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# COMMERCIAL BUILDING ENERGY PERFORMANCE ANALYSIS USING MULTIPLE REGRESSION PROCEDURES

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## ABSTRACT

Regression analysis is used to define algebraic expressions which can be used to study the effects of various configuration parameters on building energy performance. The DOE-2.1B energy analysis simulation program was used in conjunction with a prototypical building modules to generate a large data base for five geographic locations. Configuration variables parameterized included orientation, wall and roof conductance, glazing properties of windows and skylights (area, U-value, shading coefficient, visible transmittance, well depth) and installed lighting power. Incremental effects due to external shading (overhangs) and daylighting were also examined. The modular concept used in the building definition permits generalization to configurations other than that analyzed and therefore the results can be used in studying building design trade-offs.

## INTRODUCTION

This paper details the continuation of a study reported in Ref. 1 concerning the use of multiple regression analysis techniques in understanding the complexities of building energy performance. In the earlier study, a data base was defined from a series of DOE-2.1B energy analysis simulation program digital computer runs in which building module fenestration properties such as size, conductance, shading coefficient and visible transmittance were parameterized. Also investigated were the effect of internal lighting wattage, daylighting and overhangs. Subsequent analysis resulted in the derivation of an algebraic expression which related energy usage to the aforementioned window properties. Although the Ref. 1 work was somewhat limited in nature, it did indicate the viability of using regression analysis techniques for building energy usage studies. The current study resulted in the creation of a greatly expanded data base in which, in addition to the above parametrics, envelope conductances (wall and roof), overhang width variations and the use of skylights were investigated.

The technique used in the study consisted of the creation of a large integrated data base constructed from a series of DOE-2.1B (Ref.2) hour by hour energy analysis simulations. Once the data base was prepared, a series of multiple regressions (Ref.3) were undertaken to define coefficients for selected configuartion variables which could accurately predict various energy usage quantities. Multiple regression is a statistical analysis procedure in which relationships between different variables are established mathematically using a least squares approach. Generally, sets of independent variables are defined from which a dependent variable is predicted.

Five WYEC weather profiles (Ref.4) were used in the analysis. These consisted of the following cities: Madison WI, Lake Charles LA, Seattle WA, Washington D.C. and El Paso TE. The selection of these five was based on the expectedly large thermal load differences resulting from their geographic location and thus, to some extent, insured a satisfactory bound on the problem. It was realized at the start of the project that the intent was not to yield a climatic correlation for the results per se but that the selection of the five would indicate a direction for future studies in which a climate/configuration interface is to be examined.

The configuration modeled in the DOE-2.1B program consisted of two modules representative of intermediate floors and rooftop floors in a low or high rise building (Fig.1). The intermediate floor model was partitioned into five distinct thermal zones: four perimeter zones (4.47m deep, 30.48m wide) each facing one of the primary orientations of north, south, east and west surrounded a core zone of $929m^2$ floor area. Floor to ceiling height was 2.6m. 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. The rooftop model consisted of the above core zone dimensions with a ceiling height of 3.5m. Adiabatic surfaces were assummed for all surfaces except the rooftop.

Configuration variables parameterized are presented on Tab. 1. The nominal base overall U-values were related to the particular geographic location. The wall values varied from a low of $U_o$=0.727W/$m^{2o}$C for Madison to a high of 1.153W/$m^{2o}$C for Lake Charles. Roof values were from $U_o$=0.312 to 0.568W/$m^{2o}$C. Multipliers of 0.75 and 1.5 were used in each case to yield three values. For the windows, the product of window/wall ratio and shading coefficient were varied (.0,.1,.2, .3, .4). These values were attained using, in most cases, window/wall ratios of .0, .15, .3 and .5. Either double ($U_g$=2.8W/$m^{2o}$C) or triple ($U_g$=1.8W/$m^{2o}$C) pane glass was used depending on the particular overall U-value being run. The skylight parameters varied included the product of skylight/roof ratio, visible transmittance and well factor (.0,.005,.01,.02,.03,.04). The skylight/roof ratios were fixed at .0 and .05. Double pane glass conductance was 3.84W/$m^{2o}$C.

Additional shading using a curtain type device was implemented in the perimeter zones each hour based on a preset quantity of transmitted direct solar radiation (60W/$m^2$) or when the window luminance resulted in a glare index of 20. This shading reduced the solar heat gain by 40% and the visible transmittance by 65%. Results were also obtained on the effect of overhangs for four specific overhang width/window height ratios (0.0,0.21,0.42,0.85). Daylighting was analyzed through a recent addition to the DOE-2.1B program (Ref.5). A continuously dimmable electric lighting system in which lighting output varied linearly and continuously with input power was used. The illuminance set point was set to 538 lux and a minimum light output of zero lux at 10 percent input power. For perimeter zones, daylighting illuminance levels were calculated at two reference points in each zone at a height above the floor of 0.76m and at depths of 1.52m and 3.05m. The skylight model consisted of 16 skylights square and centered at points every 3.81m in four 15.24m by 15.24m zones (Fig.1). Daylighting reference points were defined at the center of each zone (7.62m in from each end and 0.76m above the floor).

Internal loads arising from occupants, lighting and equipment were scheduled according to the Standard Evaluation Technique, Ref. 4. These amounted to an average heat gain input of 280KJ/$m^2$ for occupants and 118 KJ/$m^2$ for equipment. Lighting heat gain was a distinct parametric varying from 7.34W/$m^2$ to 29.06W/$m^2$.

Each zone was equipped with its own variable temperature, constant volume system. Daytime operational hours were from 7am to 6pm weekdays. Thermostat setpoints were 22.2°C and 25.5°C. These were changed to 17.2°C and 32.2°C during unoccupied hours. The design supply air flow rate per square meter of floor area was 0.031 l/s-$m^2$. Minimum amount of outside air per zone occupant was 2.36 l/s. The economizer limit temperature (outside air temperature above which the economizer returns to minimum outside air operation) was 16.67°C. Air infiltration was fixed at an equivalent value of 0.6 airchanges per hour.

## FORM OF THE REGRESSION EQUATION

One of the more important tasks in regression analysis is the selection of appropriate independent variables to be used in subsequentely defining the dependent variable. In most instances, it is desired that the selected variables make physical sense as well as being useful predictors. Since the dependent variables to be predicted in this study consisted of annual heating and cooling energy (coil loads) and cooling peak, the independent variables were chosen as functions of the input heat gain/loss components. For perimeter and roof zones, four groups were defined: conduction, solar radiation through glazing, internal lighting and other internal loads, i.e. occupants, equipment, infiltration and ventilation. The specific variables used corresponded to the parameters varied in the construction of the data base, i.e. overall envelope U-value, glazing size and shading coefficient and lighting wattage.

