
THERMAL ANALYSIS OF BUILDINGS - CONFIGURATION PERTURBATIONS AND OBSERVED CLIMATE INTERFACE

R. Sullivan, Y.J. Huang, J. Bull, I. Turiel, R. Ritschard, and S. Selkowitz

April 1985
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

THERMAL ANALYSIS OF BUILDINGS - CONFIGURATION PERTURBATIONS AND OBSERVED CLIMATE INTERFACE

R. Sullivan, Y.J. Huang, J. Bull, I. Turiel, R. Ritschard, and S. Selkowitz

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley CA 94720

April 1985

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.
ABSTRACT

Results are presented that indicate a proportional relationship between building thermal loads for varying configuration parameters. Through the use of numerous building energy simulations using both the DOE-2.1 and BLAST energy analysis computer programs, it is shown that the relationship is independent of climatic location and covers a broad spectrum of those variables that influence a building's energy use. The theoretical justification associated with such a phenomenon is treated using a multiple regression-derived algebraic expression that clearly establishes the linear independence of a building's heat gain/loss components. Procedures are defined for the simplification of future parametric studies of the thermal analysis of buildings using a methodology that incorporates the observations reported herein.

INTRODUCTION

Various groups of the Applied Science Division at Lawrence Berkeley Laboratory have been involved in a series of building energy studies that have as their goal a better understanding of the thermal load contributions of a building's configuration components. Interests cover a variety of buildings including single-family residential and multi-family apartment dwellings, as well as commercial office structures. Components studied have been exterior envelope construction, window properties, internal heat gain and infiltration characteristics, and floor type. The approach taken in these analyses has been one that involves definition of a parametric set bounding the particular variables of interest and the subsequent creation of integrated databases using hour-by-hour building energy analysis simulation programs such as DOE-2.1 (Lawrence Berkeley Laboratory and Los Alamos Scientific Laboratory, 1981) and BLAST (Hittle, 1979).
In addition to the primary goal mentioned above, each of these studies has also had as a specific requirement the development of simplified methodologies and/or analysis tools that permit the evaluation of energy conservation measures. The techniques employed for such end products have relied on the use of regression analysis to define algebraic expressions that are used to predict energy usage quantities.

Recently, a task was defined that had as its objective the development of a procedure that would reduce the number of required parametric computer runs in creating and/or expanding a data base. Such a task was deemed necessary to minimize the cost of performing annual building energy simulations. Work reported by the Energy Analysis Program (1984) of the Applied Science Division provided the starting point for this investigation primarily because of the availability of a comprehensive data base constructed over the course of several years. The data base was formed from DOE-2.1A computer simulations for five prototype residential buildings (one-story, two-story, split-level, middle unit townhouse, and end unit townhouse) using a climate base of 45 weather locations. Table 1 presents relevant dimensions of each of the prototypes. Configuration parameters varied were floor type (slab, basement, crawl), wall, roof, and floor insulation, glass conductance, and infiltration levels. The specific floor type simulated for each prototype was based on survey data that determined the most prevalent foundation type in new home construction at each location. Each parametric set was run for approximately 22 locations.

The basic objective was to expand, in as accurate a manner as possible, the size of this data base so that data would subsequently exist for all five prototypes, three floor types, and all 45 weather locations. On the surface, such a task does not seem unreasonable considering the size of the initial data set and the fact that one would expect to use various simplifying assumptions well accepted within the building design community. However, after beginning the investigation, it became apparent that such assumptions would not be necessary because of an implicit relationship that existed among configuration parameters, regardless of climate input. This report documents this relationship and defines the climate interface that is apparent between building configurations.

DISCUSSION

A portion of the Energy Analysis Program (1984) data base consisted of simulation results for building variations as outlined on Table 2. These characteristics represent perturbations to the slab-on-grade prototype. Comparable parametrics were also defined for the basement and crawl space configurations. All prototypes modeled consisted of wood frame construction with wall framing corresponding to wood studs 2 in (5.1 cm) x 4 in (10.2 cm) on 16 in (40.6 cm) centers which occupied 25% of the wall area for insulation levels less than R=19 (3.34) and 2 in (5.1 cm) x 6 in (15.2 cm) studs on 24 in (61.0 cm) centers for insulation levels equal to or greater than R=19 (3.34). Ceiling and roof stud values corresponded to the latter for all insulation levels and occupied
10% of the area. Because of space limitations, results in this report are only presented for the single story ranch, slab-on-grade configuration. However, the trends and conclusions are valid for all the prototypes. In addition, data from three other parametric studies are also discussed. These studies yielded similar results and are seen as verification of the characteristics established through the analysis of the Energy Analysis Program (1984) work.

