LBL-16369 c.2

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY
JUN 12 1984
LIBRARY AND
DOCUMENTS SECTION

APPLIED SCIENCE DIVISION

Presented at the ASHRAE Semi-Annual Meeting,
Atlanta, GA, January 29 - February 2, 1984; and
to be published in ASHRAE Transactions

MULTIPLE REGRESSION TECHNIQUES APPLIED TO FENESTRATION EFFECTS ON COMMERCIAL BUILDING ENERGY PERFORMANCE

R. Sullivan and S. Nozaki

June 1983

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782.

APPLIED SCIENCE
DIVISION

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

LBL-16369 c.2

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.

LBL-16369
EEB-DOE-2 83-7

Presented at the ASHRAE Semi-Annual Meeting, Atlanta GA, January 29-February 2, 1984, and to be published in ASHRAE Transactions 90 (I).

MULTIPLE REGRESSION TECHNIQUES APPLIED TO FENESTRATION EFFECTS ON COMMERCIAL BUILDING ENERGY PERFORMANCE

R. Sullivan and S. Nozaki

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

June 1983

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.

MULTIPLE REGRESSION TECHNIQUES APPLIED TO FENESTRATION EFFECTS ON COMMERCIAL BUILDING ENERGY PERFORMANCE

R. Sullivan and S. Nozaki

Applied Science Division
Lawrence Berkeley Laboratory
Berkeley, CA 94720

ABSTRACT

Multiple regression statistical methods are used in the analysis of fenestration effects on space conditioning requirements of commercial buildings. The procedure permits the quantification of changes in energy usage due to certain factors that influence the selection of fenestration, namely, the basic window properties of size, conductance, and shading coefficient. In addition, the usefulness of daylighting and overhangs was examined. A representative range of climatic zones, orientations, and installed lighting power, in addition to the primary parametric on glazing properties (area, U-value, shading coefficient), were considered during the course of the study. The DOE-2.1B energy-analysis simulation program was used to define the thermal response of a prototypical building module, which was used to create a data base for the regression analysis.

INTRODUCTION

Defining a building's energy performance has become an integral part of today's design process. The tools available for performing such a task cover the spectrum from the very sophisticated and complex hour-by-hour energy analysis simulation programs to very simple methods based on rules of thumb gathered over years of experience. While large simulation programs, such as DOE-2.1B (Lawrence Berkeley Laboratory 1980), are responsive to most aspects of a building's thermal environment in hour-by-hour detail, these programs, in spite of the speed and power of present day computers, are expensive to run and time consuming to set up. Testing more than a few building parameters through a parametric analysis is prohibitively expensive to most users. The multiple regression technique described in this paper utilizes the power of the DOE 2.1B program to reduce the problem of design energy calculations to a set of simple algebraic expressions. Factors influencing building space conditioning can be defined relative to the external and internal environment of the building. Externally, climatic variables such as solar radiation, wind speed, air temperature, and humidity ratio have a significant effect. Internally, usage patterns, building envelope parameters, and the HVAC system greatly influence the energy requirements between buildings. For the multiple regression approach to be applicable to all building configurations in all climates, simulation runs would be required where each of the aforementioned factors was

parameterized. The present study restricted attention to various window property variations, including the use of daylighting and overhangs. Since these factors are relatively independent of the internal building configuration variables, the sample of parametric runs could therefore be limited to a reasonable number. Further work is in progress to expand the data base, thus increasing the dimensions and applicability of the regression results.

METHODOLOGY

The procedure used in the study consisted of the creation of a large data base on which a multiple regression was performed. Multiple regression allows the researcher to study the linear relationship between a set of independent variables and a dependent variable while taking into account the interrelationships among the independent variables. The basic goal of multiple regression is to produce a linear combination of independent variables that will correlate as highly as possible with the dependent variable. This linear combination can then be used to "predict" values of the dependent variable, and the importance of each of the independent variables in that prediction can be assessed (Nie et al. 1975).

The data base was constructed from a series of DOE-2.1B hour-by-hour simulations. Four base climates (Crow 1980) consisting of Madison, WI; Washington, DC; Seattle, WA; and Lake Charles, LA, were selected for analysis. The configuration modeled for use in the DOE-2.1B program consisted of a module representative of a single floor in a commercial office building (figure 1). Four perimeter zones consisting of ten 15 ft (4.57 m) deep and 10 ft (3.05 m) wide, each facing one of the primary orientations of north, south, east, and west, surrounded a core zone of 10,000 ft^2 (929 m^2) floor area. Floor to ceiling height was 8.5 ft (2.6 m). Heat transfer surfaces consisted of the perimeter zone exterior walls and the core/perimeter wall interface. No heat transfer was permitted between perimeter zones and through the floor and ceiling.

