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Performance Metrics of Fixed and Dynamic Shading in The Semi Arid Climate of Lahore for Commercial Buildings

M. Rasheed[1], A. M. Malik[2], S. Gulzar[3]

[1,2,3]*School of Architecture and Planning, University of Management and Technology, Johar Town, Lahore, Pakistan*

[3]memoona.rashid@umt.edu.pk

Abstract- Commercial buildings consume a significant amount of energy for heating, cooling, lighting, and maintaining the thermal comfort of the space. The façade design of these buildings is one of the key contributing factors. The window is an important part of a building's façade since it allows for a lot of air leakage and the least amount of insulation. Increased Window Wall Ratio and glass facades result in excessive heat gain in hot climates such as Lahore. Solar control is performed through shading devices in the energy efficient design of windows. This study aims to investigate whether a dynamic/automated shading device is more efficient than a fixed shading device in terms of energy efficiency of a window opening. The study is carried out using dynamic method of simulation using software named as “Comfen”. The software is selected as it is designed to calculate the impact of window related parameters on energy performance of commercial buildings. The significance of study is the generation of graphical data generated through software and results are based on the climate and geographic variables of Lahore, which has a semi-arid climate. The simulation results revealed that installing dynamic shading devices reduces energy consumption in buildings more than installing traditional fixed shading and is always advantageous on all orientations.

Keywords- Energy Consumption, Dynamic Shading Devices, Energy Performance, Semi-Arid climate

I. INTRODUCTION

The world is changing at a very fast pace. There is also a change in the lifestyle of people all over the world. This change in lifestyle along with the increasing population is causing an increase in energy consumption in various sectors of life. It can be concluded that globally, the energy consumption is steadily increasing, owing to the changing lifestyle demands of a growing population. [1].

The energy use at the world level has been increasing annually at the rate of 2.2% since 1965. This exponential energy use is predicted to increase up to 30% till 2040 from now onwards.[2]. The increasing use of energy all over the world has raised worries regarding the energy supply difficulties and the adverse impacts on the environment like climate change, global warming and the deteriorating ozone layer. [3]. It can be stated that there are 3 main problems the whole world is confronted with and these are depletion of value able energy resources, population growth and climate change. All the rest are associated with these 3 issues. All sectors are working to address these issues. The case of building sector is not different. Building sector is note able as it is responsible for 40% of energy consumption and 19% of GHG gas emissions.[4]. A significant amount of GHG emissions is a result of direct use of energy in the buildings.[5].

It is necessary to have overview of the impact of COVID 19 outbreak on building sector. In the past years after the adoption of Paris agreement in 2015, the GHG emissions, from the building sector, have been risen continuously. The trend continued until the outbreak of COVID 19. There is a decrease in GHG emissions in 2020 and 2021 from the building sector due to lockdowns in the said years and the levels dropped down to 2007. It is also estimated that the energy use in building sector has been reduced from 40 to 36 percent in 2020 due to pandemic of COVID related lockdowns. [6]. There has also been a reduction in power industry after 2015 and some countries adopted policies and codes to enhance efficient use of energy in buildings as well. Efficient use of energy in building sector is the only solution to mitigate climate change, global warming and environmental degradation.

In building sector, a considerable contribution in this excessive energy consumption and GHG emissions has been made by commercial buildings due to entire glazed facades which have become a trend all over the world. The building envelope is responsible for much of the heat exchange through the outside environment. The building envelope must acts a modifier between outdoor and indoor climate. [7]. Commercial building energy consumption accounts for a considerable portion of overall yearly energy consumption, which is rapidly increasing. Space cooling systems account for a significant portion of the energy used in such buildings in countries like India which have hot climate. Heat transmission through the building envelope increases the need for space cooling and the use of power for space cooling systems, resulting in greater levels of emissions that contribute to climate change.[8]. This case is similar to Pakistan in terms of hot climate. Therefore, facades of commercial buildings need careful design considerations and construction technologies.

