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GLAZING OPTIMIZATION STUDY FOR ENERGY EFFICIENCY IN COMMERCIAL OFFICE BUILDINGS

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Glazing Optimization for Energy Efficiency in Commercial Office Buildings

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ABSTRACT

A principal component of annual energy consumption in a building is attributable to energy transfers in the fenestration system. Annual energy requirements are not only a function of glazing properties, but also of other building design characteristics, operating characteristics, site conditions, and climate. This paper describes results of a study in which annual energy consumption with and without daylighting utilization in a office building module was modeled parametrically for a wide range of glazing properties in three different climates. We present results which suggest optimal combinations of glazing properties which frequently result in lower energy consumption than opaque insulated walls.

RESUME

Une des principales causes de la consommation annuelle en énergie d'un batiment est imputable aux transferts énergètiques au niveau des fenêtres. Les besoins annuels en énergie ne sont pas seulement fonction des propriètes du vitrage mais aussi d'autres caractéristiques de la nature même du batiment et des conditions locales et climatiques. Ce papier décrit les résultats d'une étude dans laquelle la consommation en énergie, avec ou sans utilisation de la lumière du jour, annuelle d'un immeuble de bureaux a éte modélisée paramètriquement, pour une gamme étendue de propriétés de vitrage, pour trois climats différents. Nous présentons les résultats qui montrent les combinaisons optimales des propriétés de vitrage et qui trés souvent conduisent á une consommation en énergie moindre que l'isolation de murs opaques.

BACKGROUND AND OBJECTIVE

The energy performance of building fenestration systems results from a complex interrelationship among glazing properties, window management, orientation, building interactions, and climatic characteristics. The interaction of these factors is sufficiently complicated that it is difficult to identify fenestration design strategies that optimize annual energy performance.

A primary objective of this study is to develop results that can be readily generalized and applied in order to optimize glazing in a wide variety of design considerations. The performance of several specific fenestration systems has been previously studied[1-6] in the context of specific building designs. These studies generally compare a limited number of commercial products and conditions. In some studies, only the architectural loads are calculated rather than actual plant energy requirements. While the comparisons provide useful information, the results frequently are not easily generalized to other design conditions and may not provide a good indicator of annual energy consumption.

In this study, rather than comparing performance of specific products, the generic properties of glazing materials are varied so that any fenestration system whose properties lie within the parametric limits can be evaluated. Values for overall thermal conductance (U), shading coefficient (SC), and visible transmittance (T_v) are parametrically varied through representative ranges. Annual energy use in a prototypical module of an office building is calculated as a function of glazing material properties, glazing area, orientation, and climate.

BUILDING MODULE

A module configuration representative of commercial office building construction was evolved through a series of sensitivity studies as the basis for a building block approach for calculations. The building module is square in plan and 60.96 meters on a side. It contains four identical perimeter zones each 9.14 meters deep, surrounding a core zone. Ceiling height is three meters. The module can be considered as a single floor in a multistory building. No net heat transfer occurs through the floor or ceiling, or between perimeter zones. Outside air is supplied at $8.5 m^3/hr$ per person with an occupancy based upon $9.3 m^2$/person.

Glazing is flush with the exterior surface and no exterior shading elements or obstructions exist. The windows are furnished with drapes having a shading coefficient multiplier of 0.6. There is an eighty percent probability that the drapes are closed when direct solar transmission exceeds 63 $watts/m^2$.

A ceiling mounted fluorescent lighting system provides 538 lux and requires 21.5 $watts/m^2$. The electric lighting in the outer 4.57 meters of each perimeter zone can be reduced in response to daylight. The lighting controls are assumed to dim linearly to 30% power, thus providing a maximum saving of 70% of the electric lighting.

Annual energy consumption was modeled with a development version of DOE-2.1, which was modified to improve the analysis of fenestration performance. A simplified daylighting algorithm[7] was added and annual energy performance was calculated both with and without the utilization of daylighting in the perimeter zones.

GLAZING PARAMETERS

For this study the conductance of single glazing (U = 6.3 $w/m^2 {}^oC$) and triple glazing (U = 1.8 $w/m^2 {}^oC$) were taken as limiting values. Intermediate cases of single glazing with a low emissivity surface and conventional double glazing were also studied.

Shading coefficient of the glass was varied in increments of .2 from 0 to 1.0. A constant value of 0.8 was taken for visible transmittance within a shading coefficient range of 0.4 to 0.8. Results for other visible transmittance values can be estimated as described in a later section. Window-to-wall ratios of 0.9, 0.6, 0.3, .15, and 0.0 were used to provide a full range of glazing areas.