Overall exterior wall/window U-values were held fixed at values related to the particular geographic location. The values varied from a low of U_o=.17 Btu/ft^2 hr ^oF (.96 W/m^2 ^oC) for Madison, WI, to a high of .27 Btu/ft^2 hr ^oF (1.53 W/m^2 ^oC) for Lake Charles, La. Fenestration properties parameterized were window/wall ratio (0.0,0.15,0.3,0.5), type (single U=1.02 Btu/ft^2 hr ^oF (5.79 W/m^2 ^oC), double U=.49 Btu/ft^2 hr ^oF (2.8 W/m^2 ^oC), triple U=.28 Btu/ft^2 hr ^oF (1.59 W/m^2 ^oC)), and shading coefficient/visible transmittance (varied according to climate, i.e., for Lake Charles, SC=.2,.4,.6 and VIS=.13,.27,.4). Additional internal shading was provided using a shading coefficient multiplier of 0.6. This shading was implemented based on a preset quantity of direct solar radiation.

Parametrics were also obtained on the effect of overhangs, sized to the sun position in May/July at each location. Overhang width to window height ratios varied from a low of 0.18 in Lake Charles, LA, to a high

of 0.52 in Seattle, WA. Daylighting was analyzed through a recent addition to the DOE-2.1B program (Winkelmann 1983). A continuously dimmable system in which lighting output varied linearly and continuously with input power was used. The illuminance set point was set to 50 footcandles (538 lux) and a minimum light output of zero footcandles (lux) at 10 % input power. Daylighting illuminance levels were calculated at two reference points in each zone at a height above the floor of 2.5 ft (0.76 m) and at depths of 5.0 ft (1.52 m) and 10.0 ft (3.05 m).

Internal loads arising from occupants and equipment were scheduled according to the Standard Evaluation Technique (Fleming and Associates 1982). These amounted to an average heat gain input of 24.56 Btu/ft^2 day (280 KJ/m^2 day) for occupants and 10.35 Btu/ft^2 day (118 KJ/m^2 day) for equipment. Lighting heat gain was a distinct parametric varying from 31.32 Btu/ft^2 day (357 KJ/m^2 day) to 57.46 Btu/ft^2 day (655 KJ/m^2 day).

Each zone was equipped with its own variable temperature constant volume air-handling unit with economizer. Thermostat setpoints were 72 ^{o}F (22.2 ^{o}C) and 78 ^{o}F (25.5 ^{o}C). These were changed to 63 ^{o}F (17.2 ^{o}C) and 90 ^{o}F (32.2 ^{o}C) during unoccupied hours. The design supply air flow rate per square foot of floor was 0.7 cfm/ft^2 (0.031 l/s m^2). Minimum amount of outside air per zone occupant was 5 cfm (2.36 l/s). The economizer limit temperature (outside air above which the economizer returns to minimum outside air operation) was 62 ^{o}F (16.67 ^{o}C). Air infiltration was fixed at an equivalent value of 0.6 airchanges per hour.

FORM OF THE REGRESSION EQUATIONS

The dependent variables to be predicted in the study were annual building heating energy and cooling energy. The independent or predictor variables were functions of the parameters varied in construction of the data base, namely, orientation, window/wall ratio, shading coefficient, lighting wattage, use of daylighting, and presence of overhangs. Glazing U-values were eliminated from consideration because of the fact that the product of shading coefficient and window/wall ratio yielded approximately the same thermal load value regardless of glazing type. This is a direct result of the fixed overall exterior wall/window U-value used in the study for each climate. Additional work to be reported at a later date will reflect influences due to changes in these overall U-values.