There is a need to design façade which must respond to outdoor climatic conditions. Window is an important element of façade design as it is a weak thermal link in the façade. Window needs to be carefully designed as it is responsible for the heat gain as well as heat loss [9]. Large window sizes and glazing surfaces in commercial buildings are responsible for high solar gains and excess light accounts for glare problems in hot climates like that of Lahore. [10]. Solar control can provide an optimal solution to counter excessive heat gain and heat loss through windows. Shading is a way to add solar control value and to increase the resistivity of windows. All kinds of shading devices can help but automated shading has some extra benefits over the conventional fixed shading. This research is conducted in the semi-arid climate of Lahore in order to investigate the role and benefits of shading systems in commercial facades specifically focusing on automated shading systems.

II. Literature Review

Dutta, Samantha & Neogi investigated the impact of programmable Logic Controller based moveable exterior shade through an experimental study. The research is carried out for tropical climates. The study concluded that maximum energy savings is achieved in the month of June. The research highlighted the benefits of moveable shades in terms of finance and payback period as well. [11]

De Luca, Voll & Thalfeldt analyzed the different kinds of shading including fixed and dynamic and their influence on energy performance of office building in Tallinn Estonia. It is a simulation-based study carried out for a typical office building. The results highlighted the uniform performance of dynamic blinds over the rest fixed and dynamic shading systems.[12]

Tzempelikos & Athienitis investigated the role of shading control for commercial and office buildings in combination with glazing properties. The approach adopted to conduct the research is simulation based integrated thermal and daylighting analysis for perimeter office buildings. The façade design alternatives like glazing area and shading properties are analyzed at early design stage. The case study building was selected in Montreal's warm humid (continental) climate. Exterior Roller shade is inquired through simulation in combination with electric lighting control for a window with 30% WWR. Results show that with 20% transmittance having control of shading device and electric light accounts for 50% decrease in yearly cooling load.[10]

Heidari, Taghipour & Yarmahmoodi studied the impact of fixed shading (Horizontal, Geometric and Egg-Crate devices) on energy consumption of residential buildings in the hot and dry climate of Shiraz. The study is based on simulations carried out in the software Ecotect. The results proved the suitability of above-mentioned fixed shading devices on reducing the heating and cooling load and peak energy demand. [13]

Bazazzadeh et al investigated the role of efficient shading devices in achieving design solutions for high performance office building in the climatic conditions of Tehran. A three-step research process was employed to examine the topic. Three alternative window shades (fixed and dynamic) were modelled as the major options for evaluation, one of which was influenced by historic Iranian architecture at the start of the research. On crucial days throughout the year, each shade was evaluated for energy efficiency and daylight-related variables, taking into account climatic and daylight conditions (equinoxes and solstices including 20 March, 21 June, 22 September, and 21 December). Finally, all possible options for fixed and dynamic shades, as well as the results of the comparison of three options, were analysed through a multi-objective optimization to compare fixed and dynamic options and to find the optimal condition for dynamic options at different times of the day, in order to achieve a reliable result. The findings suggest that, first and foremost, dynamic shading devices are more energy efficient, occupant visual comfort, and daylight efficient than fixed shading devices. The comparison shows that dynamic shading has (roughly 10 percent). Furthermore, the best shape of this shading device was discovered by analyzing dynamic shading devices in various seasons and times of the year. The findings suggest that considering adequate shading devices can help achieve high-performance architecture in office buildings.[14]

All the relevant literature highlighted the following conclusions.

1. The significance of the solar control in window design which can only be achieved through shading devices.

2. All types of shading devices are beneficial in achieving energy efficiency in buildings.
3. Advantages of dynamic shades are more as compared to fixed shading because of the ability of dynamic shading to adjust with the sun angles.

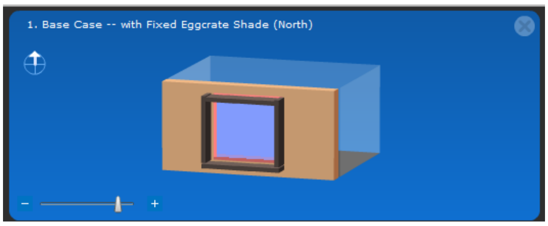
III. MATERIAL & METHODS

The target of the research is to compare the impact of dynamic shading on energy performance with the impact of fixed shading on energy performance in commercial buildings in the climate of Lahore. The objective is achieved by adopting the dynamic method which is based on simulation to find the results. Computer simulation approach is adopted and façade is modelled in a software named as Comfen. The name "Comfen" is derived from commercial fenestration and is well suited for the research. The reason for selecting this particular software is that it is a focused software to analyze the window design parameters including shading devices with reference to energy efficiency for commercial buildings. The other reason is that it uses the ENERGY PLUS engine to run the simulations which is most widely accepted software for running simulations. It is the reason for selection of the software to achieve the target.