Figures 1 and 2 present the DOE-2.1A heating and cooling thermal load values for 22 weather locations for various alternate configurations (annotated on Table 1) compared to a selected base case model [Roof $R=19$ (3.340), Wall $R=11$ (1.94), Floor $R=5$ (.88), double pane glass, infiltration 0.7 air-changes/hr]. The alternate configurations correspond to changing glass conductance, wall and roof conductance, and infiltration level. Immediately obvious on both figures and the primary reason for this report is the proportional nature of the change in load values regardless of geographic location. Essentially a linear relationship exists between the base case load and the alternate configuration loads as follows:

$$Q_{\text{base}} = s Q_{\text{alt}} + t \quad (1)$$

Thus, if a base case value is known for a specific location, the alternate value is readily definable. This fact is prevalent on both figures with perhaps the heating load being somewhat more linear. The surprising nature of this development led to an investigation of several other parametric studies to establish consistancy.

Table 3 shows heating load correlations coefficients resulting from a least squares fit among the configurations shown on Table 2 for the 22 weather locations. The $R^2$ values are very close to 1.0 for perturbations that do not involve a major configuration change (primarily occurring diagonally). As one proceeds vertically down or horizontally across (right to left), the $R^2$ values decrease. This is because larger variations exist between the configurations being compared. Such tables were generated for all the prototypes in the Energy Analysis Program (1984) study and each yielded the same conclusive verification of the observed phenomenon.

Further substantiation was provided by three other independently accomplished studies reported by Carroll et al. (1984), Sullivan et al. (1984), and Turiel et al. (1984). In the Carroll work, which was done by the Solar Program at LBL, the BLAST energy analysis program was used for the purpose of characterizing the thermal mass effects of the envelope of a single-family ranch style house. The four zone (living, kitchen, bedroom, attic) 1200 ft$^2$ (111.5 m$^2$) structure is similar to the Hastings (1977) ranch house. Hypothetical external walls covering a range of thermal parameters (thickness, conductivity, density, specific heat, insulation level and placement) provided the primary configuration perturbations. In addition, BLAST simulations were also made for typical frame, masonry, and massless walls at the same value of resistance. Also studied were the effects of thermostat setpoint position and night setback. Six weather locations were selected for analysis under the
assumption that the resultant input excitations of temperature, solar radiation, and humidity would adequately bound expected variations throughout the continental U.S.

Heating and cooling loads on Figs. 3 and 4 show the variation from a base case condition \( [\text{Thk}=4 \text{ in (9.14 cm)}, \text{Cond}=0.5 \text{ Btu/hr*ft}^\circ\text{F} (8.64 \text{ W/m}^2\text{K}), \text{Dens}=90 \text{ lbs/ft}^3 (1440 \text{ kg/m}^3), \text{SH}=0.29 \text{ Btu/lb}^\circ\text{F} (1.22 \text{ KJ/kg}^\circ\text{C})] \) for varying wall properties for the six locations. As was the case with the DOE-2.1A results, a proportional relationship is again apparent. Heating in Denver appears to be the only condition that is somewhat offset from the lines drawn through the other points. Very interesting results are shown on Figs. 5 and 6 for the base case frame wall versus the masonry and massless walls. The effects of varying thermostat set-points and night setback are also presented. Again, the results are linear; however, the incremental differences between the masonry and massless walls are nearly constant with geographic location for both heating and cooling. The same is true for the setpoint and setback variation.

Results from Sullivan et al. (1984) are shown on Figs. 7 and 8. This work was undertaken by the Windows Group at LBL using the same ranch style prototype as in the Energy Analysis Program (1984) study. Its purpose was the analysis of fenestration systems through definition of a comprehensive parametric set bounding those items that affect the energy performance of windows, namely: glass conductance, shading coefficient, window size, external and internal shading, and night insulation. Also parameterized to establish component linear independence were internal heat gains, infiltration, and natural ventilation levels. Heating and cooling energies for six alternate fenestration systems are shown on the two figures for five weather locations. In each case a well defined linear relationship exist.