CLIMATE PARAMETERS

Cities were chosen to represent the range of climatic conditions within the contiguous forty-eight states of the United States. We selected Bismarck, North Dakota as a northern, heating dominated climate; New York City with significant heating and cooling requirements; and Miami, Florida characterized by low latitude and a cooling dominated climate.

RESULTS AND DISCUSSION

Over 250 DOE-2.1 annual energy analyses were completed for the three cities studied, providing data on total annual energy consumption and a breakdown of energy use for heating, cooling, fans and lighting. Four general conclusions were drawn.

First, glazing of a perimeter zone office will have a major impact on energy consumption for both heating and cooling. The relationship of energy consumption to glazing is a complex function of glazing size, orientation and climate.

Second, in all climate zones and on all orientations a glazed wall with properly selected glazing can usually provide equivalent or better energy performance than an unglazed wall. Energy efficiency can be achieved while retaining the desirable architectural qualities of windows.

Third, net annual performance can be fully understood only by examining the component loads in detail, and by accounting for the performance of heating and cooling equipment and building operation schedules.

Fourth, no rule of thumb consistently allows for selecting optimal glazing properties. In most cases if a desired energy budget is chosen, several glazing system approaches will be available to the building designer, allowing flexibility in the design of energy efficient solutions without compromising other design requirements.

Heating Dominated Climate

Bismarck, North Dakota is located at latitude 46.8°N in a climate having 5085 Celsius heating degree days (base 18.3 °C). Figures 1a-d show sample results from this analysis. On a north orientation with a large glazed area (Fig. 1a), energy consumption is largely a function of U-value and relatively insensitive to shading coefficient. Examination of the component loads for the U3 case in Figure 1c indicates that there is sufficient solar gain to produce a small downward trend in heating energy use vs. SC and a corresponding upward trend in cooling energy use vs. SC. For the daylit cases the net savings in lighting, fan, and cooling energy use are partially offset by an increase in heating requirements because internal heat gain decreases as electric lighting use diminishes. These trends are repeated for smaller window size. In all cases heating is the largest load.

On the south orientation, the heating and cooling trends described above are accentuated due to the increased solar gain. Comparing component energy use (Fig. 1b and 1d) for a very low SC, results for the south zone are similar to the north, as would be expected. As SC increases, heating energy use falls, steeply at first and then more gradually as the utilizability of the incremental solar gain decreases (Fig. 1d). For larger U-values, additional solar gain can be utilized to offset heating loads; for small U-values less solar gain is useful. As SC increases, cooling energy use and associated fan energy use also increase. As SC increases from 0, total energy use first decreases because heating decreases more rapidly than cooling and fan energy use increases. A minimum is reached at SC = .45. Total energy then rises to a maximum at SC = 1 due to the predominant increase in cooling and fan requirements. In Figure 1b, as one increases U value moving from U3 to U2 to U1, the minimum point shifts to higher S.C.

as more solar gain can offset conductive losses. These trends are repeated for smaller windows (WWR = .6 and .3) although the magnitude of the effects is diminished.

For the large windows considered in Fig. 1a-d, electric lighting savings due to daylighting are large in the outer 4.97 meters of the perimeter zone (approximately 60% of zone lighting energy consumption). The net energy savings include reductions in cooling and fan requirements, and increased heating loads. The size of these thermal impacts changes with SC as can be seen in Figs.1b,d. Note that for the case of large windows shown here (WWR = .9), the daylighting savings are "saturated" since we assume a high visible transmittance, Tv=.80, independent of SC. Potential daylighting savings for any other Tv are thus bounded by the Tv = .80 case and the non-daylit case. A procedure to provide the proper non-linear interpolation between these two extremes is described later.

Cooling Dominated Climate

Heating requirements in Miami, Florida (latitude 25.8°N) are insignificant and fenestration performance is dominated by the influence of shading coefficient. On a south orientation, increasing the shading coefficient from 0 to 1.0 more than doubles the annual energy consumption (Fig. 2b). Even on a north orientation, this same change in SC increases consumption 50%. The consumption differences between U-values are insignificant. Daylight utilization results in larger savings than in the colder climate since in this case savings are the sum of lighting energy savings and reductions in cooling requirements. Small windows (less than 30% glazing) with daylight utilization consistently perform better than insulated walls.

