RATIONAL USE OF GLASS IN TROPICAL URBAN CLIMATIC CONDITIONS

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ABSTRACT

Glass is a common material used in buildings, mainly for penestration purposes. Although the physical properties and performance data of the wide variety of glass can be easily obtained from technical literature, their performances under specific environmental conditions are not commonly known. While the technical literature presents performance data under laboratory conditions, the same under ambient conditions are not available. However, the post application performance of glass largely depends on the external environmental conditions. This paper attempts to understand the performance of popularly used variety of glasses under tropical urban climatic conditions of Sri Lanka. It presents the findings of an experiment conducted under ambient conditions, using a scaled model of a typical office building.

Introduction

Since its invention, glass has been used in buildings primarily as a light and ventilation regulator. However, this primary function has been transformed to various functions with the advancement of knowledge on the versatility of this wonder material. During this transformation glass also became a material which is used irrationally. It is most commonly observed that in contemporary buildings, either unsuitable glazing material is used or suitable material is used in incorrect manners.

Some contemporary buildings even use 'structural glazing systems' where only glass (not even frames or other fixtures) is visible from outside. In such cases glass provides neat envelopes for buildings, especially for high rises. Also, glass is used in a variety of ways in buildings to create different qualities of spaces and expressions such as prestige and elegance. Regardless of climate, culture, purpose, or function of the building, glass is used extensively due to its sleek and modern appearance. Glass has become an essential material for high-tech buildings. However, irrational use of glass sometimes causes undesirable effects such as glare, heat, loss of privacy, loss of safety, discomfort, high cost of maintenance and energy consumption.

Glass is one of the most flexible modern materials with its variety of products available. This is clearly visible when observing the application of glass in all types of buildings despite their different functions. Glass in almost every imaginable kind such as plate and sheet glass, ribbed, wired and patterned glass, thermally toughened glass, translucent glass, and various forms of decorative glasses such as stained glass, glass blocks, glass mosaics, fused glass and slab glass are used in combination with other materials in buildings. Technological advancements in glass applications provide new means of enriching qualities of buildings.

Though glass is a material that can be successfully used to achieve various architectural expressions, care must be taken in using glass while also considering its utility functions. Therefore, creating functional buildings and spaces while keeping in touch with the new trends in architecture is a challenge in front of architects today. Hence it is important to know how to make use of this exciting material in correct proportions and in a rational manner to achieve the required results. This study is an attempt to find out how to balance the utilitarian and expressive uses of glass in tropical urban architecture by identifying its performance under tropical urban climatic conditions.

Rational and Irrational Use

Different materials may have different inherent properties. They perform according to those innate properties as well as the context that is, climatic conditions, materials that are connected to it, etc. If the glass application is purposeful and appropriate, that then is a rational use. For example, the main requirement of a shop front is to display the merchandise available for sale. Therefore, the glazing should necessarily be a transparent material. Clear glass for a shop front is suitable because it is transparent and also other qualities such as the clarity and the shine add positively to the needs of display. If glass is used unsuitably, it is an irrational use. For example, if a building is mostly glazed with less shading, poor ventilation and incorrect orientation, excessive light penetration and heat build-up inside make it an irrational use.

Irrational glass use causes problems when it fails to cut-off unwanted sunlight coming into buildings. Due to their location closer to the equator tropical countries always get plenty of natural light. Natural light enters buildings as direct light, reflected light or diffused light. Since direct sunlight is the predominant component, which makes adverse light and heat conditions in buildings in the tropics, the design considerations need to focus more on direct light rather than diffused or reflected light. Whatever the form of light that a building receives, the light gain through windows or glass facades of that building should be based on the design parameters for optimum lighting and thermal levels for a comfortable living environment inside the building. Otherwise excessive indoor temperatures and lighting conditions will lead to excessive demand for energy to disperse excessive heat by means of air-conditioning. The devices added on to building interiors such as curtains and blinds to cut undesirable light and glare lead to more demand for energy for supplementary artificial lighting. This is a common phenomenon seen in excessively glazed buildings in the tropics.