Figures 8 and 9 present results from Turiel's et al. (1984) work on low rise multi-family housing. The prototype analyzed was a two-story building consisting of six 1200 ft\(^2\) (111.5 m\(^2\)) apartments. A parametric set similar to the Energy Analysis Program (1984) work (Table 2) was used in creating the data base; however, a smaller number of geographic locations provided the climate variation. The heating and cooling loads shown are average values for the four end units. Similar data was generated for the two middle units. This averaging procedure seems to cause a deterioration of the correlations, as compared to the other studies, when the configuration perturbations involve multiple changes. For example, in comparing Figure 1 and 9, it is seen that as the heating load, for the alternate configurations, decreases because of increased roof and floor insulation, the multi-family results yield a least squares fit that is not as good as the single story ranch. However, the observed proportionality is still apparent.

-4-
THEORETICAL CONSIDERATIONS

The studies reported in Johnson et al. (1983) and Sullivan et al. (1984) detailed the use of multiple regression procedures to generate simplified algebraic expressions relating building configuration parameters to the heating and cooling thermal load and/or energy use. Although different building models were used in each analysis, it was shown that a very convenient and compact equation form could be used to accurately predict load or energy. The equation presented below contains the major components contributing to building thermal loads, namely: envelope conductance, solar gains, internal gains, and infiltration.

\[ Q_{ij} = \phi_1 C_j + \beta_1 S_j + \gamma_1 L_j + \delta_1 I_j \]  

(2)

where

- \( \phi, \beta, \gamma, \delta \) = regression coefficients
- \( C \) = envelope conductance, \( W/°C \)
- \( S \) = solar aperture, \( SC \cdot A \) (m²)
- \( L \) = internal heat gain saturation level (W/m²)
- \( I \) = infiltration level (air-changes/hour)
- \( i \) = geographic location
- \( j \) = configuration

The regression coefficients represent the climate dependent effect as well as containing conversion factors to insure proper units. Each of the other terms is related to a particular configuration variable. This expression does not contain all load producing items; for example, natural ventilation could be an additional term. However, those items generally deemed necessary for adequate building energy analysis studies are included. Also, the solar gain term \( \beta \cdot S \) has been simplified by neglecting a non-linear quadratic effect. The incremental configuration changes of concern in this study makes this assumption a valid one.

The convenient separation of variables provided by (2) permits an analysis of the influence of each component as well as providing a method of showing under what conditions, the \( (Q) \) values of two configurations are linearly related and climate independent. It is easily seen from the nature of this basic expression that the change in a component of \( (Q) \) is proportional to the change in a particular configuration variable. However, the linearity to be dealt with is the total heating or cooling load or energy which can be expressed as:

\[ \frac{(Q_{b2} - Q_{a2})}{(Q_{b1} - Q_{a1})} = \frac{(Q_{c2} - Q_{a2})}{(Q_{c1} - Q_{a1})} = \frac{(Q_{a2} - Q_{b2})}{(Q_{c1} - Q_{b1})} \]  

(3)

where \( a, b, \) and \( c \) refer to specific weather locations and 1 and 2 to different configurations. This form is used rather than a direct ratio, for example \( (Q_{b2}/Q_{b1}) \), since the intercept does not necessarily go through the origin. For equation (3) to be true, the variables \( \phi, \beta, \gamma, \) and \( \delta \) must be related to a specific weather parameter \( (X_i) \) in the following fashion:

\[ \phi_i = m \cdot X_i + k \]  

(4)
where (\(\phi\)) represents the regression coefficient and (m) and (k) are slope and intercept values that define the functional dependence on the climate variable (\(X_i\)). This statement implies that each coefficient or those which dominate be linearly related to the same weather parameter.

Such a condition is easily seen when one considers the heating requirement. For example, envelope conduction and infiltration, which are both temperature driven, are usually the largest components of the heating load; thus, heating degree hours can be representative of (\(X_i\)). Actually, the solar and internal gain terms also correlate with heating degree days, but not in as linear a fashion as the conduction and infiltration, Johnson et al. (1983). The cooling load is somewhat more complicated than heating because of the influence of solar radiation and humidity as well as temperature. Huang (1985) has shown, however, that the cooling load can be linearly related to cooling degree hours that are calculated considering not only outside air temperature but also humidity ratio. Additional work remains to be accomplished in this area both at the total load and component level. The requirement that the form of equation (4) yields the proportion of (3) justifies the search for a weather parameter giving such a result.