Examination of component energy consumption (Fig. 2c, 2d) reveals that although lighting is the primary end use for S.C. = 0, it is rapidly replaced by cooling as S.C. increases. Energy use for fanpower also rises rapidly with increasing S.C.

The data suggest that for the nondaylit condition the lowest shading coefficient provides the minimum energy consumption. With daylight utilization the optimal solution will be a function of window area and will occur at other than the lowest possible shading coefficient.

Temperate Climate

Glazing performance was calculated for New York City (latitude 40.8°N, 2825

Celsius heating degree days), a location with significant heating and cooling requirements. The performance follows the general trends illustrated in the two climatic extremes with the details determined by orientation, glazing size, and glazing properties.

For the case of windows with high U-values, thermal performance is dominated by heating load and total energy consumption generally falls with increased shading coefficient since the solar gain usefully offsets heating loads. To make significant reductions in total energy consumption, the U-value must be reduced. As the U-value is reduced, the thermal balance point in the perimeter zone shifts, resulting in an increased cooling contribution. In this situation, an increase in shading coefficient adds significantly to the cooling load, particularly on east, south and west orientations. The results presented in Figures 3a-d show an increased total energy consumption at high shading coefficients with an optimum at an intermediate value of SC. Thus with large windows, the primary conservation strategy is to reduce conductance. This in turn requires a reduced shading coeffient to avoid negating the heating load savings by increased cooling loads. However, as window size is reduced the optimum shading coefficient increases. More solar gain per unit glass area can then be utilized in the heating season, and the negative cooling impact is controlled by the smaller window size.

Daylighting

The daylighting calculations were performed using a visible transmittance of 0.8. Using this value as an upper limit for daylighting savings and taking the non-daylit case as a lower limit, it is possible to interpolate to estimate savings for any intermediate transmittance value. Daylighting savings vary with latitude, climate, orientation, hours of occupancy, lighting control system, glazing transmittance, and glazing area. The primary variables of interest in this study are glazing transmittance and area. Although for a given hourly climatic condition, daylight illumination in an interior space is a nearly linear function of glazing area and transmittance, the relationship between annual savings and these glazing parameters is more complex. For example, daylight illuminaton above the desired lighting level produces no additional energy savings. Thus, as window area and/or transmittance increase, savings do not increase proportionally. For a given window area, interpolation between the non-daylit case and the .8 transmittance case is therefore highly non linear.

Table 1 provides sample data for New York from a simplified daylighting model[7] which allows daylight savings to be estimated for any glazing area

Table 1 Annual Percentage of Total Electric Light Demand Required for 9 14 Meters Deep Daylit Spaces New York City

T_v	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Window/Wall Ratio (WWR)										
.1	100	97.9	96.5	94.4	92.3	90.8	89.4	88.0	86.6	85.2
.2	97.9	94.4	90.8	88.0	85.2	83.1	81.7	79.6	78.2	76.8
3	96.5	90.8	86.6	83.1	81.0	78.2	76.1	74.6	73.2	72.5
4	94.4	88.0	83.1	79.6	76.8	74.6	73.2	72.5	71.8	71.1
5	93.0	85.2	81.0	76.8	74.6	72.5	71.8	71.1	70.4	70.1
6	90.8	83.1	78.2	74.6	72.5	71.8	71.1	70.3	69.9	69.7
.7	89.4	81.0	76.1	73.2	71.8	71.1	70.2	69.9	69.6	69.4
.8	88.7	81.0	75.3	72.5	71.1	70.4	70.0	69.7	69.5	69.4
9	88.7	81.0	75.3	72.5	71.1	70.4	70.0	69.7	69.5	69.4
1.0	88.7	81.0	75.3	72.5	71.1	70.4	70.0	69.7	69.5	69.4

and glazing transmittance. The values in the matrix are the percent of total electric lighting energy consumption averaged over all four perimeter zones. The highest value in the table (T_v = .1, WWR = .1) represents 100% electric lighting. The lowest value (T_v = 1.0, WWR = 1.0) represents a 31% reduction in electric lighting energy. The lowest value representative of parameters used in this study corresponds to T_v = .8, WWR = .9, about a 30% reduction. This is close to the theoretical maximum savings (35%) since only the outer half of the primeter zone is daylit and the dimmable lighting control system never reduces lighting energy by more than 70%. Note that for a given shading coefficient the full range of visible transmittance may not be realizable.

