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Impact Assessment of Window Orientation and Aspect Ratio on Building Energy Performance Using Comfen in the Climate of Lahore

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Abstract- Windows provide outside vistas and natural light, but because they are the least thermally efficient part of a building's façade, they can also be an undesired able source of glare and direct sunlight. While maintaining a thermally and aesthetically pleasing atmosphere for building occupants, a well-designed window system in addition to appropriate control measures can drastically cut building energy usage. In this paper, window design studies for high-performance buildings are examined and evaluated. The focus area is to determine the impact of two very important window design variables i.e orientation and window aspect ratio on energy performance of commercial buildings. The afore mentioned objective is achieved by adopting employed a dynamic method of energy calculation using the Software "Comfen" as a tool. The results are presented in bar diagrams showing statistical values obtained through software in the form of a table. The results showed that the horizontal windows performed better as compared to vertical windows on East & West orientation in the climate of Lahore.

Keywords- Window Aspect Ratio, Energy Efficiency, Commercial Buildings, Semi-arid Climate.

I. INTRODUCTION

Energy is extremely important because it is required for mankind's survival on a global scale. There are numerous characteristics associated with the usage of energy in living processes. First and foremost, the growing need for energy in various industries has a negative impact on the environment, which is deteriorating day by day. Second, the increased usage of energy is causing the depletion of valuable non-renewable natural resources, which are used to generate energy. The above two factors, together with global population expansion, are exacerbating the problem. All three are linked to excessive energy consumption. As a result, energy management and regulating excessive energy use are becoming increasingly critical.[1] [15]. There is an increasing gap between the demand and use of energy globally. Several countries around the globe are encountering the said issue. Like other countries, Pakistan is also facing the aforementioned issue. [12].

Various research highlight the building industry as the biggest contributor to global energy consumption. Department of Energy (DOE) declared that buildings are responsible for 40 % of the world's energy consumption and commercial buildings are responsible for 18% of this 40% share. [7]. Significant environmental problems like the greenhouse effect, acid rain, eutrophication of land and waters, etc. are related to excessive use of energy in buildings. These environmental problems occur due to the burning of fossil fuels. [2]. Due to the said environmental problems, the use of renewable energy has increased these days [13].

The scenario of energy use in buildings along with tremendous damage to the environment became worst after the Covid 19 pandemic. The pandemic of Covid 19 has had a profound impact on the building and construction sector in 2020, globally. The change in building-related energy use patterns caused CO_2 emissions from building operations to drop 10% to around 8.7 gigatons in 2020 from about 9.6 gigatons in 2019. Building operations reduced the world's CO_2 emissions by 10%, however, this decrease seems to be just transitory as emissions start to increase again with rising economic activity. 2020 proved to be an extraordinary year in terms of lesser energy use in the building sector and reduced energy-related CO_2 emissions in the buildings sector, there are still many improvements and measures that need to be taken. Countries of the world need to focus on energy-efficient buildings to build back better. [18]. The pandemic of Covid 19 has also emphasized the significance of healthy buildings including good air quality, natural ventilation, natural lighting, and green open space to prevent the spread of viruses. The attributes of a healthy building preferably a green building are good air circulation, proper window design, environment building materials, and green open spaces. [9] It can be concluded that window design is a crucial component of the building envelope and has a large impact on energy-efficiency of a building.

A. Window

Windows can significantly impact a building's thermal comfort and can cause a 30% effect on the heating and cooling load of a building. [11]. When analyzing energy-efficient windows, the daylight should be taken into account in addition to the thermal performance. Not only are most lighting systems inefficient, but they also produce a lot of waste heat, which increases the cooling load of the buildings in hot climates. So one of the primary functions in analyzing the window is lighting [4]. The various factors which determine the efficiency and performance of windows include glazing type, window wall ratio (WWR), construction material, shading, aspect ratio, window position, operational control, airflow control, etc. [7]

This study examines the impact of window orientation and window aspect ratio/window dimension on the energy efficiency of commercial buildings in the climate of Lahore. The reason of selection of these parameters is that these are the less explored side of window design. The outcome of this research will develop guidelines at the early stages of design to develop energy-efficient windows with respect to their dimensions and orientation in the climate of Lahore.