Another area that warrants continued investigation is the study of the thermal loads resulting from the stepwise progression from one configuration to another through many intermediate ones. Such a situation was briefly treated by Cleary et al. (1982). This situation arises when the two configurations being compared are significantly different and thus would not be expected to yield the linear relationship being discussed. The intermediate configurations, however, because of the incremental nature of the changes involved, could be related in such a manner. The following expression demonstrates how the loads of two disparate configurations at the same location can be related to each other.

\[
Q_{a1} = s_n Q_{an} + t_n
\]

where

\[
s_n = \prod_{i=1}^{n-1} s_i \quad \text{and} \quad t_n = \sum_{i=2}^{n-1} t_i \cdot \prod_{j=1}^{i-1} s_j + t_1
\]

The subscript (n) is set to one value higher than the number of intermediate configurations being stepped through.

CONCLUSIONS AND RECOMMENDATIONS

The results discussed in this document have implications in regards to future parametric studies involving the thermal analysis of buildings. Understanding the performance of different building parameters in varying geographic locations is greatly simplified through definition of a procedure utilizing the linearity reported herein. It can be tentatively stated that incremental thermal load/energy results can be obtained for any location for an alternate configuration provided the
performance of a base case configuration has been defined for all loca-
tions interested in and at least two locations have been used to define
the changes due to the alternate variations.

Table 4 shows the steps that would be taken to reduce the number of
simulations from \([NC\cdot NP]\) to \([NC+(2\cdot NP-2)]\) where \((NC)\) is the number of
climate locations and \((NP)\) the number of configuration parametrics.
This represents a reduction of \([(NC-2)\cdot (NP-1)]\) computer runs. As an
example, consider the case where \((NC=45)\) and \((NP=17)\). The number of
required runs would be \((765)\) without the simplifications described
herein. Using the procedures outlined on Table 4, changes this number
to \((77)\); a net reduction of \((688)\). Such a dramatic change would signi-
fically alter the computer costs associated with performing parametric
energy analysis studies. If costs are not of concern, one could greatly
increase the number of weather locations or size of the parametric set
and achieve a more comprehensive data base for the same original cost.

The figure used in this paper to show the proportional nature of the
thermal loads is in itself a very useful tool for comparing configura-
tion options. By creating a grid, as shown on Figure 11, that shows the
fractional relationship between the base case configuration values and
the alternate configuration values, an indication of the thermal load
differences can be indicated (the data corresponds to that presented on
Figure 1). What is particularly appealing, of course, is that the
presentation covers a wide spectrum of geographic locations.

Certain tasks remain to be accomplished as follows:

Continued investigation of the theoretical considerations and
specific definition of the weather variables (particularly those
associated with cooling) that justify the linearity as defined in
the paper.

With the exception of the results presented on Figures 7 and 8 (Sul-
ivan et al., 1984), all the data relates to residential thermal
loads and not energy. Additional work should be done to insure that
at the energy level the proportions are still valid. The authors' feeling, based on regression results carried out in the Sullivan et
al. (1984) study, is that the thermal load and energy are linearly
related in themselves which implies the existence of a multiplier to
the load curve presented herein.

The limits of the stepwise progression mentioned in the discussion
should be thoroughly defined. This would entail a more rigorous
analysis of the present data bases and possibly creation of other
parametric studies so that a broader cross section of prototypes can
be covered. Also of importance, in this regard, is the examination
of commercial building parametric studies. The data from the modu-
lar approach used by Johnson et al. (1984) indicates similar relations-
ships to those reported in this paper, however, a more thorough
review is recommended.
REFERENCES


Energy Analysis Program. 1984. "Affordable housing through energy conservation, a guide to designing and constructing energy efficient homes, technical support document, Lawrence Berkeley Laboratory.