A decision was made to run separate regressions for each climate, since four locations were considered an inadequate number from which to draw general conclusions based on climatic variables. After experimenting with the regression fit using different forms of the independent variables, the final regression expression was of the form:

E_i in GJs = Cooling or Heating Energy for the ith orientation =

$b0_i$	constant
$[b1_i(SC\ WWR)^2 + b2_i(SC\ WWR)]$	solar
$b4\ (WSOM)\ +$	lighting
$IOV\ [b5_i(SC\ WWR)^2 + b6_i(SC\ WWR)]\ +$	overhang
$IDL\ (WSOM)\ [b7\ (SC\ WWR)^2 + b8(SC\ WWR)]$	daylighting

where the b's are solved for regression coefficients, SC is the shading coefficient, WWR the window/wall ratio, and WSOM is the lighting wattage per square meter of floor area. The variables IOV and IDL are either 1 or 0, depending on whether overhangs and daylighting are used or not used respectively. Note that the constant term, b0, represents the energy contribution from all sources held constant in the study (i.e., equipment and occupant load, wall conductance, and infiltration/ventilation). The daylighting effect enters only in relation to lighting wattage as would be expected. Also, the daylighting is not a function of orientation - the regression analysis rejected the variation as statistically insignificant.

The same form of the regression expression was used for both heating and cooling energy. In all climates analyzed, the regression fit was extremely good. The squared multiple correlation coefficient, r^2, the proportion of variation explained by the variables included in the regression equation, was 0.94 or greater with the exception of heating in Lake Charles, LA. The r^2 value in this location was 0.89, which can be attributed to the very low heating energy values. The standard error of the estimate for the regressions, which can be interpreted as the standard deviation of the residuals (the difference between the actual value and the regression value), was on the order of 5 %. Tables 1 and 2 present the regression coefficient values for the perimeter zones for cooling and heating energy. Also shown are the mean, the squared multiple correlation coefficient, the standard deviation, and the standard error of the estimate. These coefficients were generated from a data set of 1368 points by the methodology previously described.

USE OF THE REGRESSION EQUATION

Example 1

The regression coefficients given in Tables 1 and 2 can be used in the following way. Suppose a building designer is interested in determining the appropriate window size in a south-facing zone in Lake Charles, LA. Considering a window/wall ratio of 35 %, a shading coefficient of 0.4 and a lighting wattage of 1.85 W/ft^2 (20.0 W/m^2), the predicted cooling energy use with no daylighting and no overhang would

be:

$$E(C) = 22.55 + [146.5*(.4*.35)^2 + 124.02*(.4*.35)] + 1.05*(20.0) = 63.78 \text{ GJ}$$

base solar lighting

Now suppose the designer is interested in the energy savings resulting from the addition of an overhang. The predicted cooling energy savings would be:

$$= [-34.2*(.4*.35)^2 - 43.86*(.4*.35)] = -6.81 \text{ GJ}$$

overhang

Similarly, if one wanted to estimate the energy savings using daylighting, the regression equation yields:

$$= 20.0*[11.30*(.4*.35)^2 - 5.83*(.4*.35)] = -11.89 \text{ GJ}$$

daylighting

Note that while the base cooling energy of 63.78 GJ is dependent on the constant coefficient of the regression expression (i.e., other internal gains, conductance gain, infiltration and ventilation), the change in energy usage due to the addition of the overhang and the use of daylighting is independent of these quantities and can be considered a more general phenomena.

Example 2

Consider that one is interested in the effect of increasing lighting wattage from 1.39 W/ft^2 (15.0 W/m^2) to 2.31 W/ft^2 (25.0 W/m^2) in Madison, WI, for varying shading coefficients and window/wall ratios on a south-facing orientation. Also of interest is the change due to daylighting. For the no-daylighting situation, the incremental cooling energy is:

$$E(C) = [103.86*(SC\ WWR)^2 + 104.28*(SC\ WWR)] + 0.50*(25.0 - 15.0)$$

solar lighting

or in tabular form:

SC WWR	E (C)
.1	16.47
.2	30.13
.3	45.63
.4	63.33

When using daylighting, an additional term is required, i.e.:

$$= (25.0 - 15.0)*[3.36*(SC\ WWR)^2 - 2.34*(SC\ WWR)] \qquad \text{daylighting}$$

The change in the above tabular values would be:

SC WWR	E (C)
.1	-2.01
.2	-3.34
.3	-3.99
.4	-3.98

The above examples give some indication of the usefulness of the procedure developed. The technique can be generalized for any arbitrary floor area by dividing the results by 139.35 m^2, which is the floor area of the module used in the study. In this manner, values are obtained per square meter which can then be applied to the desired area.