Transparent materials not only absorb and reflect, but also transmit insolation (incident solar radiation). Therefore, as a transparent material solar control and thermal insulation properties of glass are also very critical factors which need to be considered.

It is observed that the commonly used types of glass in buildings include, Clear glass, solar control glass (tinted and reflective glass varieties), translucent glass (patterned glass varieties), safety glass (toughened, laminated and wired glass varieties), and decorative glass (stained glass, glass blocks etc.). Selecting a glass type from these varieties and available thicknesses should be determined according to the intended applications. When selecting a glass type, it may need to consider the properties like resistance to wind loading, safety, security, fire resistance, clear vision, privacy, aesthetics, thermal insulation and solar control properties.

However, there seems to be a keen interest to use the most fashionable or latest type of glass, irrespective of its suitability for the application. The fact that a tropical country has a variety of environmental conditions even in different geographical areas is not considered in the use of glass in many instances.

Architectural Applications of Glass

Some of the parameters to be considered at the design stage of any building in tropical countries include;

1. Orientation of building
2. Side lighting concepts
3. Top lighting concepts
4. Sun controlling devices
5. Ventilation devices

Natural light available on the outside would enter an interior through a window or a glazed wall on a vertical façade, depending on its orientation, size, shape, glazing type of sash, wall façade and its reflectance factors of light and heat. According to Fathy (1986:46) tropical sunlight falling on a 3m X 3m clear glass will contribute to 2000 Kilo calories of energy per hour, through-out the day. Therefore, direct sunlight falling on glazing contributes to excessive heat gain in buildings.

As experimental work done by the Building Research Station (UK) on preferred window shape in relation to external view indicates that satisfaction falls off steeply if less than 20% of the window wall is glazed. It rises to near maximum with glazed areas that occupy between 20% and 30% of the wall, provided that the window head height can be kept near the optimum for the view, and that the ratio of window width to solid wall width is between 3:2 and 3:1. Such information is needed in relation to tropical environmental conditions as well.

Penetration of daylight in to a space depends on proportional relationships of side lighting systems. (Robbins, 1986) Height and length of aperture (i.e., size of the window) is very important in this situation. Robbins also states that the penetration of daylight into space cannot be substantially increased once the aperture has reached about 4:1 length to height ratio. Therefore, having full face glass facades is not needed to achieve maximum light to the interiors. As emphasized so far there is a trend in using glass in large proportions for buildings, especially for commercial buildings. The main reason for this is the versatile properties of glass, which cannot be obtained by any other single material, even with the best of poly-carbonated plastics.

Modern architecture emphasizes the transparent qualities of buildings very prominently. As a result new developments are seen in glazing materials. Glazing that balance the light transmission, solar control and thermal gain with aesthetic enhancement are being extensively researched and as a result new varieties are coming into the market. Due to its durability, resistance to attack by corrosive media, translucence, abrasion resistance and pleasing appearance glass has a good demand for architectural applications in both temperate and cold countries. But in both situations, the main problem in its use is the lack of knowledge about the properties of the glass and their performance in the respective environmental conditions. To a large extent only the aesthetic beauty and the trends of using glass are given emphasis, which ultimately results in many costly side effects.

Clear glass is the most commonly used type of glass in the tropics, and too much direct sunlight transmission is its main deficiency. According to a technical catalogue of a very reputed glass manufacturer, clear glass allows at least partial radiation from 300 to 2500 nanometers to pass, which is that part of the solar radiation spectrum charged with energy. Six millimeter clear glass transmits 86% of the solar energy as light and heat and therefore the large amount of clear glass facing sun will create uncomfortable thermal environment inside buildings.

Compared to clear glass, tinted glass is a good solution in minimizing the excessive sunlight inside. However, when darker tints are used in large quantities, artificial lighting is necessary to supplement natural light since tinted glass absorb more energy than clear glass and it creates greater heat build-up within the building resulting in greater expansion of the glass surface. Perhaps this might damage the glass as a consequence.

