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Performance Analysis of Vertical Fins as Shading Strategy in Commercial Buildings in Lahore; Emphasizing on the Optimal Depth of Vertical Fin

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Abstract- The buildings all over the world demand huge amount of energy for space heating, cooling and daylighting. This trend has raised concerns for energy consumption. Energy efficient buildings have become a norm to counter the issue. In this context, the role of building envelope is very important. Building envelope should act as a filter for unwanted climatic conditions. Excessive amount of heat gain has become note able due to increased WWR and glazed facades in commercial buildings in hot climates all over the world. Shading is a passive strategy which can provide solar control and mitigate the excess amount of heat entering the building. This research is carried out to understand the dimension of vertical fins and to evaluate the impact of Vertical Fins on energy performance of a window opening. The depth of shade is calculated first and then the designed shade is evaluated through simulation. Comfen program is used to conduct simulations. The results are generated in terms of heat gain, energy demand and daylighting. This study is conducted for the climate conditions and geographical values of Lahore with a semi-arid climate. Results show the reduction in energy consumption is highest on East after installation of vertical shades. Simulations showed the highest performance of vertical fins on east and west orientations as far as energy consumption is concerned.

Keywords- Energy Consumption, Vertical Fins, Thermal Performance, Semi-Arid climate, Heat Gain

I. Introduction

The building sector is very important as it was reported to account for 32% of global energy consumption and 19 % of GHG emissions in 2010. It is reported to be responsible for 28% of CO2 emissions in 2020. It was estimated to get double or triple in 2050 if the trend continued. [1]. The main reasons for this increase in the impact were worked out to be the population growth, urbanization, raised standards of living (cooking) and wealthy lifestyle specially in the developing countries.[2]. The above mentioned phenomenon can be best expressed in the following equation which is a result of a previous research.

$$I = P \times A \times T \quad [3]$$

Where I being the impact on the environment, P showing the population growth, A showing the affluence and T being the use of technology. But one parameter is missed in the above equation. That is energy needed by buildings for heating, cooling and lighting. The impact (I) can be decreased by reducing the use of energy in the building sector. The first step, in this domain, is designing the buildings using passive strategies so that they need lesser energy to heat, cool and lighten the spaces in order to create comfortable environment for the occupants. The depletion of non-renewable energy resources and high cost of renewable energy resources posed the demand of buildings with efficient use of energy. Energy efficient buildings, therefore, has become the most appropriate measure to counter the issue of energy related emissions and energy consumption mentioned in the start of this section [4].

Like other developing countries, building sector is responsible for 50% of energy consumption in Pakistan as well. This emphasized the need of energy efficient building design employing passive strategies in the country. [5] Passive design principles suggest the blocking of unwanted climatic conditions to remain outside the building to maximum extent. The building envelope, therefore, becomes important as it should limit the unwanted heat or chilled air to remain outside the building. [2] In this context, hot climates have become important all over the world because the demand for energy needed for space cooling has increased in hot regions with the passage of time. (Fig 1) [6].

The architectural design and the ways of construction of buildings also contribute to the above mentioned scenario along with other factors

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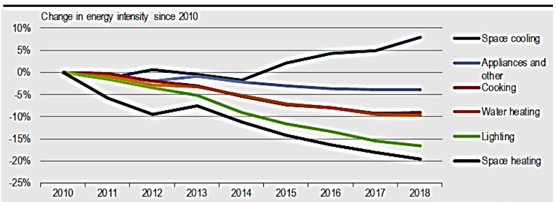


Fig.1. Global buildings sector final energy intensity changes by end use, 2010-18 [6]

like population growth, floor area energy service demand, climate etc. [6-7] The hot regions like Lahore needs mitigation measures to counter the situation and passive design is one of the mitigation strategy.

The major objective in the hot climate like that of Lahore is to keep the excessive heat out of the building in order to achieve cooling and save energy. There are number of parameters that can help to achieve the objective like orientation of building, building shape, thermal capacity of building materials and use of optimal shading devices. [8] Shading is a very important approach to avoid excessive heat and to cool a building. Shading of buildings and windows as avoidance of excessive heat is the first step of the three steps approach to passive cooling. [9][7].

In hot climate, the protection of windows with proper shading devices has become desire able with the increase of use of glass in building envelope. The fully glazed facades have been widely designed all over the world to provide view, light, transparency and have become a trend k. These facades, simultaneously providing light and view have the possibility to make the interior space over heat in summer. This requires more energy for space cooling, lighting etc. [10-11] This scenario poses some challenges for architects. The facades of commercial buildings, therefore, have potential in terms of design for energy saving in hot climate, for which shading is a good strategy.

