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The Efficacy of Shading Design in Commercial Buildings in The Semi-arid Climate of Lahore; Focusing on The Geometry of Horizontal Shade

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Abstract- A building envelope acts as a barrier between outside and inside environmental conditions. A window provides the weakest thermal link in the building envelope between outdoor and indoor environment as it is least resistant to the outdoor environmental conditions. An optimal shading device can manage this situation by increasing the resistivity of the window which is important in semi-arid climates such as that of Lahore, Pakistan. This paper focuses on the geometry of horizontal shade that is desirable in Lahore's climate and its efficacy in terms of heat gain, daylight level, energy efficiency and thermal comfort in commercial buildings. The depth of the horizontal shade is calculated and verified by mathematical models as a first step in this research. The second step is the simulation which is conducted to evaluate the performance of designed horizontal shade on a window with 40% WWR and double low-E bronze glass on east, south and west orientations. The results show that the efficacy of a horizontal shade is the most for a southern orientation in climate of Lahore.

Keywords- Horizontal Shade, Heat Gain, Semi-arid Climate, Commercial Buildings.

I. INTRODUCTION

The current world is confronting three major challenges including population explosion, reduction of valuable resources and environmental deterioration. The population of the world has been multiplying at an alarming rate. Urbanization is taking place all over the world. The human race has caused exhaustion of the precious natural resources to fulfil their needs and this has resulted in the deterioration of the environment. It can be concluded that the above-mentioned problems have arisen due to human activity on the planet. Fulfilling the demands of increasing population has accelerated excessive use of energy (for employing fossil sources) in all sectors of life. In this context, building sector is very important and cannot be ignored [1]. Buildings are responsible for 32% of total global energy consumption and 19% of GHG emissions. This consumption and emissions estimated to get double and triple by the mid-
century. The major factors responsible for this increase is urbanization and affluence especially in developing countries [2]. In developing countries like Pakistan, the building sector is responsible for 50% of energy consumption, the maximum as compared to other sectors like transportation, agriculture, industry etc. [3]. The reason for this huge energy consumption is that buildings are being designed and constructed ignoring the local climatic conditions thereby needing huge amount of energy to attain thermal comfort level. Buildings can be designed to achieve thermal comfort with low energy consumption. This goal can only be achieved by designing buildings according to passive design principles. The role of architect or designer should be, therefore, to avail the renewable energy sources (wind, solar) to fulfil the demand for heating, cooling and lighting in buildings [4].

The basic idea behind the passive design concept is that a building should obstruct the outdoor climatic extremes to negatively impact the building. The building envelope, therefore, must filter the incoming solar radiations to penetrate inside the building. The excessive solar radiation entering the building can cause over-heating inside the building especially in the hot climates like that of Lahore. As far as building envelope is concerned, fenestration area is very important as it acts as a point of exchange between the outdoor and indoor climatic conditions. In an earlier study, a detailed analysis was conducted to investigate the role of orientation and glass type in the climate of Lahore using computer simulation for fenestration parameters. A critical limitation of this previous study was the lack of consideration of shading devices as a parameter of fenestration. [5]

The role of shading devices in reducing the thermal gains inside the building is very important. It is an acceptable reality that penetration of daylight inside the building produces a beneficial effect on occupant health and also increases their productivity. The appropriate shading has ability to filter the incident solar radiation and allowing daylight with reduced solar gain inside the building.

This shading strategy is very useful in the hot climate like that of Lahore. Furthermore the design of the shading device depends upon various factors like the location of the building, climate of the area etc. [6] [7]. Numerous research studies have been conducted in all parts of the world to determine the characteristics of shading devices which have been discussed in section 2. And this study is unique as it has been specifically targeting the climate of Lahore, Pakistan.

A. Shading

Shading the window is important and desired where buildings get excessive heat in summer. These buildings getting solar gain result in increased cooling loads of the buildings and installation of mechanical cooling systems in the buildings. This excessive demand for cooling energy should be avoided by exclusion of undesirable heat from the building. An effective way to do so is to provide shading. Shading is the first tier to sustainable cooling approach. Fig 1. [4]

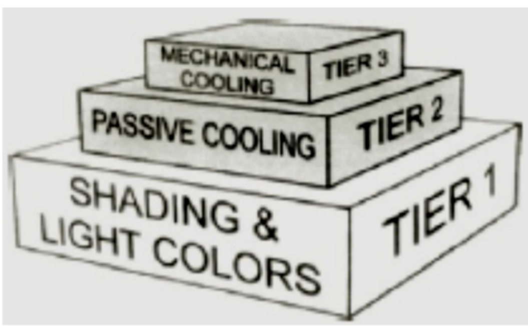

Fig. 1 Three tier approach to sustainable cooling design. [4]

The shading devices can be internal as well as external. But the external shading devices are comparatively more desirable as these are more efficacious in reducing solar gains. [8] [9]. As these are externally installed, these do not allow the excessive heat to penetrate the building space while internal ones block the excessive heat in the interior space after thermal heat gain has already penetrated into the building. External shading obstructs up to 95 % of the solar radiation striking the building surface. Fig 2.