B. Window Dimension (Window aspect ratio)

The term "window aspect ratio" or "window dimensions" refers to the proportion of a window's width to its height. It is a window design parameter that is connected to the geometry of windows. Window position (where it is on a wall) and window-to-wall ratio are two more geometry-related elements of window design (the area of the window to the area of the external wall). Even the same WWR can have various aspect ratios. In literature, this is also referred to as window shape.

Only the Window Wall Ratio has been thoroughly investigated to determine an ideal range among the geometries linked to window design. The remaining two window design factors have received the least attention.

[6]Researched to examine the effects of all three design factors connected to window geometry on commercial buildings' energy usage. The study's goal was to identify the window design's ideal geometry values for both cold and hot climates. A genetic algorithm and Energy Plus simulation are built to accomplish the study's goal. A two-story commercial building model was also created with the aid of the Design-Builder software. The study was limited in that daylighting control and external shading were not taken into account. The findings provided recommendations for the form of windows in various climate zones, for instance, in Memphis, Tennessee, vertical windows facing south can reduce energy usage. Similar to this, in Helena (MT), orienting horizontal ribbon windows eastward can reduce energy usage. According to the study, a 2% reduction in energy consumption is possible in cold climates by adopting the ideal values of WWR, aspect ratio, and window placement in walls. The same can result in a 15% reduction in energy use in hot climates.[6]

[13]Investigated the integrated impact of 4 design parameters like window wall ratio, window shape, window position along with orientation on heating / cooling energy consumption and daylight performance in a fenestration system in office buildings. The study is conducted through computer simulation with the software Design Builder as a tool to achieve optimal characteristics along with the reduction of energy performance and achieving visual comfort. The research progressed by creating 180 scenarios with a set of characteristics regarding WWR, window shape, window position, and orientation. The optimal characteristics have been deduced for each orientation by the efficiency of the fenestration system. For North and East orientations, 30 % WWR along with square and horizontal shapes in central and upper positions are a good combination in terms of window efficiency. For the South orientation, 2 combinations proved to be fruitful in terms of energy efficiency and visual comfort. One combination is 30% WWR along with the horizontal shape of the window in a central position and the other combination is 40% WWR along with the square shape window in the central and lower position. West orientation configured best results with 30% WWR with a horizontal window shape in the upper position of the wall. [13].

[5]Reviewed and analyzed window design studies for high-performance buildings. To provide a full overview, the decision-making strategies of window systems are categorized and examined. A detailed study of sequential knowledge-based design methods and simulation-based optimization techniques is then provided. First, an overview of the design options that are currently available for window systems is presented. Finally, to support the development of all autonomous simulation-based optimization design approaches for high-performance fenestration systems, relevant obstacles and emerging research trends are highlighted and examined. The research stated that these studies could be seen as decision-making procedures to reach the window performance objectives by regulating several design variables (e.g., location and dimensions of windows, glazing

type, etc.) According to this review, window shape is an important variable among the concluded variables. [5]

II. MATERIALS & METHODS

The research is carried out using the dynamic method of calculation for the energy performance of buildings. The dynamic methods are accurate and the calculations have been done through computer simulation [10]. The tool adopted for simulation is the software “Comfen”. Comfen, name is derived from the combination of 2 words; Commercial and fenestration. As the name is indicating that this software is specifically designed to test the façade and window design parameters and their impact on energy performance of commercial buildings. The objective is to determine how the window aspect ratio affects commercial buildings' energy efficiency in Lahore's climate. The research is carried out in 3 steps. The first step is to analyze the climate of Lahore. In the second step, the façade models have been prepared with keeping all other parameters constant like window-to-wall ratio, window glazing, window frame, window position, etc. the only variable which changes is the window aspect ratio (window shape). The two types of shapes i.e aspect ratios are analyzed at 4 cardinal orientations and results are obtained in the climatic conditions of the study area which is Lahore.