A. Shading

Shading is the passive strategy that require the knowledge of solar geometry, climate and window characteristics to become effective. Shading can be achieved in three ways;

- By installing external shading device
- By using high performance glazing or limiting the size of glazing
- By installing internal shading device

External shading devices are important in terms of shading a building because these are most in expensive and noticeably enhance the aesthetic appearance of the building façade. [7] External shading devices are categorized as the following.

a. Horizontal Shading device (Overhang)
b. Vertical Shading device (Vertical fin)
c. Combination of the above two (Egg crate) [12]

This research is about the performance of vertical shading device in the climate of Lahore in commercial buildings. This is a study conducted in continuation of a previous studies conducted to evaluate other parameters of passive design like window size, window glazing, window orientation and optimal geometry of horizontal shade in climate of Lahore for commercial buildings.

B. Objective

This study will focus on the following objectives

a. To find the appropriate depth of vertical fins
b. To study the performance of vertical fins with on four cardinal orientations with respect to heat gain, daylight, glare control, energy consumption and thermal comfort.
c. To study the effectiveness of designed vertical shading device in the climate of Lahore.

There are numerous researches which have been carried out to determine the optimal characteristics and effectiveness of shading devices. The horizontal shade is found to be more effective on all orientations instead of vertical shading device and especially on south. The vertical shading devices have been explored less as compared to horizontal and egg crate devices. There is still the potential of vertical shading to be explore. The different studies employed different procedures and tools to conduct researches. These studies cannot be compared with each other due to lack of uniformity in them regarding procedure, locations, window characteristics, result outputs and research tools. The results of researches are focused on different parameters like thermal performance, heat gain, daylight, energy consumption, space cooling, method to determine the efficiency etc. [13] This study is, as already mentioned, is a continuation to previous research conducted in the same region, climate with the same tool to find the optimal design (depth) of horizontal shading device and evaluating its performance through simulation.

The researchers conducted about the performance of vertical shading device has been reviewed in the next section.

II. Literature Review

Berkouk evaluated the efficacy of vertical shading devices in terms of thermal performance in the apartment building in hot climate. Different shading scenarios having no shade and vertical shades of 12, 25, 50 and 100 cm have been compared on cardinal orientations using simulation technique. TRANSYS software was used as a tool to find ambient air temperature difference as a parameter for thermal comfort. The study concluded that the vertical shading devices with projection ranging from 12-100cm are more effective in summer as compared to winter. And the efficacy of above mentioned shading devices was found to be maximum at east and west orientation. [14]

Freewan analyzed the impact of fixed shading devices in the south west facing offices in the campus of a university in Jordan. The vertical fins, diagonal fins and egg crate were evaluated by installing on the office windows on two stages; one with temporary material and the other with improved design and materials. The research was carried out with experimentation and simulation as well. Results were concluded with respect to Air Temperature, Daylight Quantity, Daylight Quality, and View and User Interaction. Diagonal fins performed well in terms of Air Temperature, User Interaction and Daylight Quality. Vertical fins provided good view for the whole day and good environment for users until 2 pm. [10]

Alam studied the influence of window glass and external shading on the solar energy gained and lost through window area in residential buildings in the climate of Bangladesh. Energy Plus software was used to carry out the research as a tool. The over hangs and side fins of optimal depth were found to reduce the annual energy transferred through windows to a considerable extent on east, south and west facades.[15]

Idchabani explored the potential of overhangs and side fins in reducing heating and cooling demand in hot climate through computer simulation. The study was carried out using varied projection factors (PF) for overhangs and side fins (0.15, 0.25, 0.4, 0.6) and for varied orientations (S, SW, W, NW, N, NE,E, SE). Results showed that influence of side fins and overhangs on heating follow the same pattern as far as orientations are concerned. Heating requirements increase with the use of overhangs and side fins at south, SE, SW orientations. The heating energy demand reduced to one third on East and West orientations in case of both overhangs and side fins. The influence of vertical fins is less as compared to overhangs. The noticeable reduction in cooling requirements is recorded on NE and NW orientations in case of vertical fins. [16]

Ali & Ahmed conducted a simulated study to notice the effect of horizontal overhang, vertical fins and egg crate shading devices on the thermal performance of residential buildings on cardinal orientations in New Assuit city of Egypt. The research was carried out using TAS software as research tool which is specifically designed to analyze the thermal performance of buildings. A semi-detached house type from existing typologies of the city had been selected to run the simulation. The reduction of about 1.5^{o}C was achieved on N,E and W facades with the use of vertical fins.[17]