ACKNOWLEDGEMENT

Special thanks to Bruce Birdsall, Frederick Winkelmann, William Carroll, and Peter Cleary of LBL for their comments and suggestions. This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.
### TABLE 1 - ENERGY ANALYSIS PROGRAM (1984) RESIDENTIAL PROTOTYPE DIMENSIONS

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Floor Area m² (ft²)</th>
<th>Window Area m² (ft²)</th>
<th>Dimensions m (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-story</td>
<td>143.1 (1540)</td>
<td>14.3 (154)</td>
<td>8.53x16.76x2.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(28x55x8)</td>
</tr>
<tr>
<td>Two-story</td>
<td>208.1 (2240)</td>
<td>20.8 (224)</td>
<td>8.53x12.19x4.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(28x40x16)</td>
</tr>
<tr>
<td>Split-level</td>
<td>176.88 (1904)</td>
<td>19.51 (210)</td>
<td>8.53x14.63x4.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(28x48x16)</td>
</tr>
<tr>
<td>Mid-townhouse</td>
<td>111.48 (1200)</td>
<td>13.38 (144)</td>
<td>6.10x9.14x4.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(20x30x16)</td>
</tr>
<tr>
<td>End-townhouse</td>
<td>111.48 (1200)</td>
<td>13.38 (144)</td>
<td>6.10x9.14x4.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(20x30x16)</td>
</tr>
</tbody>
</table>

### TABLE 2 - ENERGY ANALYSIS PROGRAM (1984) PARAMETRIC SET ALL PROTOTYPES, SLAB-ON-GRADE

<table>
<thead>
<tr>
<th>Parametric Identifier</th>
<th>Roof Insulation m²°C/W (hr·ft²°F/Btu)</th>
<th>Wall Insulation m²°C/W (hr·ft²°F/Btu)</th>
<th>Floor Insulation m²°C/W (hr·ft²°F/Btu)</th>
<th>Number of Infiltration air-changes/hr Panes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A01</td>
<td>0.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>1</td>
</tr>
<tr>
<td>B01</td>
<td>1.94 (11.)</td>
<td>0.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>1</td>
</tr>
<tr>
<td>C02</td>
<td>1.94 (11.)</td>
<td>1.94 (11.)</td>
<td>0.0 (0.0)</td>
<td>1</td>
</tr>
<tr>
<td>D01</td>
<td>3.34 (19.)</td>
<td>1.94 (11.)</td>
<td>0.0 (0.0)</td>
<td>1</td>
</tr>
<tr>
<td>E01 *</td>
<td>3.34 (19.)</td>
<td>1.94 (11.)</td>
<td>.09 (5.0)</td>
<td>1</td>
</tr>
<tr>
<td>F02 **</td>
<td>3.34 (19.)</td>
<td>1.94 (11.)</td>
<td>.09 (5.0)</td>
<td>2</td>
</tr>
<tr>
<td>G05 *</td>
<td>3.34 (19.)</td>
<td>3.34 (19.)</td>
<td>.09 (5.0)</td>
<td>2</td>
</tr>
<tr>
<td>G01</td>
<td>5.28 (30.)</td>
<td>1.94 (11.)</td>
<td>.09 (5.0)</td>
<td>2</td>
</tr>
<tr>
<td>H04</td>
<td>5.28 (30.)</td>
<td>3.34 (19.)</td>
<td>.09 (5.0)</td>
<td>2</td>
</tr>
<tr>
<td>I07 *</td>
<td>5.28 (30.)</td>
<td>3.34 (19.)</td>
<td>.09 (5.0)</td>
<td>3</td>
</tr>
<tr>
<td>I06</td>
<td>6.69 (38.)</td>
<td>3.34 (19.)</td>
<td>.09 (5.0)</td>
<td>2</td>
</tr>
<tr>
<td>J06</td>
<td>6.59 (38.)</td>
<td>3.34 (19.)</td>
<td>.09 (5.0)</td>
<td>3</td>
</tr>
<tr>
<td>K03</td>
<td>5.28 (30.)</td>
<td>3.34 (19.)</td>
<td>1.76 (10.)</td>
<td>3</td>
</tr>
<tr>
<td>K01</td>
<td>6.69 (38.)</td>
<td>3.34 (19.)</td>
<td>1.76 (10.)</td>
<td>2</td>
</tr>
<tr>
<td>L04</td>
<td>6.69 (38.)</td>
<td>3.34 (19.)</td>
<td>1.76 (10.)</td>
<td>3</td>
</tr>
<tr>
<td>M03</td>
<td>6.69 (38.)</td>
<td>4.75 (27.)</td>
<td>1.76 (10.)</td>
<td>3</td>
</tr>
<tr>
<td>H54 *</td>
<td>5.28 (30.)</td>
<td>3.34 (19.)</td>
<td>.09 (5.0)</td>
<td>2</td>
</tr>
</tbody>
</table>