Reflective glass also absorbs more energy while reflecting sunlight. Therefore when extensively used facing the direct sun, it will naturally cause problems of heating the interiors and causing glare in the exterior. Higher light reflectance will create nuisance for adjacent buildings and visual illusions.

Extensive use of glass with top lighting concepts can turn the buildings into virtual greenhouses. This can also create energy management problems in buildings.

Wrong application methods with exposure to rain or moisture for a long time before application, wrong transportation and storing may reduce the expected qualities of glass. It is necessary to get the proper advice of skilled personnel before application in order to prevent defects in the long run. Normally aluminum channels, silicon and beading are used in framing and sealing glass in buildings. When they are applied incorrectly, it could result in pealing off of beading, brittling of silicon, oozing of sealant oil, seepage of water, and discoloured or distorted glass. The rainbow effect is a particular discolouring defect, which is caused due to moisture condensation on glass surface for a long time (about 6 months). Discoloured surface could be cleaned with corrosive media, which is very expensive and risky. Therefore much attention should be paid to glass application to prevent these defects at the design stage of buildings.

Performance Test

The intention of this study is limited only to investigate whether the glass types available are rationally used in buildings in tropical urban climatic conditions with the desired effects and expressive qualities.

In order to widen the understanding, a performance analysis was carried out for selected types of glass under ambient conditions. Finally, with the findings of the experiment the existing knowledge about the use of glass was reviewed both in terms of utility purposes and expressive purposes.

The performance analysis was based on an experiment carried out using a scale model. The focus of this experiment was on the microclimate the glass creates inside buildings.

The aim of this experiment was to find out the suitability of most commonly used glass types by investigating the performance of them under natural light in different orientations and times of the day. The conditions were limited due to practical difficulties, and in this context the conditions would mean orientation of the glass and the availability of shading with the full-face glass façade. From an analysis of the information recorded, an attempt was made to determine the daylight factor[1] for selected glass types.

It has been assumed that the findings of this experiment would be applicable to actual situations on the basis that the trial was carried out with a simulated model and an accurate Digital Luxmeter and mercury thermometer with utmost care.

It is a known fact that the technical data available on the performance of glass in catalogues are based on experiments done under laboratory conditions. However, this performance test was carried out to investigate how glasses act in tropical urban climatic conditions with respect to practical situations. The test was conducted in the open air in Gampaha, Sri Lanka.

The experimental model had proportions of an actual office room, 3600 X 3600 X 2700 mm (LBH), and constructed to a scale of 1:3. The internal dimensions of the model were 1200 X 1200 X 900 mm (LBH). One wall was kept open with groves to insert glass panels and with fixed rubber beading. That wall could be fully glazed as in an office space adjacent to a curtain wall while the other three walls, ceiling and the floor were completely insulated to prevent light and heat coming in. The wall opposite the glazing

[1] An indication of the amount of daylight at a point within a room is the ratio of the daylight illuminance at the point to the instantaneous illuminance outside the building from complete hemisphere of sky (excluding direct sunlight). (Pritchard, 1995:90)

was openable in order to go inside the model for measurement purposes.

The model was made out of two layers of 6mm thick marine plywood sheets with 75mm thick "Rigifoam extruded Polyurethene" insulation sandwiched between the two layers. The interior of the model was painted matt white using emulsion paint with a reflection factor of 80, while the exterior was painted in "Weather shield" paint to simulate realistic conditions. A grove was made in the model to enable insertion of a shading device at the top of the glazed wall and the device was also painted in the same emulsion paint. The projected length of the shading device was taken with regards to the sun's position at midday, which is the optimum that shades the full face of the glass. For easy rotation and moving, the model was mounted on caster wheels.

Tested Glass Types

The selection criteria for glass for the test were twofold, considering the most common types in buildings and the present demand for glass. They were selected from 6mm thickness as it is the common size used for full-face glass facades in commercial application, and the types of glass were, clear, laminated clear, blue tinted, and reflective glasses of blue, grey, silver and pink. All the selected glasses were from a leading glass manufacturing company in Europe.

Procedure

The experiment was to compare the daylight illuminance level at the center point of the model interior. The experiment was repeated by placing different types of glass on the exposed surface of the model.