III. RESEARCH METHODOLOGY

The research is carried out to have an understanding about the optimal depth of vertical fins and its performance evaluation in case of commercial buildings in the climate of Lahore. The performance regarding heat gain, daylight, thermal comfort and glare will be evaluated. In this study, first step is to design vertical fin with optimal depth, mathematical formula is applied. Then the next step will be the computer simulation to examine the values of hat gain, daylight, thermal comfort and glare by application of designed vertical fin on cardinal orientations. The values obtained will be compared with the base case i.e without shading device. The tool selected for conducting simulation is a software “COMFEN”. COMFEN is developed by Lawrence Berkley National Laboratory (LBNL). It is a tool to evaluate window design parameters of commercial buildings. [18]. This tool is best suited for this particular research as it targets the concerns related to high performance window systems.

The first step of the study (designing the vertical device) is achieved by the analysis of the climate of Lahore, determining the overheated period of time. The designing of any external shading device required to calculate the overheated period of time (defined as time when partial shading is required in a specific climate) and calculation shadow angles. [12] For designing vertical shading, horizontal shadow angle (HAS) needs to be calculated. (Fig.2)

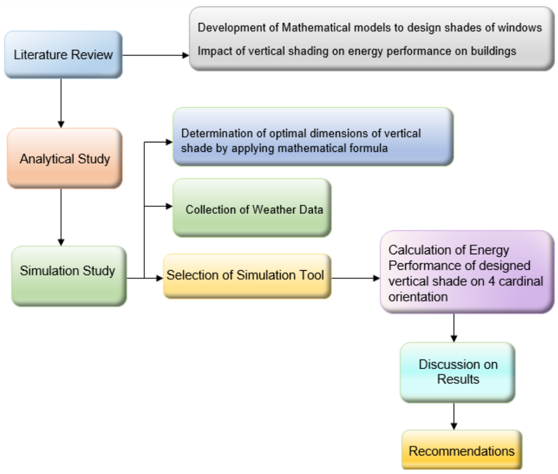


Fig.2 Flow diagram showing research methodology

A. Climate of Lahore

The Koppen Geiger classification of climate tagged the climate of Lahore as “BShw” which mean Semi-Arid/Steppe with dry winter.[19] Lahore experiences long and hot summers and short and cold winters. Overheated period of any climate can be traced out when outdoor mean temperature exceeds the thermal neutrality. The Fig. 3 shows the overheated period of time for Lahore.

The mean temperature rises above Thermal Neutrality (declared by ASHRAE 2005 model of comfort) in April and falls again in Comfort zone in October. The overheated period for Lahore is calculated to start from 23rd March to 23rd September after applying cut off dates. [2]

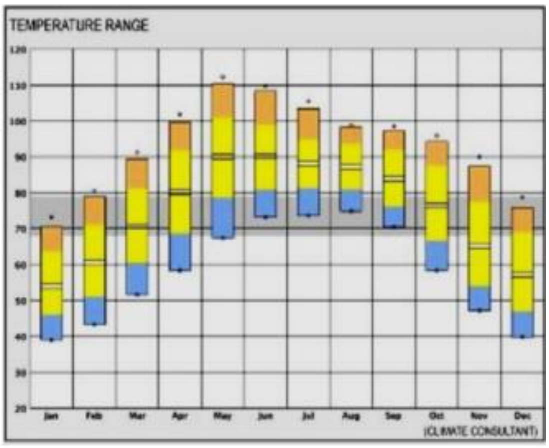


Fig.3. Temperature Chart of Lahore; y-axis shows temperature in °F and x-axis shows months of year [20][2] (Grey band shows thermal neutrality; Orange color showing the Average High Temperature, Yellow showing the Mean Temperature and Blue showing the Average Low Temperature in °F month wise)

B. Calculating Optimal depth of Vertical fins:

The designing of external shading devices requires two angles which are known as shadow angles. One is Horizontal shadow angle (HSA) and the other is Vertical Shadow angle (VSA). [21] The efficiency of vertical shading is determined by Horizontal Shading Angle (HSA). And HSA can be calculated by the following equation.

HSA= Az – ORI------- (i) [22]

Where HSA is Horizontal Shadow Angle and Az is Azimuth Angle and ORI is orientation of the window.

And also it is scripted that

d = w / tan HSA-------- (ii) [21]

Where d represents depth of vertical fin, w shows width of window.

