Effect of External Shading and Window Glazing on Energy Consumption of Buildings in Bangladesh

by

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September, 2014

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A Project submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Department of Energy Technology

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Khulna 9203, Bangladesh
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Declaration

This is to certify that the project work entitled "***Effect of External Shading and Window Glazing on Energy Consumption of Buildings in Bangladesh***" has been carried out by *Md. Jahangir Alam* in the Department of *Energy Technology*, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above project work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Approval

This is to certify that the project work submitted by *Md. Jahangir Alam* entitled "***Effect of External Shading and Window Glazing on Energy Consumption of Buildings in Bangladesh***" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of *Master of Engineering* in the Department of *Energy Technology*, Khulna University of Engineering & Technology, Khulna, Bangladesh in September' 2014.

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Abstract

Energy efficiency of buildings is attracting significant attention from the research community as the world is moving towards sustainable buildings design. Energy efficient approaches are measures or ways to improve the energy performance and energy efficiency of buildings. This study investigated various energy-efficient approaches for residential building. External shading controls the solar energy on a window and the energy transfer within the room through the window. In the present study, the effect of overhang and fin on single clear glazing window as well as the effect of advanced glazing on the solar energy transmitted into or lost from the room through the fenestration areas have been evaluated for typical residential buildings in Bangladesh, using EnergyPlus software in different frontage wall orientation. Four types of glazing (single clear, double low-E opaque, double layer argon gapping, and double clear glazing) and six types of window shading (with different dimensions of overhang and fin) are used in this project. It was found that appropriate overhangs or side fins in the north, south, west and east windows would lead to the optimal reduction of the annual energy transferred into the buildings and can have an energetic behavior equivalent to high performance glazing. As well as the energy consumption for north facing window with overhang and side fin in left side is the lowest and generously shaded (like north facing) south-facing window can also be used for residential building with considering cp index i.e., energy consumption can be reduced by proper window shading. In addition, double low-E opaque glazing in window is more efficient for energy saving in building. But with considering illuminance and energy consumption Double low-E clear (Argon) is best selection for Bangladeshi climate.

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CHAPTER I

1.1 Introduction

Population growth and economic progress have led to an increase in the demand for energy. The worldwide increase in demand for energy has put rising pressure on identifying and implementing ways to save energy. Energy efficient buildings is an important factor related to the energy issue; according to Omer [1] a building has three parameters directly related to energy consumption: thermal comfort (thermal conditioning), visual comfort (lighting) and air quality (ventilation). Energy consumption analysis of buildings is a difficult task because it requires considering detailed interactions among the building, HVAC system, and surroundings (weather) as well as obtaining mathematical/physical models that are effective in characterizing each of those items. The dynamic behavior of the weather conditions and building operation, and the presence of multiple variables, require the use of computer aid in the design and operation of high energy performance buildings [2-3].

Energy efficient buildings can be defined as buildings that are designed to provide a significant reduction of energy need for cooling and heating. Windows have long been used in buildings for day-lighting and ventilation. Many studies have even shown that health, comfort, and productivity are improved due to well-ventilated indoor environments and access to natural light. However, windows also represent a major source of unwanted heat loss, discomfort, and condensation problems. But in recent years, windows have undergone a technological revolution. High-performance, energy-efficient window and glazing systems are now available that can dramatically cut energy consumption and pollution sources: they have lower heat loss, less air leakage, and warmer window surfaces that improve comfort and minimize condensation. These high-performance windows feature double or triple glazing specialized transparent coatings, insulating gas sandwiched between panes that reduce the energy lost through windows. In addition, well-designed shading devices features reduce heat transfer, cooling requirements of buildings. Shading devices can also improve user visual comfort by controlling glare and reducing contrast ratios. This often leads to increased satisfaction and productivity. Shading devices offer the opportunity of differentiating one building facade from another. This can provide interest and human scale to an otherwise undistinguished design [4]. Rahman and Satyamurty [5] investigate the difference between the values of shading factors for windows with overhangs calculated under extraterrestrial and terrestrial conditions and showed that the shading factor values evaluated under terrestrial conditions can differ by 25% compared to the extraterrestrial values for non-south facing windows shaded by over hangs.

The worldwide increase in demand for energy has put always increasing pressure on identifying and implementing ways to save energy. Furthermore, the energy supply is still based mainly on non-renewable energy resources, primarily oil and gas (37 and 24% of total energy consumption in the EU) [6]. The depletion of non-renewable fuels, global climate change, and awareness of the impact of harmful emissions on health and the environment has led to an increased interest in renewable energy and energy efficiency applied to every major energy sector. Energy efficiency of buildings has recently become a major issue because of growing concerns of CO_2 and other greenhouse gas emissions, and scarcity of fossil fuels. Buildings worldwide account for a surprisingly high 40% of global energy consumption [7]. If the energy consumed in manufacturing steel, cement, aluminum and glass used in construction of buildings is being considered, this consumption would be more than 50% [8]. Energy efficiency of buildings plays a vital role in designing a new building, assessing its energy consumption as per design, and application of energy efficient technologies during construction and operation of the building. As buildings consume about half of global energy consumption, energy efficiency of buildings is critically important in addressing climate change. In Australia, the energy used by buildings accounts for approximately 20% of Australia's greenhouse gas emissions, this is split fairly evenly between homes and commercial buildings [9]. In the event that global oil supply is inadequate to meet the growth in demand which would otherwise occur, it therefore seems likely that the developing countries may be able to outbid the developed countries and command a growing share of the oil (and gas, and coal) available. They may not, however, be able to get all they want; and if prices are higher that may adversely affect the customers for Asia's export machine. The remarkable growth of coal consumption in Asia looks set to continue, regardless of carbon emissions - subject to availability, which is increasingly dependent on Australia. Asia-Pacific exporters - Australia, Indonesia, China, Vietnam and Indonesia - currently supply 66% of world seaborne trade in thermal coal; Australia alone supplies 64% of the trade in coking coal. With Korea, Thailand, China and India no longer self-sufficient; and Vietnamese, Indonesian, and South African exports dwindling, Australia's expanding coal production should be readily taken up. Australian coal reserves are said to be huge: 76bn tones in 2008. In that year, coal accounted for 79% of Australia's primary energy production. Gas will be developed to the extent available. The number of countries using nuclear energy seems likely to rise dramatically. For all this, it may not be possible to assume, as one could in the past that any shortfall in energy availability could be made up at a price. Asia builds nuclear capacity as fast as possible. The World Nuclear Association's high scenario, based on announced and updated plans, including very aggressive build out by China, India and Pakistan, and new nuclear programs by six of the ten ASEAN countries plus Bangladesh, currently envisages an additional 387GW of capacity in Asia by 2030, equating to 744Mtoe. There are considerable doubts as to whether this rate of expansion will be achieved in practice, but let's take this as the maximum contribution: nuclear would then represent 12% of the increase in Asia's energy demand, compared to 3% of current consumption. Hydro probably cannot contribute much more than it does already; wind, solar, biomass etc seem unlikely to help significantly. Over 30 years, however, the fastest growth was in Bangladesh, up more than 8 times; consumption by South Korea, Malaysia and Thailand rose more than 7-fold. Bangladesh is mainly dependent on gas: locally produced and consumed, and representing 75% of the formal energy mix. 22% is from oil, all imported that is shown in Fig.1.1 [10].

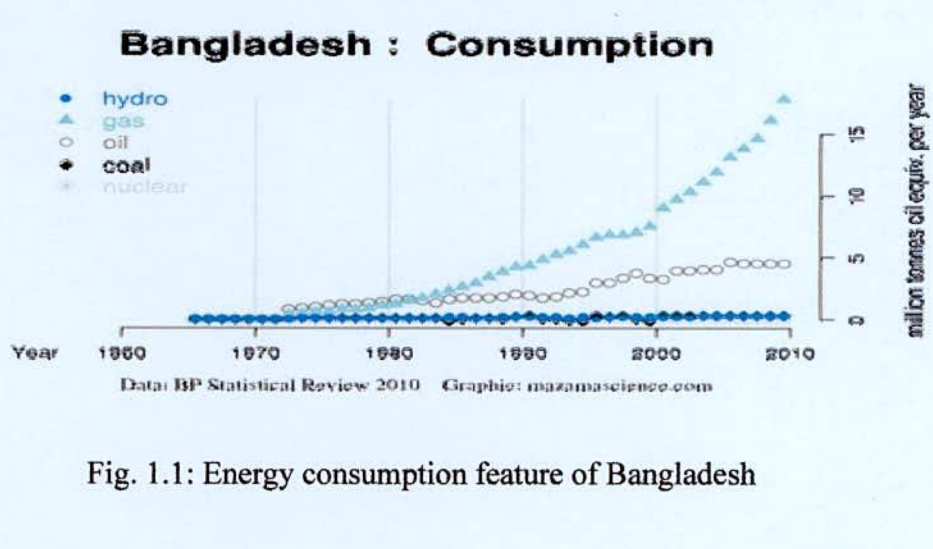


Fig. 1.1: Energy consumption feature of Bangladesh

Electricity consumption increased during 2001–2008 in Table 1.1. The total number of connections increased over 4.3 million by 2001 (electrification rate of over 17%). The majority of the new consumer connections were provided by REB. By 2008, the total number of electricity consumers had reached 10.6 million (i.e., electrification rate of over 37%). REB alone connected over 3.9 million consumers during this period. The level of electricity consumption has increased steadily in all consumer categories over the past 7 years. The highest rate of increase is in the small commercial and residential categories and the lowest in the large industrial and commercial consumers. This may reflect the success of rural electrification programs and the increasing use of captive generators by large consumers.

Table 1.1: Electricity Consumption by Consumer Group (GWh) [11]

Fiscal Year	Residential	Agriculture	Small Industrial	Small Commercial	Large Industrial and Commercial	Total
2001	3,102	372	466	369	2,403	6,712
2002	3,619	358	523	403	2,838	7,740
2003	4,537	408	604	621	3,948	10,118
2004	7,084	616	1,086	1,254	5,740	15,780
2005	7,456	681	1,128	1,349	6,248	16,862
2006	7,760	795	1,143	1,400	6,602	17,700
2007	8,194	857	1,205	1,544	6,329	18,129
2008	9,376	915	1,293	1,813	6,368	19,765

Source: Bangladesh Power Development Board, Dhaka Electricity Supply Authority, Dhaka Electricity Supply Company, West Zone Power Distribution Company, Rural Electrification Board.

Energy-efficient approaches are the measures that aim to improve the energy efficiency of buildings. These measures are the ways through which the energy consumption of a building can be reduced while maintaining or improving the level of comfort in the building. Therefore, an energy-efficient approach for buildings can be defined as an approach that can assist in reducing energy consumption in the form of electricity, improving the green house gas (GHG) impact of operations and reducing operating costs of buildings. The energy efficiency of a building is the extent to which the energy consumption per square meter of floor area or per square meter of envelope area (kWh/m^2 yr) can be reduced compared to benchmarks for that particular type of building under defined climatic conditions. The benchmarks are derived by analyzing data on different building types within a given country. The typical benchmark is the median level performance of all buildings in a given category and good practice presents the top quartile performance. Comparisons with simple benchmarks of annual energy use per floor or envelope area allow the determination of the energy efficiency level of the building and therefore, priority areas for action can be identified. Benchmarks are applied mainly to heating, cooling and air-conditioning. These benchmarks vary from country to country and depend on the agreement of corresponding countries' building code, boards and experts in that area.

An efficient building is one that applies energy-efficient technologies while operating as per design, supplies the amenities and features appropriate for that kind of building, and which can be operated in such a manner as to have a low energy use compared to other similar buildings. The concept of "energy-efficient buildings" has some implications that depend on regulations, economics, energy demand and the environment. There are many concepts regarding energy-efficient buildings; the elements can be divided into three parts [12].

(a) The building must contain energy-efficient technologies, when operating as designed, to effectively reduce energy use.

(b) The building must deliver the amenities and features appropriate for that kind of building.

(c) The building must be operated in an efficient manner. The evidence of this operation is low energy use relative to other similar buildings.

An aggravating factor in this heterogeneous environment is the fact that the degree of industrialization in the building and construction industry is rather low. Each building is essentially a prototype. This is coupled with traditionally high costs and a complex planning process, which is usually hierarchical according to the different trades acting as a barrier for innovation. In order to make innovation possible, improved components and operational concepts are necessary to achieve an optimal design of buildings. The deployment of innovative concepts in building design would provide future efficient buildings for climate protection. This can be achieved by an integral view of building functionality, performance and characteristics. Energy saving concepts includes passive and active measures. In the passive approach, investigation of innovative building envelope characteristics, increasing the use of natural ventilation, and the application of building thermal mass as energy storage are providing promising opportunities for energy efficiency. The active measures involve optimization of HVAC system operation taking into account the combination and performance of renewable technologies. Designers of buildings must reach a numerous goals. Architects and Civil Engineers are not concern about thermal comfort and visual comfort from day-lighting during construction. But these facilities would be achieved to optimize window glazing and shading of building.

1.2 Objective

The main objectives of this work are:

i. To investigate the various glazing and external shading of window
ii. To investigate the heat transfer through buildings peripheral using numerical technique
iii. To analyze the energy consumption of building
iv. To recommend effective glazing and external shading for Bangladeshi condition

1.3 Dissertation organization

This dissertation is organized in several chapters as follows:

Chapter 2 describes the literature review of window glazing, shading as well as energy efficiency improvement of a building.

Chapter 3 introduces building energy simulation software and its brief discussion.

Chapter 4 presents the energy simulation technique in building with definite window dimension; describes the method on effect of glazing and shading on window in the climate condition of Bangladesh.

Chapter 5 explains the results obtained by using software simulation and discusses the feasibility of those results.

Chapter 6 describes the concise conclusion of this project work.

Chapter 7 presents the references of this project report.