This research is carried out by creating a general façade and varied scenarios have been designed having the same façade dimensions and different aspect ratios with same window wall ratio. The following are the limitations of this research

The rest of parameters of window design like window wall ratio, window glass & window frame are kept constant.

The shading devices have not been considered. The suurounding buildings are assumed to be non existant

C. Comfen

The software “Comfen” is selected to achieve the specific objectives of the research. California's Lawrence Berkley National Laboratory created the "Comfen" software. The Software uses the calculation engine of Energy Plus. The specific software is selected due to its simple user interface and free access [17]. Secondly, the software is specifically designed for architects to analyze the envelope design parameters specifically window design, and their impact on the energy performance of the buildings. And Comfen enables the architects to take decisions at the early design stage.

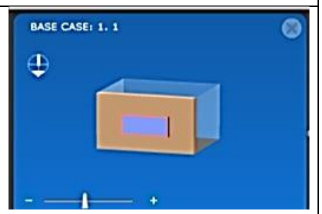
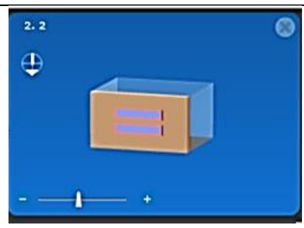
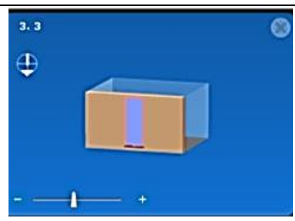
At the beginning of each project, Comfen requires the necessary information to execute the simulation. Each project requires a title, a location, a building type, and a vintage.

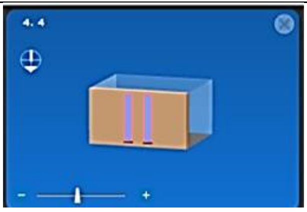
a. The location includes simulation and weather data. The file format for weather data is withextension .epw (energyplus weather format)
b. Two things to take into account are the lighting and occupancy of a structure.
c. Office, mid-rise residential, hotel, or hospital buildings, among others, can be chosen as the building type. Each type has its occupancy, illumination, and equipment schedule controls.
d. The acceptable vintage is the new ASHRAE , 2022.

D. Scenarios Created

Four distinct scenarios with four different window dimensions (having the same window wall ratio) have been designed to evaluate the impact of window aspect ratio on external walls. Some window design factors, such as window glazing material have been held constant. The glazing material is double low solar low emissivity with an air cavity and is used in every window due to its high performance. Considering that 20% is the ideal number for hot regions, the window wall ratio is 18%. Results from simulating these designed scenarios on the four cardinal orientations have been produced. The information about the two scenarios that were developed to investigate the effects of window aspect ratio is expressed in the table below.

TABLE 1 showing Four scenarios with different window aspect ratios in the wall are termed horizontal & vertical windows having the same WWR in each scenario

Sr. #	Name	Descriptio n	Picture
1	**Scenario 1** Horizonta l window Frontage	A frontage that is 11ft high, 20ft wide, and 15ft. deep has a 20% rectangular window (10' X 4') with thermally efficient glass and a sill height of 3'-0" on it.	
2	**Scenario 2** Frontage with two small horizontal windows	A frontage that is 11ft high, 20ft wide, and 15ft. deep has 18% area covered with 2 small rectangular windows (10' X 2') with thermally efficient glass and a sill height of 3'-0" on it	
3	**Scenario 3** Vertical window Frontage	A frontage that is 11ft high, 20ft wide, and 15ft. deep has 20% area covered with rectangular window (4' X 10') with thermally efficient glass and a	

		sill height of 0'-6" on it.	
4	**Scenario 4** Frontage with two small vertical windows	A frontage that is 11ft high, 20ft wide, and 15ft. deep has 18% area covered with 2 small rectangular windows (2' X 10') with thermally efficient glass at a sill height of 0'-6" on it.	