The calculation of depth of vertical shading device requires the value of azimuth angle on the day at which shading is required (23rd March) at the time when sun is at low altitude i.e. sunrise. Vertical fins are more efficient on the North orientations in the regions with low latitudes and lie in equatorial plane. The vertical shade will perform better as compared to horizontal overhang because sun will be at low altitude. [12] The sun rises from North east and sets in North West in hot climate in regions with low latitude.

Now, the Azimuth Angle (Az) on 23rd March at 7:00 am (local time) is 92.3°, putting the value of Az in (i)

HSA = 92.3 – 0 (orientation is North; ORI 3 0)

HSA = 92.3

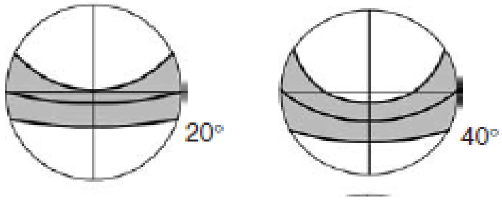


Fig.4. Sun Path Diagrams with low latitudes [23]

The façade with a width of 6.096 m and height of 3.048 m have a window with dimensions of 4.8768 m x 2.286 m in COMFEN façade model. This presents s facade with 30% WWR which is maximum recommended ratio for hot climates in previous studies. [24] Now putting the values of w and HSA in (ii).

d = 2.4384 / tan 92.3

d = 2.4384 / 2.5257

d = 0.9654 m

d = 1 m approximately

As in the next section, the length are determined in feet so 1m when converted into feet equals to 3 feet approximately. So the result is as under

d = 1m or 3 ft.

A previous study conducted in hot and dry climate also recorded the most effective vertical shade with a depth of 1 m or 3 ft. [25]

C. Computer Simulation:

The software selected for conducting the study is “COMFEN” which is specifically designed to test the parameters of window design in commercial buildings. Research is conducted by creating different scenarios. One is termed as base case which is a façade 10ft high and 20ft wide with a 30% Window Wall ratio (WWR) which is in the optimum range of WWR for hot climates. The window has high performance glass (double Low E Bronze glass) with air gap with no shade. The reason for selection of the type of glass is that this research is in continuation of a previous study which was done to evaluate the impact of a horizontal overhang in the climate of Lahore. [2] The second scenario created has all the conditions similar to base case except that it also has vertical shades of depth calculated in the previous section. The both scenarios are compared on North, East, South and West orientation to analyse the impact of vertical fins on the performance of the window in the climate of Lahore.

IV. RESULTS AND DISCUSSIONS

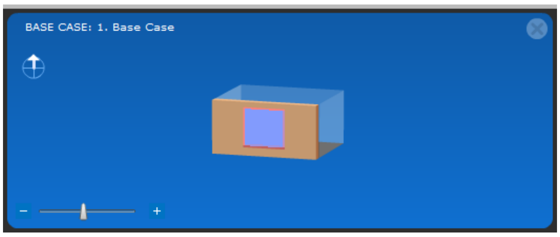
A. Scenarios:

As scripted in previous section, different scenarios have been created and simulated as far as window design and façade design is considered. Details of the scenarios is given in the table below.

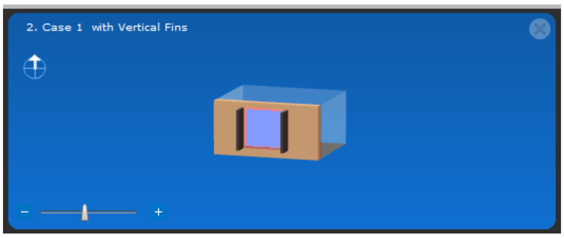
Table 1. Details of the scenarios created

Sr. No.	Name	Façade Dimension	WWR	Window Glass	Shading Device	Orientation
1.	Base Case	20 ft x 10 ft	30%	Double low solar low E Bronze Glass	No	N, E, S, W
2.	Case 1	20 ft x 10 ft	30%	Double low solar low E Bronze Glass	3ft vertical fins on either side	North
3.	Case 2	20 ft x 10 ft	30%	Double low solar low E Bronze Glass	3ft vertical fins on either side	East
4.	Case 3	20 ft x 10 ft	30%	Double low solar low E Bronze Glass	3ft vertical fins on either side	South
5.	Case 4	20 ft x 10 ft	30%	Double low solar low E Bronze Glass	3ft vertical fins on either side	West

Fig.5 (a) & (b) are showing the façade models developed which are compared on all orientations.