These results with daylighting utilization are predicated on an electric lighting load of 21.5 w/m^2, which is representative of current energy efficient lighting design practice. If daylighting is utilized to offset the higher electrical lighting loads (30-50 w/m^2) found in many existing building it would provide far more dramatic benefits.

FUTURE RESEARCH

In future papers we will report the results of additional analysis of this data set to examine daily and monthly performance patterns, load management and peak load issues, cost benefit analysis, methods by which the zone energy consumption figures can be combined to predict overall building performance and results for a broader range of climates. This work will be expanded to include the performance of additional fenestration systems including a variety of fixed and operable sun control and insulating window systems. We also expect to experimentally validate these glazing performance predictions using a newly developed outdoor window thermal test facility.[8]

A longer version of this paper with appendices containing more extensive performance results is available from the authors as an LBL Report.

ACKNOWLEDGEMENT

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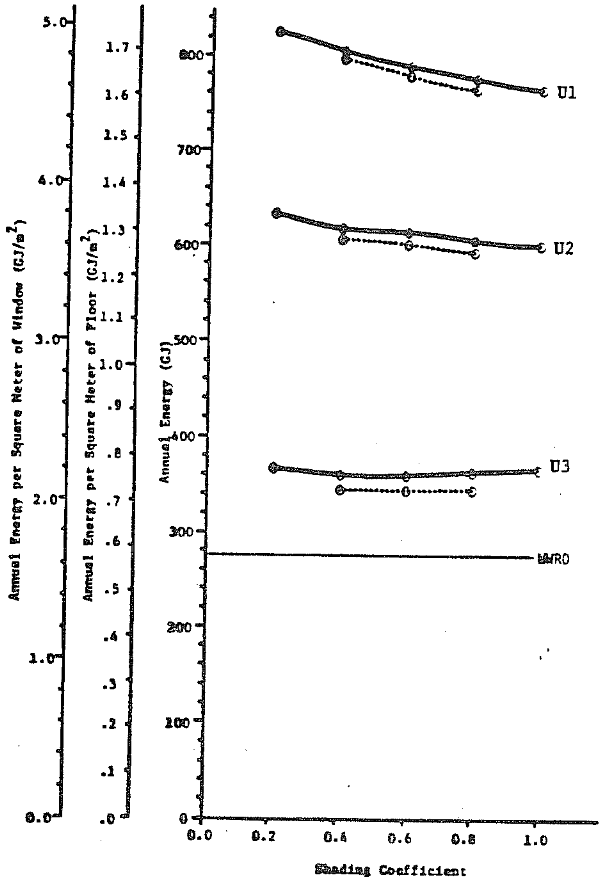