E. Study Area

Lahore was chosen as the study location for this investigation. It serves as the provincial capital of Punjab. It is also Pakistan's second-largest metropolitan area. One of Pakistan's oldest cities, it serves as the state of Punjab's commercial center. It is situated between longitudes 31o 25'52" N and 74o 16'40" E. (Fig) Lahore only has 3% of its land set aside for green areas, which is much less than the global standard, which calls for a minimum of 25–30% of urban area for green open space. In terms of the urban population, Lahore was rated 56th in the world in 1975, 38th in 2007, and 24th in 2025.[8]

According to the Koppen Geiger categorization of climate, Lahore's climate is always referred to as Semi-Arid (steppe), marked by the abbreviation BSh. It experiences a hot temperature for eight months and a pleasant winter for the remaining four. The summer season begins in March and lasts through October. When it comes to the thermal comfort of places, it can be noted that the region experiences hot seasons more often than cool ones. [14-15]

The facts above on the climate of Lahore have been corroborated by a recent study on Pakistan's climate. With the aid of GIS, Sarfraz, Arslan, and Fatima created climate maps for 59 meteorological locations in Pakistan (Geographic Information Systems). The 30-year average monthly temperature data from the aforementioned sites were used to create maps. To regionalize Pakistan's climate, maps were created using the Koppen Geiger classification model to identify the climate variables. (see Figure 3) [16]

The results are discussed in terms of heat gain, thermal comfort, energy use and daylight. The nomenclature used is described as under

Kbtu / ft^2-yr = Unit of Heat Gain and Energy Use

fc = unit of Illuminance, termed as foot candle, defined as lumen per square foot

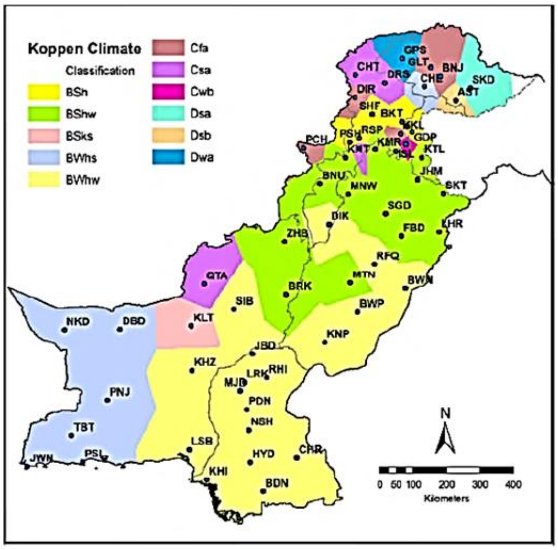


Figure 3 Pakistan climate classification map based on the Köppen climate classification model SOURCE: [16]

III. Results & Discussion

First of all, the following results are produced after scenarios, explained in section ***B***, were simulated by orienting the facades North

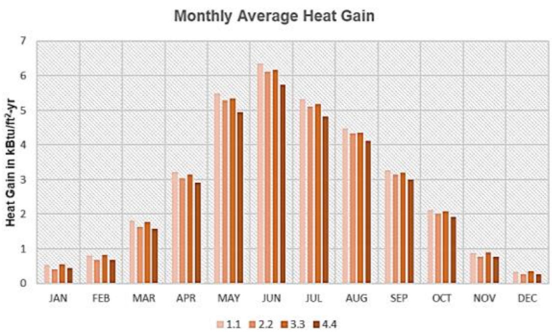


Figure 4 Monthly Heat Gain Comparison of the 4 types of window aspect ratios facing North

In terms of monthly heat gain, Figure 4 displays a comparison graph of four different window aspect ratios facing North. According to the graph presented in Figure 1, there is a clear indication of no significant change in statistics in terms of heat gain all year around. However, the heat gain reduces when a single window with a certain WWR is divided into 2 smaller windows of the same WWR. This reduction can be observed all year round. June experiences the highest heat gain which is up to 6.3 k Btu/ ft^2 -yr. The heat gain reduced up to 5.7 k Btu/ ft^2 -yr with 2 small vertical windows. It is evident in Figure 1 that heat gain is slightly reduced with 2 small vertical windows as compared to the rest of the 3 window aspect ratios in every month of the year. It can be concluded that 2 smaller vertical window aspect ratios with a certain WWR are a good design strategy for North in the climate of Lahore.

