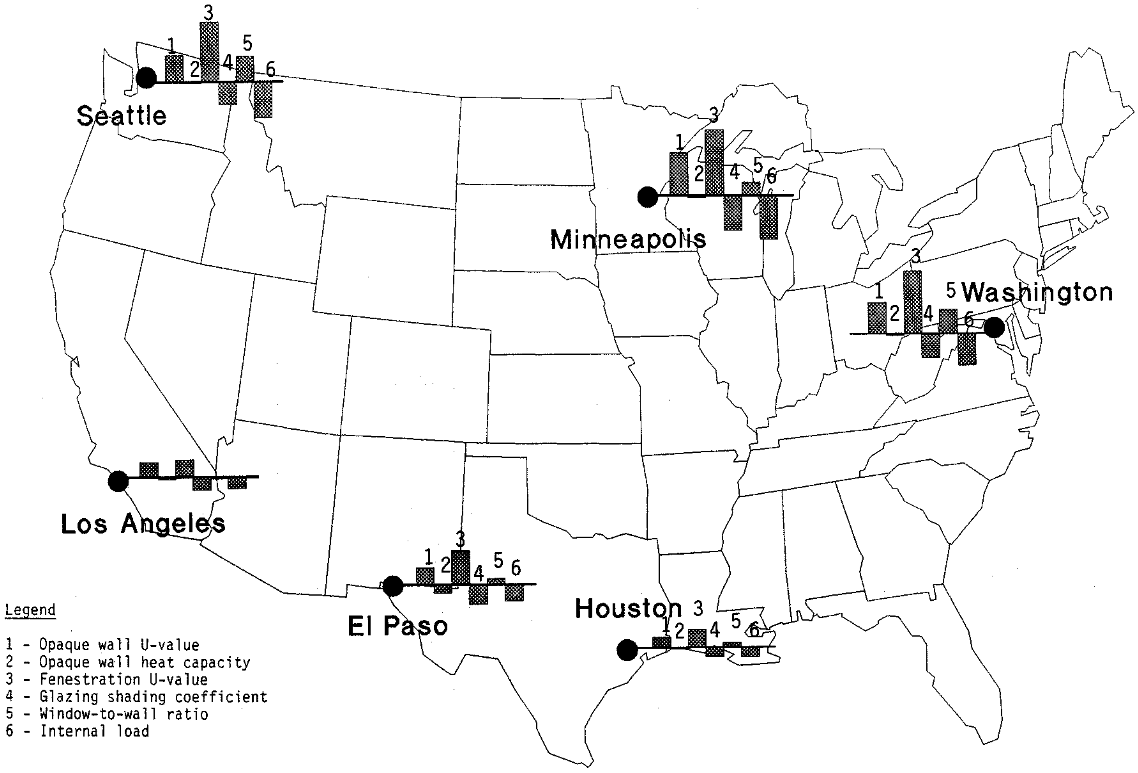

Figure 7. Heating Load Parameter Sensitivities for Selected U.S. Locations

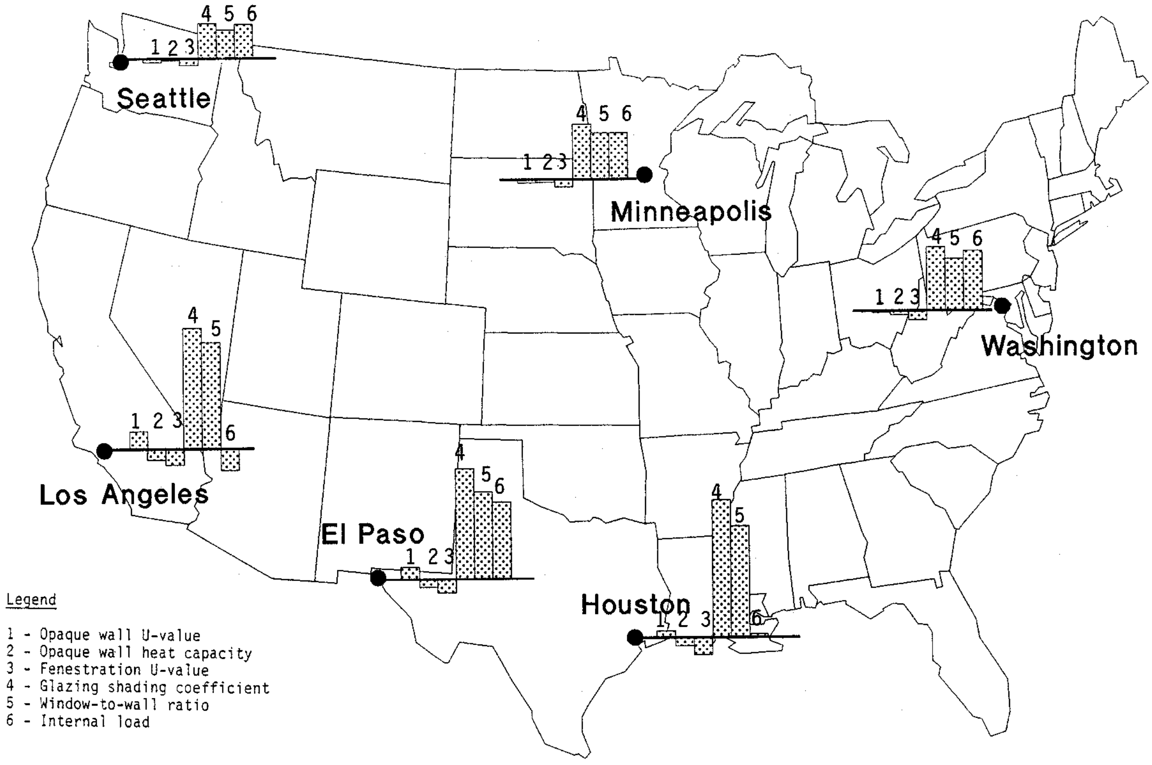

Figure 8. Cooling Load Parameter Sensitivities for Selected U.S. Locations