Fig. 1a. Bismarck North Zone WWR = 0.9

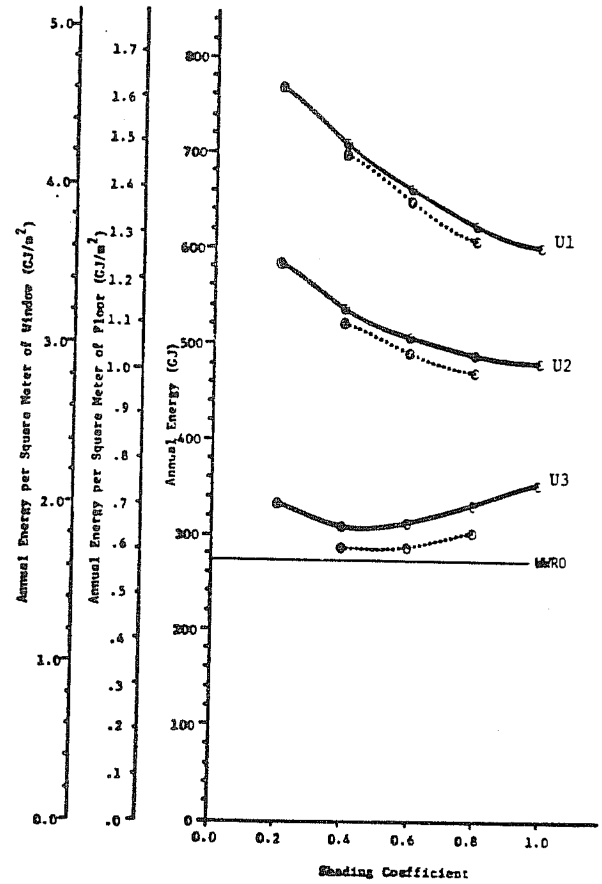

Fig. 1b. Bismarck South Zone WWR = 0.9

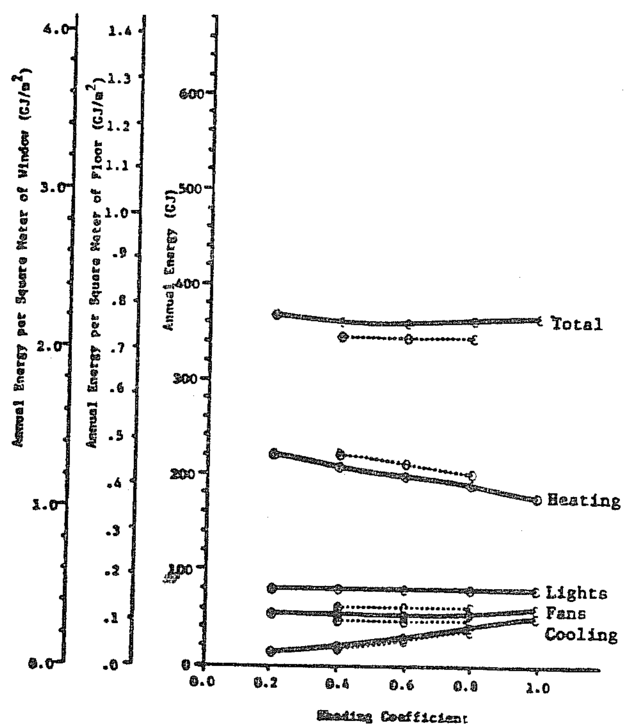

Fig. 1c. Bismarck North Zone U3 WWR = 0.9

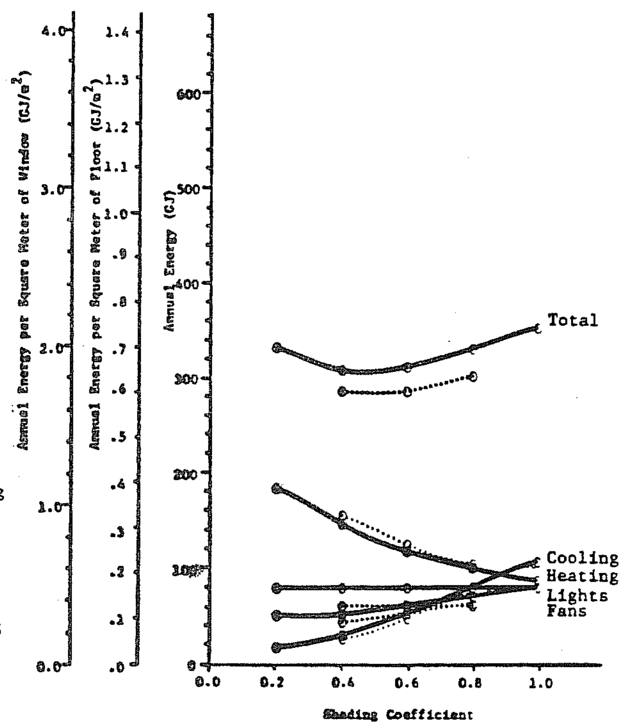

Fig. 1d. Bismarck South Zone U3 WWR = 0.9

U1 = Normal single glazing, nominal 6.28 w/m^2°C.
U2 = Single glazing low emissivity, nominal 4.33 w/m^2°C.
U2A = Normal double glazing, nominal 2.78 w/m^2°C.
U3 = Normal triple glazing, nominal 1.8 w/m^2°C.

Suffix X — No drapes deployed as a shading device.
Solid Line — Energy use with no utilization of daylighting.
Broken Line — Energy use with daylighting utilization.