Starting time of the experiment was recorded with the sky condition. Measurements of the internal and external temperatures were noted. The model was placed in such a way to avoid direct sunlight falling on the lux meter sensor and the sky illuminance was measured. The sensor illuminance reading was taken as quickly as possible by entering the model. Soon after that, external illuminance was measured in the same way. Lux meter readings were repeated in the same manner with the shading device fixed to the model. Readings were recorded at every half an hour intervals. This was continued for two to three hours or until the sky conditions remained same.

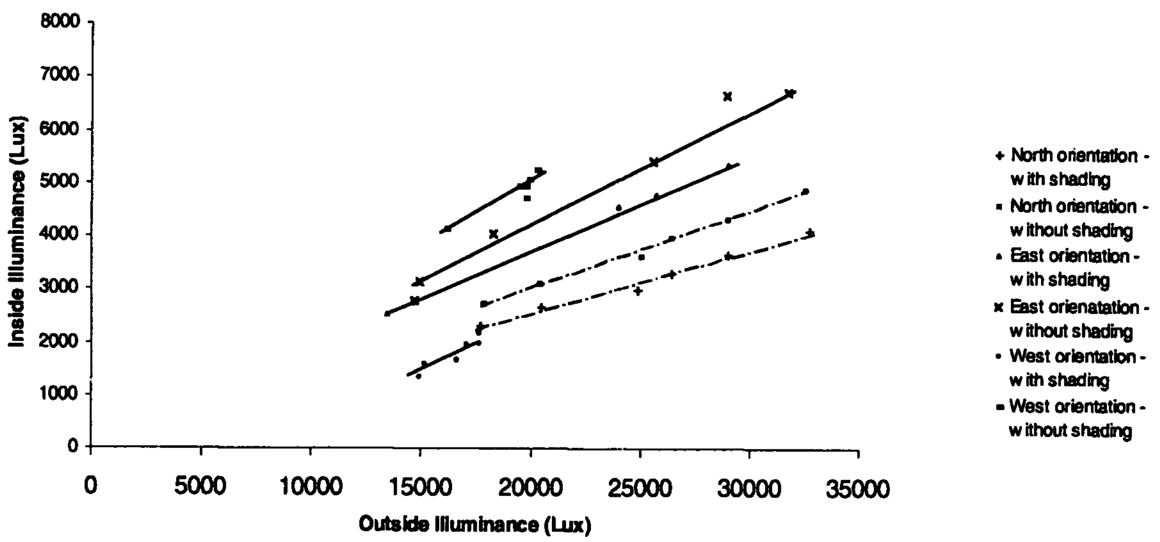
The same experiment was repeated with all the glass panels and in different days and at different times to the same orientation. Then the same types of readings were taken by placing the model to face both North orientation and South orientation to check the accuracy. The different sets of readings obtained were analyzed by means of computer generated graphs. Time periods when the experiment was conducted and the sky conditions were indicated in each graph prepared for different types of glass. The daylight factors were computed from the gradient of each graph, with or without shading device.

Analysis of the test results

Readings pertaining to heat showed an increase in heat build-up in almost all the tests. There were very few variations in the reading sets and therefore they were not plotted on graphs.

A typical graph with plotted readings on Illuminance levels for Clear Glass to North, West and East orientations are shown below in Graph 1.

Graph 1 - Illuminance levels of Clear Float Glass



Referring to graphs obtained for clear glass, the following conclusions could be made.

Inside illuminance readings were always high with the clear glass. When the shading device was applied the percentage reductions were 16.07% and 16.88% respectively for North and East orientations. In both these situations the direct sunlight falling on to the glass was minimized by shading device and due to by sun's position at the opposite side respectively.

Further the daylight factors have changed due to increase in the level of internal illuminance. This increase is due to the orientation, which is east. Since there were no considerable obstructions, it could be expected that there were no external reflections or reduction of external illuminance. This indicates that there was a considerable effect on the internal illuminance not only with the shading device but also with the orientation.

