Solar control devices; balance between thermal performance and daylight

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ABSTRACT

The concern to achieve energy efficient performance during the activation of natural ventilation mode inside an office building in New Delhi, India addresses the need of study. This paper is based on a MA research project and describes the relationship observed in co-ordinating thermal performance and illuminance levels achieved with different depths and designs of shading devices. Research results from computer simulations carried out in A-TAS to observe the effect on resultant internal air temperature and the amount of daylight received on the working plane through the software RADIANCE are presented. Efficient solar control devices for different orientations which would protect the aperture from direct solar radiation, prevent glare, optimize daylight and enhance passive cooling through reduced internal air temperature are proposed for the brief of a bio-climatic office building located in New Delhi.

1. INTRODUCTION

New Delhi, capital city of India, is one of the four metropolitan cities of the country and is undergoing major urban expansions in the sub-urban areas. The city lies in the Northern plains (28.4^{0}Latitude) and experiences a composite climate with long summer months and short winter months. Following the American trend, the building typology that dominates the skyline of the sub-urban areas are tall rise fully glazed and sealed office structures. The inside climate of these corporate offices are based up on the narrow range of temperatures defined by ASHRAE. To maintain such temperatures in the tropical climate of Delhi, high energy is consumed in cooling the office space in the summer months. An MA research was carried out to explore the potential passive strategies which could be adopted for a naturally ventilated and a mixed-mode office building in New Delhi.

Solar Radiation and a form of control- control of solar gain is an important factor in a naturally ventilated office building. This paper presents the methodology which was adopted to optimize solar control devices for apertures on different orientations of an office building. Two factors were considered during the design and evaluation process of the shading device. The first was the influence of the device upon the internal resultant air temperature. The second was the illuminance achieved on the work plane inside the office space. Deep shading devices could be very effective in reducing the internal air temperature, but at the same time would reduce daylight availability inside. This in turn would increase the lighting loads and cooling loads due to artificial lighting. This is not preferred and therefore there needs to be a balance between the two factors. Elimination of all the components of solar radiation is not the objective; daylight must be preserved (Fontoynont, 1998).

2. METHODOLOGY

2.1 Building Typology

Considering the present trends in high rise office building a floor plate of 30m x 30m was divided into five zones. One central atrium zone and four zones of office spaces facing four orientations, North, South, East and West (Fig. 1).

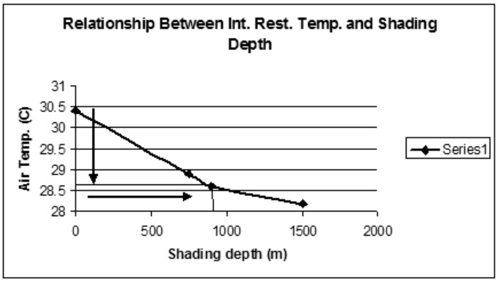

Figure 1: Relationship between internal resultant air temperature and shading depth on East orientation.

This methodology was followed to observe the differences in performance of offices facing different orientations. Each office space was 30m in length, 7.5m deep and 4.5m floor to floor height. Glass to wall surface areas ratio = 25%.

2.2 Received Solar Radiation and Solar Control

The transmission of solar radiation could be controlled through windows by: orientation of the window, size of the window, type of glazing and shading devices. To understand the critical daylight hours for solar control, simulations were performed in Ecotect v.5.2 (Marsh, A) to calculate the received solar radiation on windows with double glazed Low Emissivity glazing and Aluminium frame. The simulation results for East, South, West and North could be referred in the poster. It was observed that East orientation window receives maximum intensities in the month of April and May from 10:00 AM to 11:00 AM. This indicated that solar protection in offices facing East orientation is necessary in the morning hours from 10:00- 11:00 AM. South orientation window receives maximum intensities in the months of October, November and December from 13:00-14:00 hrs. West orientation receives maximum irradiation in the months from March till May from 16:00-17:00 hrs. North orientation receives negligible direct solar radiation. To design efficient solar control devices for different orientations, Solar Geometry was studied as a next step for the predicted crucial hours.

2.3 Solar Geometry and Efficient Shading Devices

Computer simulations were carried out in software ATAS to observe the effect of different depths of shading devices for different orientations on the internal resultant internal air temperature and their effect on daylight availability was tested through RADIANCE.

2.3.1 East Orientation

On the 1^{st} April, at the crucial hour 10:00 AM the sun path diagram for New Delhi at latitude 28.4^0 predicts sun's position at 118.4^0 (azimuth) and 47.8^0 (altitude). The horizontal shadow angle (HSA) for the vertical façade facing East orientation is equal to 28.4^0. Vertical Shadow angle (VSA) calculated for East orientation is equal to 51.4^0. It was observed that on the East orientation a 51.4^0 horizontal device measured from the wall on 1^{st} April would cut down direct solar radiation at the crucial hours on East orientation in the major part of the year. This was achieved through a horizontal device 900mm deep placed just above the aperture.