A decision was made early in the program not to attempt a correlation with climate variables since only five locations were being analyzed. Thus, distinct expressions are presented for each climate. Future work will concentrate on increasing the size of the data base to insure a climate/configuration interface. Heating peak was not considered in the study after initial results indicated that its value was a function of the startup load and thus could not be related to configuration parameters in a meaningful way. The analysis of overhangs and daylighting resulted in correction factors to the solar heat gain and lighting heat gain terms. The resulting regression expression for the perimeter and roof zones was of the form:

$$b_1 U_o A_T + b_2 k_o A_g SC + b_3 k_d A_f L + b_4 A_f \qquad (1)$$

where

- $b's$ = regression coefficients
- $U_o$ = exterior envelope overall U-value ($W/m^{2o}C$)
- $A_T$ = exterior wall or roof area ($m^2$)
- $A_g$ = window or skylight area ($m^2$)
- $SC$ = shading coefficient
- $k_o$ = correction factor due to overhangs
- $A_f$ = floor or roof area ($m^2$)
- $L$ = lighting wattage ($W/m^2$)
- $k_d$ = correction factor due to daylighting

This form of the equation was used for each orientation of the perimeter as well as the roof zone for all three energy quantities. Its compact form and conveniently segregated terms permit a qualitative as well as quantitative analysis of individual components contributing to each zone's energy use. Tabs. 2 through 5 present the regression coeficients and certain relevant statistical variables which indicate the reliability of the regression. Generally, the $r^2$ (square of the correlation between the predicted value and actual value) values are on the order of 0.97 and above (an $r^2$ of 1.0 represents a perfect correlation), with the exception of the heating energy in the perimeter zones, which is usually below this value. However, when heating approaches the magnitude of cooling (this can be seen by observing the mean value of the data), the $r^2$ increases correspondingly.

The core zone equation is much simpler than Eq. 1. This is due to the nature of the heat gain/loss components, i.e. there are no solar inputs and only small zone to zone transmission effects. Each load component is a function of the inherent internal heat gains and the external infiltration/ventilation. The regression expression therefore consists of two terms as follows:

$$b_3 A_f L + b_4 A_f \qquad (2)$$

where $b_3$ and $b_4$ are the regression coefficients for interior lighting and remaining internal load and infiltration quantities respectively. Tab. 6 presents the core zone regression coefficients. The difference between the predicted values and actual values (residual) is very small for both the cooling peak and cooling energy ($r^2$=0.99). The heating residuals tend to be large at low energy levels. However, this fact is relatively unimportant because the heating requirements are quite small.

The overhang and daylighting correction factors or modifiers were also obtained through regression techniques. Overhang results were derived using overhang width/window height as the independent variable and are presented on Figs. 2 and 3. One set of curves has been used for the cooling and heating energy for all locations; whereas, for the cooling peak, two curves are presented, one for the northern locations of Madison, Washington D.C. and Seattle and the other for Lake Charles and El Paso. Each set represents the most conservative correction factor, however, there was less than a 8% difference among the actual regression results for each climate. An expression of the following form was used:

$$k_o = 1. - b_5R - b_6R^2 \qquad (3)$$

where

$b's$ = regression coefficients
$k_o$ = correction factor to solar term due to overhangs
$R$ = overhang width/window height ratio

The curves indicate that an asymptote is approached at a ratio value of R=0.6 for all climates and orientations of south, east and west. The amount of solar radiation reduced is on the order of 50% for heating and cooling. For north facing overhangs and fenestration, the correction factor is monotonically decreasing in all cases with a typical reduction of 25% solar occurring at R=0.6.

Fig. 4 presents the daylighting correction to the lighting wattage heat gain as a function of effective aperture. The effective aperture for windows is defined as the product of window/wall ratio, visible transmittance and overhang correction factor. For skylights, it is the product of skylight/roof ratio, visible transmittance and well factor. The following expression was derived:

$$k_d = 1. - b_7E_a - b_8E_a{}^2 \qquad (4)$$

where

$b's$ = regression coefficients
$k_d$ = correction factor to the lighting wattage due to daylighting
$E_a$ = effective aperture

This correction factor can be used for the lighting contribution of all three energy quantities analyzed. Since the regression for each climate differed less than 12% between locations, one set of curves has been presented. For all perimeter zone orientations, an asymptote is approached which yields a 65% reduction in lighting at an effective aperture of 0.20. Later in the discussion, one will observe that this figure can result in cooling energy savings for perimeter zones on the order of 15% depending on the configuration being studied. Heating energy increases due to reduced electric lighting also approach or exceed this value. The base heating required for all locations is much smaller than the corresponding cooling required. The skylight reduces electric lighting from 65% in Seattle to 84% in El Paso. This variation is different than that observed for the vertical windows due to the lack of shading management in the skylight model. The trend reflects the influence of sky cover latitude.

## RESULTS AND DISCUSSION

The regression coefficients presented in Tabs.2 through 6 can be used in conjunction with eqs. 1 and 2 in examining the effects of various configuration parameters on energy use. The values give some indication of the importance in each energy usage quantity. For example, the solar radiation heat gain dominates the cooling peak and cooling energy values, followed by infiltration/ventilation, internal heat gains, and envelope conductance. Heating energy, however, is somewhat more complicated because of the presence of negative as well as positive influences. Generally, the solar and internal gains are offset by a portion of the conductance and infiltration/ventilations losses. However, there is a net loss resulting from the fact that most of the conductance and infiltration effects occur during the hours when there are no solar or internal gains. The above statement, of course, could change if the areas (wall, glazing, floor) differ significantly. This is easily seen by observing the relative size of the peimeter and rooftop zone solar radiation coefficients. The rooftop values are much larger; however, the effective apertures are generally much smaller than the perimeter zone values, which yields a lower net solar component for the rooftop zones.