When glass was tested in the afternoon with orientation to the West it was observed that the internal illuminance was higher than the external illuminance. This was due to direct sunlight coming into the model through glass. When the shading device was fixed on the west oriented glass the daylight factor was observed as having a value similar to an East oriented glass without a shading device.

As the standard Sri Lankan sky illuminance (design illuminance) was taken as 7000 lux and the standard office interior design illuminance was taken as 300 lux (which could be considered as the illuminance level for commercial office interiors), the daylight factor should have been 4.28%, which is very much less than all the daylight factors obtained from this study graphs. This means that the use of clear glass on the whole façade create interiors with enormous amount of light, which makes the interior very uncomfortable. Even the North orientation with shading could not offer comfortable lighting conditions. Therefore, while keeping around the standard daylight factor with the largely varying external illuminance levels, what can be recommended is to have a combination of glass wall with masonry wall and external shading devices.

This experiment demonstrates that the performance data given in technical catalogues cannot be observed in Sri Lanka as it is under tropical climatic conditions

Experiment with Laminated Clear Glass

Referring to graphs obtained for Laminated clear glass to different orientations, the following conclusions could be made. (Please refer Table 1 and Graph 2.)

Inside illuminance readings were always high with the Laminated glass and the percentage reduction with shading device application were 21.01%, 22.57%, and 23.17% in North, North-East and East orientations respectively. These percentages remained nearly the same, as the direct sunlight falling onto the glass was minimized by shading device and by sun's position at the opposite side respectively. Considering the two time periods the North oriented glass façade was exposed, a small percentage difference was seen as due to the sun's position close to the earth which brought direct sunlight to the glass surface at an angle and from West. (This could have been avoided with a vertical shading device). This was further proved by clear increase in the daylight factors with sun's positions at midday and afternoon with different sky conditions but with the same orientation. Therefore, it can be said that even to the North orientation the light entering inside through the glass pane may vary either with the time period of the day or sky conditions. When there is a cloud cover, the sunlight reflected as a result would be at different angles, which falls on the glass surface and affects internal illuminance.

To obtain the required daylight factor of 4.28% under these conditions, it is necessary to reduce the glass area, otherwise the full face glazing create too much light inside the building.

Experiment with Blue Tinted Glass

Referring to graphs obtained for Blue tinted glass to different orientations, the following conclusions could be made. (Please refer Table 1 and Graph 2).

The daylight factors for Blue tinted glass are comparatively less than clear and laminated clear glass, that is, because the light transmission through the glass pane is lesser in this type. Therefore, in cases where the reduced lighting level inside a building is required, blue tinted glass could be an alternative.

With the shading device, the daylight factors took nearly similar figures in all the three orientations, whereas without the shading device the readings varied much more. This was because of the direct sunlight coming inside from the West orientation. It indicated that even for the same glass, the transmission of light inside might vary with the angle of light falling on the glass pane due to the sun's position in the sky with respect to the orientation.

Experiment with Blue Reflective Glass

Referring to graphs obtained for Blue reflective glass to different orientations, the following conclusions could be made. (Please refer Table 1 and Graph 2).

The experiment readings indicated that the light transmittance through Blue Reflective glass was very much less than Clear, Laminated Clear and Blue Tinted glasses. This indicated that the reflective coating applied on the glass surface reflected most of the light that fell on it causing better performance with natural light conditions.

However, the daylight factor (1.66%) obtained for North orientation was well below the optimum daylight factor of 4.28%. Therefore, even a whole façade completed with Blue Reflective glass will not provide required lighting levels inside. As a result supplementary lighting will be necessary from artificial sources. This is a situation, which should be avoided as much as possible in a tropical country with so much natural light.

Regarding the West orientation, the west sun increases the internal illuminance that lie near the required daylight factor. However, this will not be the same in the morning and the daytime. Therefore, this type of glass applications needs to blend with other sources of light for sufficiently lit interiors.

Experiment with Grey Reflective Glass

Grey Reflective glass was observed as creating an internal illuminance, which was always very much less compared to the external illuminance. The daylight factors for Blue and Grey Reflective glass fall within a close range in terms of their performance with natural light.