** = Base Configuration
* = Alternate Configurations

---
### TABLE 3 - ENERGY ANALYSIS PROGRAM (1984) HEATING LOAD CORRELATION

COEFFICIENTS FOR PARAMETRIC OPTIONS OF THE ONE-STORY SLAB-ON-GRADE CONFIGURATION

<table>
<thead>
<tr>
<th>Option</th>
<th>A01</th>
<th>B01</th>
<th>C02</th>
<th>D01</th>
<th>E01</th>
<th>F02</th>
<th>G05</th>
<th>G01</th>
<th>H04</th>
<th>I07</th>
</tr>
</thead>
<tbody>
<tr>
<td>B01</td>
<td>0.9989</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C02</td>
<td>0.9973</td>
<td>0.9995</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D01</td>
<td>0.9967</td>
<td>0.9994</td>
<td>0.9999</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E01</td>
<td>0.9948</td>
<td>0.9984</td>
<td>0.9990</td>
<td>0.9998</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F02</td>
<td>0.9920</td>
<td>0.9963</td>
<td>0.9969</td>
<td>0.9984</td>
<td>0.9994</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G05</td>
<td>0.9870</td>
<td>0.9922</td>
<td>0.9952</td>
<td>0.9960</td>
<td>0.9980</td>
<td>0.9998</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G01</td>
<td>0.9902</td>
<td>0.9951</td>
<td>0.9957</td>
<td>0.9977</td>
<td>0.9989</td>
<td>0.9999</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H04</td>
<td>0.9873</td>
<td>0.9930</td>
<td>0.9934</td>
<td>0.9963</td>
<td>0.9979</td>
<td>0.9994</td>
<td>0.9998</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I07</td>
<td>0.9854</td>
<td>0.9915</td>
<td>0.9915</td>
<td>0.9952</td>
<td>0.9970</td>
<td>0.9990</td>
<td>0.9994</td>
<td>0.9995</td>
<td>0.9999</td>
<td></td>
</tr>
<tr>
<td>J06</td>
<td>0.9824</td>
<td>0.9887</td>
<td>0.9925</td>
<td>0.9936</td>
<td>0.9963</td>
<td>0.9988</td>
<td>0.9996</td>
<td>0.9995</td>
<td>1.0000</td>
<td>0.9999</td>
</tr>
<tr>
<td>K03</td>
<td>0.9794</td>
<td>0.9861</td>
<td>0.9904</td>
<td>0.9915</td>
<td>0.9946</td>
<td>0.9979</td>
<td>0.9991</td>
<td>0.9988</td>
<td>0.9997</td>
<td>1.0000</td>
</tr>
<tr>
<td>K01</td>
<td>0.9835</td>
<td>0.9901</td>
<td>0.9915</td>
<td>0.9941</td>
<td>0.9962</td>
<td>0.9984</td>
<td>0.9989</td>
<td>0.9991</td>
<td>0.9997</td>
<td>0.9999</td>
</tr>
<tr>
<td>L04</td>
<td>0.9800</td>
<td>0.9867</td>
<td>0.9908</td>
<td>0.9919</td>
<td>0.9952</td>
<td>0.9982</td>
<td>0.9992</td>
<td>0.9990</td>
<td>0.9998</td>
<td>0.9999</td>
</tr>
<tr>
<td>M03</td>
<td>0.9763</td>
<td>0.9836</td>
<td>0.9882</td>
<td>0.9915</td>
<td>0.9931</td>
<td>0.9969</td>
<td>0.9984</td>
<td>0.9980</td>
<td>0.9992</td>
<td>0.9997</td>
</tr>
<tr>
<td>H54</td>
<td>0.9724</td>
<td>0.9802</td>
<td>0.9854</td>
<td>0.9868</td>
<td>0.9909</td>
<td>0.9935</td>
<td>0.9972</td>
<td>0.9967</td>
<td>0.9984</td>
<td>0.9991</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Option</th>
<th>I06</th>
<th>J06</th>
<th>K03</th>
<th>K01</th>
<th>L04</th>
<th>M03</th>
<th>H54</th>
</tr>
</thead>
<tbody>
<tr>
<td>J06</td>
<td>0.9999</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K03</td>
<td>0.9997</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K01</td>
<td>0.9999</td>
<td>0.9999</td>
<td>0.9999</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L04</td>
<td>0.9995</td>
<td>0.9999</td>
<td>1.0000</td>
<td>0.9998</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M03</td>
<td>0.9998</td>
<td>0.9995</td>
<td>0.9996</td>
<td>0.9993</td>
<td>0.9998</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H54</td>
<td>0.9958</td>
<td>0.9967</td>
<td>0.9979</td>
<td>0.9963</td>
<td>0.9971</td>
<td>0.9976</td>
<td></td>
</tr>
</tbody>
</table>
Define base case building