Chapter II

Literature Review

2.1 General

Energy efficient buildings include measures to reduce energy consumption both the embodied energy required to extract, process, transport and install building materials and operating energy to provide services such as heating and power for equipment. To reduce operating energy use, designers use details that reduce air leakage through the building envelope (the barrier between conditioned and unconditioned space). They also specify high-performance windows and extra insulation in walls, ceilings, and floors. Another strategy, passive solar building design, is often implemented in low-energy homes. Designers orient windows and walls and place awnings, porches, and trees [13] to shade windows and roofs during the summer while maximizing solar gain in the winter. In addition, effective window placement (day lighting) can provide more natural light and lessen the need for electric lighting during the day.

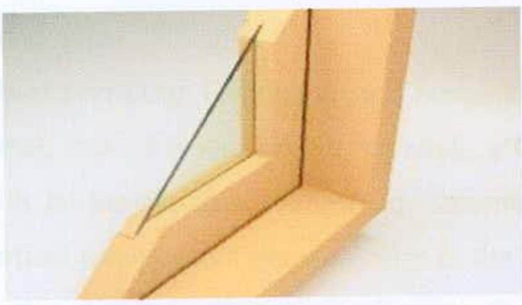
A window including glazing and shading in an air-conditioned space is an important element to be analyzed with respect to its thermal performance and impact on energy performance of that particular space. A window has its impact on energy performance of a conditioned space in two ways: i) Impact on the HVAC energy consumption of the building. ii) Impact on the lighting energy consumption. Advantages of many glazing and shading device are that they can be adjusted to vary solar heat transmission with the time of day and season.

2.2 Window glazing

Glazing is available with a range of selective coatings that alter the properties of the glass; ideally glazing should be selected with the highest light transmittance and the lowest solar heat gain factor. This will help provide daylight while reducing solar gains. All major glass manufacturers provide data on the properties of their products, including those with coatings.

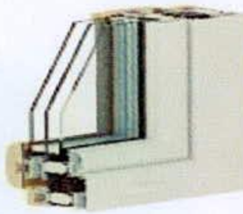
2.2.1 Different type of window glazing:

The use of single and multiple layers of various types of glass are used in window. Generally, there are three common glazing configurations. They are Single, Double & Triple Glazing. As the names imply, Single Glazing includes one layer of glass, Double Glazing includes two layers and Triple Glazing includes three layers. Until the recent availability of various high performance materials, the greater the number of glass layers, the greater the insulating value of the window or door. Now, with the advent of such products as sealed insulating glass, Low E glass, Heat Mirror and others, insulating values can be enhanced without the use of multiple glass layers. Often, combinations of certain Glazing Options, Glass Types, Metalic Films and Chemical Gas Fillers can provide significant insulating efficiency.

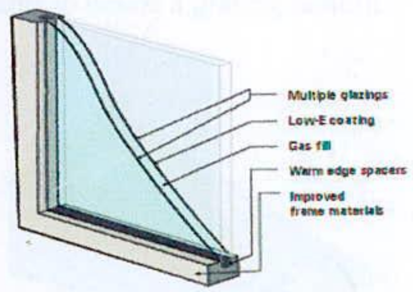


Single Clear glazing

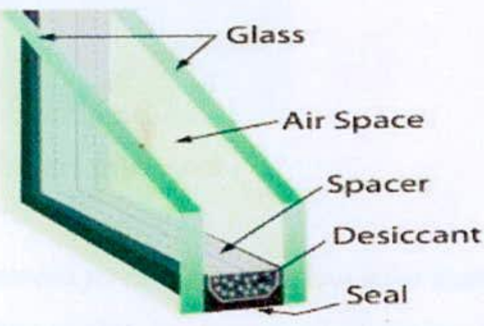
Double Clear glazing



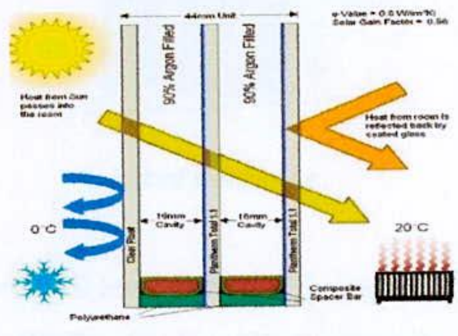
Triple Clear glazing



Double Layer low-E Opaque glazing



Double Layer Air Gap glazing



Triple Layer Argon Gap glazing

Fig. 2.1 : Different type of window glazing system

remain the same—select, orient, and size glass to maximize solar heat gain in winter and minimize it in summer.

In heating-dominated climates [14], major glazing areas should generally face south to collect solar heat during the winter when the sun is low in the sky. In the summer, when the sun is high overhead, overhangs or other shading devices prevent excessive heat gain.

To be effective, south-facing windows should have a solar heat gain coefficient (SHGC) of greater than 0.6 to maximize solar heat gain during the winter, a U-factor of 0.35 or less to reduce conductive heat transfer, and a high visible transmittance (VT) for good visible light transfer.

Windows on east-, west-, and north-facing walls should be minimized while still allowing for adequate daylight. It is difficult to control heat and light through east- and west-facing windows when the sun is low in the sky, and these windows should have a low SHGC and/or be shaded. North-facing windows collect little solar heat, so they are used only for lighting. Low-emissivity (low-e) window glazing can help control solar heat gain and loss in heating climates.

In cooling climates [14], particularly effective strategies include preferential use of north-facing windows and generously shaded south-facing windows. Windows with low SHGCs are more effective at reducing cooling loads. So, it can consider the following specifications.

U-value describes the rate of heat loss. So, lower numbers mean less heat loss. Most window manufacturers now give the U-value for the entire window unit, including the frame. Good windows are U-0.40. Super windows are U-0.25 and some products go down to U-0.15. (U-value is the inverse of R-value. To calculate R, divide 1 by U. (1÷ U 0.25 = R 4.0). To calculate U, divide 1 by R.

Shading Factor (SF) indicates how much solar heat is blocked. It compares how well a particular glazing reduces solar heat gain to a single pane of 1/8-inch double-strength clear glass. SF values range from 1.0 for clear glass (without low-e) to 0.08 for heavily reflective glass. A standard insulated glass unit (IGU) has an SF value of about 0.87.

Solar Heat Gain Coefficient (SHGC) also indicates how much solar heat is blocked by the window, but it is slightly different from SF. SHGC expresses the amount of solar heat that penetrates the window compared to the amount that strikes the outside. Lower numbers mean less heat entering the building. SHGC will eventually replace SF in manufacturer's literature. The NFRC Directory should start listing SHGC starting in January 1995.

Visible Light Transmittance (VLT) is the amount of visible light that penetrates a window expressed as a percentage. This affects daylighting and the ability to see objects and views outside. The human eye can adjust to wide variations in visible light, so it compensates to some degree for low VLT numbers. Clear glass has a value of 90 percent. Reflective glass would be anything below about 20 percent VLT. For most residential applications, VLT should be between 40 and 70 percent.

2.4 Building Energy Efficiency Improvement

There are many approaches to improve the energy efficiency of buildings. Usually the designer and architects use different tools to make a building energy-efficient at the design stage. Measures and techniques may be different for existing buildings. It varies as per nature of building systems and the age of a building itself. Some of the areas are identified by some researchers to improve the energy efficiency of buildings. These include improving the performance of building envelope system, efficient HVAC system, application of Modern technologies, Simulation design and others [15-16]. Some of the approaches are discussed in the next sections.

2.4.1 Improvement of HVAC System

Most HVAC systems are designed for temperature control without any concern regarding energy efficiency. More than 60% of the energy delivered to the buildings in hot and humid climatic regions is consumed by the HVAC system. Al-Azhari et al., and Shekhar et al., [17-18] used a simulation to evaluate the five most commonly used HVAC systems in commercial buildings, based on their thermal and energy performance. There are some techniques that can be followed and energy can be conserved in a HVAC system during operation, these techniques are recommended by many researchers, engineers and academics [19]. These include operation of HVAC systems: Operating the HVAC system only when it is required, for example there is no need to provide ventilation during unoccupied periods; this strategy can be followed by building operators and occupants. Eliminating overcooling and overheating of the conditioned space to improve comfort levels and avoid energy waste is another option.

2.4.2 Improvement in Lighting System

Lighting is a critical component of energy use in large office buildings. Hawken et al. [20] reported that homes and offices consume 20% - 30% of total energy consumption. Krarti et al., [11] proposed a simple equation to calculate the total energy used by lighting system. This equation can be used to calculate the energy saving due to any retrofit measure for the lighting systems. The energy consumption due to lighting needs to be calculated before and after the retrofit. The difference between the two estimated energy uses represents the energy savings. Krarti et al., proposed the following lighting equation

$$K_{whlit} = (N_{lum,j} - WR_{lum,j} - N_{h,j}) \qquad 2.1$$

Where, $N_{lum,\,j}$ is the number of lighting luminaries i.e. set of ballast, electrical wiring, housing and lamps of type j in the building to retrofitted.

$WR_{lum,j}$ is the wattage rating of both lamps and ballast for each luminary of type j, $N_{h,j}$ is the number of hours per year when the luminaries of type j are operating, J is the number of luminary types in the building.

To improve the energy efficiency of the lighting system, it is necessary to use reduced wattage rating of luminaries. Reduction of uses of luminaries and reduction of number of luminaries are other options to improve efficiency. However, human comfort, occupants, speed and accuracy requirements and background contrast are some factors that need to be considered as well. Energy-efficient lighting systems, for example high efficiency fluorescent lamps and compact fluorescent lamps, can improve the energy efficiency of a lighting system.

2.4.3 Thermal Energy Storage System

Thermal energy storage systems (TES) are defined as the short-term storage of energy for later use when heating and cooling is needed. TES is based on two major principles. Firstly, sensible energy storage by increasing (for heating applications) or decreasing (for cooling applications) the temperature of the storage medium (water, for instance).

Secondly, latent energy storage by changing the phase of the storage medium-phase changes materials (PCM). Recently much research is now ongoing regarding the use of PCMs in conventional building materials to enhance the energy storage capacity through latent heat of the PCM. The building material concept currently being studied uses a PCM added to gypsum wallboard, a material in widespread use in both residential and commercial buildings. The primary application is passive solar heating of a building, where the PCM wallboard would allow solar energy to supply a larger fraction of building heating. Amar and Farid (2004) used the thermal energy system concept and reported that energy storage in the walls, ceiling and floor of buildings may be enhanced by encapsulating suiTable phase change materials (PCMs) within these surfaces. This captures solar energy directly and increases human comfort by decreasing the frequency of internal air temperature swings and maintaining the temperature closer to the desired temperature for a longer period of time.

2.4.4 Living Wall and Green Facade Systems

Loh et al., [21] discussed the following three types of internal Living wall system that can improve the thermal and energy performance of a building when they are installed in indoor environment conditions. They are Panel system, Felt system, and Container and trellis system. These systems are shown in Fig. 2.2. However, these systems can be used in outdoor Living walls as well. Hopkins et al., [22] categorized these systems under Green wall or Living wall. It includes Modular Living wall, Vegetated mat wall, and Hybrid system.

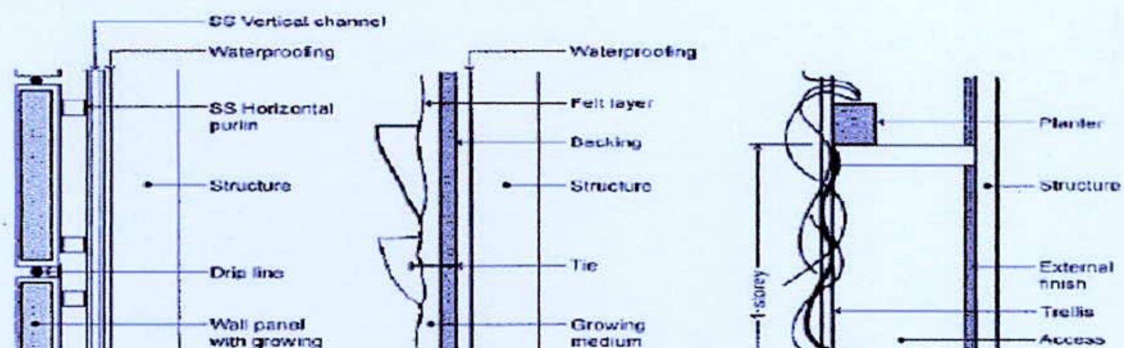


Fig. 2.2: Living wall system proposed by Susan Loh [20]

Sometimes plants with a wire, pot or container system are described as Green facade systems whereas modular and vegetated mat wall on building walls are considered as Living wall or Green wall systems in many literatures [21-22].

2.4.5 Rooftop Greenery System

One of the ways of to improve the energy efficiency of a building is to improve its thermal performance. Some researchers analyzed the Green roof application in different climate conditions and summarized that a Green roof can reduce energy consumption and keep buildings cool in summer [23]. There are many advantages of using Green roofs in buildings. Reduction of energy consumption, cooling of buildings in summer and enhancement of roof life results in longevity of roof and energy efficiency, mitigation of urban heat island effect, retention of the storm water runoff from roof surface, and reduction of the pollution of urban rainwater runoff, air pollution and noise, all of which are the key focus of using the rooftop Greenery system.

There are three types of Green roof system, as has been mentioned by the Green roof design reference manual [24]. A brief description of the three types of Green roof has been summarized from the manual and is outlined below:

(a) *Extensive Green roof System*

An extensive Green roof is the most fundamental form of Green roof. An extensive roof comprises the following components: a waterproof membrane, a root protection layer, a drainage layer, a filter mat, growing medium and finally, vegetation. The root protection layer typically can be combined with the membrane in an extensive Green roof system. It is typically found to have a soil or substrate of no more than 15cm in depth. As a result of the shallow substrate depth, the range of vegetation is limited to low-growing vegetation types including grasses, moss and sedums. The composition of the growing medium is critical in an extensive Green roof system. It is important to avoid an excessively fertile substrate as this will encourage competition amongst vegetation species and may result in an uneven coverage of vegetation. The best method is to have a moderately fertile substrate that maintains a constant coverage yearlong. An extensive Green roof system is commonly used in situations where no additional structural support is desired. Typically, an existing roof will be able to support an extensive system that can weigh up to 100kg/m^2. However it is important to have some degree of access for maintenance. Extensive Green roofs will require maintenance in the first two years to ensure that the vegetation is stabilized and that there are no weeds. After two years, maintenance is very minimal and may only be required once or twice annually.

