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SUMMARY

R. Sullivan and S. Selkowitz: Residential Window Performance Analysis Using Regression Procedures. This paper discusses the results of a comprehensive parametric study of a prototypical single-family ranch-style house. The DOE-2.1B energy analysis simulation program was used to analyze the variation in heating and cooling energy use due to changes in the following fenestration characteristics: orientation, size, conductance, and shading coefficient. In addition, the effects of night insulation, shade management, and overhangs were investigated. Climate sensitivity was established by considering results from Madison, Wisconsin and Lake Charles, Louisiana. To facilitate simplification of the analysis (more than 2000 DOE-2.1B runs were completed), multiple regression techniques were used to generate a simplified algebraic expression that relates energy use to the parameters varied. The resultant equation can be differentiated to quickly determine the window area that minimizes energy use or cost for different fenestration parametrics. This approach can form the basis for a simple, yet powerful fenestration design tool.

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Introduction

Window performance analysis has become in recent years a major concern in defining the overall energy use patterns of most types of buildings. Of particular importance among builders and designers in both the residential and commercial sectors are the interactions and tradeoffs among the various configuration parameters which define a structure. Windows represent a primary focus of study because they influence the thermal environment of a building through convective/conductive heat transfer, radiant transfer, and mass transfer. Within the past year, the Windows and Daylighting group of the Applied Science Division at Lawrence Berkeley Laboratory began work on a project whose purpose is an improved categorization and evaluation of the different factors contributing to residential energy use. Of particular importance has been the determination of the effect of varying fenestration systems on energy performance issues.

A prototypical single family ranch style house was selected for analysis using the DOE-2.1B energy analysis program (1). The intent in the study was to investigate effects arising from variations in the fenestration properties of orientation, size, conductance, and shading coefficient. An appropriate range was selected for each variable to insure coverage of the expected variations typical in a single-family residence. In addition, the glazing characteristics were defined so that most current and/or new window systems would be bracketed, thus allowing the potential values of conceptual window systems with hypothetical performance characteristics to be examined. Also of concern was the influence due to the use of night insulation, shade management, and overhangs.

Results and Discussion

The building configuration modeled in this study is a single story, 16.67 m by 8.53 m, one zone structure of wood frame construction. Window sizes were fixed on three sides at 15% of the wall area. The fourth or primary side provided the parametric variation on window size which varied from 0% to 60% of the wall area (0% to 17.1% floor area). Four conductance values representative of single pane glazing through a system with a conductance of 0.53 $W/m^{2o}C$ as well as three shading coefficient values (.4,.7,1.0) served as the glazing property parametrics. Results were obtained for eight orientations covering a complete 360^o rotation in 45^o increments. More details of the thermal and operational characteristics of the prototype are provided in Ref. 2.

Incremental changes to the glazing properties due to night insulation, shade management, and overhangs were also investigated. Insulation levels of R=5.68, 14.2, and 28.4 $m^2 {}^oC/W$ were implemented at night during the months of October to May. Shade management was simulated by deploying a shade that reduced solar heat gain by 40% if the direct solar gain on a particular window exceeded 63 W/m^2. Overhangs were modeled using a fixed width of 0.76 m above each window.

Two standard year (WYEC) weather profiles (3) were used in the analysis, Madison WI and Lake Charles LA. Their selection was based on the expected large thermal loads differences resulting from their geographic location which was intended to insure a satisfactory bound on the problem.

The data base generated by the DOE-2.1B simulations was used to develop a simplified algebraic expression to predict energy use and cost for the model. This was accomplished through multiple regression procedures using the method of least squares to define the best fit to the data sets. Sets of independent variables (configuration parameters) were defined from which dependent variables (heating and cooling energy) were predicted. The general form of the equation consisted of the explicit definition of the conductive and solar radiation effects of the fenestration system as follows:

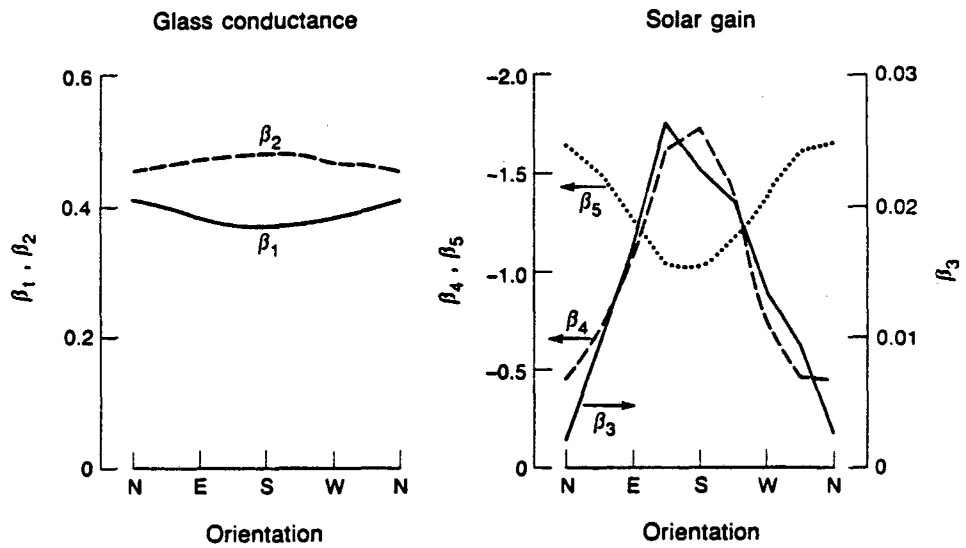
$$\begin{aligned} \Delta E = \; & \beta_1(k_n U_g A_g) + \beta_2(\Sigma k_{no} U_{go} A_{go}) && \text{conductance} \\ & + \beta_3(k_o k_s SC_g A_g)^2 + \beta_4(k_o k_s SC_g A_g) && \text{solar} \\ & + \beta_5(\Sigma k_{oo} k_{so} SC_{go} A_{go}) && \end{aligned} \qquad (1)$$