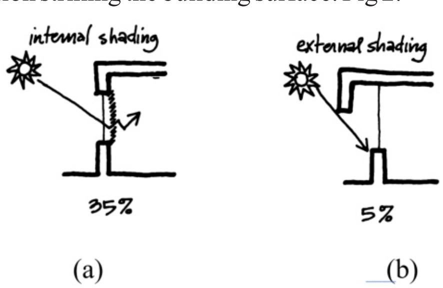

Fig. 2. (a) Percentage of solar radiation penetrating inside given internal shading and (b) Percentage of solar radiation penetrating inside given external shading

B. Types of shading devices

There are three basic types of sun shading devices, as follows:

1. Horizontal device (overhangs)
2. Vertical device (Vertical Fins)
3. Egg-crate device (combination of above two)

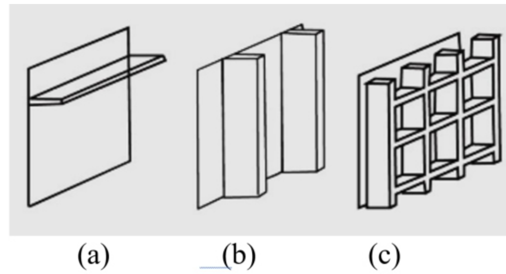

Fig 3: (a) Overhang (b) Vertical Fins (c) Combined / Egg crate device [10]

The suitability of any type of shading is dependent upon various factors such as geography (latitude and longitude) of the city, location of the building, sun angle, climate of the area, orientation of the window or façade etc. The horizontal shading device is most suitable to the scenario when sun is directly opposite to the façade of the building at high angle such as north and south facades. On the other hand, vertical shades are useful when sun is at lower altitude such as east and west orientation. [4] [8] [11] [12]. A recent study with reference to India suggested that vertical shading devices are also suitable on north facing windows on geographical locations that lie in equatorial plane having low latitudes. The reason for this is their sun path in summers where sun rises from north-east and sets in north-west [1]. (Fig. 4)

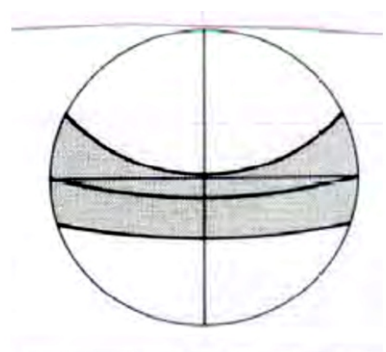

Fig 4. Sun path diagram of regions with having latitude 20° [13]

In short, the design of any type of shading device is not a very simple activity and various studies have suggested different calculators to design different kind of shading devices.

This research is focused on the design of horizontal shade in the hot (semi-arid) climate of Lahore and its impact on reducing heat gain in commercial buildings. The reason to choose the horizontal shade is that it is mostly desirable on north and south facing windows. And in the hot climate of Lahore, it is suggested to give more openings on north and south as it is easy to obstruct solar radiations to come inside the buildings on these orientations. As mentioned earlier that this research has been carried out in continuation of the previous studies that were conducted to test the impact of other parameters like orientation, glass material and window size on heat gain in Lahore's climate in commercial buildings. It is for this reason that commercial buildings are selected to study the role of horizontal shading. So the objectives of the study are:

I. To design the horizontal shade by calculating appropriate depth and width related to sun angles and window height.
II. To study the impact of designed horizontal shade in reducing heat gain in local climatic conditions through computer simulation.

II. Literature Review

Kirankumar et al. analyzed the impact of 4 different types of shading devices with combination of bronze glass (high performance glass with solar control properties) on 4 cardinal orientations on solar gains and daylight through computer simulation. Overhangs, louvers, egg crate and egg crate in combination with louvers were analysed in hot and dry climate of Jodhpur, India. Results were generated on peak days of the year i.e. summer solstice and winter solstice. The study concluded that in summer season, overhang in combination with louvers worked very efficiently regarding heat gain and daylight. On the other hand, over hang allows more heat inside the building on all orientations in winter season with ample light penetrating inside. Overhang is preferable therefore on north side in winters [14].

Alshamrani & Mujeebu investigated the effectiveness of over hangs and side fins on energy performance and aimed to find the best strategy regarding shading in the climate of Los Angeles. The research was reviewed due to its relevance regarding the evaluation of performance of overhangs and fins on east, south and west orientations. Simulations were conducting using various combinations of side fins and over hangs on a school building on east, south and west facades. The study showed that a decrease of about 13.6% in electricity consumption and about 12.1 % in annual energy cost can be achieved by installation of different combinations of overhang and side fins on three facades as compared to base case (with no shades). Another observation was that orientation also plays important role in this decrease. It was find out that all kinds of shading devices performed better on the south orientation as compared to east and west orientations. [15]

Brittle et al. reported on the most efficient shading device among multiple shading devices appropriate for use in commercial buildings in hot climates. Simulations were carried out to test 4 external shading devices i.e. horizontal over hang, angled over hang, multiple angled horizontal louvers and vertical shades. These 4 types were compared with base case i-e with internal blinds on east, south and west facades. Multiple angled horizontal shades were found to be most effective in hot climates with a decrease in cooling load on East, South and West facades up to 46.20%, 41.16% and 46.53% respectively. It was also found that with the usage of most effective external shading in combination with internal blinds can result in reducing energy to cool the space up to 30.69%. It was also worked out that increasing the depth of overhang leads to reduce the solar gains. [16] .