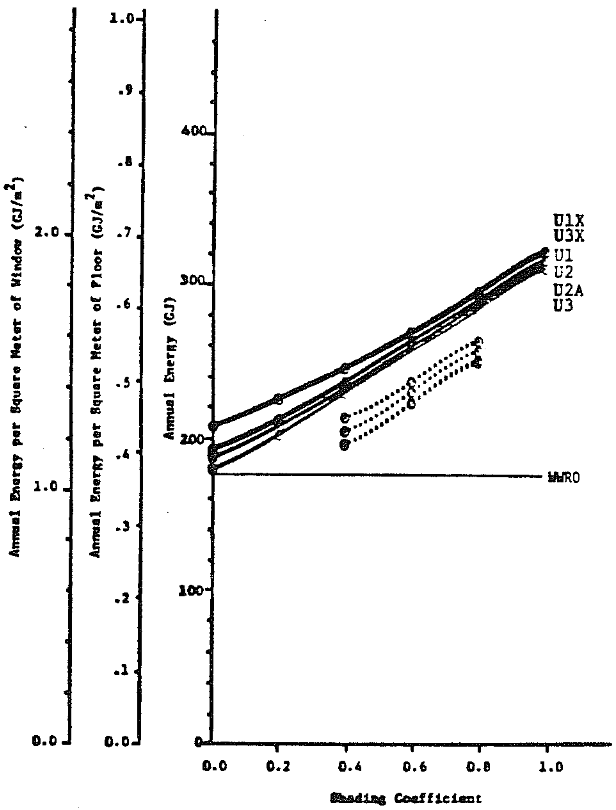

Fig. 2a. Miami North Zone WWR = 0.9

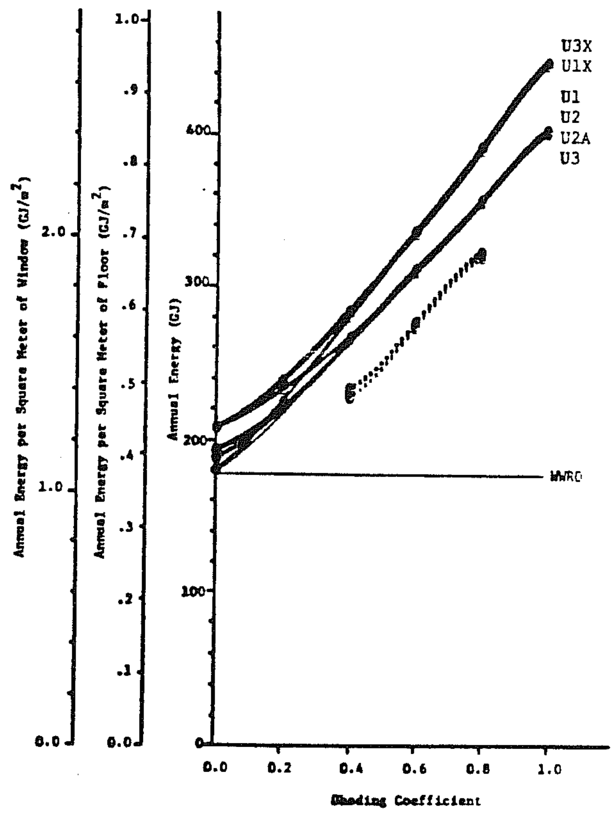

Fig. 2b. Miami South Zone WWR = 0.9

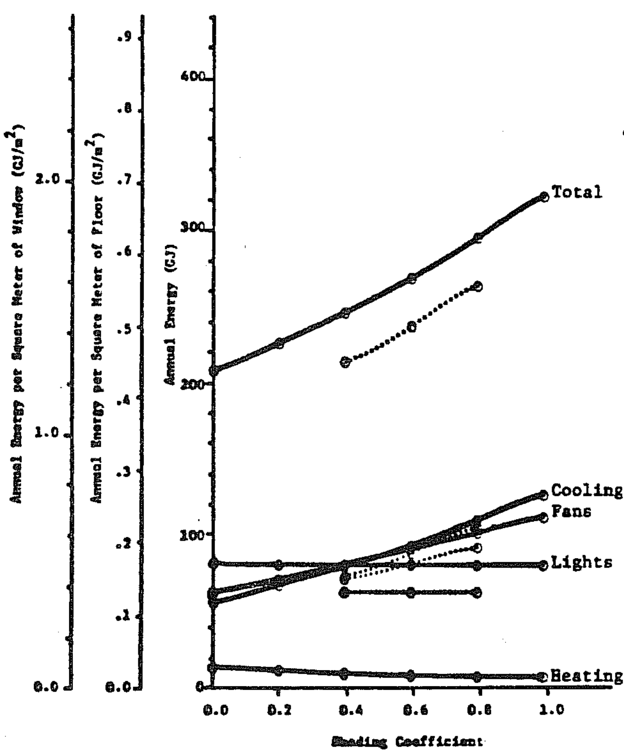

Fig. 2c. Miami North Zone U1 WWR = 0.9

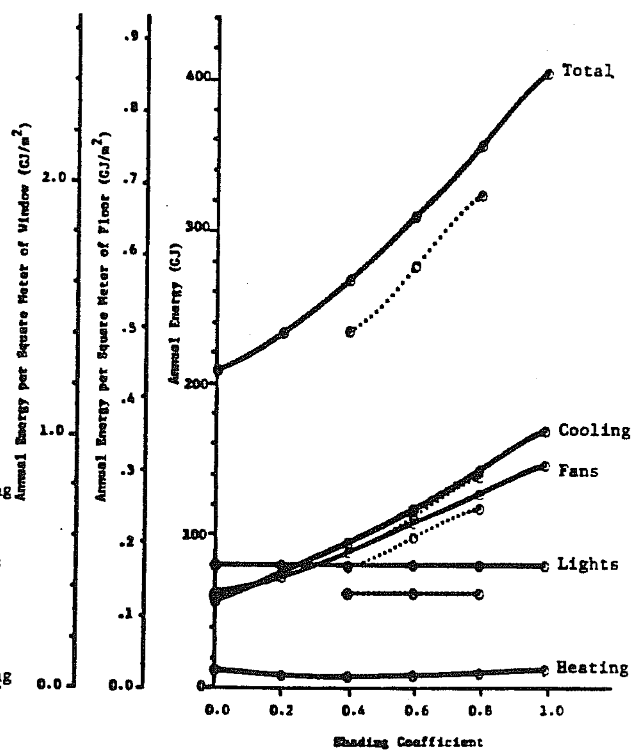

Fig. 2d. Miami South Zone U1 WWR = 0.9

U1 = Normal single glazing, nominal 6.28 w/m^2°C.