CONCLUSIONS

This paper has presented a brief discussion of a simple algebraic technique to analyze the effects of various fenestration parameters on the space-conditioning heating and cooling requirements of commercial office buildings. The parameterized variables included window size, shading coefficient, space lighting requirements, and the presence or absence of overhangs and daylighting. The intent has been to demonstrate that regression analysis can provide a useful tool for analyzing energy requirements and energy changes when the data base includes variations in the parameters of interest. As this data base is expanded, the regression technique can be used to predict both qualitative and quantitative changes in energy usage not limited to fenestration effects. Continuing studies will focus on envelope construction (variable U-values), internal load variations (usage patterns for lighting, equipment, and occupants), overhang width variations, and different HVAC system types.

REFERENCES

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

Fleming and Associates 1981. "Recommendations for the standard evaluation technique (SET) of the building energy performance standards (BEPS)." Draft. W.S. Fleming and Associates, Inc., Landover, MD.

Lawrence Berkeley Laboratory and Los Alamos Scientific Laboratory 1980. Doe-2.1B Reference Manual. Berkeley, CA and Los Alamos, NM.

Nie, N.H.; Hull, C.H.; Jenkins, J.G.; Steinbrenner, K.; and Bent, D.H. 1975. Statistical package for the social sciences. 2d ed. New York: McGraw-Hill Book Company.

Winkelmann, F. 1983. "Daylighting calculations in DOE-2." Lawrence Berkeley Laboratory, Berkeley, CA.

BIBLIOGRAPHY

Johnson, R.; Selkowitz, S.; Winkelmann, F.; and Zentner, M. 1981. "Glazing optimization study for energy efficiency in commercial office buildings." Lawrence Berkeley Laboratory, Berkeley, CA.

Sharabianlou, N. and McQuiston, F.C. 1981. "Simplified procedure for estimating energy requirements of commercial structures." ASHRAE Transactions 87 1981, Part 2.

Sullivan, R. and Cumali, Z.O. 1980. "Determination of the maximum beneficial window size in single family residences." Final Report. Consultants Computation Bureau, Oakland, CA.

ACKNOWLEDGEMENT

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.

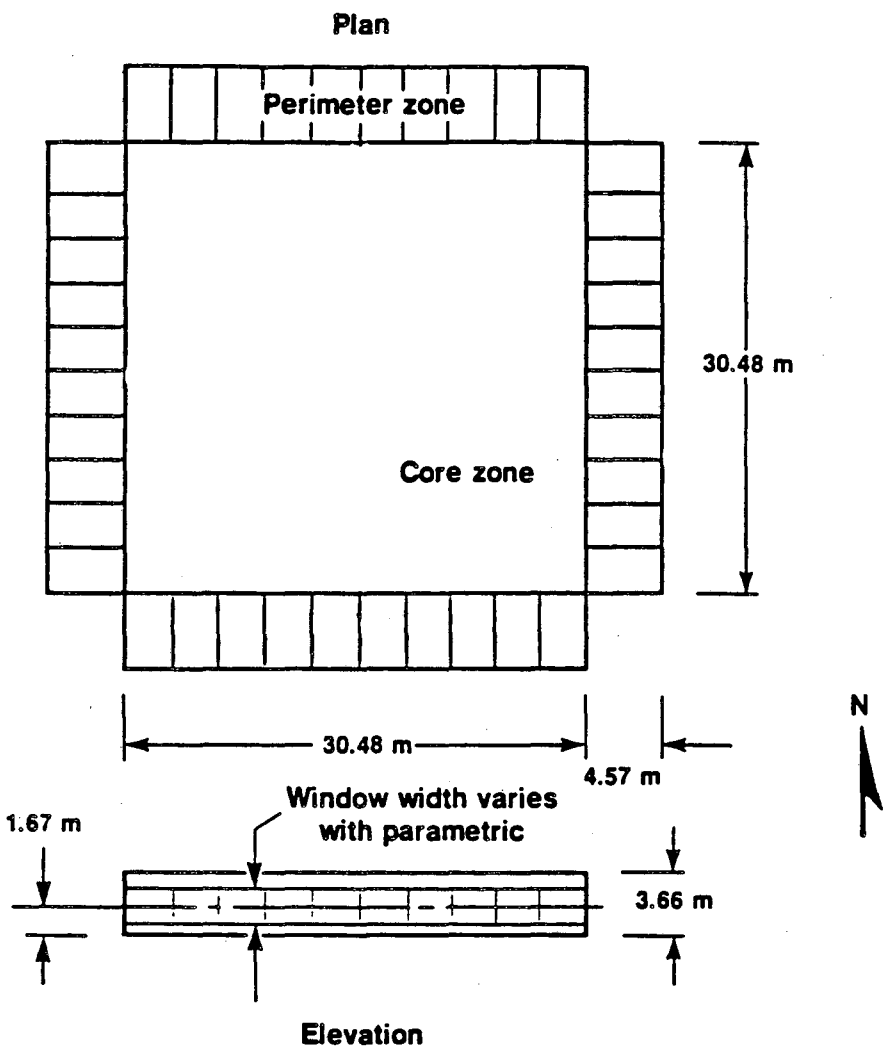
TABLE 1
Regression Coefficients: Cooling