Experiment with Silver Reflective Glass

Referring to the graphs obtained for Silver reflective glass it was found that the daylight factor was very much less with compared to other glass types considered previously. It was a 93% reduction compared with clear glass. With the use of shading device for North and East orientations there was a reduction of internal illuminance of 30% and 26.6% respectively. Therefore, it could be said that there is no need to use any shading device for Silver Reflective glass.

Experiment with Pink Reflective Glass

The illuminance data obtained for pink reflective glass indicated that this glass type lets the least amount of daylight enter through it. Uses of shading devices further reduce the daylight factor. Therefore, shading devices are not necessary in applications of Pink Reflective glass. This glass type is more suitable for use as total glass skin with artificially lit interiors.'

Graph 2 - Illuminance Levels
of Clear Float, Laminated Clear, Blue Tinted and Blue Reflective glass types to North Orientation

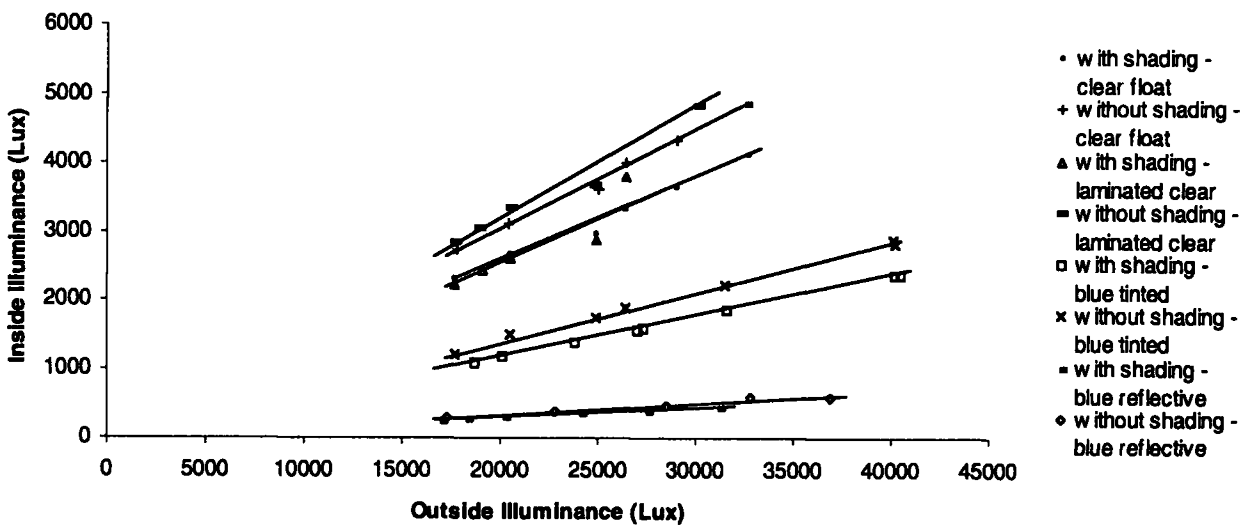


Table 1 : Experiment Results

Glass type	Day Light Factors Without Shading	Day Light Factors With Shading	Orientation	Time	Sky Condition
Clear	14.99	12.68	North	10.30am - 1.00pm	Bright, Clouds forming at low angles
	21.25	18.5	East	11.0 0am - 1.00pm	Partially cloudy
	11.69	9.74	East	3.00pm - 4.00pm	Cloudy, Sun in West sky
	25.5	11.13	West	3.00pm - 4.00pm	Cloudy, Sun in West sky
Laminated	16.08	12.7	North	10.30am - 12.00noon	Bright, Clouds forming at lo w angles
	24.23	18.76	North	3.30pm - 5.00pm	Cloudy. Sun in West sky
	10.40	7.99	East	3.00pm - 4.30pm	Cloudy, Sun in West sky
Blue Tinted	7.1	5.8	North	10.00am - 1.30pm	Cloudy, Patches of Clouds Here and there
	5.76	4.37	East	3.00pm - 4.10pm	Cloudy but Bright, Sun in West sky
	8.19	4.75	West	4.00pm - 5.00pm	Cloudy, Sun in West sky
Blue Reflective	1.66	1.42	North	10.00am - 1.00pm	Partially Clear
	2.65	1.63	East	3.00pm - 4.10pm	Cloudy, Sun in West sky
	5.05	3.39	West	3.30pm - 4.30pm	Cloudy, Sun in West sky