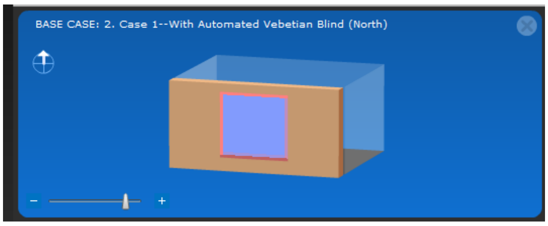
Research is conducted by creating different scenarios. The scenarios are created with managing different parameters of window design. The details of the scenarios are explained with the help of table below. (Table 3.1)

All of the scenarios feature a 10-foot-high, 20-foot-wide façade with a 30-percent Window Wall Ratio (WWR), which is in the ideal range for hot regions. The window has air gap and high-performance glass (double Low E Bronze glass). Some of the parameters like WWR and glazing material have remained constant and the type of shading systems vary in each scenario. In this simulation-based study, a fixed shading device (Egg Crate) is compared with Automated shading Device (Venetian Blinds With adjustable slat to block solar beam) is compared on all orientations. Egg crate shading is taken as it is the most efficient shading device among all the fixed devices. Automated shade is designed for exterior venetian blinds with adjustable slat as it is effective to block the solar radiation with the varying sun angle. 8 different scenarios are created in this way and their details are given the table 3.1 below. The screen shots of created scenarios are also given in Fig.1

The scenarios are created on 4 cardinal orientations, 2 on each orientation. One is the base case which is the façade having a window with fixed shade and the other one is a facade having a window with automated exterior Venetian blinds with adjustable slat.



(a)



(b)

Fig1: (a) Base case window with eggcrate shade (b) Window with automated VB with adjustable slat

The results are discussed in the later section of this article. The local climate, in which the research is conducted needs to be discussed. The climate of Lahore is discussed below.

A. Climate of Lahore:

The study focuses on the climate of Lahore, which is situated between 31 and 33 degrees north latitude and 73 and 75 degrees east longitude. Lahore's climate is classified as semi-arid (Steppe), with scorching summers and mild winters. It has a hot climate for eight months of the year and a pleasant winter for the remaining four months. As a result, the hot season dominates the entire year.

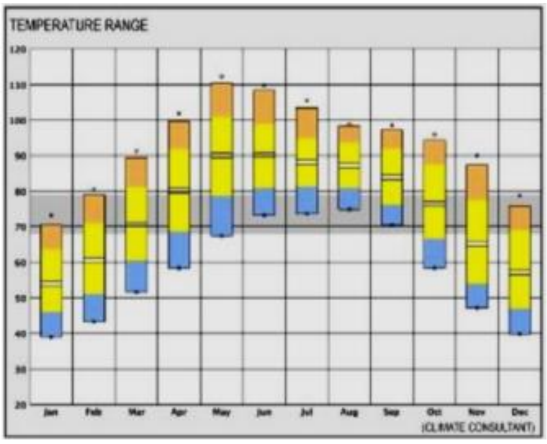


Fig. 2: Annual Temperature range of Lahore
SOURCE: [4]

The annual temperature chart of Lahore is shown in Fig. 1. The temperature increases over the comfort band (grey) in April and falls below it in October, as seen in the graph. This the overheated period for Lahore in which cooling strategies are required for the building.

Psychrometric Chart of Lahore shows the cooling strategies in the local climate and their impact on the thermal comfort. (Fig. 2) The chart clearly shows that shading accounts for 24% of human comfort and therefore is a significant cooling strategy in the local climatic conditions.