Saifelnasr developed a simple methodology to calculate the depth of horizontal overhang by knowing the latitude and shading height for different geographical locations. Methodology adopted to carry out this research was unique and it employed some measurements combined with some rationalization and suppositions to make that mechanism i-e design chart, easy. This include the application, orientation, thickness of external wall and shade etc. [8] .

III. Materials & Methods

The study is carried out to have an understanding about the geometry (depth) of the horizontal shade and its performance in terms of heat gain, day light level, energy use and thermal comfort level achieved in the overheated period of the local climate of Lahore. To design a horizontal shading device, mathematical calculation is done and the required depth of the shade is obtained. This depth is verified again by another derived formula [8]. After obtaining the depth of the horizontal shade, computer simulation has been done to analyse the performance of the designed shading device. Simulations have been conducted with the comparison of a base case i.e. a window with no shade with a window with horizontal shade installed on east, south and west orientations.. The simulations are conducted in a software by Lawrence Berkley National Laboratory (LBNL) named “COMFEN”. The reason for the selection of this software is that it is specifically designed to investigate the parameters of fenestration in commercial buildings and to address the issues of high performance fenestration systems. [17]

First of all, the climate of Lahore has been analysed and overheated period is determined by cut off time (time when partial shading is required) as well.

A. Climate of Lahore

The climate of Lahore can be termed as semi-arid or steppe (BSh) according to the Koppen classification of climates. [18] [19]. Lahore experiences long and extremely hot summers and cold but short winters. A temperature chart of Lahore for whole year is shown in Fig 5.

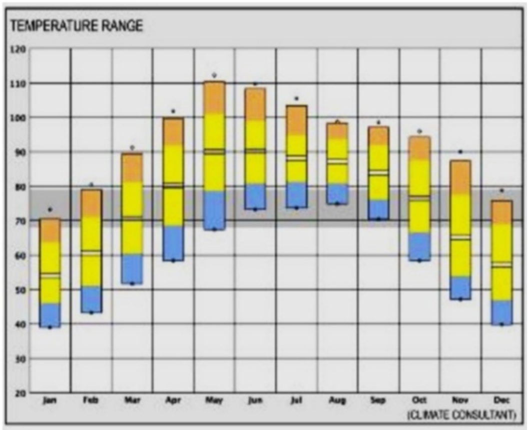

Fig 5: Annual temperature chart of Lahore [20]

The chart in Fig 5 shows the annual temperature range of Lahore. The x-axis shows the months in a year and y-axis shows the temperature in °F. From the chart, it is evident that mean temperature rises above the grey comfort range (determined by ASHRAE 2005 model of comfort) in April and it falls again into the comfort range of temperature in October. From the chart, it can be deduced that over-heating period of Lahore start from April till September. This period can be verified by the image shown Fig 6.

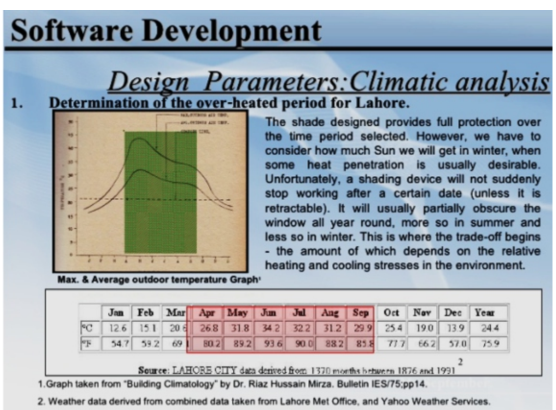

Fig 6: Overheated period of Lahore [21]

The image shown in Fig 6 is taken from a research conducted to develop a software to design shading for the climate of Lahore. It can be concluded that the time starts from 1st April. For calculating the depth of horizontal shade, 23rd March will be a convenient date as it is the equinox.