(b) *Intensive Green roof System*

Intensive Green roofing systems are wide-ranging in use. A Green roofing system can support the production of food produce and also provide a public amenity. An intensive roof can even support the production of fruit. Such food production on city rooftops can drastically minimize, if not eliminate, the need to transport fresh produce and thus reduce carbon emissions. The components of an intensive Green roof are the same as all other Green roofs; however, each component requires much more consideration with regards to its form and materiality due to the sensitive relationship between vegetation types, water harvesting and growing mediums. An intensive Green roof needs to balance the quantity of water harvested, the fertility of its substrate and the varieties of vegetation chosen.

(c)*Semi-extensive Green roof System*

A semi-extensive Green roof is a hybrid of the two systems i.e. made up of extensive and intensive. A semi-extensive roof system is appropriate when the rooftop can be viewed from adjacent buildings but the possibility for access is limited and the structural capacity of the roof deck cannot support an intensive Green roof. A semi-extensive Green roof allows for a slightly deeper substrate depth than a traditional extensive Green roof but it still enjoys the relatively minimal maintenance that an extensive Green roof system has. Due to the relatively deeper substrate, a semi-extensive roof can support a greater variety of vegetation than an extensive Green roof. The selection of vegetation on the roof in a semi-extensive Green roof system is important, as it will directly determine the level of maintenance required to keep the Green roof functioning properly. In general, depending upon the selection of materials, a semi-extensive Green roof can withstand load up to 630 kg/m^2.

2.4.6 Improvement in Designing of Building Envelope

A building's location and surroundings play a key role in regulating its temperature and heat gain. For example, trees, landscaping, and hills can provide shade and block wind. In cooler climates, designing buildings with south-facing windows increases the amount of sun entering the building, minimizing energy use by maximizing passive solar heating. Tight building design, including energy efficient windows, well-sealed doors, and additional thermal insulation of walls, basement slabs, and foundations can reduce heat loss by 25 to 50%.

To improve the thermal performance of buildings and their energy efficiency, several strategies are now being used depending on the feasibility study and cost analysis of buildings in both the design and operation stage. Improvement of thermal insulation, low emissivity glazing, reduction of air leakage and photovoltaic panels are the major options to improve the performance of the building envelope [15]. The addition of thermal insulation for building surfaces can be a cost-effective measure of improving energy efficiency [19].

Replacement of windows and use of more energy-efficient windows such as high R value, low emissivity glazing, air tight etc. can be beneficial in the reduction of energy consumption and improving indoor comfort. It is mostly effective when a significant portion of the exposed building surfaces are windows. Reduction of air leakage to lessen significant infiltration load can be other options. Leakage area of the building envelope can be reduced by simple and inexpensive weather stripping techniques. Building integrated photovoltaic panels can generate electricity while absorbing solar radiation and reducing heat gain through the building envelope. Thus this can be another option for improving thermal energy performance of the building envelope. However, improvement in the efficiency of existing building envelopes of large commercial buildings is not cost effective if expensive modifications are necessary. Energy-efficient building envelope design is suitable for the design stage of the building. Recently, several materials, systems and development practices have been proposed by many researchers for energy efficiency improvement through the design of building envelope [25]. Spectrally-selective glasses can optimize solar gains and the shading effects of a fenestration system of building. Chromogenic glazing which changes properties automatically depending on temperature and light level conditions is similar to sunglasses that become dark in sunlight. Klainsek et al. [26] studied the influence of glazing and its shape on energy consumption in commercial buildings, and energy consumption for horizontal and vertical glazing separated by opaque areas. It was reported that for traditional walls with colorless glazing, energy consumption was reduced from 0.92% to 0.78% and 0.18% to 0.16% during summer and winter months respectively. The use of curtain walls can reduce the consumption between 0.3-0.39 %. The energy consumption was higher for vertical discontinuous windows than continuous horizontal windows of the same area. There are several benefits of an energy-efficient high performance glazing system. High performance glazing systems reduce cooling demand in the perimeter areas of the building which leads to fewer requirements for smaller heating, ventilating and air-conditioning (HVAC) plants as well as reduced energy use of cooling. Higher levels of daylight enhance the visual and psychological comfort of occupants. The extra daylight can be utilized in conjunction with daylight-linked electric lighting control to reduce energy use for lighting. Over the life of the building, the reduced energy use will lead to substantial reductions in greenhouse gas emissions.

During the literature review of this research project, the author also visited the energy-efficient residential Buildings in Bangladesh. The building envelope has a significant role in energy efficiency improvement of the building. More specifically, the building's wall and window construction are critically important for heat gain and later on have a significant effect on cooling energy requirements. Envelope design i.e. wall and window design with different construction materials, affect the internal air temperature of the building. This helps to control temperature fluctuations. Again, a high level of natural lighting has been achieved inside the building through the use of advance glazing which is heat and glares reflective. With the correct orientation of the long axis of the building in relation to the passage of the sun overhead, smart glass can contribute to the control of the building temperature. A proper ventilation system within the envelope is another important consideration for the building envelope design.

All of the above design options are closely related with the cp (coefficient of performance) index Building orientation with appropriate window locations in each orientation, improvement of glazing system, building integrated systems, external shading devices, envelope constructions, U value of wall and windows, are the factors that affect the Envelope Thermal Transfer Value. As the cp (coefficient of performance) index includes all the conduction, convection and solar heat gain components of walls and windows, so design of a building envelope with a focus to reduce energy consumption and to promote the use of energy-efficient systems is a very important decision that can be made during the design stage of new buildings and the operation stage of existing buildings.

CHAPTER III

Building Energy Simulation Software

3.1 General

The global increase in demand for energy has generated pressure on saving energy. Consequently, Energy efficient buildings are an important factor related to the energy issue. Various building energy simulation softwares are used now-a-days to simulate building energy consumption and to design energy efficient building such as EnergyPro, EnergyPlus, EAB, REScheck etc. Among them EnergyPlus is developed by US department of Energy and it is getting popular to simulate and design of energy efficient building. The features available in this software are suitable to reach the objectives of this project. Therefore, EnergyPlus is used in this project to simulate the effect of external shading and window glazing on building energy consumption and details of EnergyPlus are described in this chapter. The calculation of energy consumptions spent in dwellings still to build or to retrofit allow a more accurate determination of design charges and help to decide with highest accuracy the possible devices to be used in a room (limited zone) or dwelling. Energy simulation software tools can also allow considering all the regulations in force and simultaneously provide a sense of comfort to its inhabitants through a correct design of heating and cooling systems. Such software have also available tools to improve constructive solutions through simulating the incorporation of passive solar systems in buildings, such as horizontally and vertically shading systems and a more accurate study of the glazing system, HVAC system loads to use. There is an increasing range of energy simulation software tools available, with the ability to calculate increasingly complex energy requirements, with more variables and a more rigorous approach.

3.2 EnergyPlus

Energy Plus is one of the popular energy simulation software tools. Its development began in 1996, sponsored by the Department of Energy (DoE) of United States of America (USA) [28]. Initially, the U.S. government was developing two different software tools, BLAST and DOE-2, which were abandoned after many discussions and represented a first step and the working basis of the EnergyPlus. The EnergyPlus has the features and capabilities of BLAST and DOE-2; however is an entirely new software tool that combines the heat balance of BLAST with a generic HVAC system. The Energy Plus aims to develop and organize software tools in modules that can easily work together or separately. It is important to outline that in EnergyPlus does not exist a visual interface that allow users to see and concept the building. In this case third-party software tools, i.e., Design Builder need to be used. EnergyPlus is a thermal simulation software tool that allows the analysis of energy throughout the building and the thermal load and it is used by engineers, architects and researchers to model the energy use and water use in buildings. The software tool simulates models for heating, cooling, lighting, ventilation, other flows of energy and water use. The simulation of a building is divided into two stages [28-29].

• Construction of the building;

• Introduction of data, such as environmental aspects, effects of shading, cooling system, internal gains, etc.

3.3 Steps to Perform in a Building Energy Simulation

There is an increasing range of energy simulation software tools i.e., EnergyPlus available, with the ability to calculate increasingly complex energy requirements, with more variables and a more rigorous approach. Generally speaking in all energy simulation software tools there are three steps that have to be performed in a building simulation.

3.3.1 First Step - Creation of a Building

The creation of the building is the earlier stage of an energy simulation. This process can be done for example by inserting the coordinates in the software tool such as in Energy Plus simulation software (Fig. 3.1) or by uploading files from other software, such as AutoCAD or Google Sketch Up. The introduction of coordinates is performed according to a certain reference (which is located in a pre-determined position).

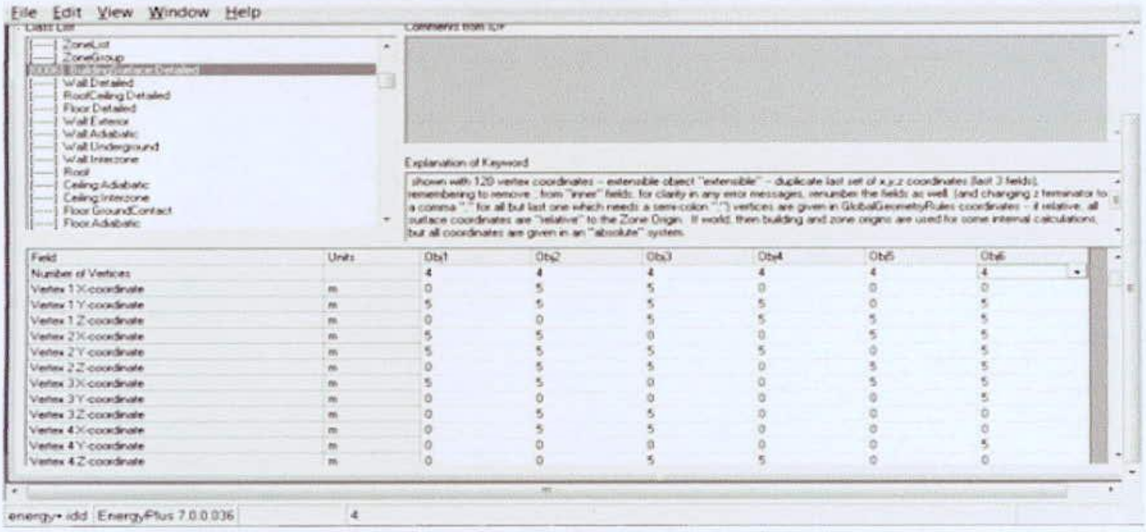


Fig. 3.1: Introduction of coordinates of a cube in the option "Detailed Surface Building" of EnergyPlus

After this procedure, it is possible to see the Fig. introduced in the software tool through the DXF button (Fig. 3.2) that connects to AutoCad.

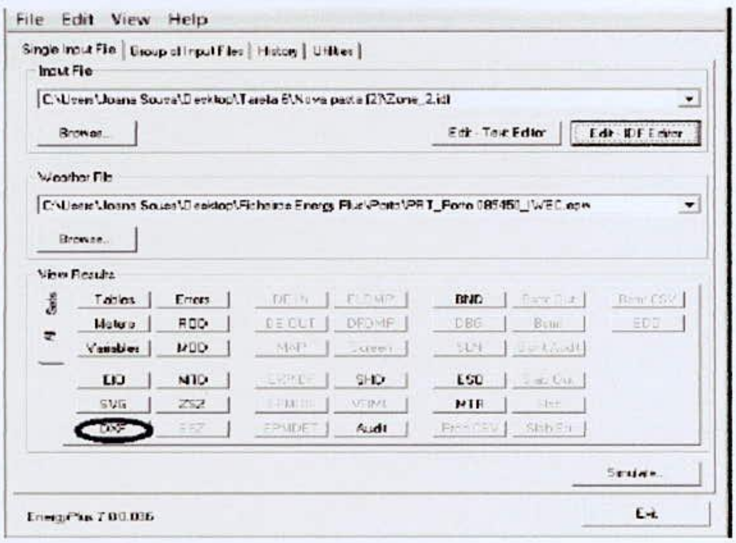


Fig. 3.2: DXF button in the EnergyPlus.

Concerning the structure of the building and its construction, it is essential to specify the dimensions of the organizational structure, geometry and materials used in the components of the building architecture (Fig. 3.3). The development of the model based on the characteristics mentioned above represent the building itself ready to be computed.

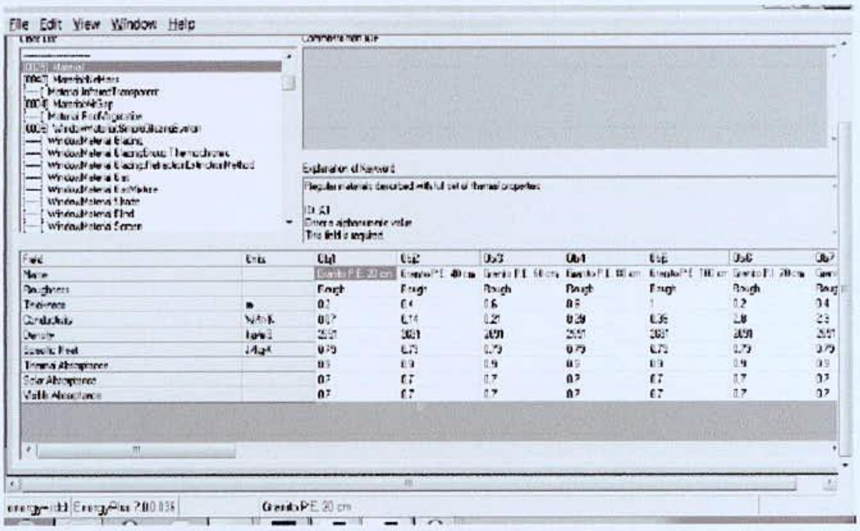


Fig. 3.3: View of the Interface to the Introduction of the Materials in EnergyPlus.