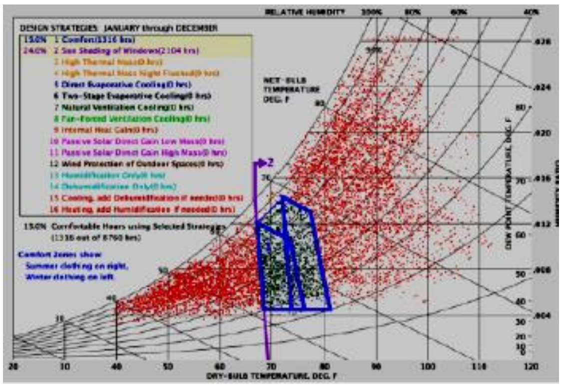


Fig. 3: Psychrometric Chart of Lahore showing the cooling strategies suggested in the local climatic conditions
SOURCE: [4]

TABLE 3.1: Details of the Scenarios Generated in Comfen

Sr. #	Scenarios	WWR	Glazing	Shading	Orientation
1	Base Case -- with fixed Egg Crate shade (North)	30%	Double Low E Bronze Glass	Egg Crate device with 2ft depth	North
2	Case 1-- With Automated Venetian Blind (North)	30%	Double Low E Bronze Glass	Exterior 3” Venetion Blind with adjustable slat	North
3	Base Case -- with fixed Egg Crate shade (East)	30%	Double Low E Bronze Glass	Egg Crate device with 2ft depth	East
4	Case 2-- With Automated Venetian Blind (East)	30%	Double Low E Bronze Glass	Exterior 3” Venetion Blind with adjustable slat	East
5	Base Case -- with fixed Egg Crate shade (South)	30%	Double Low E Bronze Glass	Egg Crate device with 2ft depth	South
6	Case 3-- With Automated Venetian Blind (South)	30%	Double Low E Bronze Glass	Exterior 3” Venetion Blind with adjustable slat	South
7	Base Case -- with fixed Egg Crate shade (West)	30%	Double Low E Bronze Glass	Egg Crate device with 2ft depth	West
8	Case 4-- With Automated Venetian Blind (West)	30%	Double Low E Bronze Glass	Exterior 3” Venetion Blind with adjustable slat	West

IV. Results and Analysis

The designed scenarios are simulated on cardinal orientations and results are discussed in terms of energy use breakdown, annual heat gain and average thermal comfort level. The results are discussed according to every orientation below.

A. Scenarios 1 & 2 on North:

The following results are generated by comparing fixed shade with automated shade on North.

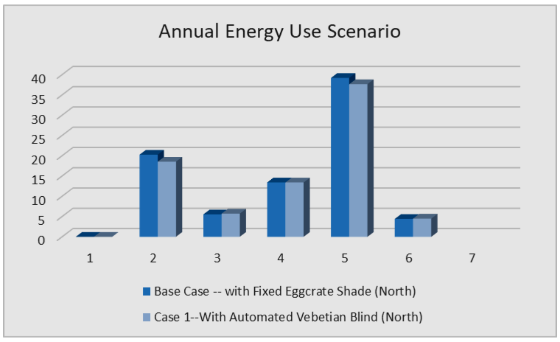


Fig. 4: Comparison of Annual Energy use (per unit floor area) of façade having a window with fixed (Egg Crate Shade) with a façade having a window with Automated (VB with adjustable slat) on North

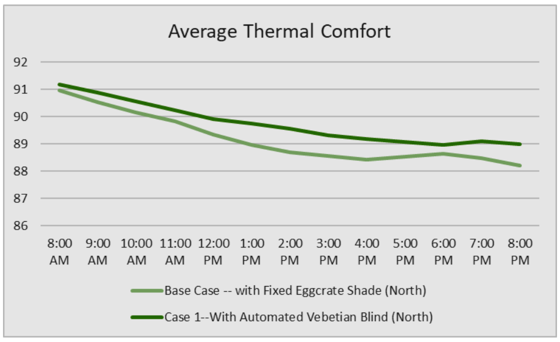


Fig. 5: Comparison of Annual Average Thermal Comfort of a window with fixed (Egg Crate Shade) with a window with Automated (VB with adjustable slat) on North