Thermal Performance Simulations

To observe the effect of shading devices on internal resultant air temperature with different depths four models were simulated in ATAS. The first model was constructed with apertures on East orientation without shading device. In the second model a shading device with 900mm depth was attached to the aperture. In the third model, a shading device with 1500mm depth was attached. This would protect and cast shadow on the aperture since 9:00AM in the morning. A fourth model was constructed to observe the effect of a narrow shading device with depth 750mm.

Observations

Model 2 with shading device of depth .900m showed a reduction in the resultant internal air temperature by 2^0C in comparison to the base case (Fig. 1). It was observed that by increasing the depth till 1.5m, there was a minimal difference in internal air temperature, while on the other hand a major reduction was observed in the daylight availability.

Daylight Simulations

The sun angles define the depth of a shading device. The shading device which would help cut solar gains would also cut out parts from the visible surface of the sky vault (Olygay, 1957). Thus various design permutation combinations were worked out and tested in RADIANCE to achieve daylight efficiency for shade depth 900mm inside an office space 7.5m deep (6m work space + 1.5m corridor). Model 1 consisted of a .900m deep overhang just above the aperture. In Model 2, 900mm overhang was divided into three louvers, each .275m deep. In Model 3, the windows were designed with vertical fins. In Model 4, to incorporate shading device as an architectural feature in the high rise building in Delhi, terraces 2.1m deep at next floor level were projected out to cast shadow on the after 10:00hrs (Figs. 2 and 3) and more daylight is available inside. Simulations carried out in RADIANCE predicted 750lux on the periphery and 500lux achieved till 6m depth. Coloured images presenting illuminance are presented in the poster. Thus a relationship was established between transmittance, and depth as well as position of the overhang.

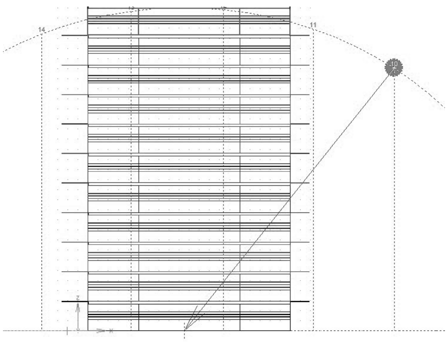

Figure 2: Model 4, Cantilevered floor plate and louvers on East and West Orientations.

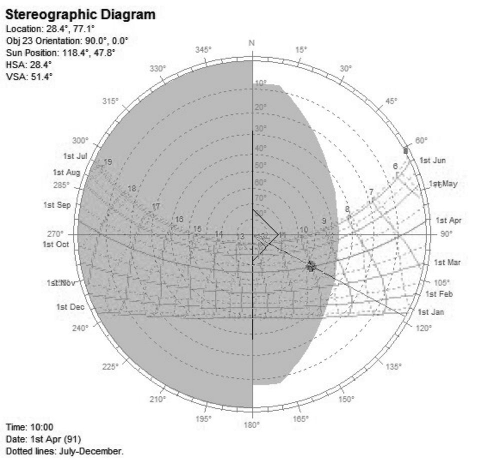

Figure 3: Model 4, Stereographic projection showing shading mask, projected on the aperture by the cantilever floor.

2.3.2 South Orientation

On the 1st March at the crucial hour 14:00, the sun path diagram for New Delhi at latitude 28.4^0 predicts Sun's position at 147.1^0 (azimuth) and 48.0^0 (altitude). Calculations of the Sun's position in relation to the South orientation predicted HAS = 3.2^0 and VSA = 52.9^0. Thus on the South orientation a 52.9^0 horizontal device measured from the wall (Vertical Shadow Angle, VSA) on 1st March would cut down the direct solar radiation at crucial hours 13:00-14:00. This was achieved through a horizontal device .850m deep over the aperture.

Thermal Performance Simulations

For the economy of shading devices and to test the efficiency of different shading depths on South orientation, the first model was constructed with no shading device attached above the aperture. In the second model a shading device with .150m depth was constructed above the aperture in ATAS. .150m projection in the masonry cuts down direct radiation in the month of June and July when the Sun is at high altitude and the vertical shadow angle was calculated to be 83.3^0. In the third model an overhang .850m deep was attached above the aperture. This overhang protects the aperture when solar radiation intensities are high while crossing its path over the South façade. A Fourth Model with 1.2m deep overhang was also simulated to test the efficiency on internal resultant air temperature due to increase in depth. All the above mentioned models built in ATAS had similar construction details.

