EFFECTIVENESS OF EXTERNAL WINDOW ATTACHMENTS BASED ON DAYLIGHT UTILIZATION AND COOLING LOAD REDUCTION FOR SMALL OFFICE BUILDINGS IN HOT HUMID CLIMATES

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ABSTRACT

This study explored the effectiveness of selected external shading devices and glazing treatments used to minimize the total annual energy consumption in small office buildings in hot humid climates. The external shading devices included a permanent horizontal overhang and a light shelf. The selected types of glazing included clear, reflective, tinted, low-emissivity coating, and heat-mirror glass.

One concern about using external window attachments is that while reducing the solar heat gains, they also reduce the amount of the daylight needed to supplement interior lighting. Therefore the objective of this study was to explore which strategy would give a balance between solar heat gain reduction and daylight utilization and result in the most energy savings in the building.

Computer simulations using an hourly energy calculation model were conducted to predict the analyzed with life-cycle costing techniques using the present value technique. Results show that properly designed overhangs that shade clear glazing are slightly more cost-effective than specialized low-e glazing systems. These results are unique for hot humid climates where winter heating is not an issue. On the contrary, when used in cold climates, external shading devices tend to increase the building's energy consumption.

INTRODUCTION AND BACKGROUND

With passive cooling of buildings, the first level defense is heat avoidance, done in such a way that it will minimize external heat gain and reduce cooling loads. One appropriate strategy at this level is to use external shading devices (2). Sun shading with external devices have been utilized extensively throughout history. These devices protect the walls or windows of the building from the direct sun light before the sun light reaches the wall.

However, with the development of modern environmental control technology and the trends of the architectural styles around the world, many buildings, especially those in cold climates, use various types of glazing instead of external sun shading. Even buildings in hot climates tend to follow the technology, models, or architectural concepts from buildings in cold climates. One reason that has been offered by the owners, developers, and the architects is that by using glazing only, the building will require less construction time, less construction cost, and less maintenance cost. However, they seldom evaluate the life-cycle cost of energy consumption in the building.

A second way to minimize the heat gain is to lower the electric lighting by strategic use of daylight. Previous research in California showed that in commercial buildings, use of daylight can significantly reduce a building's energy consumption -- as much as 40 to 50 percent (4). This condition is possible because daylight has higher efficacy than amount of light, daylight will add less heat to the room than electrical lighting sources do.

These two strategies -- shading windows and utilizing daylight -- can be combined together in order to reduce building cooling loads. However, proper size of the shading devices should be analyzed because the more the direct sunlight is minimized, the more daylight is reduced. Thus, the effort to use daylight while shading the windows can be ineffective if the shading devices are oversized.

VARIABLES USED IN THE STUDY

The study investigated the effectiveness of two external shading devices (overhang and light shelf) with clear glass windows and specialized low-e glazing systems without external shading devices. From the previous study (5), it was found that green glass with low-e coating was generally the most cost effective among six types of glazing (clear, reflective, green tinted, clear glass with low-e

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coating, green glass with low-e coating, and heat-mirror glass). Therefore, this type of glazing was the one to be further analyzed in this study.

In order to focus the study strictly on the effectiveness of fixed external shades and glazing types, no internal shading devices were assumed to exist. Overhangs were applied to shade the window from direct radiation. The light shelf, the second shading device to be analyzed, was mainly used to enhance the amount of daylight in the building, while at the same time providing shade to the window beneath it from direct sunlight. Optimum overhangs and light shelf lengths were then derived.

The building locations range from cities in hot humid tropical regions (i.e. Jakarta, Indonesia, 6.1°), to northern hot humid climates with no heating requirements (Miami, Florida, 25.8° NL) and hot humid climates with some heating requirements (Corpus Christi, Texas, 27.77° NL). For the comparison, cities in cold climates were New York, New York, and Minneapolis-St. Paul, Minnesota.

METHODS OF ANALYSIS

A. Daylight Calculations

The method used for daylight contribution in the computer program is based on the LOF/IES/Lumen Method, developed by J. W. Griffith (7). This method is probably the most flexible technique and was easily adapted to computer algorithms by using curve fitting techniques. Based on the amount of daylight received on the work plane, the amount of electrical lighting reduction was reduced proportionally. The cooling load reduction was then calculated by calculating the difference between the amount of heat from the same amount of light produced by electrical lighting before using daylight and that produced by daylight and the reduced electrical lighting load.

B. Energy Calculations

The energy analyses were done by the ENERCALC computer program, a model that estimates the annual energy consumption of buildings by using an hour-by-hour simulation technique (1). The cost savings were analyzed using its built-in life-cycle cost evaluator based on present worth. ENERCALC also estimates the annual energy performance of the building by reporting the total annual energy consumption and the overall energy utilization factor (EUF) in terms of Btu per square foot per year.