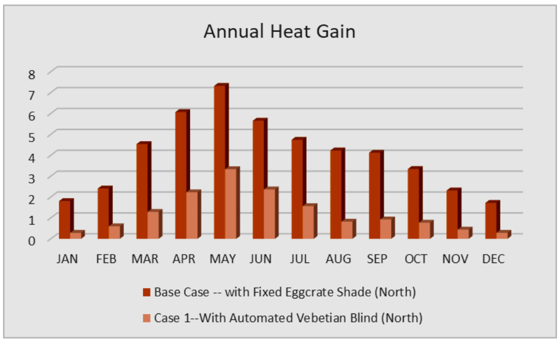


Fig. 6: Comparison of Annual Heat Gain through window with fixed (Egg Crate Shade) with a window with Automated (VB with adjustable slat) on North

Fig. 4, 5 & 6 shows the comparison two types of windows with different shading devices and their impact on the annual energy use, thermal comfort in terms of percentage of people satisfied and annual heat gain through both windows on North. It is evident that annual energy use decreases from 39.20 kBtu/ft2-yr to 37.66 kBtu/ft2-yr when fixed egg crate shade is replaced with automated exterior venetian blinds with adjustable slat. In addition, the thermal comfort level is increased from 87.90 to 88.64. The value of thermal comfort is expressed in terms of percentage of people satisfied. It can be deduced that annual energy use is decreased to 3 % and thermal comfort is increased to 0.85% by replacing fixed shade with automated one.

B: Scenarios 3 & 4 On East:

The following results are generated by comparing fixed shade with automated shade on East.

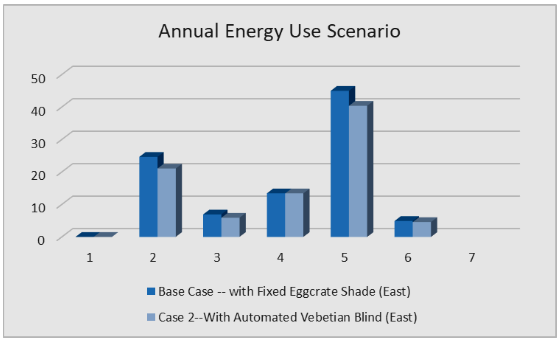


Fig. 7: Comparison of Annual Energy use (per unit floor area) of façade having a window with fixed (Egg Crate Shade) with a façade having a window with Automated (VB with adjustable slat) on East

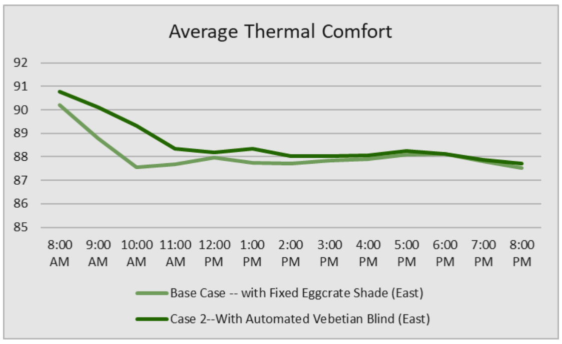


Fig. 8: Comparison of Annual Average Thermal Comfort of a window with fixed (Egg Crate Shade) with a window with Automated (VB with adjustable slat) on East

Fig. 7, 8 & 9 shows the comparison two types of windows with different shading devices and their impact on the annual energy use, thermal comfort in terms of percentage of people satisfied and annual heat gain through both windows on East.
It is evident that annual energy use decreases from 44.99 kBtu/ft2-yr to 40.39 kBtu/ft2-yr when fixed egg crate shade is replaced with automated exterior venetian blinds with adjustable slat. In addition, the thermal comfort level is increased from 86.77 to 87.36. It can be concluded that annual energy use is decreased to 10 % and thermal comfort is increased to 0.68% by replacing fixed shade with automated one.