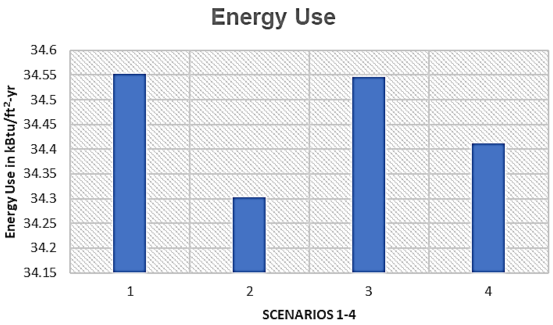


Figure 5 Energy Use Comparison of the 4 types of window aspect ratios facing North

In terms of energy use, Figure 5 displays a comparison graph of four different window aspect ratios facing North. The graph demonstrates that in this situation, scenario 2 is the best as the lowest energy consumed in this. Scenario 2 has 2 small horizontal windows with the same WWR as the rest of the 3 scenarios have. Although the energy use is also reduced when a single vertical window with a specific WWR is divided into 2 small vertical windows with same WWR. However, the reduction in energy use is not very significant when the statistical values are considered. The energy use is reduced from 34.5 to 34.3 k Btu/ft^2-yr. it can be concluded that it is always better to give 2 small horizontal or vertical windows as compared to a single large horizontal or vertical window on North in order to reduce energy use in the climate of Lahore.

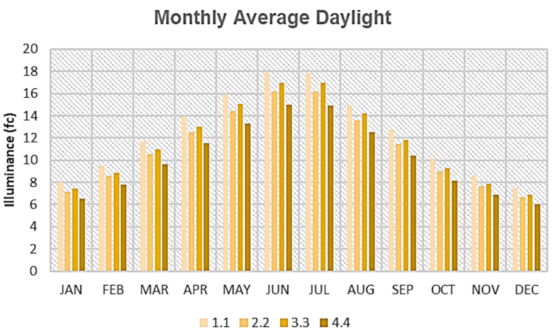


Figure 6 Daylight Comparison of the 4 types of window aspect ratios facing North

Figure 6 compares the 4 types of aspect ratios with a north orientation in terms of daylight penetration. Over the year, horizontal windows let in more light than vertical ones. And also, it can be seen that one large horizontal window is better than 2 smaller ones in terms of daylight. The difference in statistical values between January and June is considerable. In January, the one big horizontal window permits 8fc of daylight and in June, the same window admits 18fc of light. The overall maximum light (Statistical value) by one large horizontal window is not enough in commercial buildings. It should not be less than 27 fc according to guidelines for lighting design by building services engineers. (CIBSE, 2012) It can be deduced that in terms of daylight penetration, one large window preferably horizontal acts better as compared to 2 small windows with the same WWR on North Orientation. It is preferable to use large Window wall ratios on the North or glazing with less resistivity or high emissivity on the North as compared to the rest of 3 cardinal orientations to get ample daylight.
The 4 types of window aspect ratios, when simulated facing East generated the following graphs.