where

β = regression coefficients
U_g = primary glazing U-value ($W/m^2 {}^oC$)
A_g = primary glazing area (m^2)
SC_g = primary glazing shading coefficient
U_{go} = off-primary glazing U-value ($W/m^2 {}^oC$)
A_{go} = off-primary glazing area (m^2)
SC_{go} = off-primary shading coefficient
k_n = primary glazing night insulation factor
k_o = primary glazing overhang factor
k_s = primary glazing shade management factor
k_{no} = off-primary glazing night insulation factor
k_{oo} = off-primary glazing overhang factor
k_{so} = off-primary glazing shade management factor

The ΔE term represents the annual heating or cooling energy effect of the fenestration, with the total space conditioning being determined by the sum of the two. Fig. 1 shows the heating energy regression coefficients for Madison. The relative importance of each term on energy use can be ascertained from such a figure and others related to cooling energy and total energy. For example, Madison is dominated by the heating coefficients (both conductance and solar terms); whereas (although not presented), the cooling energy solar gain coefficients dominate in Lake Charles. The glass conductance effect on cooling energy is minimal in both locations. The sign difference between the conductance (β_1) and solar (β_4) terms in the heating energy coefficients indicates the capability of trading-off the two window properties. However, this is apparent in geographic locations with moderate to harsh winters; it is of course not true in climates dominated by cooling requirements.

Fig. 1. Residential heating energy regression coefficients as a function of primary window orientation in Madison, WI. (for use with SI units)



The window size which minimizes energy use or cost can be defined by taking the derivative of equation (1) with respect to primary window area and equating the result to zero:

$$A_g = [-\beta'_4 - \beta'_1*(U_g/SC)]/(2.*\beta'_3*SC) \qquad (2)$$

where the prime on the coefficients indicates the summed heating and cooling values, i.e. $\beta_1' = \beta_{1c}k_{nc} + \beta_{1h}k_{nh}$. Areas are definable for:

$$U_g/SC < \beta_4'/\beta_1' \qquad (3)$$

The minimum energy cost solution can be found by modifying the energy equation to account for the unit costs of gas and electricity. Using \$.60/therm (\$6.00/Mbtu, \$5.69/GJ) for gas and \$.07/kwh (\$20.50/Mbtu, \$19.43/GJ) for electricity, the regression coefficients become (using β_1 as an example):

$$\beta_1' = 19.43\ \beta_{1c}k_{nc} + 5.69\ \beta_{1h}k_{nh} \qquad (4)$$

when using SI units. Fig. 2 illustrates solutions for the optimum primary window area facing south in Madison, WI. for various configuration parameters and different electricity and gas cost ratios. It is apparent that the reduction in optimum area is associated with increased electricity cost (cooling) and/or reduced gas cost (heating) (progression from curve A through D). The use of night insulation has a dramatic effect on all the curves which is indicative of the high heating requirements in Madison. Note that these results do not yet indicate if the energy or cost minimizing solution is a cost effective solution.

Fig. 2. Primary window size as a function of U-value, night insulation, and ratio of the cost of electricity (cooling) to the cost of gas (heating) for two shading coefficients for a south orientation in Madison, WI.