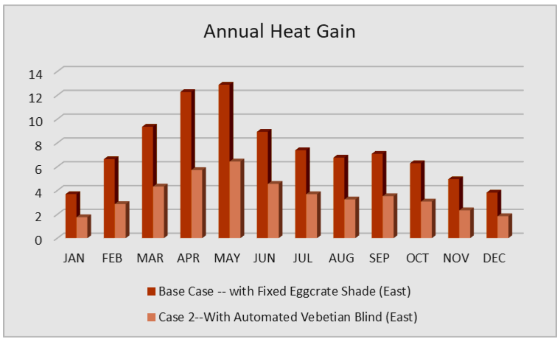


Fig. 9: Comparison of Annual Heat Gain through window with fixed (Egg Crate Shade) with a window with Automated (VB with adjustable slat) on East

C: Scenarios 5 & 6 On South:

The following results are generated by comparing fixed shade with automated shade on South

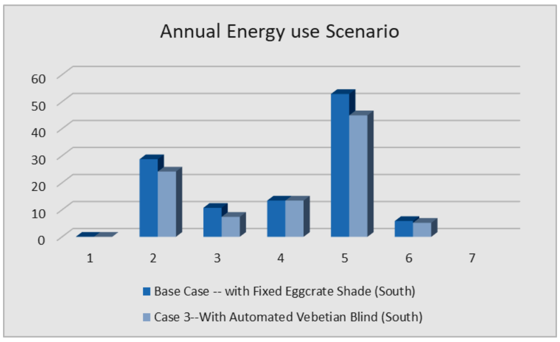


Fig. 10: Comparison of Annual Energy use (per unit floor area) of façade having a window with fixed (Egg Crate Shade) with a façade having a window with Automated (VB with adjustable slat) on South

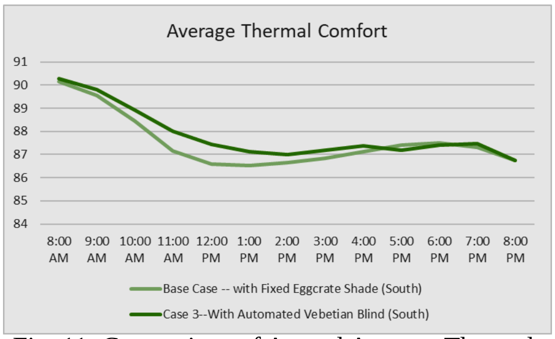


Fig. 11: Comparison of Annual Average Thermal Comfort of a window with fixed (Egg Crate Shade) with a window with Automated (VB with adjustable slat) on South

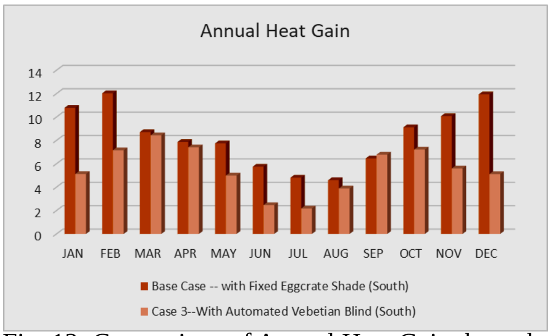


Fig. 12: Comparison of Annual Heat Gain through window with fixed (Egg Crate Shade) with a window with Automated (VB with adjustable slat) on South

Fig. 10,11 & 12 shows the comparison two types of windows with different shading devices and their impact on the annual energy use, thermal comfort in terms of percentage of people satisfied and annual heat gain through both windows on South. It is evident that annual energy use decreases from 52.84 kBtu/ft2-yr to 44.95 kBtu/ft2-yr when fixed egg crate shade is replaced with automated exterior venetian blinds with adjustable slat. In addition, the thermal comfort level is increased from 86.08 to 86.36. It can be concluded that annual energy use is decreased to 15% and thermal comfort is increased to 0.33% by replacing fixed shade with automated one.

D: Scenarios 7 & 8 On West:

The following results are generated by comparing fixed shade with automated shade on west

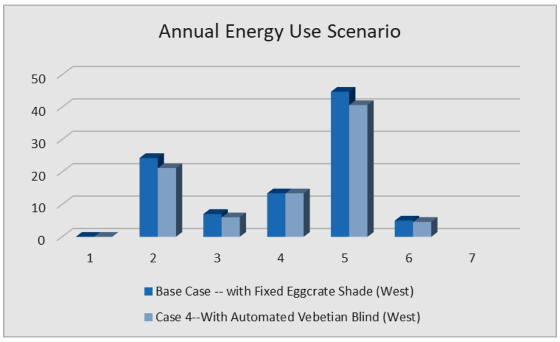


Fig. 13: Comparison of Annual Energy use (per unit floor area) of façade having a window with fixed (Egg Crate Shade) with a façade having a window with Automated (VB with adjustable slat) on West