Buildings should perform as a response to local climate of any area. This demands the understanding of climatic challenges of that area. As mentioned in earlier that overheating caused by excessive incoming solar radiation in the building is a challenge in the hot climate of Lahore. In case of Lahore, therefore, main objective is to achieve comfort by cooling strategies summer. The cooling strategies for climate of Lahore with its psychrometric chart is presented in Fig.6

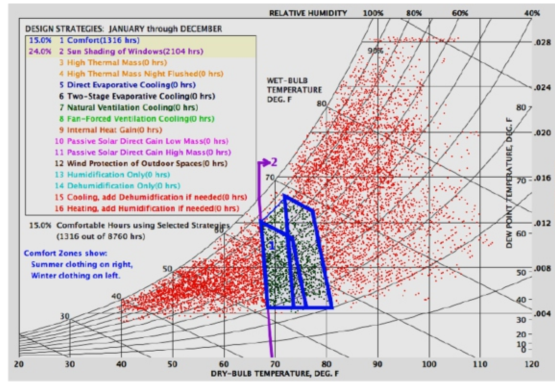

Fig. 7: Psychrometric Chart for Lahore, Pakistan (using ASHRAE Handbook of Fundamentals Comfort Model, 2005) [20]

The Fig.7 is representing passive strategies with their impact on human comfort in the climate of Lahore. The shading from sun accounts for 24% of human comfort level and so it acquires an important place as cooling strategy in the climatic context of Lahore.

B. Calculation of depth of horizontal shade

As it is a known fact now that the design of shading device is dependent upon two angles i.e. Horizontal shadow angle (HSA) and vertical shadow angle (VSA). [1] [10] [13] And also

HSA=Az-orientation……………….*i*

Where Az stands for Azimuth angle and orientation has a certain value

And also

VSA = $\tan^{-1}$[tan (Alt)/cos (HSA)]……………….*ii*

Where Alt represent Altitude angle.[10]

The equations i and ii show that we need to have the values of azimuth and altitude angles at the day from which shading is needed for the window (overheated period). These values can be obtained from sun path diagram of any specific location. So for Lahore, the values of two angles on 23rd March are

Az = 175.3^0 Alt = 58.6^0

So putting the value of Az in i and for south orientation we take the value of 180^0

$$\boxed{HSA=175.3-180^0}$$

$$HSA = -4.7^0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; iii$$

And now putting the values of HSA and Alt in ii

$$VSA = \tan^{-1} [\tan 58.6^0 / \cos -4.7^0]$$
$$VSA = \tan^{-1} (1.638 / 0.9966)$$
$$VSA = \tan^{-1} 1.643$$

$$\boxed{VSA = 58.67^0} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; iv$$

As already described by Szokolay, when Azimuth has the value as orientation has, then altitude angle and VSA will be the same. It means for an equator facing window (north or south) both angles i-e Alt and VSA will be the same.[13]. This is verifying the value of VSA obtained in *iv.*

Now it is also scripted that for horizontal shade

$$d = h / \tan VSA \; \ldots\ldots\ldots\ldots v$$

Where d = depth of horizontal shade. Horizontal shade has always been defined by VSA (vertical shadow angle).

h = height of shading (vertical distance between window sill up to the point where shade is to be installed) Fig. 8.

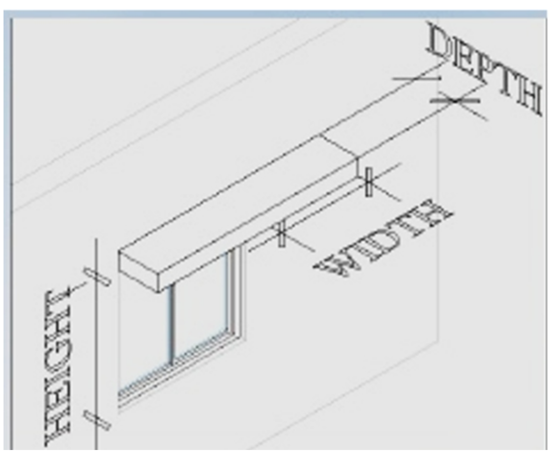

Fig. 8. Depth, Width and Height of horizontal shade

Now if the horizontal shade is to be installed at top of window (assuming window height 1.524 m with optimal 40% WWR on façade of room with 3.048m with window sill of 0.762m) then height must be 1.524 m. Putting the values of height and VSA in *v*

$$d = 1.524 / \tan 58.67$$
$$d = 1.524 / 1.642$$
$$d = 0.928\text{m}$$

C. Verification of Calculated depth of horizontal shade:

According to the formula

$$d / h = \tan (LAT^0) \; [22] \; \ldots\ldots \; vi$$

Where d shows depth of horizontal shade, height shows height of shading (vertical distance between window sill up to the point where shade is to be installed) and LAT^0 is the latitude of Lahore. Putting the values of LAT^0 and h in the equation *vi.*

$$d = h \times \tan (LAT^0)$$
$$d = 1.524 \times \tan 31.5^0$$
$$d = 1.524 \times 0.61280$$
$$d = 0.93 \text{ m (3ft approx)}$$

Since the result generated is same from both formulas, the next step is to design the calculated shade in software and generate the results after conduction simulations with different scenarios. Also the result generated is equal to the value generated by Saifelnasr in his design chart with same values of latitude and VSA. [8]

D. Computer Simulation:

The research is carried out by simulating different cases of windows with horizontal shading device of calculated depth on east, south and west orientation. The simulation tool is a software named as "COMFEN specifically formulated to investigate the impact of window parameters in specific climates on the heat gain and energy consumption in the case of commercial buildings. The graphs presented in the later section are generated through software.