(a)



(b)

Fig. 5 (a) Base case Façade, (b) Façade with vertical fins compared on 4 orientations in terms of energy performance

B. Impact on Heat gain:

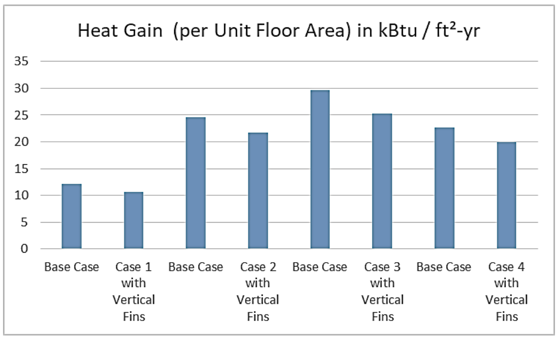


Fig.6. Comparison of all scenarios w.r.t Window Annual Heat Gain in kBtu / ft^2-yr : From left to Right (Base Case & Case 1 facing North, Base Case & Case 2 facing East, Base Case & Case 3 facing South, Base Case & Case 4 facing West)

It is clear from the graph above that Heat Gain is highest without shade on South i.e up to 30 kBtu / ft^2 yr and lowest on North without shade i.e up to 12 kBtu / ft^2 yr. The annual heat gain is high on East without shade i.e up to 24 kBtu / ft^{2}yr as compared to West without shade i.e 22 kBtu / ft^2 yr. It can be concluded that on all orientations, there is a reduction in heat gain after the application of vertical fins. At South orientation, heat gain reduces from 29.6 to 25.3 kBtu / ft^2 yr. this is highest of all the other orientations. On East and West orientations, heat gain reduces from 24.6 to 21.6 kBtu / ft^2 yr and from 21.6 to 19.9 kBt / ft^2 yr respectively. Heat gain reduction is equal on East and West. This reduction in heat gain is lowest on North, i.e from 12.0 to 10.6 kBtu / ft^2 yr. It can be deduced that reduction in heat gain due to vertical fins on south, East, West and North is from highest to lowest level.

C. Impact on Energy Demand:

The impact of vertical shade on Total annual energy use with energy use breakdown is generated and is presented as under.

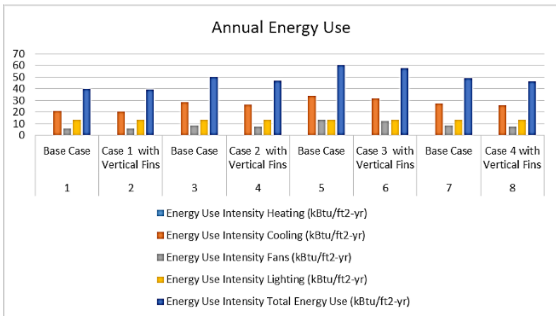


Fig.7. Comparison of all scenarios w.r.t Energy Use Intensity in kBtu / ft^2-yr

The graph presented in Fig.7 is showing the total energy consumption with a breakdown of energy use of all the scenarios. The total energy use is highest on south up to 60 kBtu / ft^2 yr and is lowest on North i.e up to 40 kBtu / ft^2 yr. It is observed that annual energy use decreases by installing vertical fins on all orientation. And the cooling energy has a major part in the energy consumption on all orientations. This is because Lahore fall in semi-arid climate zone which is hot and dry. The reduction in annual energy use is highest on East; up to 4 kBtu / ft^2 yr. The reduction in energy consumption is lowest on North i.e up to 1 kBtu / ft^2 yr. The reduction in energy use from highest to lowest is on East (7.21%), West (5.94%), South (4.77%) and North (1.3%) respectively. It is also calculated from the results that peak electricity demand on East orientation reduces by 8.45%, on South reduces by 3.64%, and on West reduces by 7.19% and on North by 0.14% by the application of Vertical fins.

D. Impact on daylight:

The impact of vertical fins on daylight is presented in Figure 8 (a),(b),(c) and (d).