C. Cost Savings Analysis

The cost analysis included the cost of investments and the total energy cost. These costs were compared in terms of present worth in dollars per square foot floor area. The cost of investments varied according to the changes in construction cost (when the size of the external device was changed), the wall and window cost (when the window area was changed), and the cost of the glass window (when different glazing was used). These changes also affected the first cost of the air-conditioning systems (at $2400 per ton). The energy cost was determined at $0.08 per kilowatt hour.

The cost for the external device was used at $8.45 per square foot of a device, and it was assumed that the device was made of precast concrete. This cost seemed to be an average construction cost of a device, while in reality less expensive device can also be used, and thus increase the cost effectiveness.

CASE STUDY BUILDING

A. Building Type

A small four-story office building was chosen as the study case (Figure 1). The smallest space was determined to be 15 feet by 18 feet. 15 feet is a typical width of one office compartment, while 18 feet depth was determined as the room depth to which the daylight can reach (3). It was assumed that there was no shading by other buildings or by vegetation. The total floor area was approximately 20,000 square feet. With the standard of 100 square feet per person, the total occupancy was estimated at 200 people. The overhang and light shelf configurations are shown in Figure 2.

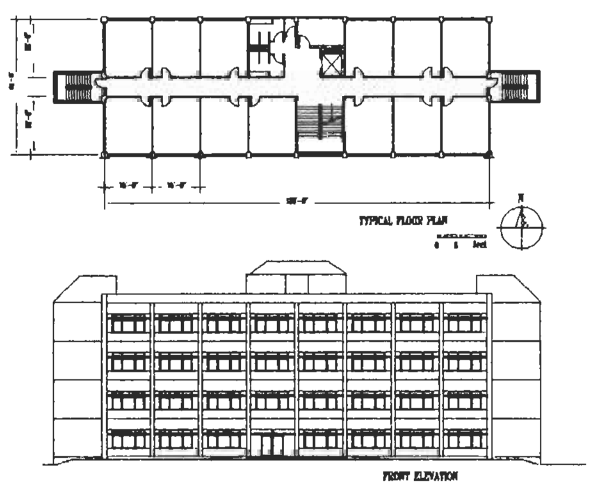

Figure 1 Floor and Elevation of Sample Building

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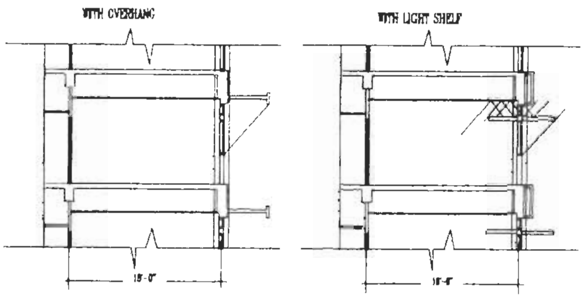

Figure 2 Overhang and Light Shelf Configurations

B. Environmental Controls

For occupied situations, the internal space temperatures were permitted to vary from 74°F to 78°F. For unoccupied periods, the temperatures were set back to 72°F in winter and 80°F in summer. Because of the warm climate, however, the low set points never created a heating energy burden, so a simple electric resistance heating system was used.

For the building in cold climates, the temperature was set to 72°F for winter and 76°F for summer occupied situations. Unoccupied situations were set to 60°F in winter and 78°F in summer. A variable air volume (VAV) system was chosen with an air handling unit on each floor of the building. lighting was provided by fluorescent lamps (i.e. cool white, 79 lumens/watt). The lighting level for the office space was about 70 foot candles and 15 to 20 foot candles for the other spaces.

C. Wall properties

Because only walls that had contact with the outside gave the impacts on the energy used, the data input only concerned the material of the exterior walls. The wall was 4-inch precast concrete with R-11 insulation. The roof was 4" heavy weight concrete deck with 6" R-19 insulation.

D. Window properties

The thermal characteristics of the glazing are shown in Table I:

Table 1. Thermal characteristics of the glazing

Glazing Type	U-F	S.C.	Emiss.	Daylt Trans.	$/ft2
Clear	0.57	0.82	0.84	79 %	11.00
Grn, low-e	0.33	0.48	0.40	64 %	21.80

(Source: ASHRAE Handbook, 1989)

All windows were double glazed, as this has a better acoustical performance (in blocking the outside noise) as well as a better energy performance (in reducing external heat gains) than the single pane, even though this does cost more than single glazing.