The base case is a façade 10ft high and 20 ft wide with 40% window wall ratio (optimum size for hot climates) having double Low E Bronze glass (high performance glass) with air gap with no shade. The other scenario is created with previous dimension, WWR and glass material. The only difference is that the second scenario has a horizontal overhang of the calculated depth calculated in section 3.2. These two scenarios are tested on east, south and west facades and the results generated are mentioned in the later section. The north orientation is not considered as it is the only orientation with diffused sunlight penetrating the building according to sun path diagram of Lahore. As the window does not experience direct sun exposure on the north orientation, it is not considered for simulation.

IV. Results and Discussion

A. Façade Models:

Different scenarios have been analysed in the software

Scenario 1. Façade, 10ft high and 20ft wide, having 40% area covered with window having Double Low E Bronze glass with air cavity without horizontal shade facing *east* orientation.

Scenario 2. Façade, 10ft high and 20ft wide, having 40% area covered with window having Double Low E Bronze glass with air cavity with horizontal shade of 3 ft depth, 16ft width and 0.5ft thickness facing *east* orientation.

Scenario 3. Façade, 10ft high and 20ft wide, having 40% area covered with window having Double Low E

Bronze glass with air cavity without horizontal shade facing *south* orientation.

Scenario 4. Façade, 10ft high and 20ft wide, having 40% area covered with window having Double Low E Bronze glass with air cavity with horizontal shade of 3 ft depth, 16ft width and 0.5ft thickness facing *south* orientation

Scenario 5. Façade, 10ft high and 20ft wide, having 40% area covered with window having Double Low E Bronze glass with air cavity without horizontal shade facing *west* orientation.

Scenario 6. Façade, 10ft high and 20ft wide, having 40% area covered with window having Double Low E Bronze glass with air cavity with horizontal shade of 3 ft depth, 16ft width and 0.5ft thickness facing *west* orientation.

B. Impact on Heat Gain:

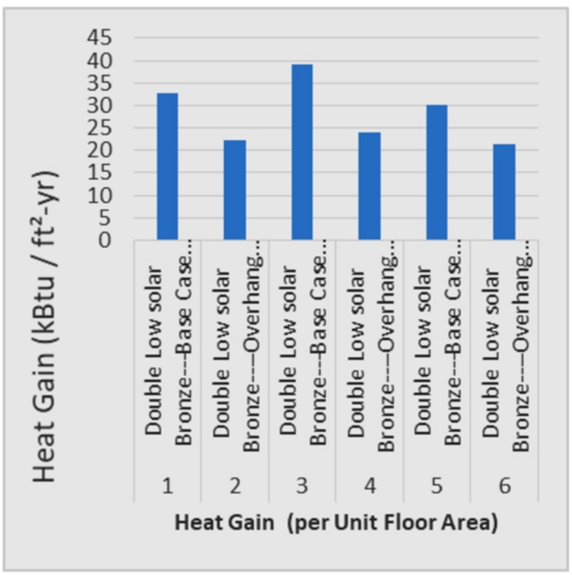

Fig. 9: Comparison graph of windows total annual heat gain of designed scenarios

Fig 9 shows the graph of heat gain in kBtu /ft^2-yr of all the scenarios explained above. Heat gain without horizontal shade is highest on the south orientation i-e 39kBtu/ft^2-yr and the value of heat gain is similar almost on east and west i-e 32kBtu/ft^2-yr on east and 30kBtu/ft^2-yr on west. It is evident from Fig 8 that with the installation of horizontal shade, annual heat gain reduces on all orientations. This decrease in the heat gain is highest on south. On south orientation it reduces from 39kBtu/ft^2-yr to 24kBtu/ ft^2-yr. As the heat gain is same on east and west orientation, the decrease pattern is also similar. The heat gain after the installation of horizontal shade decreases up to 22kBtu/ft^2-yr on east and 21kBtu/ft^2-yr on west. From the results generated from the simulation, it can be concluded that horizontal shade is the most appropriate on south orientation. On east and west orientation, the efficacy of horizontal shading device is less and therefore, additional shading is required like vertical shade or may be internal shading devices. Similar conclusions were drawn in a study of the hot climate of Jodhpur (Shaik 2016). Monthly average heat gain by window without shade and window with horizontal shade on east, south and west facades are presented in Fig 10 (a), 10(b) and 10(c) respectively.