Quantitatively, the conductance contribution to the cooling peak and cooling energy is not as consistent as the other coefficients. In the case of cooling peak, this is due to the variation in the particular hour's cooling peak calculation for each configuration. Small component contributions to the cooling peak, especially for those that are temperature-dependent, will tend to appear somewhat random. For the cooling energy coefficients, the conductance contribution is very small, with the possibility of both positive and negative coefficient values. Such a situation is indicative of actual occurences. For some northerly locations, a conductance loss occurs during some of the hours associated with cooling.

Coefficient values for the conductance portion of the heating energy are more easily examined. North orientations for all configurations and locations yield larger coefficients and thus higher energy use levels, as expected. East and west orientation quantities are approximately the same at intermediate values between north and south. It appears that an eventual climatic temperature-dependence might be extracted from the heating energy results. However, it is uncertain at present what form the cooling-related coefficient dependence will have. The rooftop zone values tend to vary in a manner similar to the north perimeter zone values.

The regression coefficients of the perimeter zone solar radiation terms for determining cooling peak are more consistent by orientation than by geographic location. First appearances indicate no substantial variation between geographic locations. However, upon closer examination, anomalies exist in both Lake Charles LA and Seattle WA. Generally, the magnitude variation follows a north, east, south and west pattern from low to high. This variation seems unrelated to the observed weather data for maximum incident solar radiation. Thus, there may be some difficulty in correlating the coefficients to specific solar variables. An additional complication with respect to the solar term involves the use of window shading management. In the methodology section of this paper, it was noted that interior shading was implemented at a transmitted direct solar radiation value exceeding 60 W/m$^2$. There is no method of indicating in the regression model if management was employed during the particular hour that the cooling peak was defined. Thus, some irregularities are to be expected between configurations. This fact also complicates the correlation of the perimeter and rooftop zones because management was not used for the skylights. Generally, the cooling peak rooftop zone solar values are about two to three times the south perimeter zone values. Seattle's coefficient, however, is more than three times as large.

The solar portion of the perimeter zone cooling energy follows a similar north, east, south, and west variation with increasing magnitude. However, there also seems to be a definite climatic variation with latitude, i.e. increasing coefficients with decreasing latitude. Seattle stands out possibly because of a larger amount of cloud cover. Heating energy solar coefficients follow a similar pattern (increasing coefficient implies less negative). The rooftop zone solar coefficients for cooling and heating energy are all larger than any of the corresponding perimeter zone values, but follow the same climatic variation.

The small incremental changes in the electric lighting coefficients for all configuartions and locations for each perimeter zone orientation indicate that a valid approximation would be to lump all four orientations into one coefficient as is the case with the other internal loads and infiltration/ventilation term ($b_4$). For cooling peak, the variation among orientations almost equals the variation among climates. The cooling and heating energy coefficients, however, vary in a manner similar to the solar term, i.e. proportional to a latitude or temperature difference. This latter statement is also true of the $b_4$ coefficients. A discernable trend is not apparent with the cooling peak values.

Core zone coefficients follow a pattern similar to the $b_3$ and $b_4$ terms of the other zones. The only difference occurs with the heating energy values because there is little or no heating required (see Tab. 6). It is interesting to note that the cooling energy coefficients for the perimeter, rooftop, and core zones are of about the same magnitude. This is related to the fact that cooling for these zones is occuring at the same instant for similar space temperatures; whereas heating requirements for the zones does not necessarily occur simultaneously, i.e. the perimeter zones will experience more heating during the late afternoon hours than the core zone.

The usefullness of the regression expressions can be ascertained by calculating thermal load values for a specific example. Figs. 5, 6 and 7 present component breakdowns per square meter of floor area (conductance, solar, lighting, other) for the cooling peak and the cooling and heating energies in Madison WI. All perimeter zones were assummed to be 4.57m in depth and the exterior wall 3.65m in height. Rooftop zone floor to ceiling height was 3.51m. Parameter values used in the example were:

| Perimeter | Rooftop |
|---|---|
| $U_o$ = 1.2 $W/m^{2o}C$ | $U_o$ = .28 $W/m^{2o}C$ |
| WWR = 0.4 | WWR = 0.05 |
| SC = 0.8 | SC = 0.06 |
| VIS = 0.48 | VIS = 0.86 |
| $E_a$ = 0.192 | $E_a$ = 0.03 |
| L = 18.0 $W/m^2$ | L = 18.0 $W/m^2$ |
| $k_d$ = 1.0 | $k_d$ = 1.0 |
| $k_o$ = 1.0 | |

Regardless of the perimeter and rooftop zone floor size (length), the percent contribution of the heat gain/loss components to each zone's respective energy is the same. This fact results from defining the problem through overall U-value, glazing size, and shading coefficient in conjunction with the fixed values of perimeter depth and wall and ceiling height. A linear variation of energy with floor area exists for each zone. This can be seen by rewriting eq.1 using the relationships between floor area, exterior wall, and glass area as follows:

Perimeter

$$E/A_f = .799\ b_1U_o + .799\ b_2k_oSC\ WWR + b_3k_dL + b_4 \qquad (5)$$

Rooftop

$$E/A_f = b_1U_o + b_2SC\ WWR + b_3k_dL + b_4$$

After substituting the configuration variables, a further reduction is obtained:

Perimeter

$$E/A_f = .959\ b_1 + .256\ b_2k_o + 18.0\ b_3 + b_4 \qquad (6)$$

Rooftop

$$E/A_f = .280\ b_1 + .030\ b_2 + 18.0\ b_3 + b_4$$

The core zone results, at a fixed lighting wattage, reduce to a similar form:

$$E/A_f = 18.0\ b_5 + b_6 \qquad (7)$$

Figs. 5 to 7 represent plots of these equations in addition to showing incremental effects to the total load due to overhangs (R=.4) and daylighting using a $k_d$=.35 at an effective aperture of .192 for windows and a $k_d$=.27 at an effective aperture of .03 for skylights.

After definiting these base curves, one can begin studying the effect of changes in configuration variables. For example, it is immediately apparent that perimeter zone conductance has little effect on cooling peak and almost no effect on cooling energy. This fact was stated previously in the discussion of the complete set of regression coefficients, and is quite obvious from this example. For heating, however, the overall U-value is the primary contributor to the eventual heating load. Decreasing the U-value by half would reduce heating requirements approximately by half also.

Perimeter zone solar radiation influences cooling and heating significantly. For cooling peak (Fig.5), the solar is approximately 37% for north and 50% for south, east, and west; whereas about 56% to 67% of the cooling energy is determined by the solar component. The effective aperture used in the example was quite high (VIS WWR = 0.192), thus some reduction of this parameter seems feasible, expecially in decreasing the visible transmittance value. For an VIS=0.24, the solar contribution is reduced by 50% , which translates into a maximum 25% to 34% reduction in cooling peak and cooling energy, respectively.