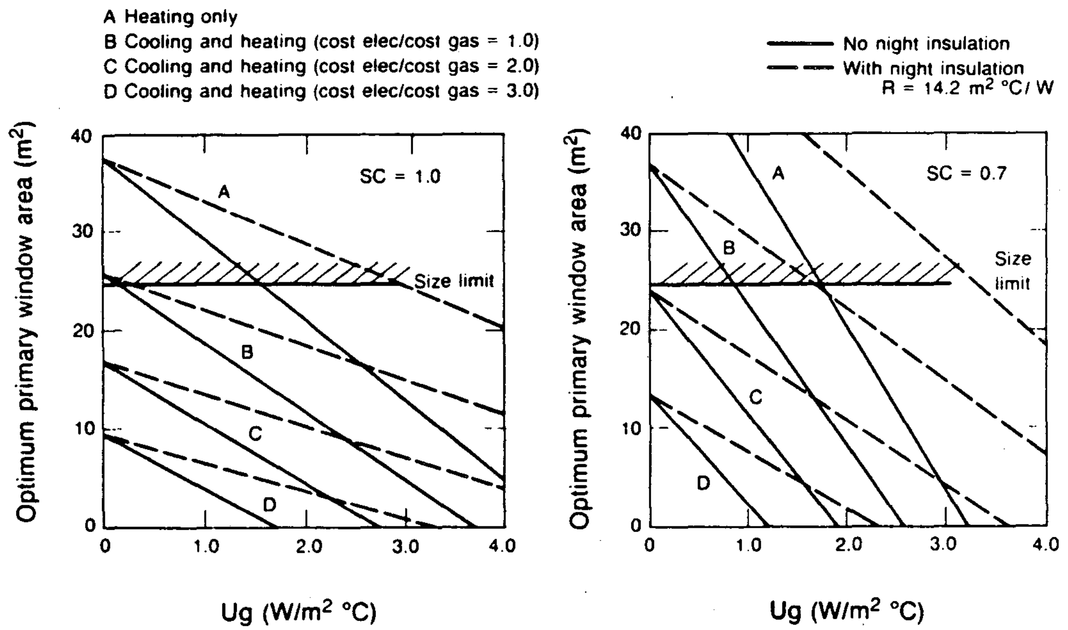
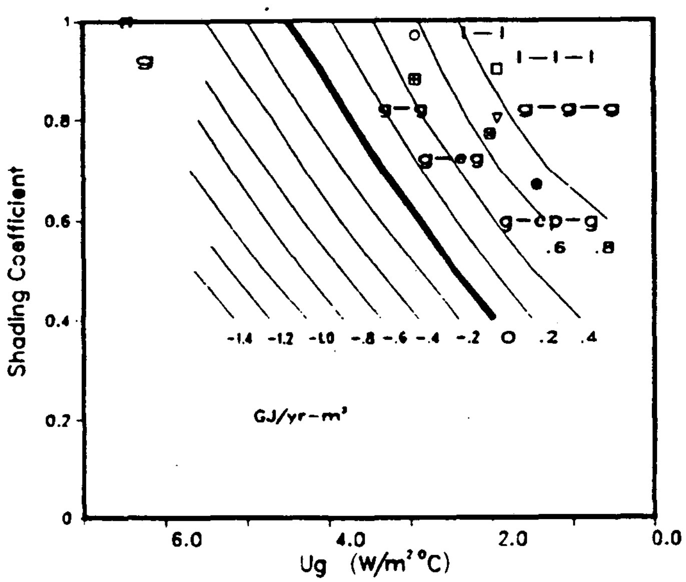


Fig. 3 presents the net annual useful flux (the solar gain which contributes to a reduction in heating load) in Madison, WI. for a south facing primary window area of 6.13 m^2. These data were obtained from a solution to equation (1) by considering only the heating energy requirement. Also shown on the figure are conductance and shading coefficient values representative of current glazing products. This type of presentation allows a quick evaluation of the winter performance of various fenestration systems in which U-value and shading coefficient can be independently varied.

Fig. 3. Net annual useful flux in Madison, WI. for a primary window area of 6.13 m^2 for an orientation due south. The performance of typical glazing properties is also shown.



	U ($W/m^2 \cdot C$)	SC
g	6.46	1.0
g-g	2.87	0.88
g-g-g	1.8	0.8
g-eg	1.92	0.77
g-ep-g	1.32	0.67
l-l	2.87	0.97
l-l-l	1.80	0.9

g: 1/8" DS float glass
l: 1/8" low-iron sheet glass
e: low-emittance coating, e = 0.15
p: 4-mil polyester
All air gaps are 12.7 mm (1/2")
U-value: Standard ASHRAE winter conditions
SC: Standard ASHRAE summer conditions

Conclusions

This paper has discussed results of an on-going study whose objective is the analysis of fenestration parameters on residential energy use and cost. The work has been structured in the form of a parametric study covering a range of residential characteristics: window orientation, size, conductance, and shading coefficient. Several conclusions can be ascertained from the work accomplished thus far:

a. Results indicate very clearly the viability of using regression derived equations to perform such analysis. In this study, a simple algebraic expression was defined which predicted the energy use and cost and optimal window size as a function of configuration parameters.

b. The regression coefficients (in addition to the configuration properties) also give insights into the residence performance associated with specific component effects and geographic locations.

c. The regression solution indicates that the components which contribute to a building's energy use are independent of each other within the range of parameters investigated.

d. The use of a set of precalculated regression coefficients with a simple energy or cost equation suggests that several easy to use but powerful fenestration design tools could be developed. Unlike many other simplified design tools based on simple calculation procedures, these results are based on the use of a sophisticated hour-by-hour simulation tool that properly accounts for complex thermal effects in a residence.

References

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(3) Crow, L.W. Development of hourly data for weather year for energy calculations (WYEC), including solar data, at 21 stations throughout the United States. ASHRAE RP 239, 1980.

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