The influence of two types of windows with different shading mechanisms on annual energy use, thermal comfort in terms of percentage of persons satisfied, and annual heat gain through both windows on the west is shown in Figures 13, 14 and 15. It is evident that annual energy use decreases from 44.75 kBtu/ft2-yr to 40.63 kBtu/ft2-yr when fixed egg crate shade is replaced with automated exterior venetian blinds with adjustable slat. In addition, the thermal comfort level is increased from 86.62 to 87.20. It can be concluded that annual energy use is decreased to 9% and thermal comfort is increased to 0.67% by replacing fixed shade with automated one.

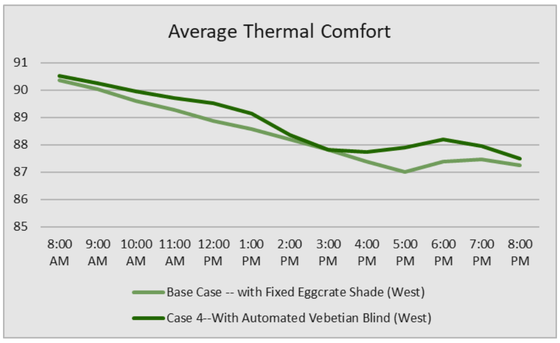


Fig. 14: Comparison of Annual Average Thermal Comfort of a window with fixed (Egg Crate Shade) with a window with Automated (VB with adjustable slat) on West

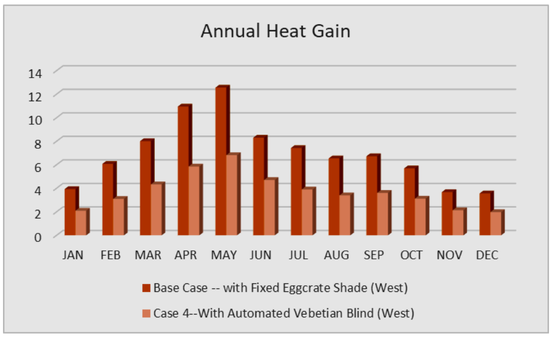


Fig. 15: Comparison of Annual Heat Gain through window with fixed (Egg Crate Shade) with a window with Automated (VB with adjustable slat) on West

In all the results generated, there is a similarity regarding energy use and thermal comfort. On 4 cardinal orientations, the energy use is decreased by replacing the fixed exterior shade with automated exterior shade. In terms of percentage, this decrease in energy use is highest on south i.e. 14 % and it is lowest on North i.e. 3 %. On East and West orientations, the percentage deceases till 10%. The numerical value of energy use in k Btu/ft 2 – yr on east and west orientation drops down to 40 kBtu/ft2 – yr which is quite an achievement. If the value of energy use on east and west is compared with a similar study conducted in the local climatic conditions, then it can be concluded that automated shading devices are beneficial on East and West more than any other orientations. East and west orientations are challenging in the local climatic conditions because the sun angle is low on these orientations

V. CONCLUSIONS

There are some conclusions which can be drawn from the research carried out. These conclusions are stated as under.

- There is a reduction in total energy use by installation of automated Venetian Blinds on all orientations
- The reduction in energy use is highest at south i.e up to 14.94%
- Two types of shades are compared. One is a fixed egg crate shade with 2 inches depth. Second is exterior venetian blinds with adjustable slat to block the solar beam.
- Automated shade on all orientations provided thermal comfort in terms of percentage of individuals satisfied.
- Automated Shading devices are more beneficial on critical orientations like East and West

The energy efficient or low energy buildings have become a topic of concern and research these days. Reason is that natural resources are depleting day by day and we need buildings which require less energy to operate and maintain comfort level. In this context, dynamic facades are being discussed as they respond to the changing external conditions well. Automated shading device, therefore, is taking lead over fixed shading devices. The automated shading device is highly efficient to control energy use. Its efficacy is best on east and west orientations with low solar angles. These benefits are a step forward from the benefits of fixed external shading. However, the performance of automated depends upon robust construction and requires high maintenance.

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