Summary of Experiment Results

As indicated above the performance data provided in glass catalogues usually correspond with data obtained under perfect laboratory conditions. Obviously these data do not tally with a performance test conducted under ambient conditions. The experiment results revealed that in a real situation, the factors like orientation in relation to the cardinal directions, obstructions in the close vicinity, sunpath, sky conditions etc., have a great impact on the amount of light entering through glass.

For the purpose of comfortable interior lighting levels it could be recommended that Clear and Laminated Clear glass types are the best, in combination with wall areas and shading devices. If a full face of glass is needed, blue tinted glass is a better choice. External shading devices are necessary to cut off the direct sunlight with this application. Reflective glass types are poor in transmitting light inside and therefore even with full face glazing the internal illuminance levels would be inadequate. They could be used with artificial lighting.

Considering the thermal data taken from the experiment, it was found that there was an increase of internal temperatures with all types of glass. The range was nearly the same for all of them (up to three degrees Centigrade increase at daytime.) This indicates that even with less visible light entering through reflective glasses, the heat increase is nearly the same. External shading devices reduce this by a small margin. Therefore, the use of reflective glass will not be very rational under tropical urban conditions.

The experiment was conducted using a fully glazed facade in order to test the maximum illuminance level, which can be entered through a glass façade. However, this experiment does not look into the effect of ground reflected component of natural light, design morphology, interior conditions including furniture and artificial lighting.

Conclusions

This study dealt with the subject of glass in architecture, with emphasis on the aspect of rational use in tropical urban conditions.

Glass being largely used in buildings as external envelopes, windows, doors, internal partitions etc., a field survey was carried out to find out the degree to which glass have been used for architecturally expressive purposes. In this regard the commercial buildings in Metro Colombo were observed and evaluated with the knowledge obtained from the existing sources. It could be judged that there were several buildings, which have successfully addressed the expressive qualities alone. Also it was observed that the emphasis paid on aspects such as performance, maintenance, energy conservation and, effects on the immediate environment were minimal. One of the common problems faced by the glass applications in tropical urban conditions is discolouring of glass. Direct exposure to weather agents, dust, careless storing, and wrong fixing methods and absence of external shading devices are its main causes. This is further aggravated by the poor maintenance of glass facades both from inside and outside.

The experiment results revealed that the data given in the glass catalogues do not adequately reflect the actual situations, because the sun path, orientation in relation to cardinal directions, obstructions in the close vicinity, sky conditions etc., have a great effect on the amount of sunlight falling on the glass façade. For instance, the daylight factors for the same glass type and orientation is different during the morning hours and afternoon hours.

Further, it could be found that Clear glass and Laminated Clear glass are the best in combination with wall areas under tropical urban conditions. Also tinted glass too can be used in cases where a full screen of glass is required. Reflective types of glass are not economical energywise as they require supplementary artificial lighting for the interior. However, the use of external shading devices can improve the interior lighting conditions as demonstrated by many contemporary buildings.

The overall research findings emphasized that the ways in which the glass has been used in most of our buildings are not rational. Although there are some buildings, which have achieved good expressive qualities by using glass extensively, in terms of environmental performance, maintenance, and energy consumption most of the contemporary commercial buildings in Metro Colombo do not demonstrate rational use of glazing materials.

It was found that the lack of knowledge about the performance and qualities of glasses, use of improper glazing materials, and non-conformity with the appropriate technology are the paramount reasons to this irrational use. It should be noted that even the principle agents of glass are either not aware of the performance of glass they import to tropical countries or they are reluctant to acknowledge if at all they are aware of the relevant facts. This too has a significant bearing towards the poor state of glass application in tropical climatic conditions.

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