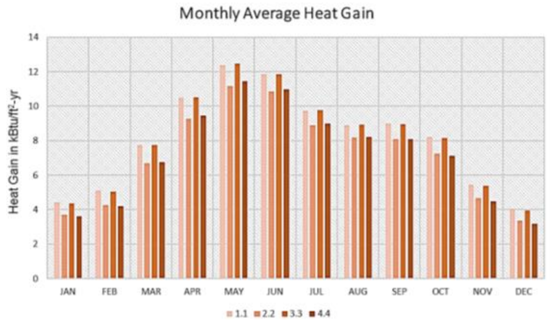


Figure 7 Monthly Heat Gain Comparison of the 4 types of window aspect ratios facing East

Figure 7 compares 4 different window aspect ratios facing east in terms of monthly heat gain. Results reveal that 2 small windows either horizontal or vertical perform better as compared to one large horizontal or vertical window as the small windows allow lesser heat to pass through. This reduction is more significant than the one observed in the North orientation. The maximum gain occurs in May and it is above 12 k Btu/ft ^{2}-yr. The gain is reduced from 12 to 11 k Btu/ft ^{2}-yr. Again, this reduction is not very noted able in terms of statistical value. It can be concluded that two smaller windows (either horizontal or vertical) are preferable in East orientation as compared to one large window in terms of heat gain in the climate of Lahore.

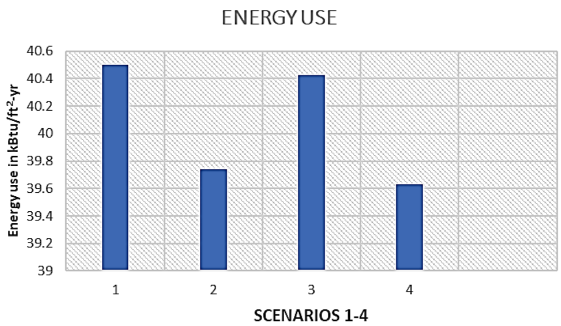


Figure 8 Energy Use Comparison of the 4 window aspect ratios facing East

Figure 8 compares 4 types of window aspect ratios facing east in terms of energy use. The graph demonstrates that in this situation, 2 small windows (either horizontal or vertical) perform better as compared to one large window. The 2 smaller windows are responsible for lesser energy consumption. This reduction in energy consumption is not very significant when the statistical values are considered. For example, the energy use reduces from 40.4 to 39.8 k Btu/ft^2-yr with the installation of 2 small windows.

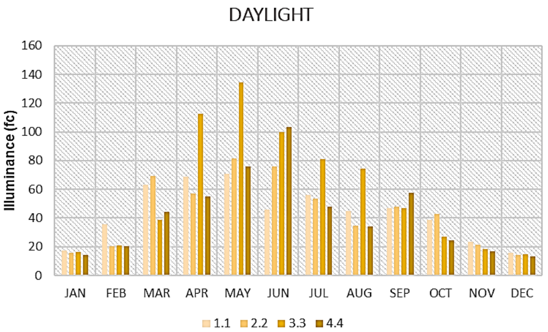


Figure 9 Daylight Comparison of the 4 types of window aspect ratios facing East

In terms of light penetration, Figure 9 compares the two kinds of aspect ratios facing East. The results are changing throughout the year. In January, November, and December, there is not much change in statistical values as far as daylight penetration is concerned. In March and October, horizontal windows let more light into the building as compared to vertical ones. From April to September, vertical windows perform better as compared to horizontal ones. The largest statistical value of daylight penetration is 135 fc which is equal to 1500 lux which is quite a large value when office space is concerned. It should not exceed 60 fc. (CIBSE, 2012). It can be observed from the graph that horizontal windows lie within the range of 20 fc to 60 fc all over the year which is according to the benchmark for commercial buildings. So, it can be concluded that horizontal windows (either a single large or two smaller ones) are more efficient in east orientation as far as daylight is concerned.
The four different window aspect ratios have now been replicated by orienting the facades towards the South, and the results are as follows.