Other major reductions in cooling are obtained by considerating daylighting and overhangs. Although the correction factor for daylighting is used in the electric lighting term, its magnitude is a function of effective aperture (see Fig.4). Daylighting, in this example, decreases total cooling energy from 15% for south, east, and west perimeter zones to 20% for north. Use of the R=0.4 overhangs gives an additional reduction of 30% for south and 8% for north. Cooling peak changes are about half the above except for the south zone, where total savings are 37%.

These design features, while beneficial for cooling, tend to increase the required heating energy. The solar term itself varies from approximately 28% of the conductance load for a north orientation to 67% for south. Although the percent increase in heating is large when using daylighting and overhangs (about 50% for a south orientation), the increase is half the cooling energy reduction.

Effects of electric lighting on the cooling peak in the perimeter zones are similar to those of conductance, i.e. small. It accounts for about 18% of the total for the north zone and 12% for the south zone. Contributions to the cooling energy vary from 31% for north to 22% for the other orientations. This represents about one half to one third of the solar component. In the case of heating energy, the lighting term is about the same as the solar term for the north zone. For the other zones, this figure drops to half. The implication here is that lighting influences heating energy but not as strongly as cooling energy. Daylighting, as discussed previously, is responsible for a maximum 65% decrease in lighting requirements.

The other internal loads and infiltration/ventilation loads exert a major effect on all energy levels. Occupant and equipment heat gain can be approximated by using the lighting wattage regression coefficient. Schedules for each are about the same and thus the lighting coefficients which represent the change in energy due to change in lighting can be used for the other heat gains. For example, eq. 1 can be rewritten as:

$$b_1 U_o A_T + b_2 k_o A_g SC + b_3 (k_d L + O + E) A_f + b_4' A_f \qquad (8)$$

where O and E are the occupant and equipment heat gain respectively. The $b_4'$ coefficient that contains the infiltration/ventilation effect can be calculated using the input values for O and E above, i.e. $O=7.26 W/m^2$ and $E=5.38 W/m^2$, therefore:

$$b_4' = b_4 - 12.64 b_3 \qquad (9)$$

From this expression, it can be seen that the occupant and equipment heat gain is about 66% of the lighting input ($18.0W/m^2$).

Core zone results for cooling are very similar to the perimeter zone data, as stated previously in the discussion on the regression coefficients. Heating energy per square meter for the core is about half that required for the perimeter for internal gains and infiltration/ventilation.

The rooftop zone data follow expected patterns when compared with perimeter zone results for the example described previously. For all energy quantities, both the conductance and solar radiation contributions per square meter of floor area are much lower (about 60%) than the corresponding perimeter zone values. This fact reflects the use of a lower surface U-value (0.28) and reduced skylight size (0.05). Internal load and infiltration/ventilation cooling peak and cooling energy levels are about the same as for the perimeter and core zones. However, these quantities account for more than 60% of the total. Because of this large percentage, daylighting reduces the cooling peak 18% and cooling energy 28%.

## CONCLUSIONS

This paper has described the derivation and use of simple algebraic expressions which can be used in analyzing various aspects of commercial building energy performance. Building modules representative of perimeter, core and rooftop zones were defined and numerous DOE-2.1B energy analysis simulations were performed which generated a data base which was subsequently used in conjunction with multiple regression procedures to predict various energy usage quantities. The final equations included effects arising from building conductance, solar radiation, internal heat gains and infiltration/ventilation as well as correction factors due to overhangs and daylighting. An example was provided to illustrate the usefulness of the developed expressions in isolating those configuration variables of importance in determining heating and cooling energy requirements.

Although the work described is complete in itself with the resulting regression equations being useful, the following additional work is currently in progress which will extend the usefulness of the results:

1. Location: Additional geographic locations and/or climates will enable a configuration/climate interface in the solved for regression coefficients. It is envisioned that each derived coefficients will be a function of various weather variables and configuration parameters.

2. Usage Patterns: The study presented results for a typical commercial office building occupancy pattern, i.e. 10 hours/day, 5 days/week. Other usage patterns representative of more extended occupancy and varying internal loads will insure a more complete spectrum for the analysis.

3. HVAC System Types: This proposed variation may be the most important. Two alternatives to the single zone constant volume system simulated are being analyzed: use of a variable volume system serving the four perimeter zones with a constant volume system for the core or using a variable volume system for all five zones. A major difficulty with these approaches is the modularization of the model so that a generalized scheme can be developed as presented in this report.

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TABLE 1 - PARAMETRIC STUDY VARIATIONS

| Location | Perimeter Zone Wall U-value | Rooftop Zone Roof U-value |
|---|---|---|
| Madison WI | .727, .966, 1.091 | .233, .312, .471 |
| Washington D.C. | .937, 1.250, 1.409 | .386, .511, .762 |
| Seattle WA | .875, 1.079, 1.312 | .375, .500, .750 |
| Lake Charles LA | 1.153, 1.534, 2.300 | .426, .568, .852 |
| El Paso TX | 1.022, 1.363, 2.045 | .420, .557, .835 |

Glazing Properties

Perimeter (SC WWR): .0, .1, .2, .3, .4
Rooftop (VIS WWR WF): .0, .005, .01, .02, .03, .04

Electric Lighting ($W/m^2$): 7.34, 18.30, 29.06

Daylighting: None, Continuous

Overhang Width/Window Height: 0.0, 0.21, 0.42, 0.85

Notes:
1. U-value given in $W/m^2 {}^oC$
2. SC = shading coefficient
3. WWR = window/wall ratio
4. VIS = visible transmittance (for vertical windows, value is 2/3 of the SC value)
5. WF = skylight well factor
6. Number of DOE 2.1B runs:
   Perim/Core: 1125 runs, 5625 zones
   Rooftop: 1320 runs, 1320 zones