3.3.2 Second Step - Building Simulation

In this step, it is established which variables are to consider in the simulation of the building and make the software tool run. The thermal performance of the building can vary according to its use. Therefore, it is important to specify the type of building (office, housing, etc.), the human activities carried out, the existing equipment (lighting, refrigeration, air conditioning systems, furnaces, etc.), and their daily schedule. The description of these parameters allows establishing the internal heat load and ventilation (Fig. 3.4).

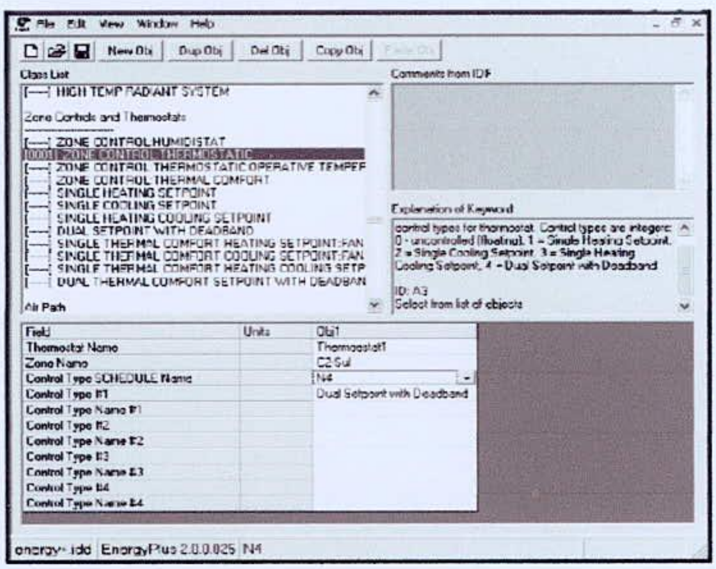


Fig. 3.4: View of the Interface to the Introduction of Thermostat Definitions in EnergyPlus.

3.3.3 Third Step - Analysis of Results

After running the software tool, it should be checked if there are any error or severe mismatch introduced in the variables set like figure 3.5. In some cases the simulation software tool issues its own warnings in a final report containing the results from which should be retained all the relevant conclusions.

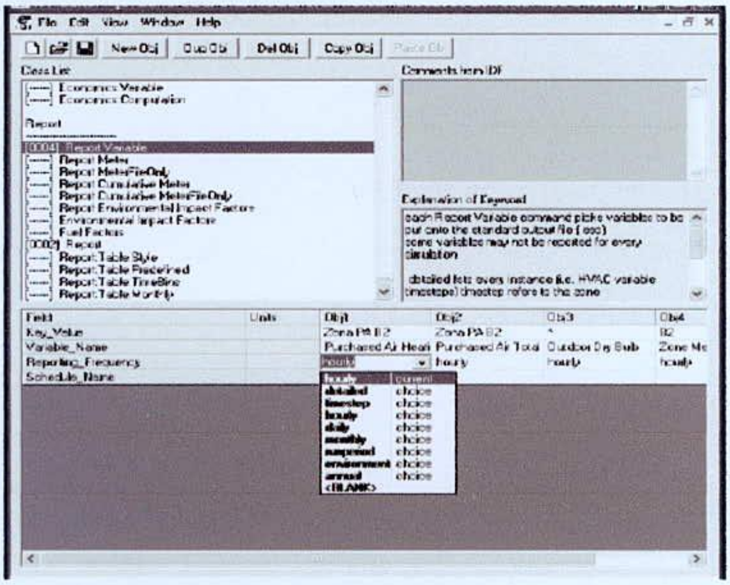


Fig. 3.5: View of the Report Variable Definitions in Energy Plus.

Depending upon the simulation software tool of energy it is used, the following aspects should be considered:

- Physical Phenomena: Hygro-thermal behavior, artificial/natural illumination, acoustics, ventilation and air distribution
- Energy Systems: Modeling energy in a building, heating and cooling, thermal mass, cogeneration and renewable energy
- HVAC Systems: Thermal loads and its forecast for optimizing control of components and modeling systems, dynamic behavior and control systems, environmental quality and energy consumption
- Human Factors: Comfort, visual modeling and indoor air quality
- Urban Simulation: Sunlight and shadow effects.

In each building simulation there are four fundamental aspects that must be taken into account:

- ✓ Structure of the building and its organization
- ✓ Physical phenomena involved in the simulation
- ✓ Weather conditions
- ✓ Use of the building.

In relation to physical phenomena, the model seeks to describe the physical behavior of building materials and their components, and their performance on the transfer of heat by conduction, convection and radiation.

3.4 Additional Software Tools used with EnergyPlus

The COMFEN 5 program is published from Lawrence Berkley National Laboratory (LBNL) in USA, used in EnergyPlus. Today's energy-efficient windows can dramatically lower the heating and cooling costs associated with windows while increasing occupant comfort and minimizing window surface condensation problems.

However, consumers are often confused about how to pick the most efficient window design for a commercial or Mid-Rise residential building. Product information typically offers window properties: U-factors or R-values, Solar Heat Gain Coefficients or Shading Coefficients, and air leakage rates. However, the relative importance of these properties depends on site- and building-specific conditions. Furthermore, these properties are based on static evaluation conditions that are very different from the real situation a window will be used in. A computer tool such as COMFEN can help architects and builders pick the most energy-efficient and cost-effective window for a given application. It calculates heating and cooling energy use and associated costs as well as peak heating and cooling demand for specific window products. Users define a specific "scenario" by specifying the building type, geographic location, orientation, and window configuration. Users also specify size, shading, and thermal properties of the window they wish to investigate. Update information, future releases, and program information about COMFEN and other software tools (such as WINDOW, THERM, REFEN 6 and Optics) from the Windows and Day lighting Group at LBNL can be found on the World Wide Web at URL: http://windows.lbl.gov, in the Software section.

If the scenarios have a triangle icon to the left, this means that they do not have current results (and therefore the Results Section will be blank) and must be simulated. To calculate the results, select as many scenarios as desired, then click the lightning bolt tool bar button, and the program will start to run the EnergyPlus simulation program for each scenario (Fig. 3.6).

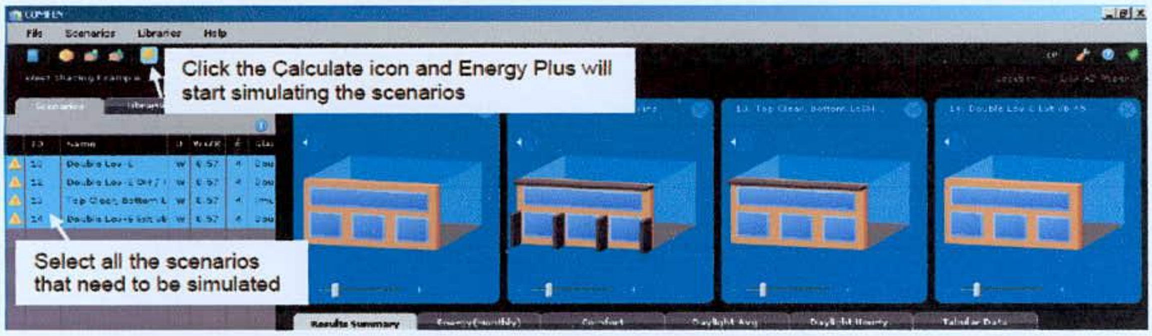


Fig. 3.6: *Scenarios to be calculated and the Lightning Bolt toolbar button.*

As the calculations are proceeding, a status box will appear (Fig. 3.7).

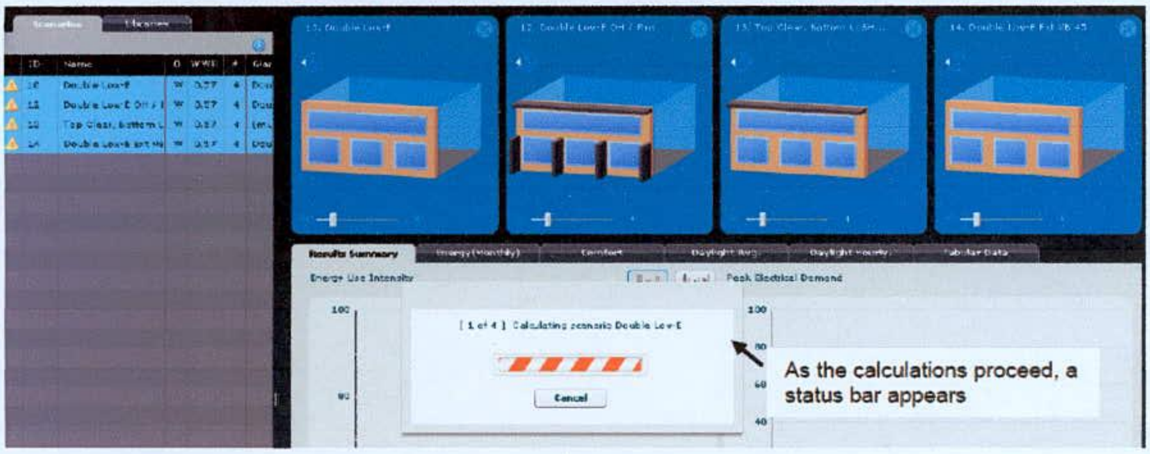


Fig. 3.7: *A status bar showing the calculated scenarios.*

When the calculations are finished, the results will appear in the results section. It can be calculated the desired parameter from the result & graph from the scenarios.

CHAPTER IV

Simulation Technique

4.1 General

The building energy simulation program EnergyPlus is used in present study to predict annual energy use in the residential buildings of Bangladesh. EnergyPlus (version-32 8.1.0.009) is made available by the LBNL in USA. EnergyPlus calculates thermal loads of buildings by the heat balance method. This method takes into account all heat balances on outdoor and indoor surfaces and transient heat conduction through the building. The simulation results of EnergyPlus have been validated through numerous analytical, comparative, and empirical tests. Although EnergyPlus is capable of simulating heating, ventilation, and air conditioning (HVAC) systems, the details of HVAC systems are not modeled since the primary objective of this study was to examine the influence of windows on thermal loads of buildings. In EnergyPlus, the heat transfer by radiation, convection and conduction is calculated at each time step. The U-values are not constant throughout the simulation because the radiative and convective heat transfers are calculated by algorithms that take into account parameters such as temperature difference between the surface and the air.

4.2 Description of the Simulation domain

The plan of the residential building which is used as a simulation domain is shown in Fig. 4.1.The residential building is one storied building with 25 m^2 floor area including 2.25 m^2 windows have been located at the center of the wall of zones 1, 2, 3, 4 (south, east, west, and, north zone respectively) that has been evaluated by computer simulation. The configuration of overhang and fin with single clear glazing in all direction and dimension of the building are shown in Table 4.1 and Fig. 4.3; respectively. All the zones have been assumed to be maintained at the same temperature and the three zones are insulated as well as the energy is transferred only the façade wall that is simulated in different orientation. The thermal properties of the wall and floor materials have been given in Table 4.2.

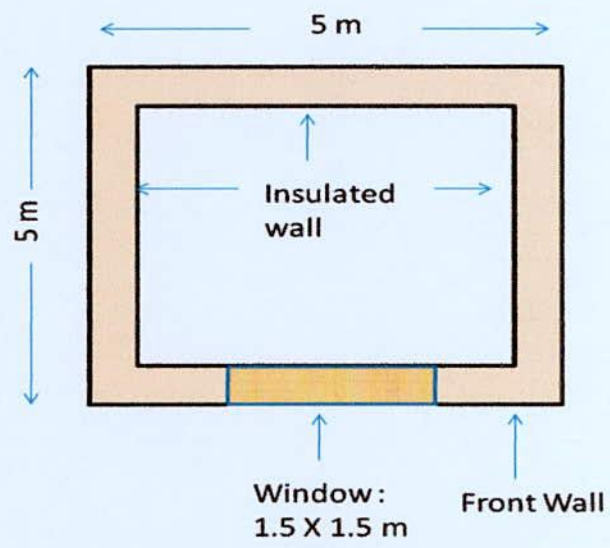


Fig. 4.1: The plan of the residential building.

The basic geometry of a vertical shaded window is shown in Fig. 4.2. A horizontal with projection P extends laterally far past both the ends of the window, so that the end effect can be neglected. The width of the window is W and the height of the window is H. In some cases the overhang is separated by a portion of vertical wall from the top of the window. Let this height, if any, from window top to the base of the overhang be G. Let E_L and E_R be the extension of the overhangs on either side of the window. In the present investigation both E_L and E_R are considered to be infinite.