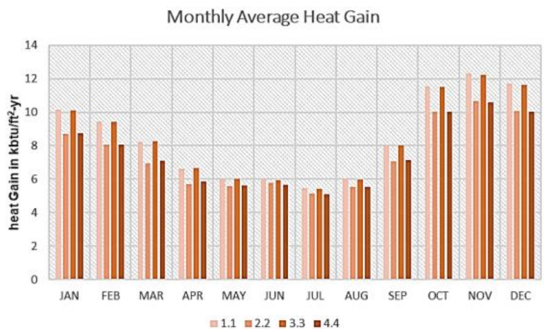


Figure 10 Monthly Heat Gain Comparison of the 4 types of window aspect ratios facing South

Figure 10 demonstrates the graph chart of annual monthly heat gain for 4 types of window aspect ratios on South orientation. The results show that there is always a reduction in heat gain by installing 2 small windows as compared to one large window (either horizontal or vertical) as far as heat gain is concerned. This reduction is more significant in winter i.e from January to April & from September to December. The Heat gain reduces from 10 k Btu/ft^2 -yr to 8 k Btu/ft^2 -yr in January. In terms of monthly heat gain, Figure 7 clearly shows the benefit of having 2 small windows of the same WWR as compared to single large windows of the same WWR.

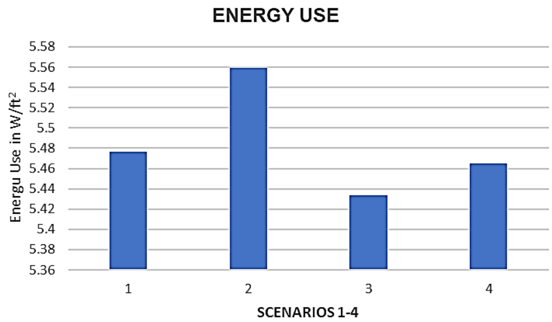


Figure 11 Energy Use Comparison of the 4 types of window aspect ratios facing South

Figure 11 compares 4 types of window aspect ratios facing south in terms of energy use. The graph demonstrates that in this situation, in terms of energy use

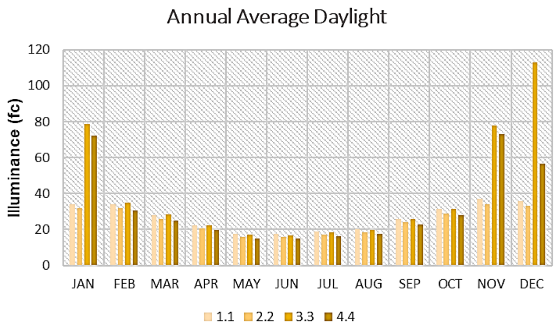


Figure 12 Daylight Comparison of the 4 types of window aspect ratios facing South

Figure 12 compares the 4 different aspect ratios with a south orientation in terms of daylight penetration. Light is roughly equally let in through horizontal and vertical windows throughout the entire year. In January, November & December, the vertical windows let in more light as compared to horizontal windows, and this change is very noticeable in the said months. Like in November, the vertical windows (either one large or 2 smaller ones) let in 80fc light while the horizontal aspect ratios let in approximately 40 fc of light. 80fc is the highest limit required for commercial buildings. (CIBSE, 2012) For the rest of the year, the window aspect ratio does not have a significant impact on the amount of daylight penetration in the buildings. The graph is showing the maximum range of daylight coming inside the building up to 20 fc which is quite low. The reason is that the window wall ratio factor is constant that is o.18 or 18% window area (see section *D*). The south orientation requires a comparatively large window wall ratio as compared to the east and west orientations. (Just like on North) Now the 4 types of aspect ratios have been simulated facing west orientation and the following results have been generated.

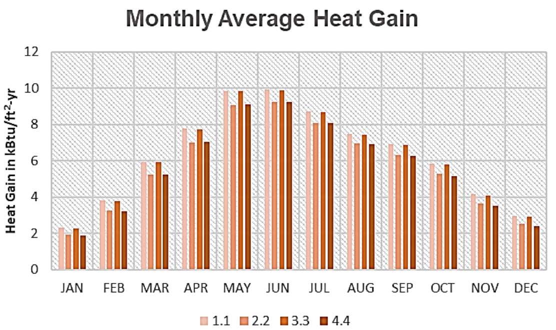


Figure 13 Monthly Heat Gain Comparison of the 4 types of window aspect ratios facing West