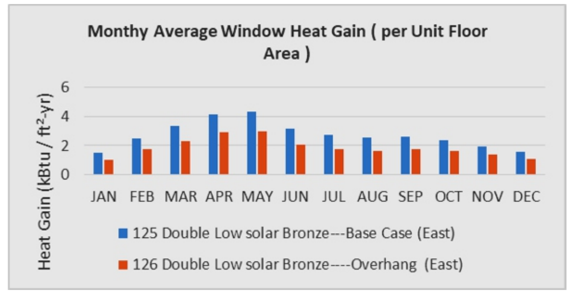

Fig. 10(a): Comparison graph of monthly heat gain of window with no shade and window with shade on East

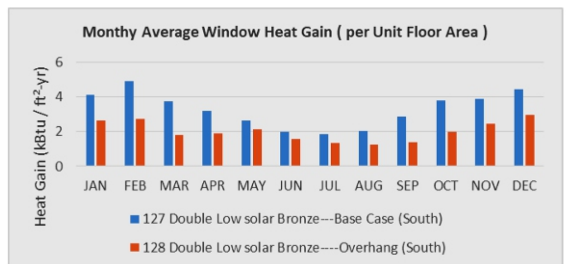

Fig. 10(b): Comparison graph of monthly heat gain of window with no shade and window with shade on South

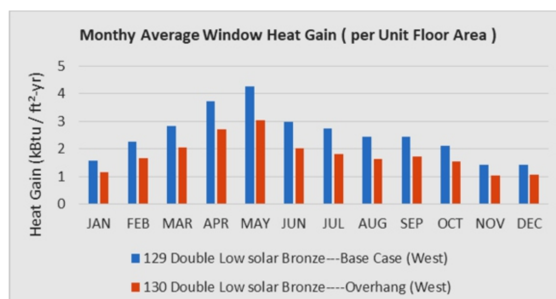

Fig. 10(c) Comparison graph of monthly heat gain of window with no shade and window with shade on West

As from the graph charts above, it is clear that heat gain pattern is different on south than on east and west orientations. On east and west orientations, heat gain increases from January to May. In these months therefore, the decrease in heat gain is high after the installation of horizontal shade especially in March, April and May.

But this pattern is different on south orientation. On south orientation, heat gain is higher to lower from January to June and then again lower to higher from June to December. The reason is that values of altitude angle are comparatively high in June and low in December and January on south orientation. It is for this reason the heat gain is higher in January and December on south. Winter gain is desirable in hot climates like that of Lahore. Excess can be eliminated with the help of horizontal shade.

B. Impact on Daylight:

The results generated regarding annual daylight summary by comparing the window without shade with the window with shade on all three orientations are shown in Fig 11 (a), (b), (c) as under.

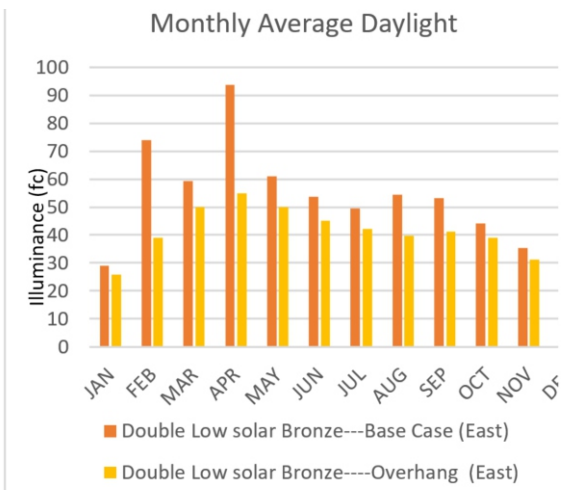

Fig. 11(a) Comparison chart of daylight level of window with no shade and window with shade on East

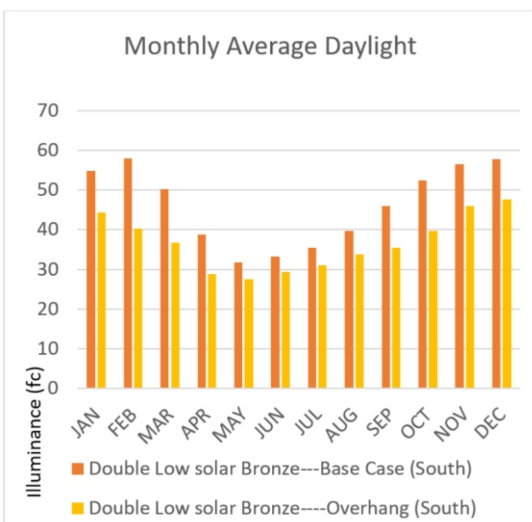

Fig. 11(b) Comparison chart of daylight level of window with no shade and window with shade on South

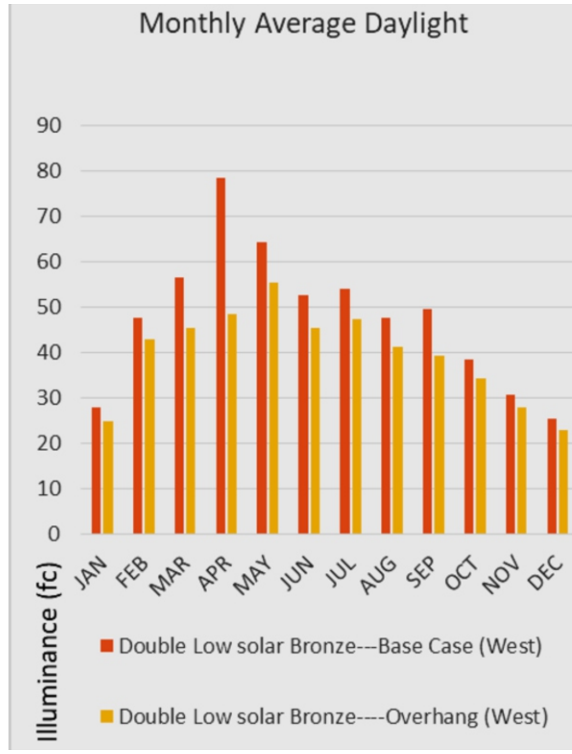

Fig. 11(c) Comparison chart of daylight level of window with no shade and window with shade on West