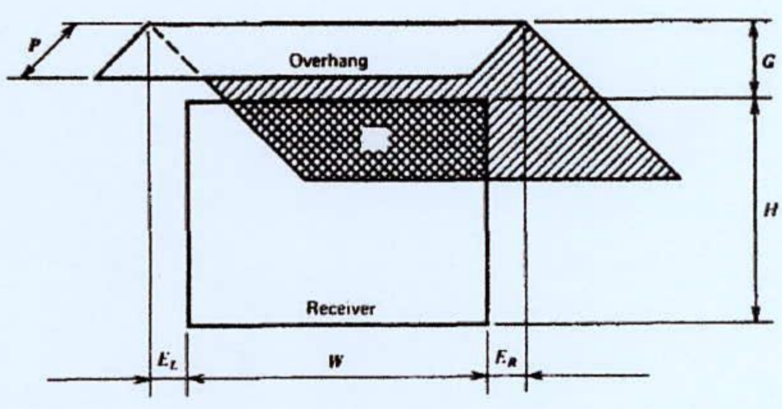


Fig. 4.2: Basic geometry of window shaded by overhang

Table 4.1: Overhang and side fin configurations with single clear glazing in all direction

Case	Overhangs (m)		Distance above the window (m)	Side fin with 1.5 m width	
	Width	Depth		Depth of the right side (m)	Depth of the left side (m)
1	1.5	0.5	...	...	...
2	1.5	0.75	...	...	...
3	2	0.75	...	...	...
4	2	0.75	0.2	...	...
5	2	0.75	...	0.75	...
6	2	0.75	...	...	0.75

Table 4.2: Wall and floor construction

Layer (outer to inner)	Thickness (mm)	Conductance ($W/m^2.K$)	Density (kg/m^3)	Specific Heat (J/kg.K)
Wall				
Cement, sand Plaster	25.4	31.8	1682	840
Brick	304.8	2.934	1922	795
Cement, sand Plaster	25.4	31.8	1682	840
Floor				
Cement plaster	25.4	9.063	720	837
Cement, sand Plaster	25.4	31.8	1682	840
Concrete block	203.2	2.63	1282	837

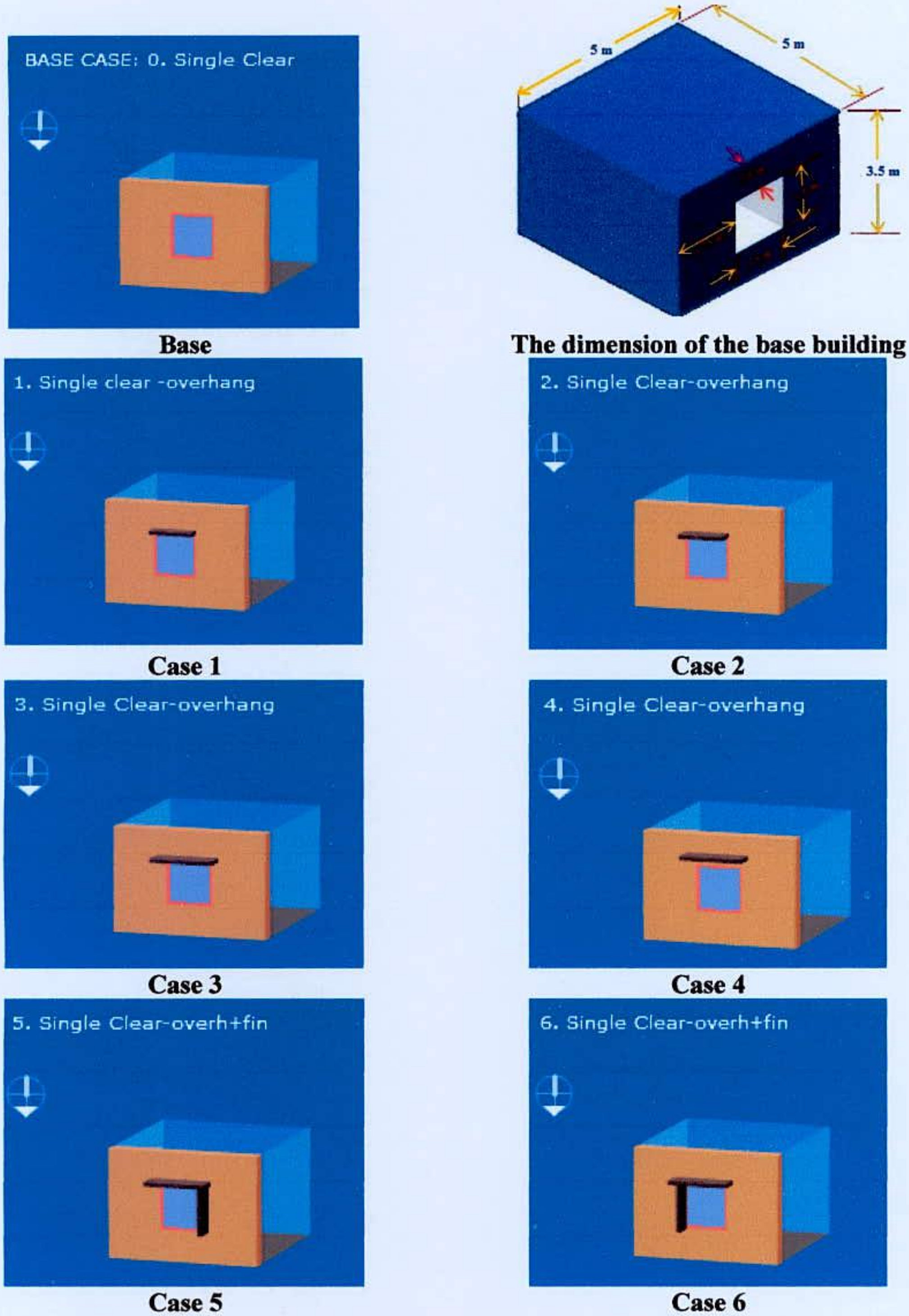


Fig. 4.3: The dimension of the building, configuration of the window overhangs and fins in the building for all 1-6 cases.

Table 4.3 shows the design values of the internal heat gains. In present study the performance of buildings with and without overhangs and also with and without side fins have been compared.

Table 4.3: Design values of internal heat gains and infiltration.

	Unit	Value
Occupants	Person/m^2	0.05
Lightings	W/m^2	10.76
Other equipment	W/m^2	8.07
Air change + infiltration	Volume/h	1

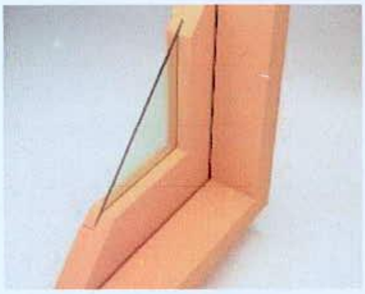
4.2.1 Description of the window

The thermal performance of external wall window is evaluated by considering different type of glazing glass.

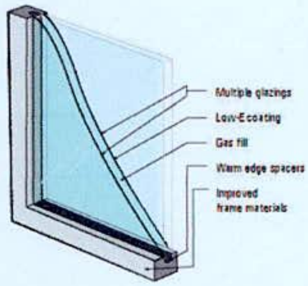
Effect of four types of windows has been studied as follow:

(1) Single clear glazing (S.Clear)
(2) Double low-E Opaque glazing (D.L.O)
(3) Double low-E Clear (Argon) glazing (D.L.C)
(4) Double clear glazing (D.Clear)

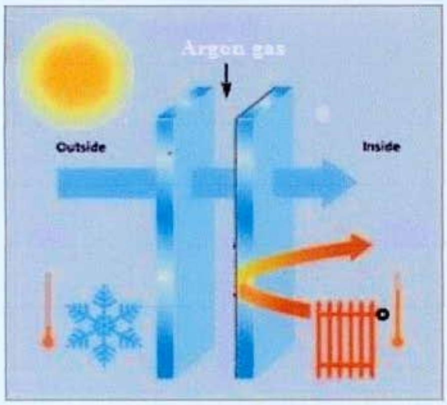
Details of the glazing are given in Fig. 4.4 and detail optical properties are present in the Table 4.4.



Single Clear glazing



Double Layer low-E Opaque glazing



Double Layer Argon Gap glazing

Double Clear glazing

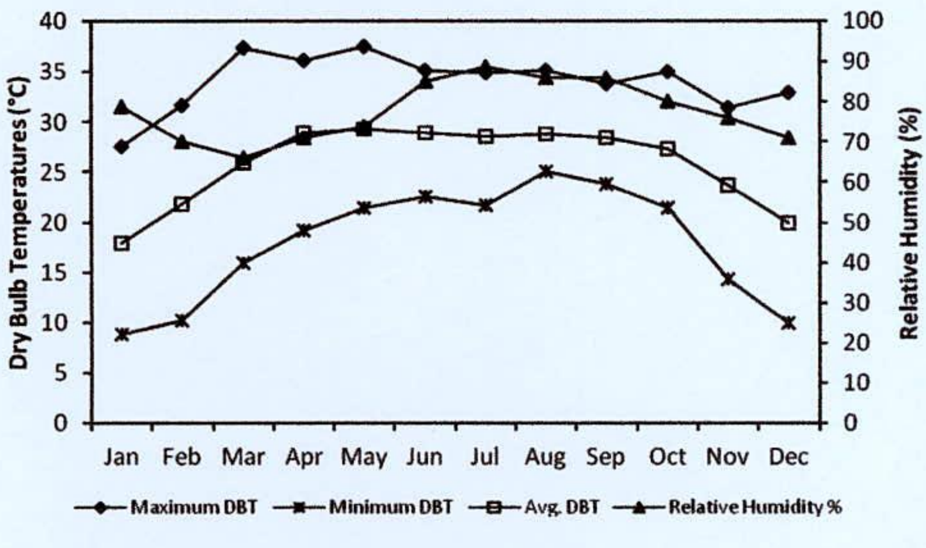
Fig. 4.4 : Different type of glazing systems that are used in the present work

Table 4.4: shows the optical properties of glasses

Glass type	Solar transmittance	Solar reflectance		Visible transmittance	Visible reflectance		IR hemispherical emissivity	
		Front	Back		Front	Back	Front	Back
Single Clear 6 mm	0.771	0.07	0.07	0.88	0.08	0.08	0.84	0.84
Double low-E Opaque	0.045	0.3	0.05	0.03	0.36	0.05	0.85	0.84
Double low-E Clear (Argon)	0.496	0.39	0.33	0.78	0.13	0.16	0.03	0.84
Double clear (air)	0.771	0.07	0.07	0.88	0.08	0.08	0.84	0.84

4.3 Climate condition of Bangladesh

Bangladesh has a subtropical monsoon climate characterized by seasonal variations in rainfall, high temperatures and humidity with hot, humid summer and a cool, dry winter. Jessore is a district in the southwestern tip of Bangladesh. The investigated residential building is assumed to be located in the city of Jessore that average height above sea-level is 7 m. Its latitude is $23^{0}10$N, longitude $89^{0}10$E, and time zone GMT + 6.0 h. The EnergyPlus weather file used in the EnergyPlus simulation is generated by Department of Energy (DOE), USA software [29]. To familiarize with the climate of Jessore, Figs. 4.5-4.7 are given by using monthly statistics for Jessore from DOE, USA weather file. For each month during entire year, Fig. 4.5 gives the dry bulb temperature (minimum, daily average, and maximum) and relative humidity. For each month during entire year, Fig. 4.6 shows direct, diffuse and global average solar radiation, and daily average wind speed. These Figures show that the city has a moderate continental climate with a gradual transition between the four distinct seasons (winter, spring, summer, and autumn). The summers are hot and humid, with temperatures as high as 37.6^{0}C. The winters are cool with temperatures as low as 8.8^{0}C. In these simulations, it is considered that the heating periods during the months December to February and cooling periods from March to October.



. Fig. 4.5: Monthly relative humidity and dry bulb temperature (minimum, daily average and maximum).

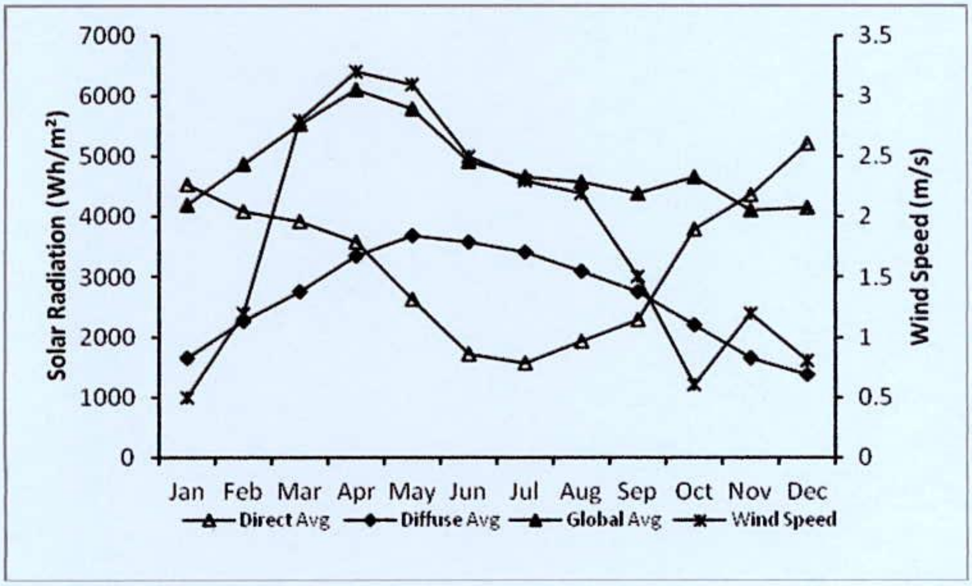


Fig. 4.6: Daily average direct, diffuse, and global average solar radiation and wind speed.

The percentage of wind direction is presented in the following Fig. 4.7 and observes that the wind direction percentage is the highest in north direction that value is 63.2 %. This is about three times higher than south direction.

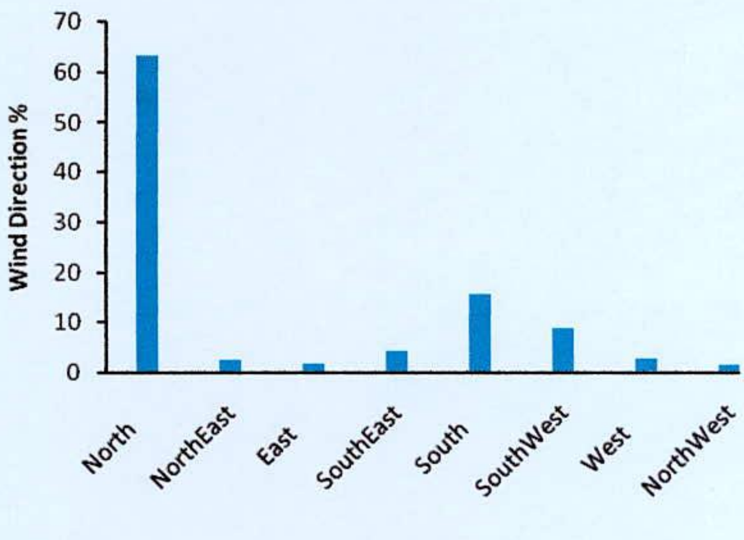


Fig. 4.7 : Wind direction percentage

4.4 Simulation procedure

Now-a-days energy-efficient windows of the residential building can dramatically lower the heating and cooling costs associated with windows while increasing occupant comfort and minimizing window surface condensation problems. However, consumers are often confused about how to pick up the most efficient window design for a residential building. Product information typically offers window properties: U-factors or R-values, Solar Heat Gain Coefficients or Shading Coefficients, and air leakage rates. However, the relative importance of these properties depends on site and building-specific conditions. Furthermore, these properties are based on static evaluation conditions that are very different from the real situation a window will be used in. The EnergyPlus simulated software can help architects and builders pick the most energy-efficient and cost-effective window for a given application. It calculates heating and cooling energy use and associated with COMFEN 5 as a tool. A brief simulation procedure is discussed in following.