		MADISON	WASH D.C.	SEATTLE	LAKE CHARLES
BASE					
	N	5.57	10.58	1.47	19.33
	S	7.25	12.85	3.28	22.55
	E	7.17	12.55	2.64	22.97
	W	6.96	12.34	2.93	22.01
SOLAR					
$(SC\ WWR)^2$	N	39.58	63.44	20.96	81.17
	S	103.86	102.28	70.45	146.50
	E	101.33	104.28	60.98	113.89
	W	108.72	109.56	77.20	99.11
(SC WWR)	N	35.99	46.86	22.86	78.74
	S	104.28	81.85	35.37	124.02
	E	49.29	74.94	30.87	128.24
	W	49.82	78.53	33.58	127.29
LIGHTING					
(W/m^2)		0.50	0.69	0.32	1.05
OVERHANG					
$(SC\ WWR)^2$	N	-15.09	-16.47	-9.73	-22.27
	S	-32.09	-26.59	-16.86	-34.20
	E	-40.43	-25.01	-27.11	-18.15
	W	-38.63	-20.58	-30.35	-8.87
(SC WWR)	N	-2.85	-3.38	-1.78	-2.01
	S	-30.72	-44.65	-25.79	-43.86
	E	-18.47	-29.77	-23.32	-35.89
	W	-20.48	-31.45	-15.50	-37.36
DAYLIGHT					
$W/m^2(SC\ WWR)^2$		3.36	5.32	2.32	11.30
$W/m^2(SC\ WWR)$		-2.34	-3.38	-1.60	-5.83
STATISTICS					
Mean		19.79	29.93	10.83	47.19
R Square		.980	.979	.974	.965
Std Dev		.867	1.22	.676	2.02
Std Error(%)		4.4	4.1	6.2	4.3

TABLE 2
Regression Coefficients: Heating

		MADISON	WASH D.C.	SEATTLE	LAKE CHARLES
BASE					
	N	37.81	22.26	20.79	7.15
	S	35.66	20.80	19.18	6.49
	E	36.63	21.59	19.61	6.66
	W	36.98	21.94	19.92	6.96
SOLAR					
$(SC\ WWR)^2$	N	-7.91	-8.55	3.60	-0.84
	S	13.40	19.20	13.29	8.76
	E	-22.16	0.63	2.55	4.22
	W	-26.48	-0.32	0.02	5.17
(SC WWR)	N	-21.94	-14.03	-16.90	-6.33
	S	-57.70	-36.41	-29.92	-12.77
	E	-31.65	-26.38	-24.06	-10.23
	W	-30.81	-26.69	-24.49	-10.97
LIGHTING					
(W/m^2)		-0.45	-0.30	-0.33	-0.11
OVERHANG					
$(SC\ WWR)^2$	N	-0.32	0.68	-4.62	0.95
	S	-27.22	-26.06	-21.50	-7.81
	E	-3.06	-14.03	-11.39	-5.80
	W	-6.96	-13.61	-13.32	-5.28
(SC WWR)	N	2.53	1.48	3.62	0.0
	S	25.32	18.25	17.18	5.06
	E	13.40	11.82	11.62	3.48
	W	12.55	10.76	13.32	3.38
DAYLIGHT					
$W/m^2(SC\ WWR)^2$		-1.29	-1.19	-0.50	-0.33
$W/m^2(SC\ WWR)$		0.84	0.66	0.34	0.18
STATISTICS					
Mean		23.54	12.89	10.72	3.85
R Square		.941	.939	.941	.893
Std Dev		.928	.631	.558	.282
Std Frror(%)		3.9	4.9	5.2	7.3

FIGURE 1 – BUILDING MODULE DESCRIPTION



XBL 838-2960

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.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720