It is deduced from the charts shown in Fig 11(a),(b) and (c), that by applying horizontal shade on the window, the average daylight level falls between 40 to 60 fc (445 lux-645lux) on the three orientations. The workplaces or commercial areas should have daylight in a range between 27 to 46 fc (300-500 lux). (CIBSE F). It is evident from the results that efficacy of horizontal shade is more on south orientation as compared to east and west orientations. The values with shade are not exceeding 45fc (484 lux) throughout the year. It can be concluded that by installation of horizontal shading device, the decrease is high as compared to other two orientations. On the other hand, the scenario on east and west orientations is different from South. The daylight level of the window with horizontal shade reaches up to 55 fc (592 lux) on east and west orientation.

C. Impact on Energy Demand:

The results generated regarding Annual energy use by comparing the window without shade with the window with shade on all three orientations are shown in Fig 12 (a), (b), (c) as under.

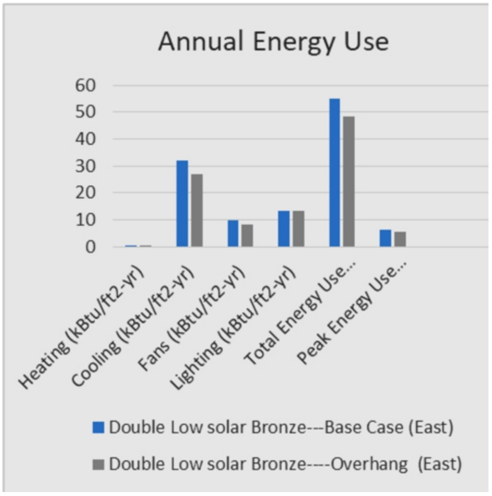

Fig. 12(a) Comparison Chart of Annual Energy Use by window with no shade and with shade on East

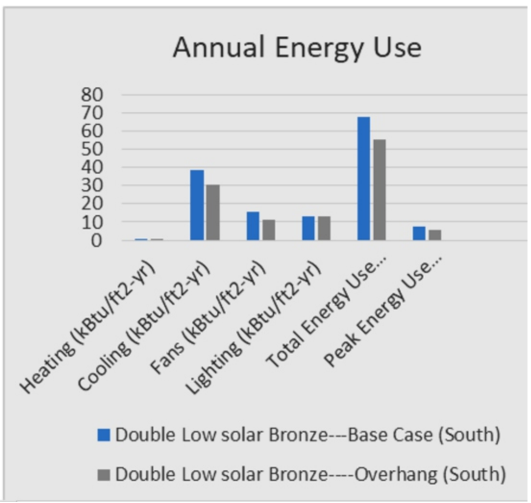

Fig. 12(b) Comparison Chart of Annual Energy Use by window with no shade and with shade on South

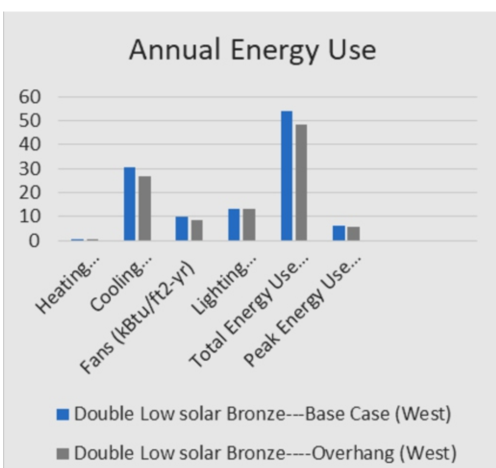

Fig. 12(c) Comparison Chart of Annual Energy Use by window with no shade and with shade on West

It is evident from Fig 12 (a), (b) and (c), the decrease in the value of total energy use is highest on south orientation after applying horizontal shade as compared top east and west orientations. The total energy use reduces from 55.23 to 48.37 kBtu/ft^2-yr on east, from 67.92 to 55.08 kBtu/ft^2-yr on south, from 53.94 to 48.44 kBtu/ft^2-yr on west orientation by applying horizontal shade. Thus it can be concluded that with the application of horizontal shade, the total energy use reduces 12.43%, 18.90% and 10.20% on east, south and west respectively. The reduction is higher on south orientation. It was also worked out from the results generated that peak electricity demand is reduced by applying horizontal shade up to 11%, 20% and 8% on east, south and west orientations respectively.