At first starting the program and a general tab is used to give the project a name (required), a description (optional), and specify a building type (required). The Site tab is used to define the properties of the site, such as location that is shown in Fig. 4.8. Weather data file of Jessore inputted before simulation process has started.

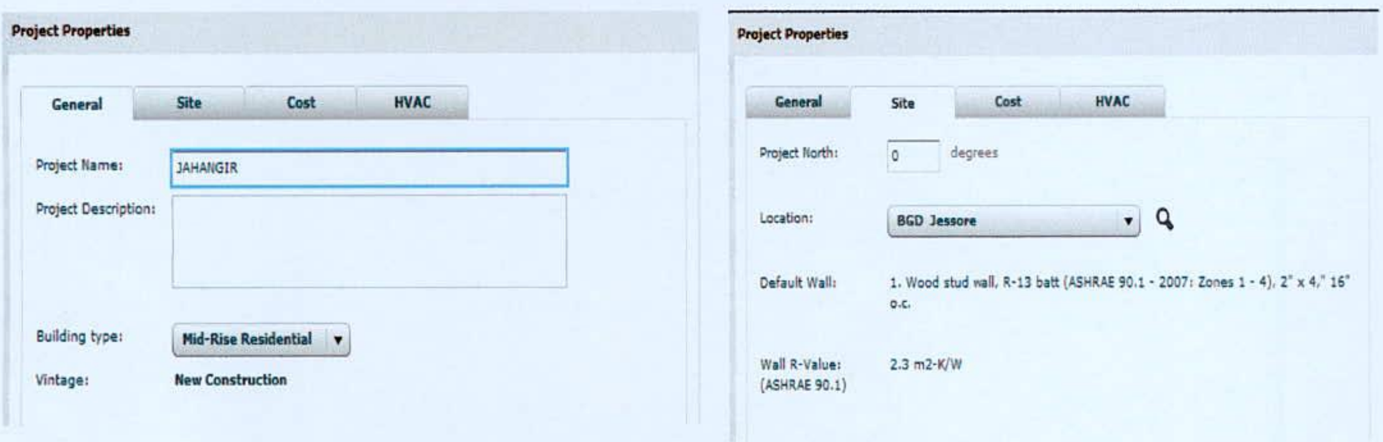


Fig. 4.8: General properties of simulated project

Now to start a new Project, there are no scenarios defined. To create a new scenario to the scenarios menu and it should select some parameters as geometry and material and environment in scenario menu. In this project the building dimension is 5x5x3.5m and lighting as well as equipment load are 10.06, 8.07 W/m^2; respectively that is shown in Fig. 4.9.

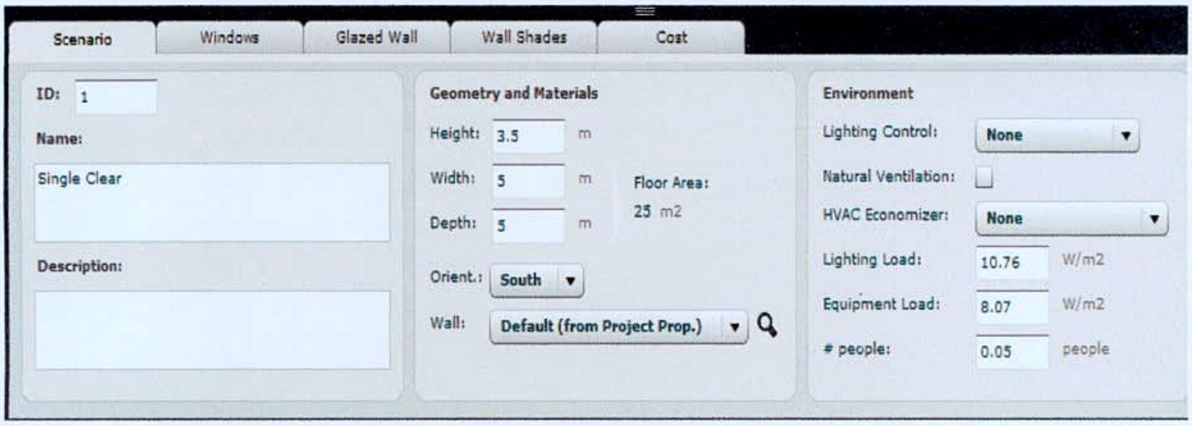


Fig. 4.8: Parameters of scenario of the project

Then from the Edit Scenario Windows tab, from this dialog box it can be selected the dimension of window as 1.5x1.5m, position of window i.e., sill height 1m and distance from the left wall 1.75 m, also glazing system and operable window that is shown in following Fig. 4.10.

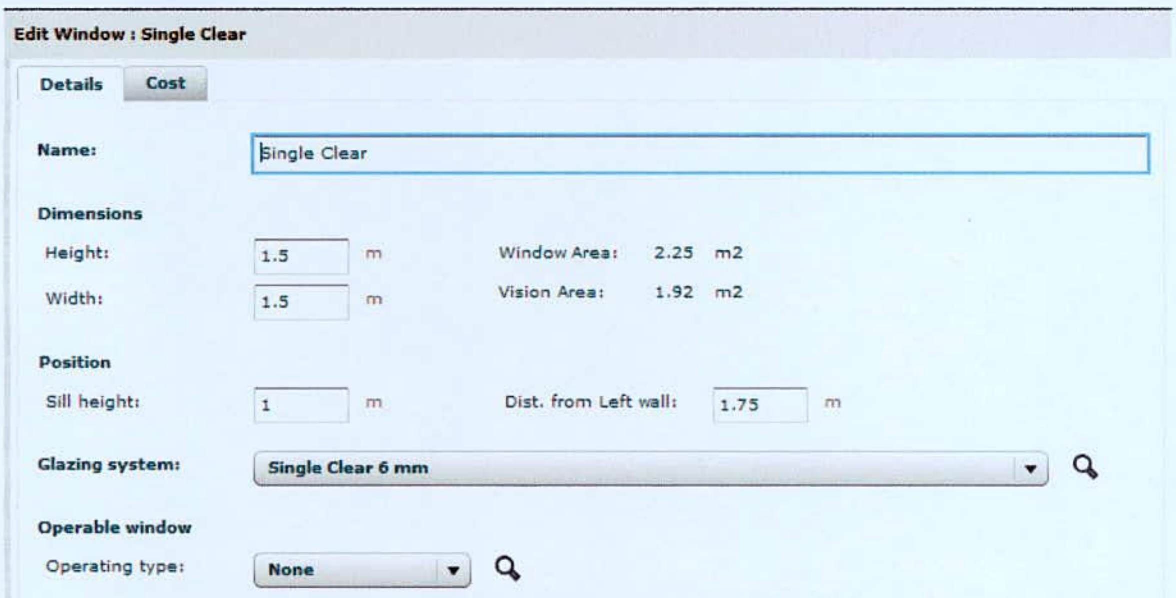


Fig. 4.10: Dimension and Glazing system of the window

After that the overhang and fin dimensions are selected via the Edit Wall Shade tab. This project chose different dimensions overhang and fin as case 1-6. The overhang and fin dimension for case 5 are shown in the following Fig. 4.11.

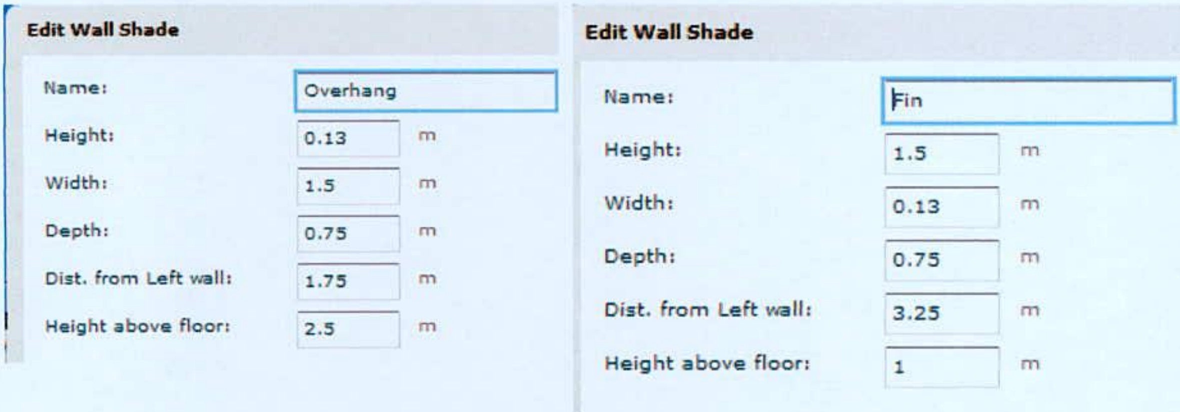


Fig. 4.11: Dimensions of overhang and fin.

After editing building, window, overhang and fins dimension, material composition and environment condition the scenario can be run to find the data of desire parameters that is shown in the Fig. 4.12.

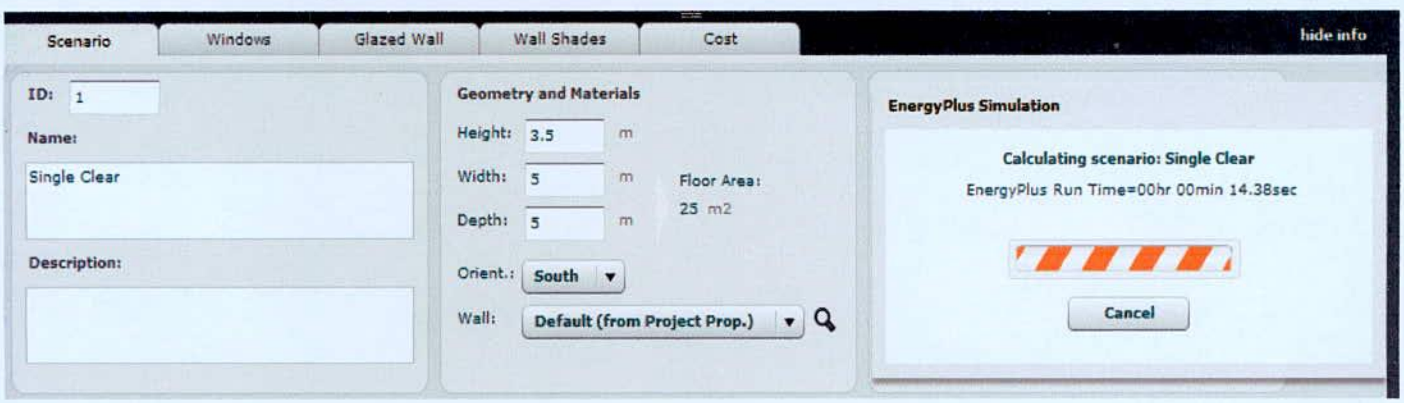


Fig. 4.12 : Running condition of EnergyPlus simulation.

In the present study, the effects of external window shading have been investigated for three cases:

(1) Windows without overhangs and side fins.

(2) Windows with overhangs and without side fins.

(3) Windows with overhangs and side fins.

Simultaneously the depth, the width and the distance above the window of the overhangs and the depth of side fins have been changed.

Chapter V

Results and Discussion

The residential building of this project work that is one storied building with 25 m^2 floor area including 2.25 m^2 windows have been located at the midpoint of the different facing wall. Simple overhang (case 1) is used with increasing depth (case 2) and width (case 3). In case 4 both length of depth and width are increased as well as right & left side fin are used in window in case 5 and 6; respectively. Heat gain, monthly heat gain, Energy use intensity, daylight and *cp* index are evaluated from this simulation program. The U-factors for single clear glazing for all cases are same (5.82 W/m^2-K) i.e., the heat losses from interior to outside through window are same. But considering advance glazing the U-factors value vary with different type. The U-factors are 1.65, 1.39 and 2.69 W/m^2-K for D.L.O, D.L.C. and D. clear; respectively. As well as, the *cp* index has been calculated for the heating and cooling periods as well as the whole year.

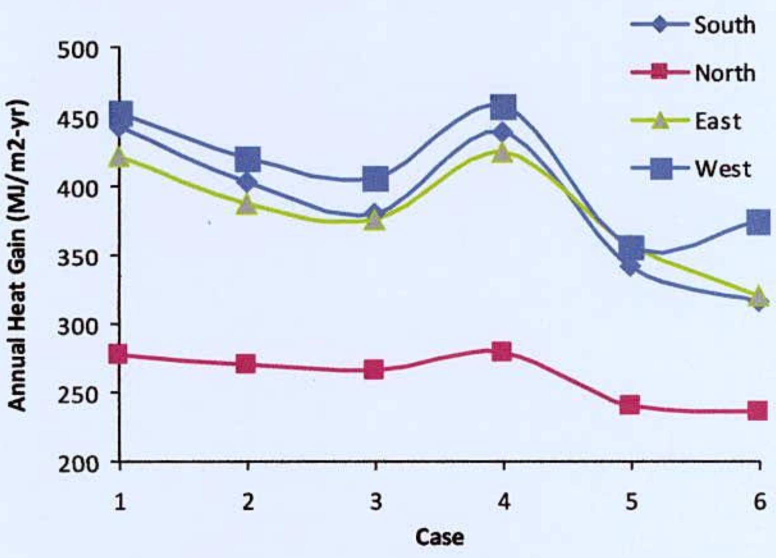


Fig. 5.1: Annual heat gain per window area for different cases

Heat gains per window area of building are evaluated for all directions and shown in Fig. 5.1. It showed that heat gain is lowest for the position of the north facing window of the building and higest heat gain is observed for west facing window for cases 1-6. Heat gain for the window of south and east facing are almost similar. For case 6, the heat gain are 236.2, 315.8 and 320.34 MJ/m^2-yr that are much lower than other cases for north, south and east facing window; respectively. As well as for west facing window, the heat gain value is the lowest for case 5 is 355.7 MJ/m^2-yr. Furthermore Monthly heat gains are shown in the following Figs. 5.2-5.5.