Observations

Model 2 was observed to have minimal or no reduction in resultant internal air temperature as compared to Model 1. At the crucial hour 14:00, Model 3 with .850m overhang predicted reduction in internal air temperature by 1.59^0C in the month of March and by 2.82^0C in October. Figure 4 shows the relationship between internal resultant air temperature and depth of a shading device on the South orientation on the 1st of March. It was also observed that increasing the depth after a limit, has no effect on internal air temperature. On the contrary, has disadvantage of reducing the amount of daylight entering in-

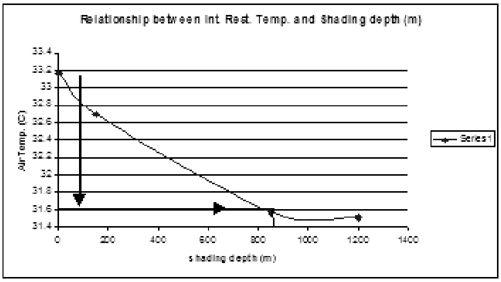

Figure 4: Relationship between Internal Resultant Air Temperature and depth of the shading devices.

side the office space. This could be visualized in the results predicted for depth 1200 in Figure 4. Thus it was concluded to take forward .850m depth shading device to optimise the design as per daylight studies.

Daylight Simulations

Two options were modelled in RADIANCE to achieve daylight efficiency on the work plane for a shade depth .850m. option 1 consisted of .850m deep overhang above the aperture, results in RADIANCE for an overcast sky in Delhi predicted 800lux on the periphery of the office and 425lux was observed 7.5m deep inside the office. In Option 2 .850m deep overhang was divided into three louvers, each .265m deep. It was observed that daylight illuminance on the periphery reduced and more uniform light was achieved. Figure 5 shows the Option 2 and Figure 6 shows the shadow mask obtained on the aperture. Coloured images from RADIANCE would be presented in the poster during the conference.

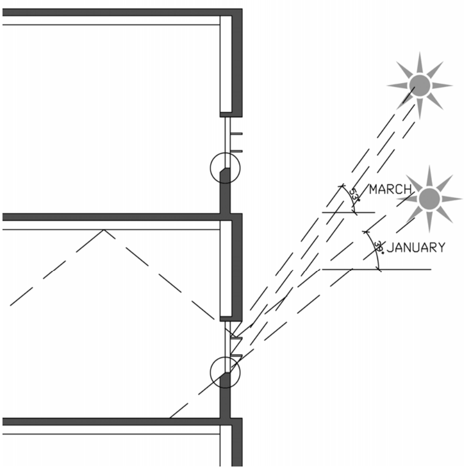

Figure 5: Option 2.

2.3.3 West Orientation

Solar data from Chartered Institute of Building Services Engineers (CIBSE) Guide predicts high solar radiation intensities in the months of April and May. Offices facing West orientation could be critical as they get affected by both high internal loads and late afternoon solar radiation (Szokolay, 1975). On the 1st April, at 16:00 crucial hour the Sun path predicts Sun's position at 105.2^0 (azimuth) and 33.7^0 (altitude). The horizontal shadow angle (HSA) for the vertical façade facing West orientation is equal to -15.2^0. The Vertical Shadow Angle (VSA) from the wall is equal to 34.6^0. On overlaying the shadow mask over the sun path diagram it was observed that on the West orientation a 34.6^0 horizontal device measured from the wall on the 1st April would satisfy the crucial hours on West orientation all the year round. This could be achieved through a horizontal shading device 1.63m deep above the aperture.

Thermal Performance Simulations

Computer simulations were carried out in ATAS to observe the effect of solar control shading devices on the resultant air temperature. First Model was constructed with apertures without shading device. In the Second Model a 43.1^0 horizontal device 1.2m deep would protect the aperture on West orientation till 15:00 hrs.

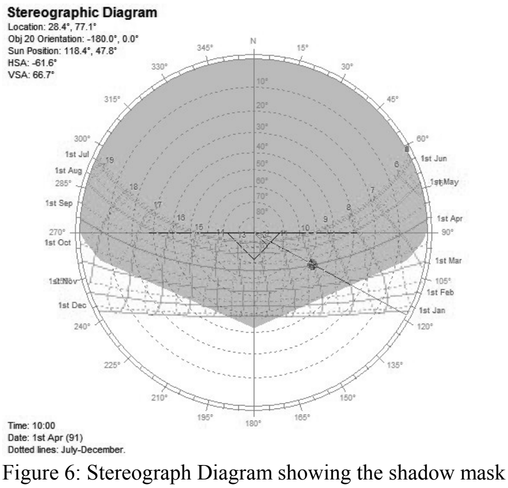

Figure 6: Stereograph Diagram showing the shadow mask obtained over the aperture in Option 2.

throughout the year. In the Third Model a 34.6^0 horizontal device, 1.63m deep would protect the aperture till 16:00 hrs. In the Fourth Model the office space was simulated with 3.68m deep overhang, which would protect the aperture from direct irradiation till 17:00 hrs throughout the year.