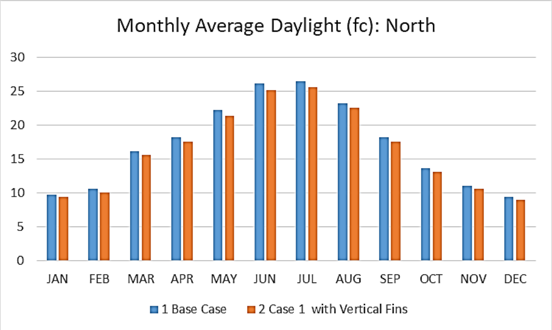


Fig. 8(a). Comparison chart of daylight level of base case with case 1 on North

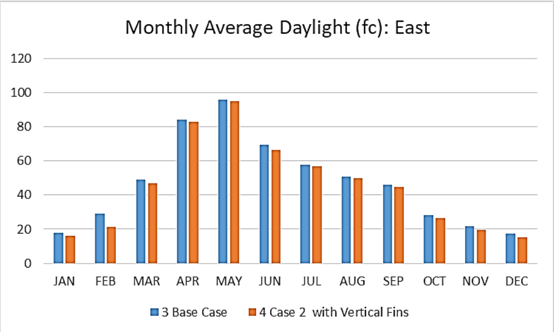


Fig. 8(b). Comparison chart of daylight level of base case with case 2 on East

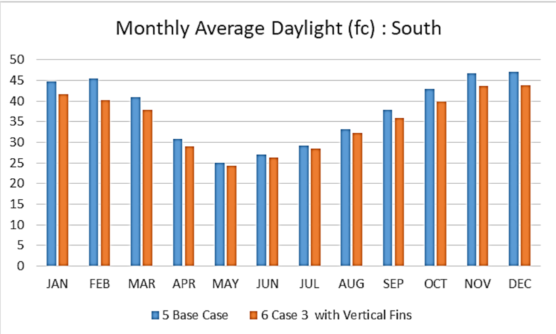


Fig. 8(c). Comparison chart of daylight level of base case with case 3 on South

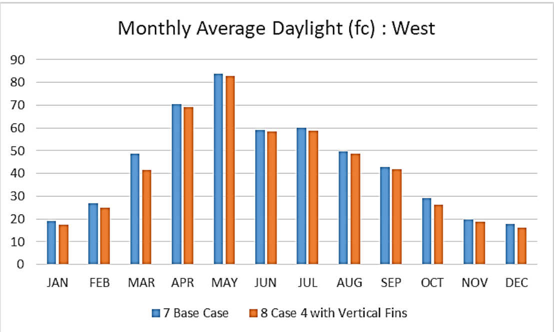


Fig. 8(d). Comparison chart of daylight level of base case with case 4 on West

The graphs above are showing daylight levels of different scenarios. The values of illuminance are marked along y axis in fc (foot candela). The above results are compared with a standard of illuminance range from 27-46fc on all workplaces (CIBSE F). It is observed that illuminance decreases with the installation of vertical fins on all the orientations. It is observed from the results generated that on North, the illuminance level is below the aforementioned range for most of the year. It lies in the standard range in May, June and July only. It can be concluded that illuminance is low on North. The illuminance on East and West lies in the standard range in February, March, August, September and October (for 5 months). For rest of the months, the illuminance on East and West is higher than the standard range. On South orientation, the illuminance lie in the range in all months. The same conclusion was found by Alam in their study scripted in section II. The optimum value of 3 ft for vertical shade was also concluded by Berkouk in their research mentioned in section II in previous half of this paper.

V. Conclusion

This research targeted to evaluate the performance of vertical fins with respect to heat gain, daylight and energy use intensity annually in the climate of Lahore. The depth of vertical fins was calculated with the formula. The simulation was carried out to study the impact of designed vertical fins on heat gain, daylight and energy consumption. The façade was designed with 30% WWR and high performance glass. Different cases were designed one having a façade with a window without shade, the other having the same window with vertical fins on both sides. These two facades were tested on 4 cardinal orientations to evaluate the performance of vertical shades. The following conclusions are derived from the research.

1. The heat gain reduces with the installation of vertical fins on all orientations. This reduction is highest on South and lowest on North. However, the reduction in heat gain is near to South on East and West.
2. Vertical fins are more efficient on East and West as compared to South and North as far as energy consumption is concerned. The vertical shades reduces the cooling energy demand particularly. The performance with respect to energy use is best on East.
3. The daylight is controlled best by vertical fins on South for whole year in commercial buildings in the climate of Lahore. On East and West, day light is controlled for almost half of the year.

   Overall the performance of vertical fins is more on East and West orientations as compared to South and North.

This study was the first step in the local climatic conditions to determine the impact of vertical fin on energy performance of commercial buildings. This can further open the doors of research in finding the optimum range of depth of vertical shades which can reduce the energy consumption in the local climatic conditions. Further, the research is suggested to find the cost analysis of such window systems as well.

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