TABLE 2 - REGRESSION COEFFICIENTS: PERIMETER ZONE COOLING PEAK
Units: KJ/hr

| | | Madison | Wash D.C. | Seattle | LakeChas | El Paso |
|---|---|---|---|---|---|---|
| $U_oA_T$ | N | 24.400 | 43.050 | 4.524 | 43.974 | 49.485 |
| | S | 45.267 | 68.764 | 38.633 | 80.270 | 97.283 |
| | E | 54.341 | 68.946 | 77.739 | 102.773 | 121.307 |
| | W | 46.911 | 85.327 | 73.699 | 84.694 | 137.377 |
| $k_oA_gSC$ | N | 469.435 | 477.998 | 439.012 | 512.919 | 466.017 |
| | S | 983.678 | 930.544 | 979.189 | 799.883 | 947.954 |
| | E | 933.188 | 830.544 | 925.189 | 796.953 | 999.731 |
| | W | 1022.012 | 927.792 | 1062.418 | 869.173 | 1059.938 |
| $k_dA_fL$ | N | 3.348 | 2.884 | 3.480 | 2.667 | 2.881 |
| | S | 3.254 | 2.690 | 3.161 | 2.602 | 2.270 |
| | E | 3.104 | 2.619 | 2.764 | 2.261 | 2.547 |
| | W | 3.165 | 2.486 | 2.651 | 2.545 | 2.447 |
| $A_f$ | | 122.814 | 131.177 | 77.450 | 155.570 | 109.282 |
| Mean | | 47.458 | 50.794 | 41.858 | 57.009 | 55.278 |
| $r^2$ | | 0.981 | 0.973 | 0.979 | 0.970 | 0.959 |
| Std Dev | | 2.149 | 2.422 | 2.396 | 2.540 | 3.722 |

TABLE 3 - REGRESSION COEFFICIENTS: PERIMETER ZONE COOLING ENERGY
Units: MJ

| | | Madison | Wash D.C. | Seattle | LakeChas | El Paso |
|---|---|---|---|---|---|---|
| $U_oA_T$ | N | -17.991 | -2.405 | -16.932 | 5.223 | 12.606 |
| | S | -11.652 | 14.471 | -6.345 | 32.752 | 50.243 |
| | E | -13.275 | 9.627 | -9.479 | 40.266 | 60.828 |
| | W | -16.326 | 8.310 | -9.719 | 27.998 | 56.134 |
| $k_oA_gSC$ | N | 472.036 | 655.134 | 290.131 | 1020.693 | 879.466 |
| | S | 819.732 | 1062.859 | 565.328 | 1535.849 | 1527.877 |
| | E | 802.970 | 1024.111 | 492.739 | 1508.637 | 1630.821 |
| | W | 833.541 | 1068.605 | 574.084 | 1476.637 | 1684.821 |
| $k_dA_fL$ | N | 3.669 | 4.949 | 2.380 | 7.726 | 6.629 |
| | S | 3.863 | 5.088 | 2.473 | 7.907 | 6.765 |
| | E | 3.780 | 5.046 | 2.410 | 7.734 | 6.736 |
| | W | 3.772 | 5.104 | 2.418 | 7.865 | 6.809 |
| $A_f$ | | 44.653 | 64.390 | 17.886 | 118.196 | 70.750 |
| Mean | | 28.486 | 42.259 | 17.083 | 69.190 | 63.139 |
| $r^2$ | | 0.986 | 0.988 | 0.986 | 0.990 | 0.984 |
| Std Dev | | 1.595 | 1.931 | 1.073 | 2.531 | 3.386 |

TABLE 4 - REGRESSION COEFFICIENTS: PERIMETER ZONE HEATING ENERGY
Units: MJ

| | | Madison | Wash D.C. | Seattle | LakeChas | El Paso |
|---|---|---|---|---|---|---|
| $U_oA_T$ | N | 200.840 | 101.733 | 114.359 | 29.789 | 49.733 |
| | S | 151.950 | 70.551 | 86.591 | 18.655 | 24.880 |
| | E | 176.014 | 85.013 | 90.853 | 20.068 | 28.206 |
| | W | 182.429 | 86.879 | 96.428 | 23.608 | 32.450 |
| $k_oA_gSC$ | N | -216.224 | -162.543 | -141.988 | -65.935 | -92.690 |
| | S | -383.071 | -240.106 | -219.154 | -77.779 | -112.291 |
| | E | -331.559 | -218.859 | -194.829 | -70.023 | -100.935 |
| | W | -343.857 | -224.083 | -211.750 | -75.678 | -109.588 |
| $k_dA_fL$ | N | -3.420 | -2.334 | -2.681 | -0.809 | -1.137 |
| | S | -2.499 | -1.610 | -1.923 | -0.531 | -0.602 |
| | E | -2.890 | -1.910 | -2.088 | -0.555 | -0.661 |
| | W | -2.910 | -1.929 | -2.147 | -0.640 | -0.748 |
| $A_f$ | | 130.268 | 71.340 | 62.312 | 19.351 | 25.177 |
| Mean | | 24.218 | 13.162 | 11.261 | 3.689 | 4.719 |
| $r^2$ | | 0.975 | 0.963 | 0.944 | 0.955 | 0.958 |
| Std Dev | | 1.495 | 1.149 | 1.411 | 0.421 | 0.585 |

TABLE 5 - REGRESSION COEFFICIENTS: ROOFTOP ZONE

| | Madison | Wash D.C. | Seattle | LakeChas | El Paso |
|---|---|---|---|---|---|
| **Cooling Peak (KJ/hr)** | | | | | |
| $U_oA_T$ | 55.140 | 102.791 | 52.566 | 122.968 | 169.875 |
| $k_oA_gSC$ | 2586.681 | 2384.744 | 2834.873 | 2364.961 | 2980.597 |
| $k_dA_fL$ | 3.408 | 3.269 | 3.334 | 3.222 | 3.181 |
| $A_f$ | 92.985 | 93.973 | 56.191 | 93.883 | 61.676 |
| Mean | 203.630 | 234.631 | 181.420 | 250.752 | 274.713 |
| $r^2$ | 0.999 | 0.998 | 0.997 | 0.997 | 0.998 |
| Std Dev | 1.415 | 2.036 | 2.498 | 2.620 | 0.844 |
| **Cooling Energy (MJ)** | | | | | |
| $U_oA_T$ | -9.251 | 13.921 | -0.388 | 30.787 | 71.712 |
| $k_oA_gSC$ | 1921.611 | 2440.344 | 1327.336 | 3570.341 | 4773.166 |
| $k_dA_fL$ | 3.332 | 4.467 | 2.076 | 7.116 | 6.189 |
| $A_f$ | 43.517 | 67.740 | 20.703 | 119.275 | 62.834 |
| Mean | 125.410 | 185.708 | 75.915 | 307.428 | 312.751 |
| $r^2$ | 0.999 | 0.999 | 0.999 | 0.999 | 0.998 |
| Std Dev | 1.301 | 1.578 | 0.884 | 2.097 | 3.034 |
| **Heating Energy (MJ)** | | | | | |
| $U_oA_t$ | 199.829 | 101.625 | 118.719 | 34.371 | 46.623 |
| $k_oA_gSC$ | -473.456 | -392.587 | -323.802 | -193.080 | -383.457 |
| $k_dA_fL$ | -1.598 | -1.178 | -1.340 | -0.437 | -0.585 |
| $A_f$ | 93.019 | 50.183 | 38.464 | 14.161 | 22.145 |
| Mean | 114.040 | 72.596 | 67.422 | 22.253 | 28.054 |
| $r^2$ | 0.982 | 0.977 | 0.966 | 0.981 | 0.974 |
| Std Dev | 3.265 | 2.977 | 4.030 | 1.043 | 1.628 |