GLAZING PERFORMANCE

Using green glass with low-e coating, window areas were analyzed from 15 percent to 50 percent of the exterior walls. Figure 3 shows that the optimum window area is at 25 percent of the wall area.

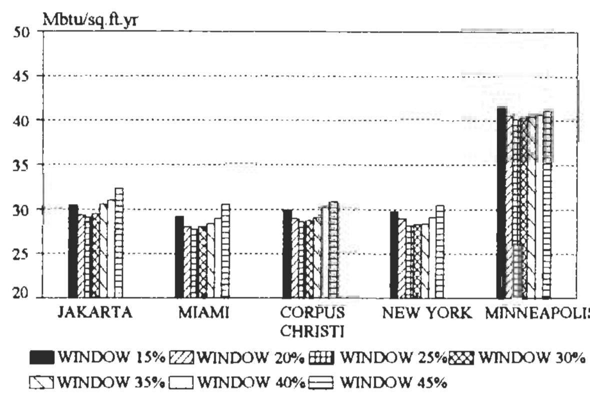

Figure 3 Window Area Optimization with Low-e Glazing

EXTERNAL SHADING PERFORMANCE

A. Overhangs

The optimum ratio of the overhang length to the window height varies according to the building location. From the previous study it was found that in Jakarta, Indonesia, the optimum overhang length ratio was 1.0 on the north wall and 0.3 on the south wall (5). In this particular location, the need of overhang did not solely depend on the sun position. Because the climate dictates that there was never a need for heating and the average outside temperature was relatively high, there was a tendency to have more overhangs even though the sun was at higher angle.

In Miami, the optimum overhang ratio on the south wall was 1.0 while on the north wall it was 0.1. In Corpus Christi, where the building had some heating requirements, the optimum overhang ratio was 0.6 on the south wall and none on the north wall.

For the building in cold climates (New York and Minneapolis-St. Paul), the optimum overhang ratio was 0.1 on the south wall and none on the north wall (Figure 4). This ratio seemed to be very small;

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however, this is clearly understandable because in these areas, there is less need to block solar heat gains. Even longer overhang can prevent the building from getting a direct sun radiation when needed in the winter.

The window areas with these optimum overhang lengths were then optimized. Figure 5 shows this optimization.

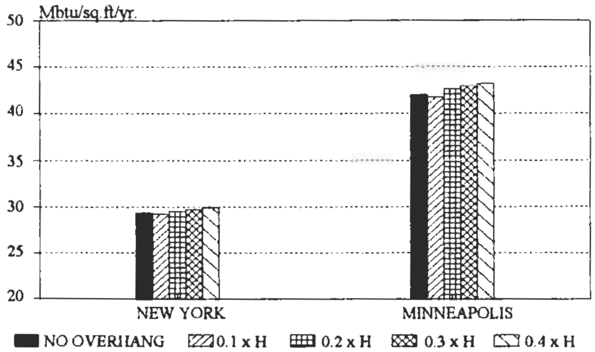

Figure 4 Overhang Optimization in New York and Minneapolis

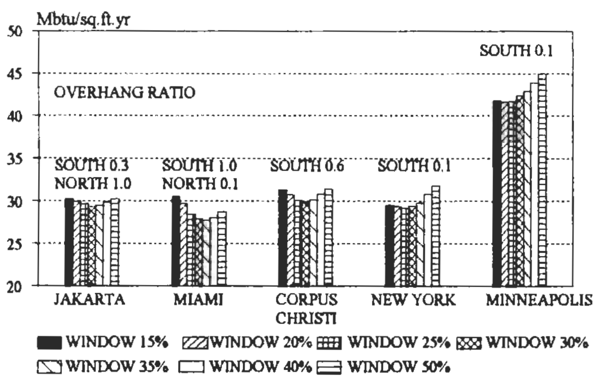

Figure 5 Window Area Optimization with Overhang

B. Light Shelf

The top surface of the light shelf had high reflection factor (white colored with 80% reflection). This was so daylight would enter well within the occupied spaces. The optimum ratio of the light shelf length to the window area was found to be relatively the same as that of the overhang length. Figure 6 below shows the window area optimization by using light shelf.