Observations

It was observed that by designing the shading device for 16:00hrs on West orientation, Model 3, 1.63m deep, the Resultant Internal Air Temperature were reduced by 3.5^0C from the base case, Model 1 (Fig. 7). It was also observed that in the hot months of June and July, the effect of shading device reduces (Fig. 8). Shading device 1.630m deep above the aperture was taken forward to carry out daylight studies on the West orientation.

Daylight Simulations

Various design permutation combinations were worked out and tested in RADIANCE to achieve daylight efficiency for shade depth 1.63m. Option 1 consisted of 1.63m deep overhang above the aperture. Simulation results from RADIANCE predicted 450lux on the periphery and 300lux 6m away from external apertures. In Option 2, 1.63m overhang was divided into three louvers, .495m each. Simulation results predicted more uniform daylight inside the office space. 530lux was observed on the periphery and 450lux 6m away from the external face. This is preferred. In Option 3, louvers were designed away from the façade of the structure to allow air movement and cut low vertical shadow angle formed at 17:00hrs. Simulation results predicted very bright illuminance levels upto 900lux on the periphery of the office space. Gap between the façade of the structure and louvers could cause glare problems. Coloured images could be referenced in the posters. In Option 4, an opaque vertical shading device away from the façade was designed to protect the aperture from direct radiation till 17:00 hrs throughout the year. This option also allows air movement between the shading device and building structure as well as protects the aperture from late afternoon sun rays; however, the gap between the shading device and building structure causes bright conditions near the periphery which is not proffered. To incorporate shading device as an architectural feature in the high rise office building in New Delhi- Gurgaon area, Option 5 was worked out to project overhangs at floor level. Through this option late afternoon Summer Sun was obstructed and more uniform daylight was available (Littlefair, 1999).

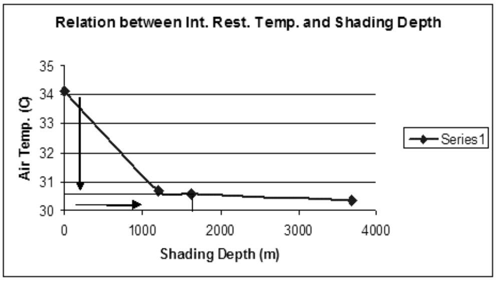

Figure 7: Relation between Int. Rest. Temp. and Shading Depths observed in April.

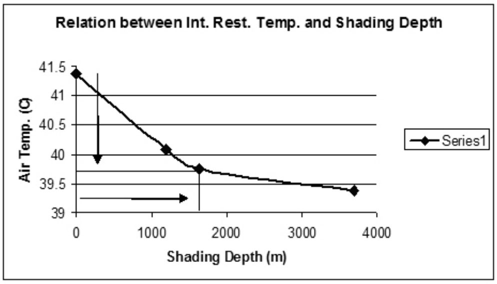

Figure 8: Relation between Int. Rest. Temp. and Shading Depths observed in June.

3. CONCLUSIONS

The effectiveness and success of a solar control device in reducing internal resultant air temperature depends upon the shading mask achieved on the aperture in the cooling period. It was also observed that after certain depth an increase in depth may not further reduce internal air temperature. Therefore it is important to design economical shading devices.

As observed in Figures 7 and 8, simulation results predicted different shading depths and different designs on different orientations had different impact on the internal resultant air temperature during different months. Different shading depths were co-ordinated with different amount of light available inside the office space.

There might be cases, when a good depth of shading device could be very effective in reduc-

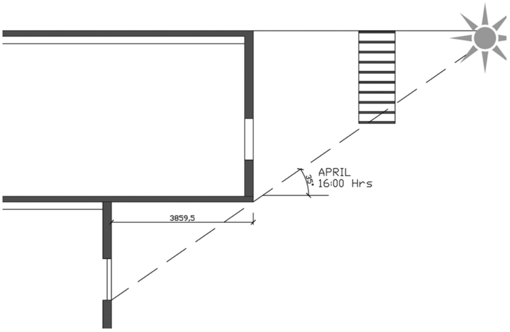

Figure 9: Option 5.

ing internal air temperature, but at the same time would also reduce daylight availability inside. This is not preferred, because it would result into higher lighting loads.

Depth of a single overhang, when divided into a few small horizontal louvers allows more uniform light inside the office space.

Gap between the louvers and building façade is not preferred, as this could result into very bright conditions on the periphery of the office space, near the exterior window.

Overhangs as depicted in Figure 9, at a distance above the head of the window, cuts high summer sun from getting inside, and allows increased low angle sun and daylight to penetrate inside. This option was taken forward in the design stage of bioclimatic office structures in New Delhi- Gurgaon area.

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