Obtain base case thermal loads/energy results for all weather locations of interest

Define alternate building configuration parametric set

Obtain thermal load/energy results for the parametric set for extreme weather locations to establish relationship between base case and the alternate configurations

For any other location, use the base case value and the established relationship between the base case and the alternate configuration value to define the thermal load/energy
FIGURE 1  Residential Heating Load Comparison for Various Configurations and Geographic Locations (TRY) Using DOE-2.1A, Ranch Style House, Slab-on-Grade, One Zone 143 m$^2$

Effect of Envelope Conductance and Infiltration

Base is Ceiling Insulation (RC=3.34 m$^2$°C/W), Wall Insulation (RW=1.94 m$^2$°C/W), Double Pane (NP=2), Infiltration (I=.7 ac/hr)
Residential Cooling Load Comparison for Various Configurations and Geographic Locations (TRY) Using DOE-2.1A.

Ranch Style House, Slab-on-Grade, One Zone 143 m²
Effect of Envelope Conductance and Infiltration

Base is Ceiling Insulation (RC=3.34 m²°C/W), Wall Insulation (RW=1.94 m²°C/W), Double Pane (NP=2), Infiltration (I=.7 ac/hr)

Legend
+ RC=3.34 RW=1.94 NP=1 I=.7
X RC=3.34 RW=3.34 NP=2 I=.7
△ RC=5.28 RW=3.34 NP=3 I=.7
▽ RC=5.28 RW=3.34 NP=2 I=.4
RESIDENTIAL HEATING LOAD COMPARISON FOR VARIOUS CONFIGURATIONS AND GEOGRAPHIC LOCATIONS (TMY) USING BLAST, RANCH STYLE HOUSE, SLAB-ON-GRAGE, FOUR ZONE 111.5 m\(^2\) EFFECT OF ENVELOPE MASS PROPERTIES

Base Exterior Wall Thickness (T=9.14 cm), Conductivity (K=8.64 W/m \(\cdot\) \(\circ\) C), Density (D=1440 kg/m\(^3\)), Specific Heat (SH=1.22 KJ/kg \(\circ\) C), No Insulation

Legend

+ T=9.14 K=1.21 D=1440
\(\times\) T=9.14 K=17.28 D=1440
\(\bigtriangleup\) T=9.14 K=8.64 D=480
\(\bigtriangledown\) T=9.14 K=8.64 D=2400
\(\Diamond\) T=18.39 K=8.64 D=1440
\(\Box\) T=27.43 K=8.64 D=1440
\(\bigcirc\) T=36.58 K=8.64 D=1440
Residential Cooling Load Comparison for Various Configurations and Geographic Locations (TMY) Using BLAST.

Ranch Style House, Slab-on-Grade, Four Zone 111.5 m²
Effect of Envelope Mass Properties

Base Exterior Wall Thickness (T=9.14 cm),
Conductivity (K=8.64 W/m²°C), Density (D=1440 kg/m³),
Specific Heat (SH=1.22 KJ/kg°C), No Insulation

Legend

- T=9.14 K=1.21 D=1440
- T=9.14 K=17.28 D=1440
- T=9.14 K=8.64 D=480
- T=9.14 K=8.64 D=2400
- T=18.39 K=8.64 D=1440
- T=27.43 K=8.64 D=1440
- T=36.58 K=8.64 D=1440
FIGURE 5 Residential Heating Load Comparison for Various Configurations and Geographic Locations (TMY) Using BLAST, Ranch Style House, Slab-on-Grade, Four Zone 111.5 m² Effect of Envelope Mass, Thermostat Setpoints, Night Setback