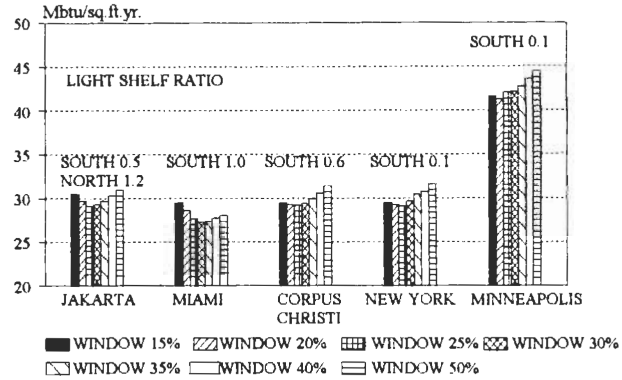

Figure 6 Window Area Optimization with Light-Shelf

COMPARISONS

Figure 7 below shows the comparisons of using optimum size of overhang, light shelf and low-e glazing, for the optimum window areas (shown as percentage of wall area). These show that using external shading devices (overhang or light shelf) can have the same energy performance as using low-e glazing. In colder climates, using specialized glazing systems will result in a better energy performance than using permanent external shading devices. However, in locations where heating is not critical, using external shading devices can be more cost effective than using specialized glazing systems (Figure 8).

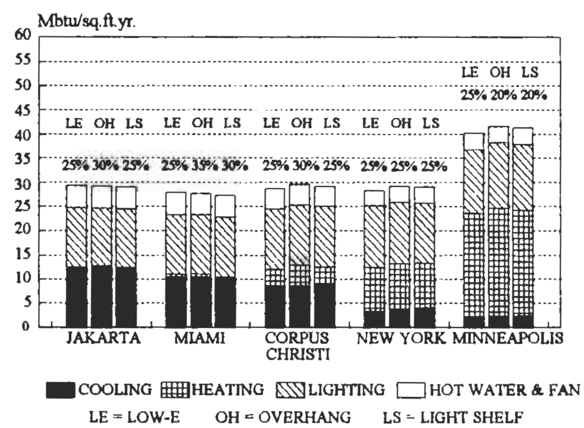

Figure 7 Comparisons of the Optimum Strategies

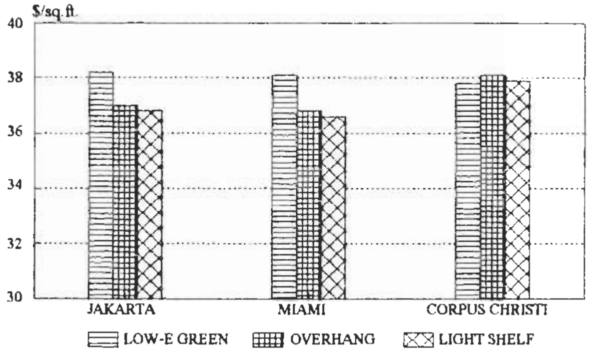

Figure 8 Comparisons of Present Worth of Cost

All of the above results can only be obtained when daylight is used. If daylight is not used, however, significant energy savings will not be achieved as the energy for electrical lighting and cooling greatly increase. Figure 9 shows the differences when daylight was not utilized.

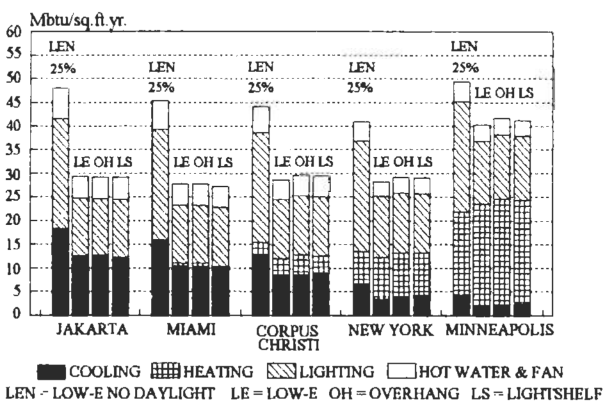

Figure 9 Comparisons of Using Daylight and Without Using Daylight

CONCLUSIONS AND RECOMMENDATION

A. External Shading Devices and Glazing Type

The results show that the traditional configuration - that of having clear glass windows shaded by a shading device - will compete favorably with various types of specialized glazing systems. In many cases, using the ordinary horizontal overhang is the most cost-effective solution. The exact design of the overhang, however, does not have to match the one used in this study. The bottom line is that the window should be fully shaded from direct solar radiation and most of sky radiation with properly sized devices.

Using specialized glazing systems gives a better energy performance when heating needs are significant. However, since in most hot humid climates heating is not critical, the use of external shading devices is favored.

B. Window Area

Properly sizing the windows is also an important key to achieving optimum results. In hot humid climates, the optimum window area to minimize cooling loads and optimize the use of daylight is 25 to 35 percent of the wall area.

Additionally, the results show that using external shading devices offers another advantage compared to using specialized glazing systems only. In many cases, having an outside view is a desirable feature of the building design. The idea of using exterior shading devices, therefore, becomes desirable since it yields optimal energy performance at larger window areas.

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