D. Impact on Thermal Comfort:

The results generated regarding Annual Avg Thermal Comfort use by comparing the window without shade with the window with shade on all three orientations are shown in Fig 13 (a), (b), (c) as under.

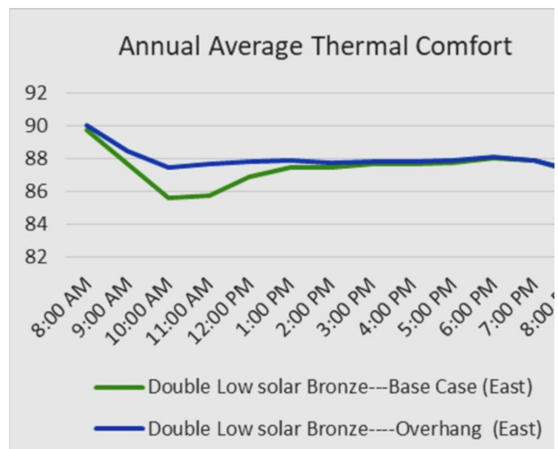

Fig. 13(a) Comparison Chart of Annual Avg Thermal Comfort with no shade and with shade on East

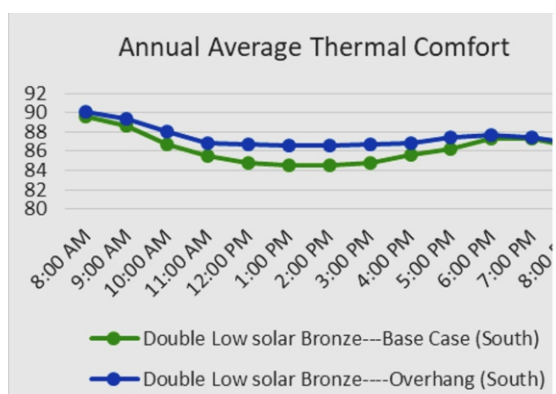

Fig. 13(b) Comparison Chart of Annual Avg Thermal Comfort with no shade and with shade on South

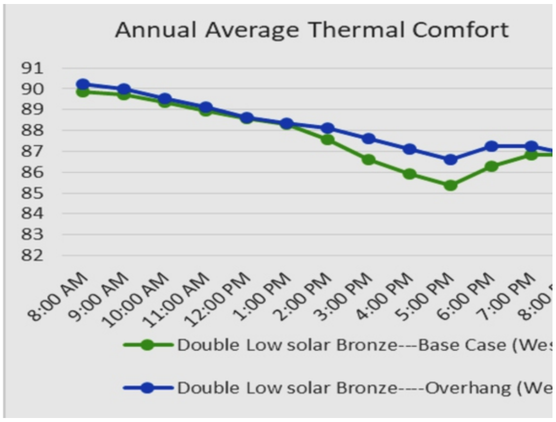

Fig. 13(c) Comparison Chart of Annual Avg Thermal Comfort with no shade and with shade on West

The Fig 13 (a), (b) and (c) show the comparison graphs of Annual Avg Thermal Comfort of window with no shade and window with shade on east, south and west orientations. The y axis in Fig shows the scale for thermal comfort expressed in PPS (percentage of people satisfied). It can be deduced from the results generated that the efficacy of horizontal shade is highest on south orientation in terms of calculation of thermal comfort. It was observed that on south orientation, the thermal comfort increases for a longer period of time i-e from 8 am to 6 pm after the installation of horizontal shade. It increases from an average value of 84.87 to 86.09 PPS. The scenario is different on east and west orientations. It is observed that thermal comfort value increases from 8 am to 1 pm on east and from 2 pm to 7 pm on west with the installation of horizontal shade. The value changes from 86.14 to 86.71 PPS on east and from 85.80 to 86.45 PPS on west orientation after installing the horizontal shade. It can be concluded that horizontal shade is most effective on south as compared to east and west regarding average thermal comfort value in terms of magnitude as well as time duration.

V. Conclusion

This paper investigates the influence of horizontal shading device, the depth of which is calculated through derives formulas from previous studies, on heat gain, daylight level, energy efficiency and thermal comfort on east, south and west orientations in the semi arid climate of Lahore. The glass used in the window was a high performance double Low E Bronze glass with air cavity. The reason was that high performance glass is gaining popularity in construction of commercial buildings. The following conclusions can be made after this study.

- Horizontal Shading device of optimal depth is preferable on south orientation with respect to heat gain, daylight level, total energy use and thermal comfort in terms of percentage of people satisfaction in the climate of Lahore. It can reduce the electricity demand in peak season up to 20%.
- It can achieve adequate daylight level in commercial buildings and in workplaces.
- Horizontal shade can increase the magnitude of thermal comfort for almost the whole day with an increase of average 1.44% with the base case.
- On East and West orientations, the horizontal shading device does not have a significant impact on heat gain and excess daylight level. On these orientations, additional shading along with horizontal shading or different types of shading devices or smaller openings can work well. Further research can help to find an optimal solution on these orientations.

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