Base is Frame Wall Construction (RW=2.43 m²°C/W), Thermostat Settings: Heating (TH=21.1°C), Cooling (TC=25.5°C), Night Setback (NS=5.5°C)

Legend
- Masonry RW=2.43
- Massless RW=2.43
- Frame TH=22.2 TC=24.4 NS=5.5
- Frame TH=21.1 TC=25.5 NS=0.0
Residential Cooling Load Comparison for Various Configurations and Geographic Locations (TMY) Using BLAST, Ranch Style House, Slab-on-Grade, Four Zone 111.5 m² Effect of Envelope Mass, Thermostat Setpoints, Night Setback

Base is Frame Wall Construction (RW=2.43 m²C/W), Thermostat Settings: Heating (TH=21.4°C), Cooling (TC=25.5°C), Night Setback (NS=5.5°C)

Legend
+ Masonry RW=2.43
× Massless RW=2.43
△ Frame TH=22.2 TC=24.4 NS=5.5
∇ Frame TH=21.1 TC=25.5 NS=0.0
FIGURE 7 Residential Heating Energy Comparison for Various Configurations and Geographic Locations (WYEC) Using DOE-2.1B, Ranch Style House, Slab-on-Grade, One Zone 143 m² Effect of Window Parameters

Base is Double Pane (NP=2)
Shading Coefficient (SC=1)
Window/Wall Ratio (WWR=.3)

Legend
+ NP=1 SC=1 WWR=.3
X NP=3 SC=1 WWR=.3
△ NP=2 SC=.7 WWR=.3
V NP=2 SC=.4 WWR=.3
□ NP=2 SC=1 WWR=.15
□ NP=2 SC=1 WWR=.45
Residential Cooling Energy Comparison for Various Configurations and Geographic Locations (WYEC) Using DOE-2.1B, Ranch Style House, Slab-on-Grade, One Zone 143 m²

Effect of Window Parameters

Base is Double Pane (NP=2)
Shading Coefficient (SC=1)
Window/Wall Ratio (WWR=.3)

FIGURE 8

Legend
+ NP=1 SC=1 WWR=.3
X NP=3 SC=1 WWR=.3
△ NP=2 SC=.7 WWR=.3
▽ NP=2 SC=.4 WWR=.3
□ NP=2 SC=1 WWR=.15
□ NP=2 SC=1 WWR=.45

C base (GJ) vs. C alternate (GJ) for various geographic locations and window configurations.
FIGURE 9  Residential Heating Load Comparison for Various Configurations and Geographic Locations (TRY) Using DOE-2.1A, Multi-Family Apartment, Slab-on-Grade, Six Units 11.5 m². End Unit Average, Effect of Envelope Conductance and Infiltration

Base is Ceiling Insulation (RC=3.34 m²°C/W), Wall Insulation (RW=1.94 m²°C/W), Double Pane (NP=2), Infiltration (I=.7 ac/hr)

Legend
+ RC=3.34 RW=1.94 NP=2 I=.7
X RC=3.34 RW=3.34 NP=2 I=.7
Δ RC=5.28 RW=3.34 NP=3 I=.7
▽ RC=5.28 RW=3.34 NP=2 I=.4
Figure 10  Residential Cooling Load Comparison for Various Configurations and Geographic Locations (TRY) Using DOE-2.1A, Multi-Family Apartment, Slab-on-Grade, Six Units 111.5 m² End Unit Average, Effect of Envelope Conductance and Infiltration

Base is Ceiling Insulation (RC=3.34 m²°C/W), Wall Insulation (RW=1.94 m²°C/W), Double Pane (NP=2). Infiltration (i=7 ac/hr)

Legend
+ RC=3.34 RW=1.94 NP=1 i=.7
× RC=3.34 RW=3.34 NP=2 i=.7
△ RC=5.28 RW=3.34 NP=3 i=.7
▼ RC=5.28 RW=3.34 NP=2 i=.4
Residential Heating Load Comparison for Various Configurations and Geographic Locations,
Presentation for Use as a Developmental Tool

FIGURE 11

H base (GJ)

H alternate (GJ)

Ratio H alternate/H base

0 10 20 30 40 50 60 70 80

0 10 20 30 40 50 60 70 80

Chicago
New York
Oklahoma City
Memphis
Fort Worth
Honolulu

.25
.50
.75
1.00
1.33
2.00
4.00
This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.