TABLE 6 - REGRESSION COEFFICIENTS: CORE ZONE

| | Madison | Wash D.C. | Seattle | LakeChas | El Paso |
|---|---|---|---|---|---|
| **Cooling Peak (KJ/hr)** | | | | | |
| $W/m^2A_f$ | 3.749 | 3.732 | 3.734 | 3.805 | 3.770 |
| $A_f$ | 97.948 | 103.501 | 64.722 | 122.864 | 95.416 |
| Mean | 154.728 | 159.594 | 123.831 | 178.825 | 152.731 |
| $r^2$ | 0.995 | 0.998 | 0.998 | 0.991 | 0.993 |
| Std Dev | 2.211 | 1.329 | 1.549 | 3.049 | 2.558 |
| **Cooling Energy (MJ)** | | | | | |
| $W/m^2A_f$ | 3.562 | 4.771 | 2.265 | 7.453 | 6.024 |
| $A_f$ | 46.004 | 74.168 | 21.361 | 127.997 | 100.571 |
| Mean | 103.294 | 149.996 | 58.345 | 245.608 | 195.835 |
| $r^2$ | 0.987 | 0.992 | 0.989 | 0.994 | 0.993 |
| Std Dev | 3.300 | 2.400 | 3.400 | 1.900 | 2.100 |
| **Heating Energy (MJ)** | | | | | |
| $W/m^2A_f$ | -1.166 | -0.556 | -0.532 | -0.135 | -0.149 |
| $A_f$ | 69.603 | 29.061 | 21.611 | 5.344 | 7.120 |
| Mean | 44.842 | 17.551 | 11.030 | 2.665 | 4.098 |
| $r^2$ | 0.931 | 0.924 | 0.910 | 0.864 | 0.826 |
| Std Dev | 2.659 | 1.337 | 1.402 | 0.447 | 0.568 |