Figure 13 compares 4 different window aspect ratios facing West in terms of monthly heat gain. Results reveal that 2 small windows either horizontal or vertical perform better as compared to one large horizontal or vertical window as the small windows allow lesser heat to pass through. The maximum gain occurs in May & June and it is up to 10 k Btu/ft ^{2}-yr. The gain is reduced from 10 to 9 k Btu/ft ^{2}-yr. Again, this reduction is not very noted able in terms of statistical value. It can be concluded that two smaller windows (either horizontal or vertical) are preferable in West orientation as compared to one large window in terms of heat gain in the climate of Lahore.

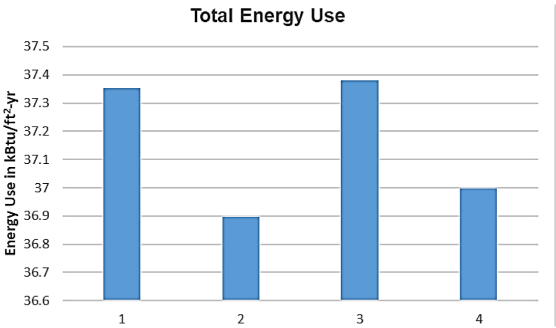


Figure 14 Energy Use Comparison of the 4 types of window aspect ratios facing West

Figure 14 compares 4 types of window aspect ratios facing West in terms of energy use. The graph demonstrates that in this situation, 2 small windows (either horizontal or vertical) perform better as compared to one large window. The 2 smaller windows are responsible for lesser energy consumption. This reduction in energy consumption is not very significant when the statistical values are considered. For example, the energy use reduces from 37.3 to 36.9 k Btu/ft^2-yr with the installation of 2 small windows horizontal windows as compared to one large horizontal window. It can be concluded that horizontal small windows are more beneficial on west orientation in the climate of Lahore.

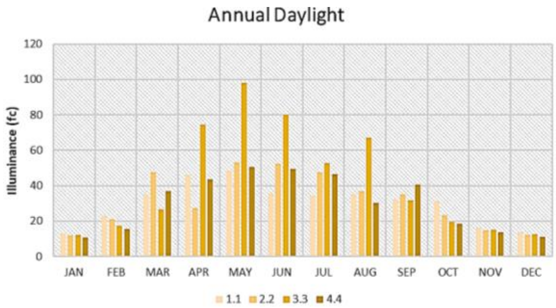


Figure 15 Daylight Comparison of the 4 types of window aspect ratios facing West

Figure 15 compares the 4 different aspect ratios with a West orientation in terms of daylight penetration. The results are changing throughout the year. In January, November, and December, there is not much change in statistical values as far as daylight penetration is concerned. In February & October, horizontal windows let in more daylight as compared to vertical ones. This reduction in daylight lies in the comfortable range i.e 25 to 65 fc in March & October. From April to September, vertical large windows admit more daylight i.e from 80 to 100 fc which is not desired able for commercial buildings. So it can be concluded that on West orientation, horizontal windows and small vertical windows are preferable as compared to large vertical windows as far as daylight penetration is concerned.

IV. Conclusion

This study uses thermal modeling and the dynamic technique of energy computation to determine the impact of window shape/aspect ratio on the energy efficiency of commercial buildings in the hot, dry climate of Lahore. The software used for thermal modeling of façade design of commercial buildings is "Comfen". The following conclusions are deduced by carrying out specific research.

- The window shape/aspect ratio does not have a significant impact on heat gain on 4 cardinal conditions in the climate of Lahore in terms of statistical value.
- The large windows are needed in the north orientation for better daylight penetration in the local climatic conditions as compared to the size of the windows for the rest of the orientation.
- On East & West, horizontal windows (large as well as 2 small) perform better as compared to large vertical windows. In the case of vertical window shape, it is better to use 2 small vertical

windows on the East & West in the climate of Lahore.

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