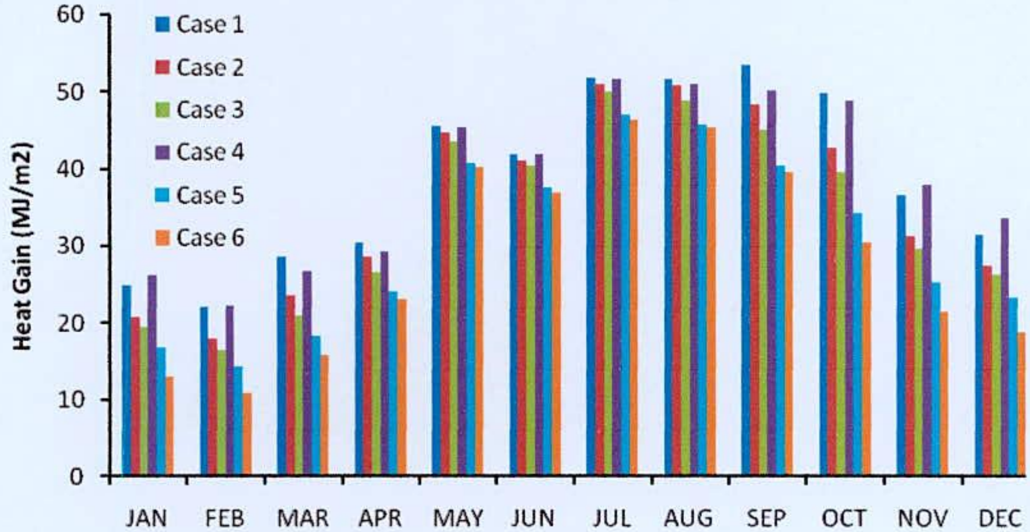


Fig. 5.2: Monthly heat gain per window area for different cases in south facing

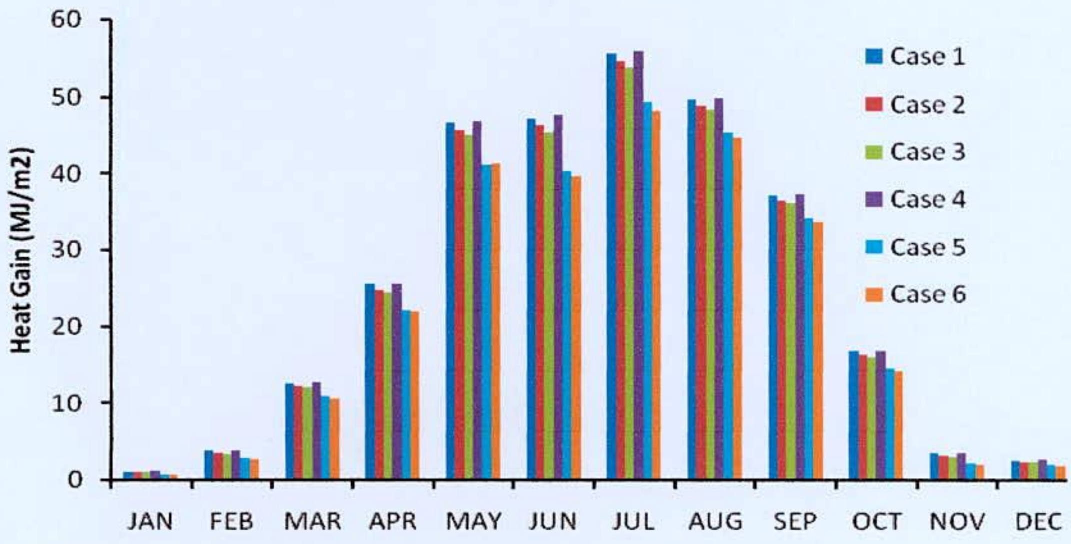


Fig. 5.3: Monthly heat gain per window area for different cases in north facing

For all cases, monthly heat gain for May to September are higher (during these time the average temperature is higher) than other months. From Figs. 5.2-5.5, the heat gain is high for a simple overhang at case 1 & 4. With increasing the length of depth and width of overhang, the heat gain are decreased that appear in the case 2 & 3; respectively for the reason of more heat is blocked by overhang . In addition to increase the height of overhang from window, the heat gain is increased for getting scope of more solar heat to strick the window in case 4. Adding side fin in the window the heat gains are decased as observed in case 5 and 6.

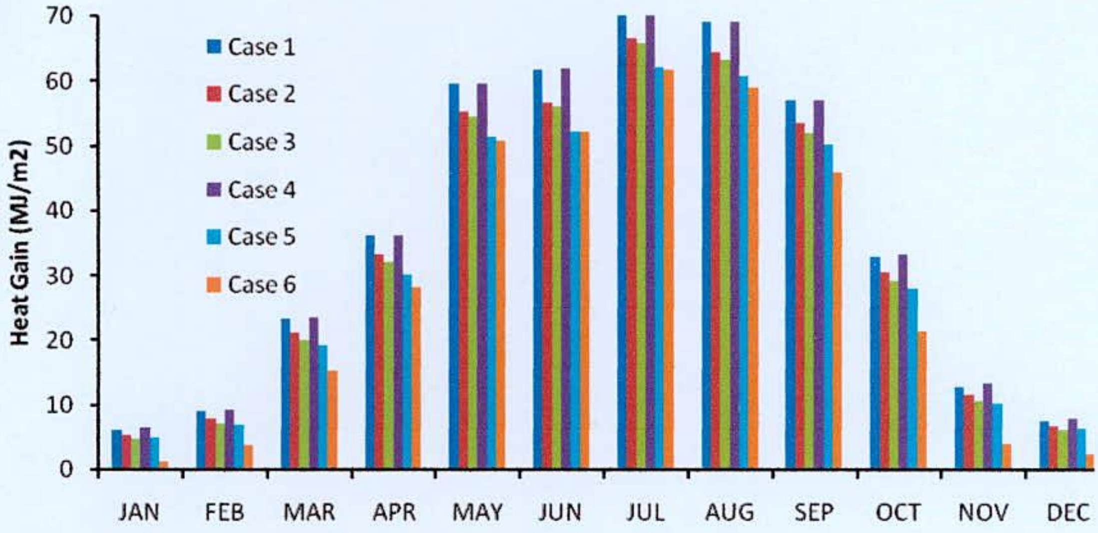


Fig. 5.4: Monthly heat gain per window area for different cases in east facing

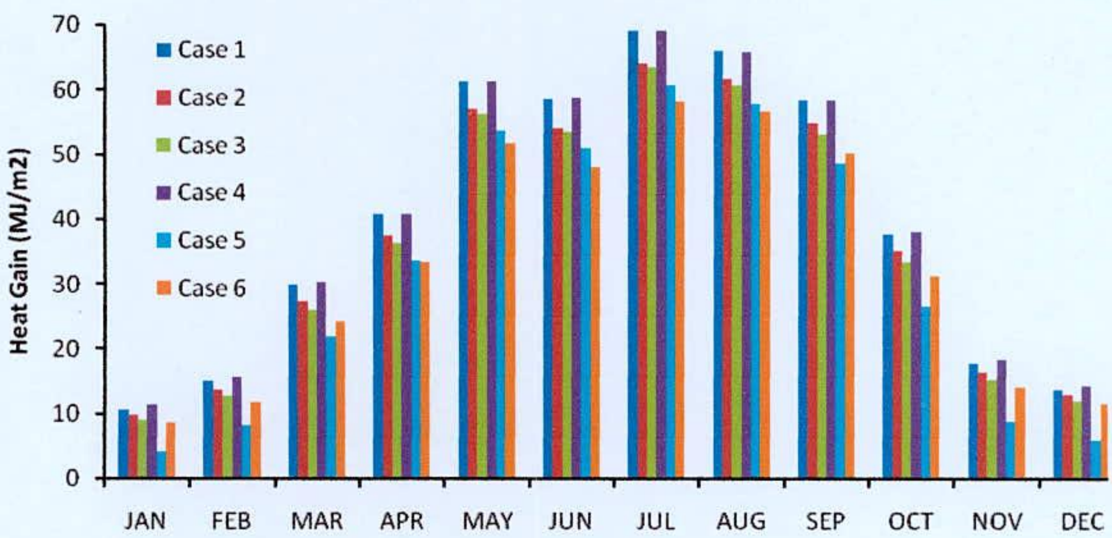


Fig. 5.5: Monthly heat gain per window area for different cases in west facing

For the north facing window, during cooling period (March to October) the average heat gain is lower from the other facing window (Fig. 5.2-5.5). So the energy consumption to keep the room in a comfort level for north facing window is less in comparison to other facing window. In addition, in north facing window the average heat gain during heating period (December to January) also more lower than other facing window.

Shading factor:

Shading Factor indicates how much solar heat is blocked. The non-dimensional width, projection, gap and extension are w =W/H, p =P/H, g =G/H and e_R= E_L/H or e_R = E_R/H. The value of w, p, g and e are shown in the following Table 5.1 for 1-4 cases of window configuration.

Table 5.1: Value of parameters of window with overhang to find shading factor

Parameters	Case 1	Case 2	Case 3	Case 4
w	1	1	1	1
p	0.3	0.5	0.5	0.5
e	0	0	0.17	0.17
g	0	0	0	0.13

Then, monthly average shading factors for overhangs evaluated from Duffie et. al [30] for 1-4 cases of window configuration with latitude, ϕ= 23.18^o by interpolation method. In addition to evaluate average shading factor by using analytical equation is complex in these cases.

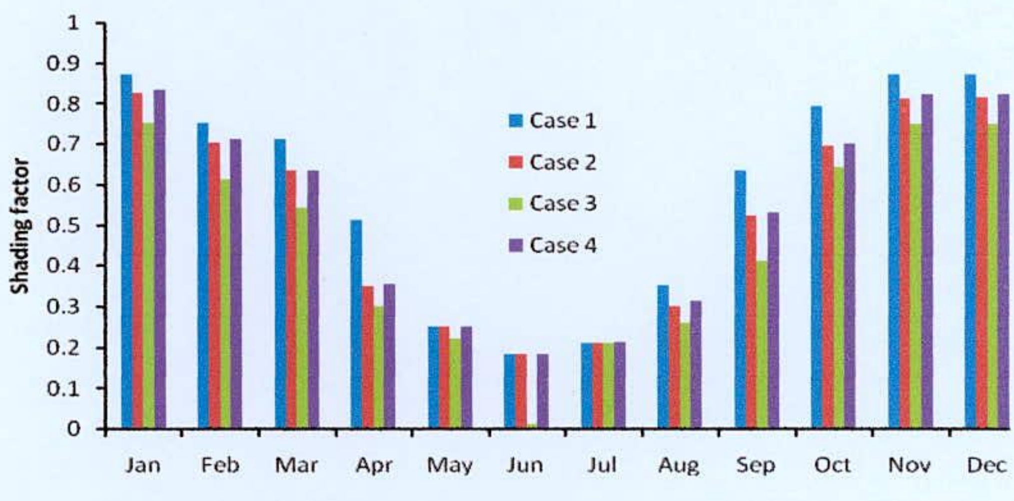


Fig. 5.6: Monthly shading factor for 1-4 cases of south facing window

In Fig. 5.6, the average shading factors indicates how much solar heat is blocked. For case 1, considering a simple overhang and shading factor is significant. Other than in increasing the length in depth and width of overhang decrease the value of shading factor i.e., more solar heat are blocked in cases 2 & 3; respectively. In addition, increasing in height of overhang from window (case 4), the shading factor also increases for less contribution of window in blocking the solar heat. Furthermore the average shading factor is lower during months April to August that means window get opportunity (during these months the average temperature is utmost) to block more heat.

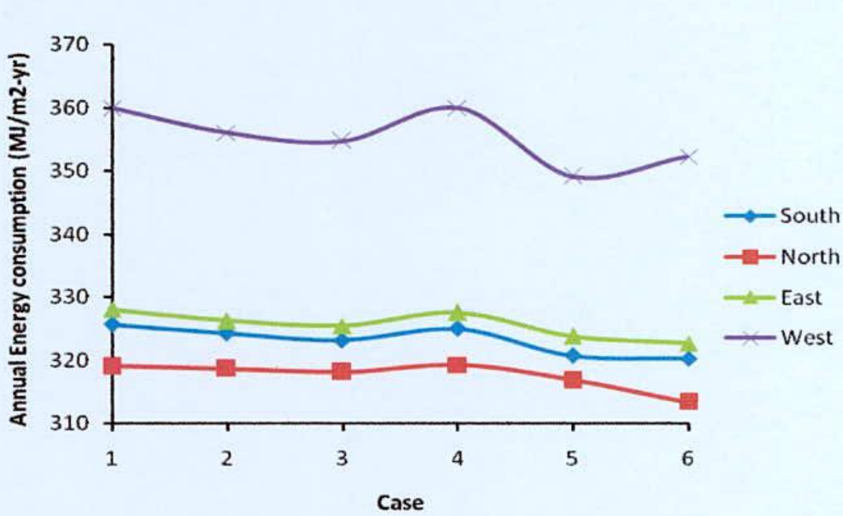


Fig. 5.7: Annual energy consumption for different cases and facing window

The solar heat gain is proportional to the energy consumption required to keep the room in comfort level. From the Fig. 5.7, It can be scrutinized that energy consumption is the lowest for the north facing window of the building as well as highest energy consumption is required for west facing window with respect to the 1-6 cases. In addtition, the energy consumption of north facing window is about 13 % less regarding west. Required energy consumption for the window of south and east facing are moderate. For the Case 6, the energy consumption are much lower than other cases of south, north and west facing window. Additionally, in west facing window, the energy consumption for case 5 is minimum. As well as monthly consumptions are lower during months December to February judge against with other months.