U2 = Single glazing low emissivity, nominal 4.33 w/m^2°C.
U2A = Normal double glazing, nominal 2.78 w/m^2°C.
U3 = Normal triple glazing, nominal 1.8 w/m^2°C.

Suffix X — No drapes deployed as a shading device.
Solid Line — Energy use with no utilization of daylighting.
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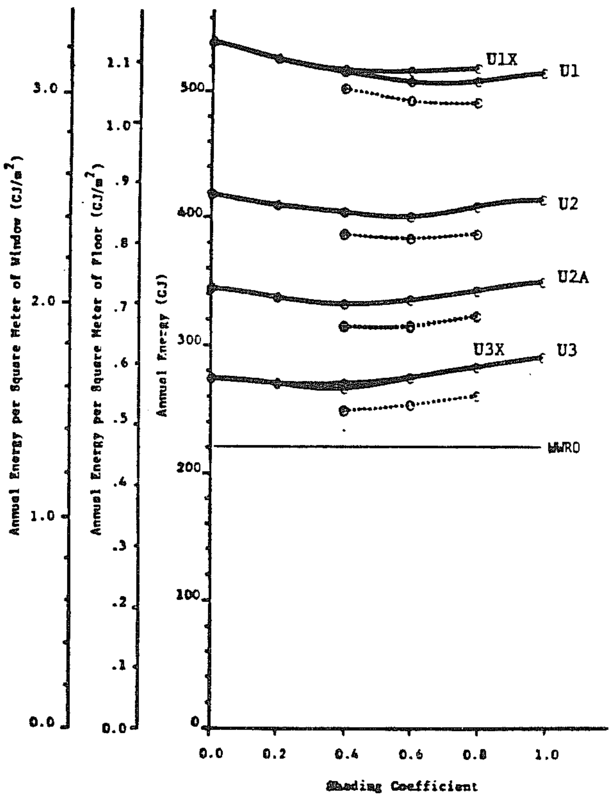