# FIGURE 1 — BUILDING MODULE DESCRIPTION

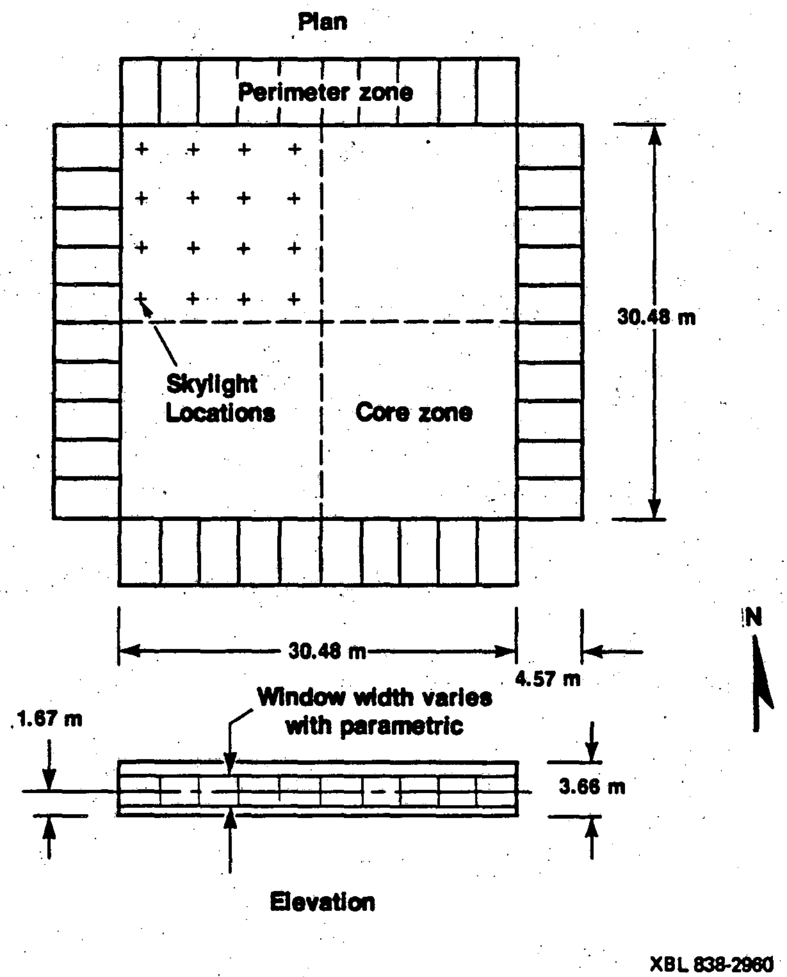


FIGURE 2 – COOLING PEAK SOLAR LOAD CORRECTION FACTOR DUE TO OVERHANGS

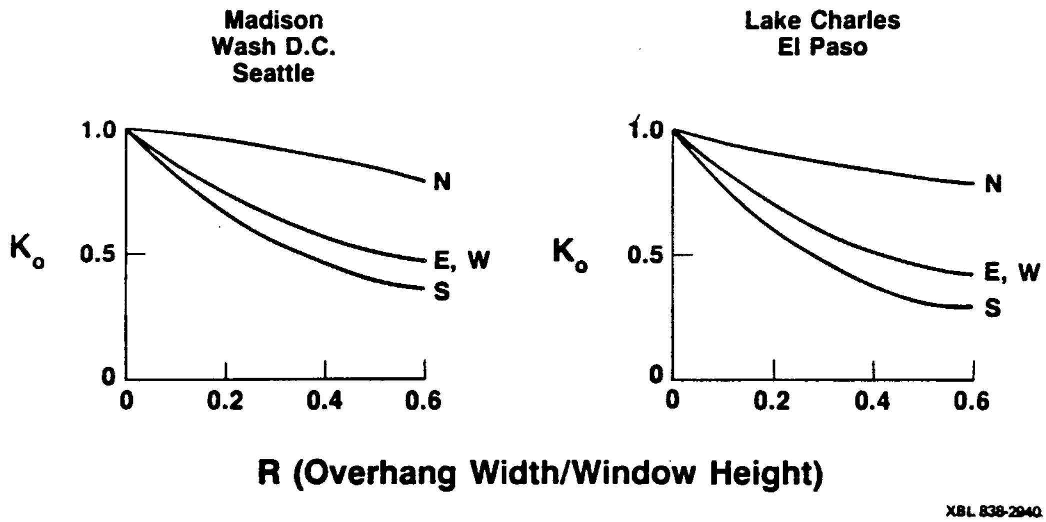



FIGURE 3 – COOLING AND HEATING ENERGY SOLAR LOAD CORRECTION FACTORS DUE TO OVERHANGS
All Locations

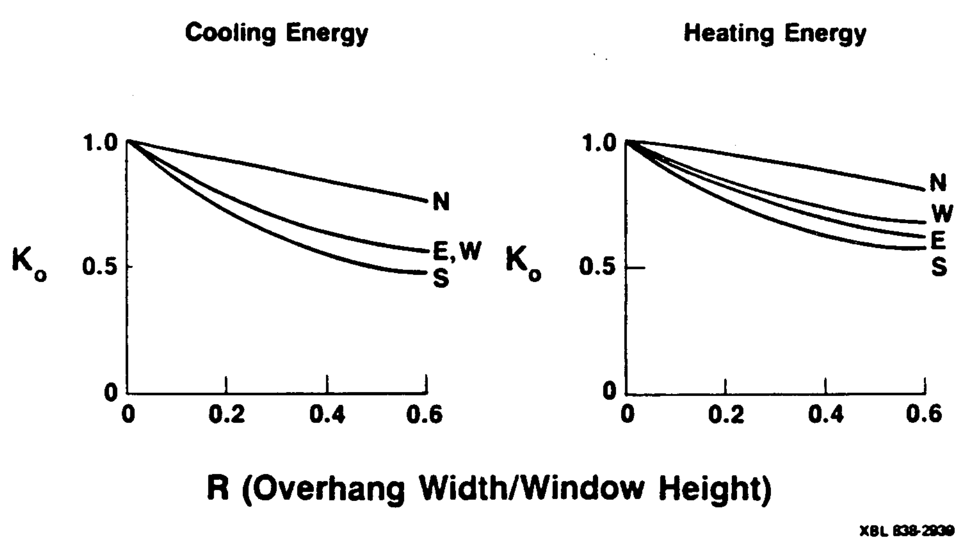


FIGURE 4 — LIGHTING LOAD CORRECTION FACTOR DUE TO DAYLIGHTING

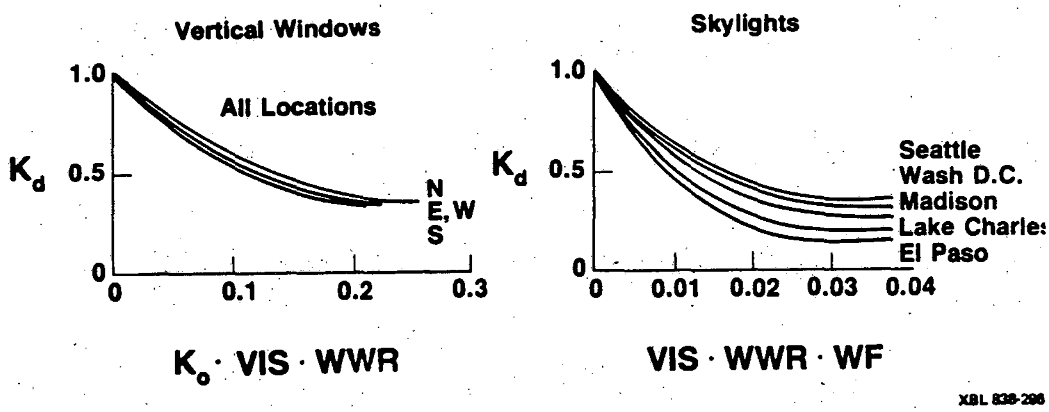
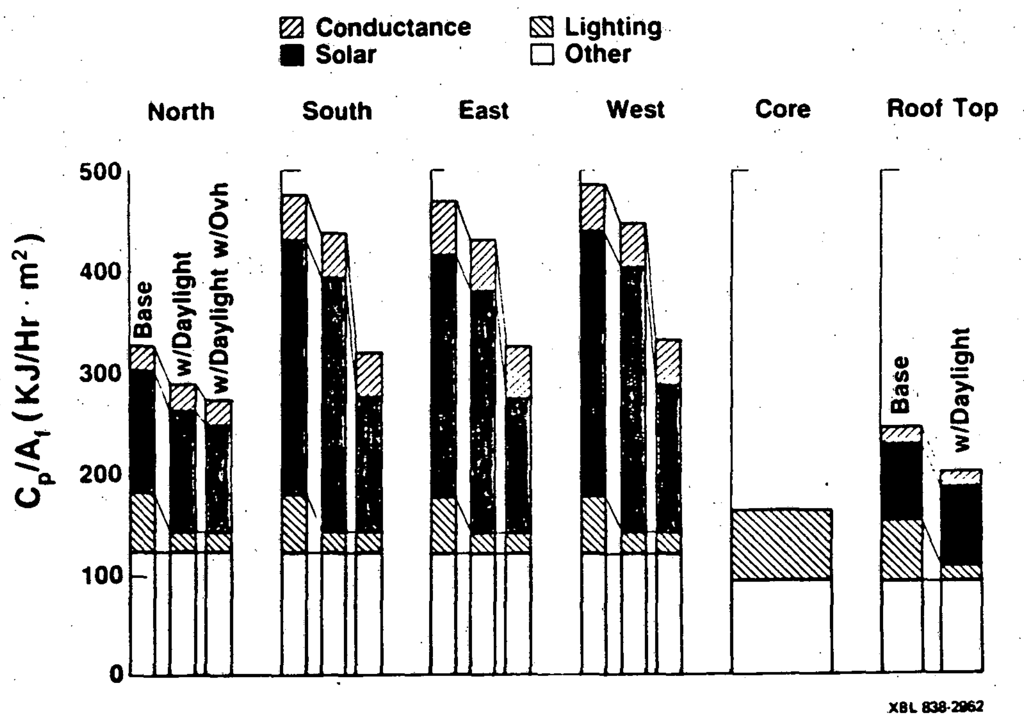



FIGURE 5 — COOLING PEAK/FLOOR AREA
Madison



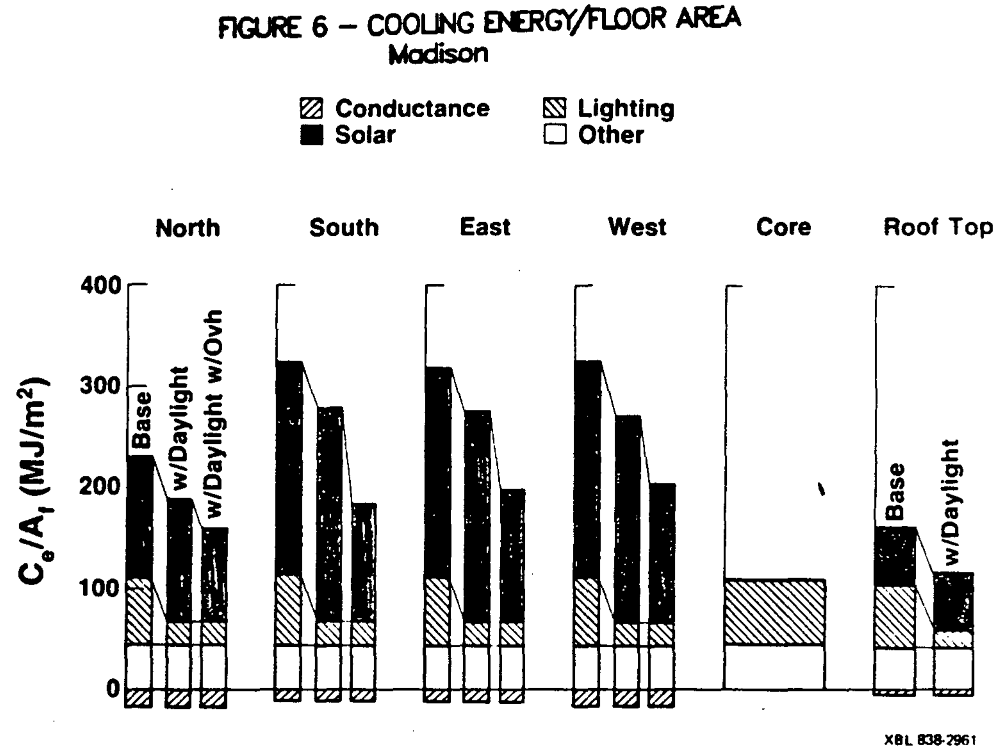


FIGURE 6 – COOLING ENERGY/FLOOR AREA
Madison
Conductance
Solar
Lighting
Other
North
South
East
West
Core
Roof Top
400
300
200
100
0
$C_e/A_f$ (MJ/m²)
Base
w/Daylight
w/Daylight w/Ovh
XBL 838-2961

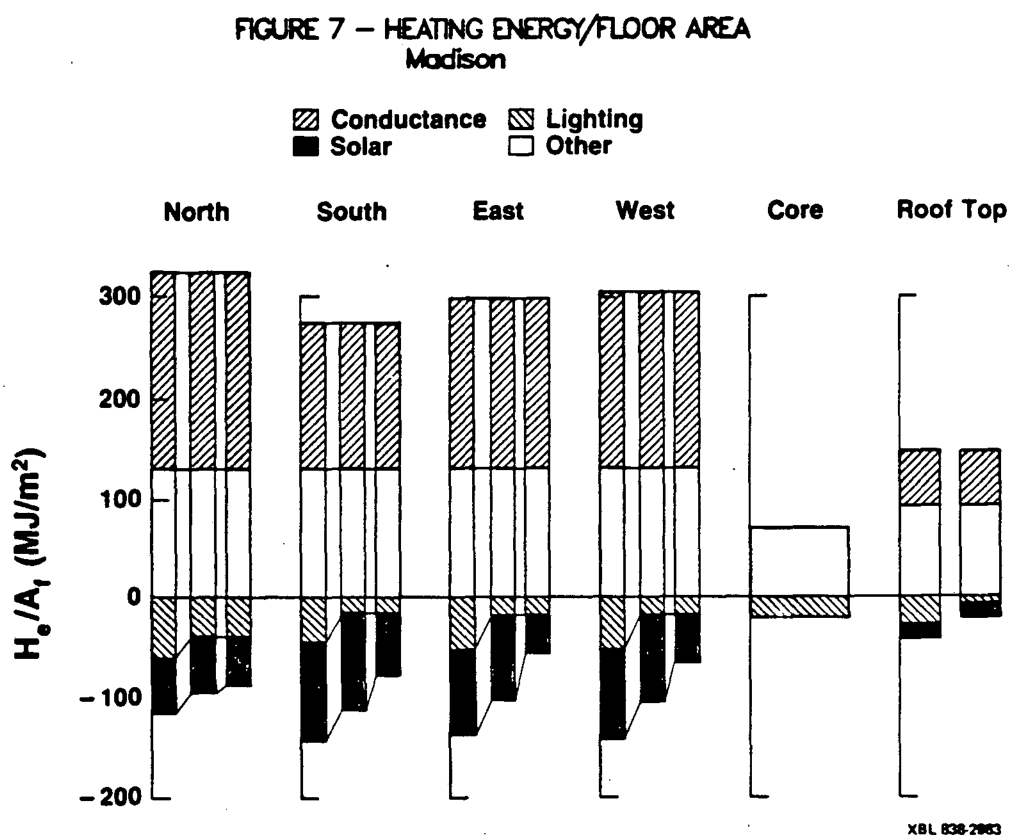


FIGURE 7 – HEATING ENERGY/FLOOR AREA
Madison
Conductance
Solar
Lighting
Other
North
South
East
West
Core
Roof Top
300
200
100
0
-100
-200
$H_e/A_f$ (MJ/m²)
XBL 838-2963

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