Fig. 3a. New York North Zone WWR = 0.9

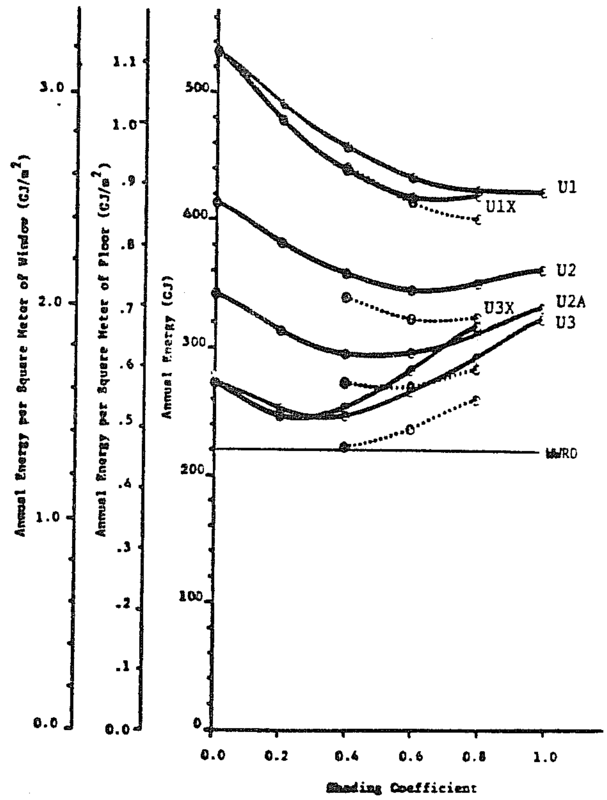

Fig. 3b. New York South Zone WWR = 0.9

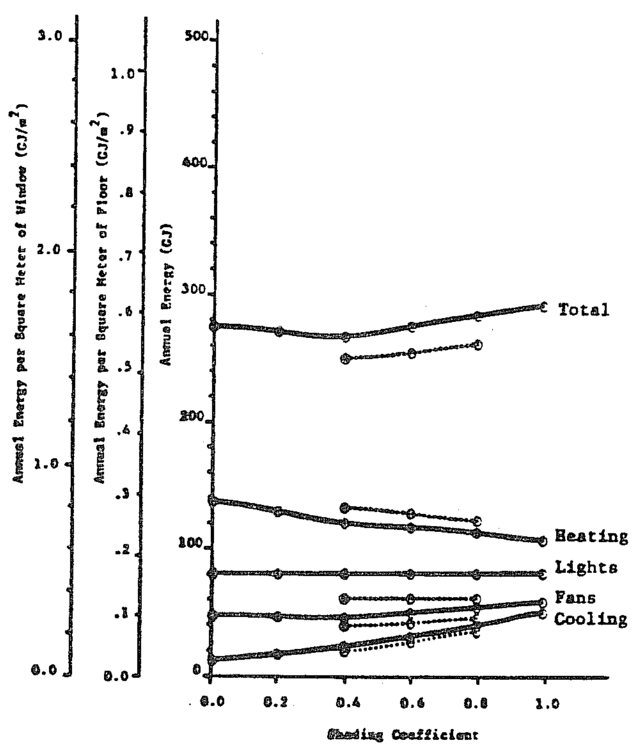

Fig. 3c. New York North Zone U3 WWR = 0.9

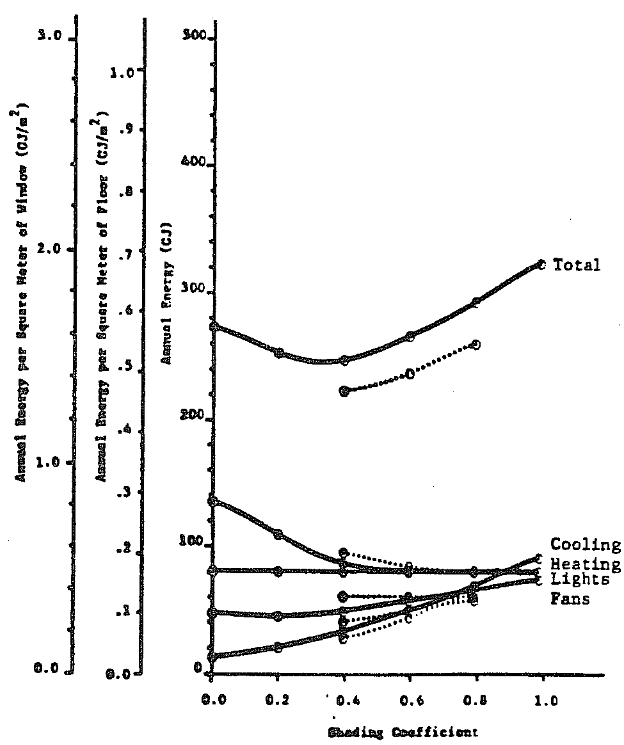

Fig. 3d. New York South Zone U3 WWR = 0.9

U1 = Normal single glazing, nominal 6.28 w/m²°C.
U2 = Single glazing low emissivity, nominal 4.33 w/m²°C.
U2A = Normal double glazing, nominal 2.78 w/m²°C.
U3 = Normal triple glazing, nominal 1.8 w/m²°C.

Suffix X — No drapes deployed as a shading device.
Solid Line — Energy use with no utilization of daylighting.
Broken Line — Energy use with daylighting utilization.