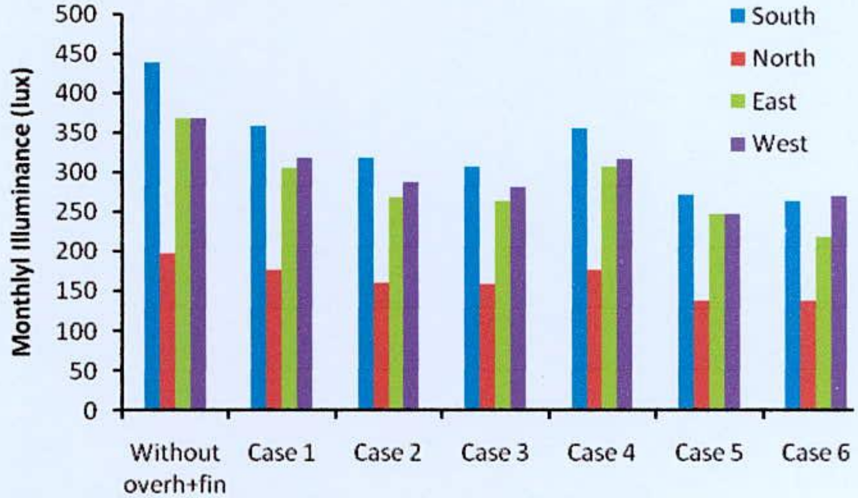


Fig. 5.8: Monthly daylight for different cases

The daylight scheme values for different cases are presented in the Fig. 5.8. In this figure, It can regarded that the illuminance values (lux) of daylight are highest for the window (simple) without having any overhang and fin as well as to some extent decreasing for the different cases. In Case 6 having daylight around 28% less than the simple window. Furthermore Monthly heat gains are shown in the following Figs. 5.9-5.12.

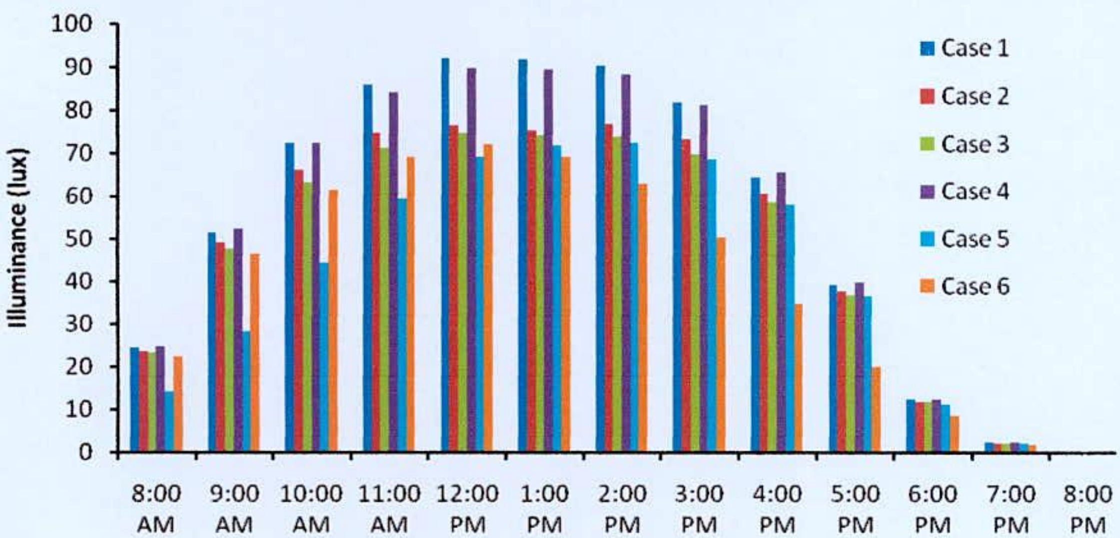


Fig. 5.9: Daily daylight for different cases in south facing window

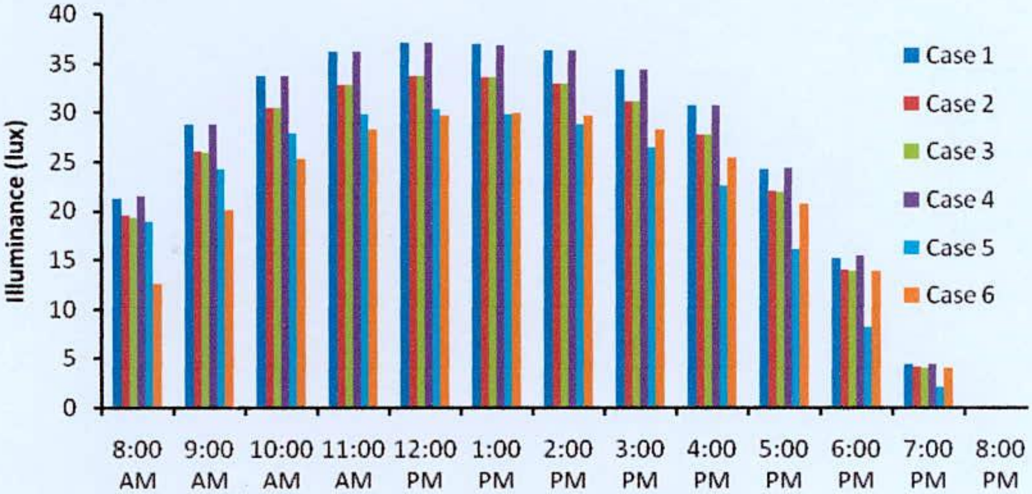


Fig. 5.10: Daily daylight for different cases in north facing window

As the Fig.s 5.9-5.12, the daylights are shown with respect to daily time basis for south and north facing window; respectively. From the observation of illuminanace of the daylights is steadily increase upto 12.00 PM from morning 8.00AM and beyond that time the illuminance value become decreasing upto 8.00 PM. Compare between Case 5 & 6 where fin are used, Case 6 (fin is used in left side) daylight is higher than case 5 upto 12.00 pm and at 1.00 pm they are almost same, after that time case 6 daylight become lesser than case 5.

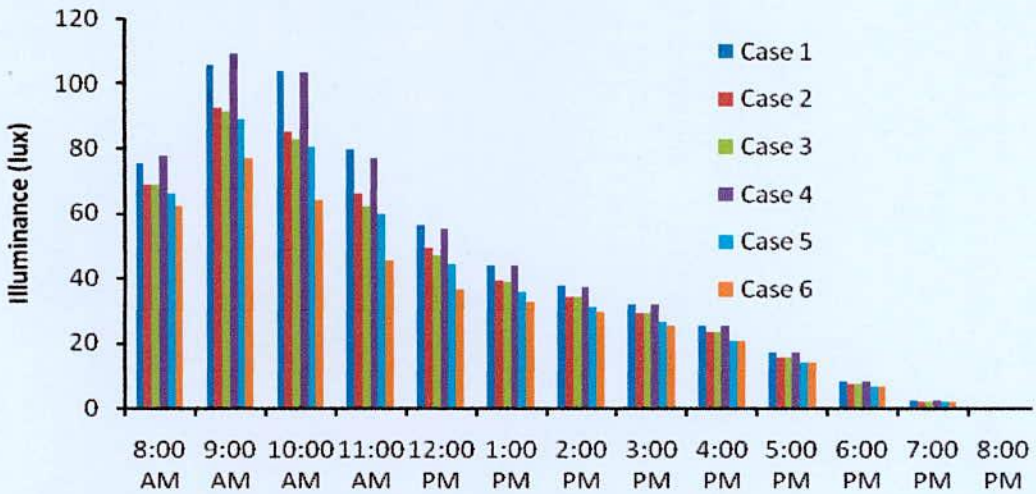


Fig. 5.11: Daily daylight for different cases in east facing window

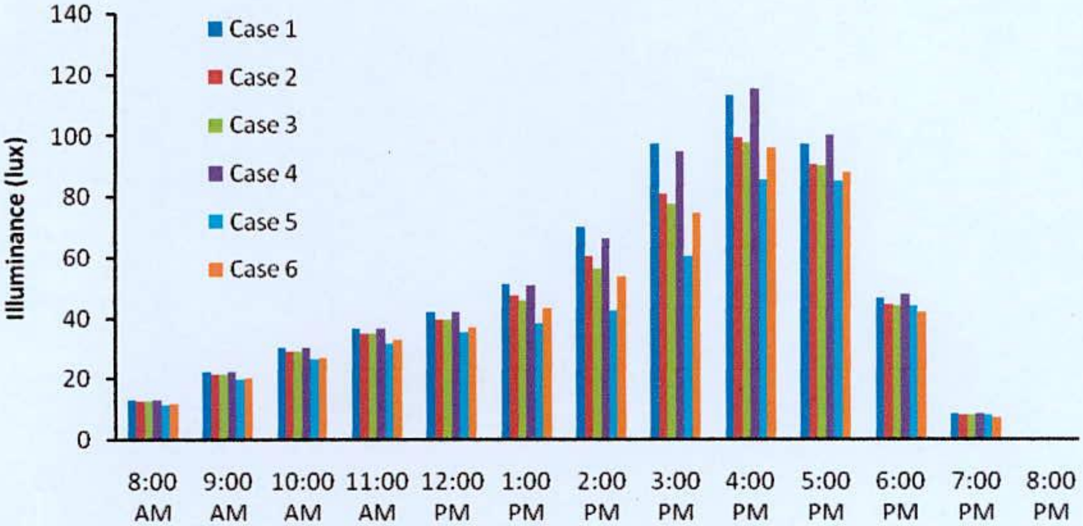


Fig. 5.12: Daily daylight for different cases in west facing window

In the Figs. 5.11-5.12, the daylights are shown with respect to daily time basis for east and west facing window; respectively. As of the study of illuminanace of the daylight is steadily deccreases upto 8.00 PM from morning 9.00AM for east facing window and deccreases upto 4.00 PM from morning 8.00AM for west facing window. In discuss between Case 5 & 6 where fin are used, Case 6 (fin is used in left side) daylight is gradually reduce in east facing window from 9.00 am to 8.00 pm and increase upto 5.00 pm for west facing.

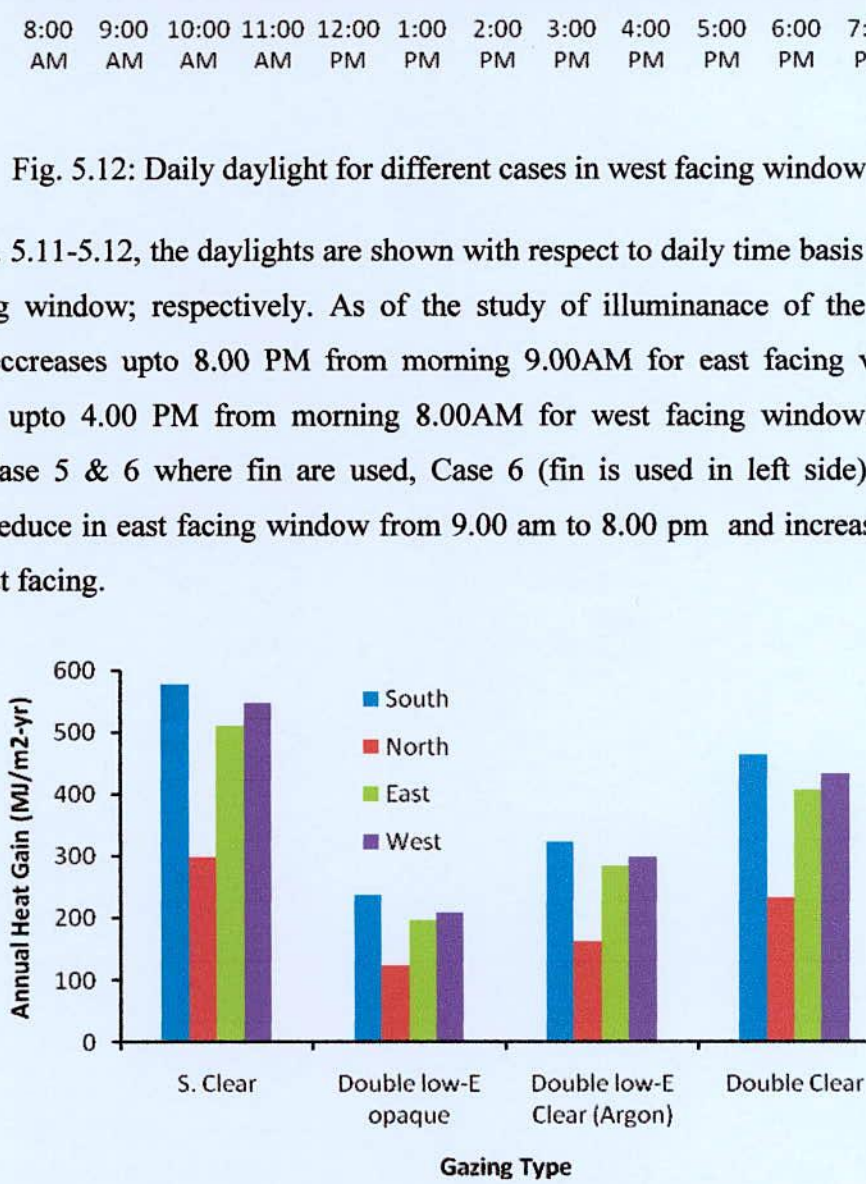


Fig. 5.13: Annual heat gain for advance glazing

Heat gain per window area of building is evaluated in all direction of facing window in the Fig. 5.13 for advance glazing system. It can be studied that heat gain is lowest for north facing window of the building than the other orientation of the window and heat gain for double low-E opaque is lowest with respect to other type glazing system. Heat gain for the window that using single clear glazing is utmost.

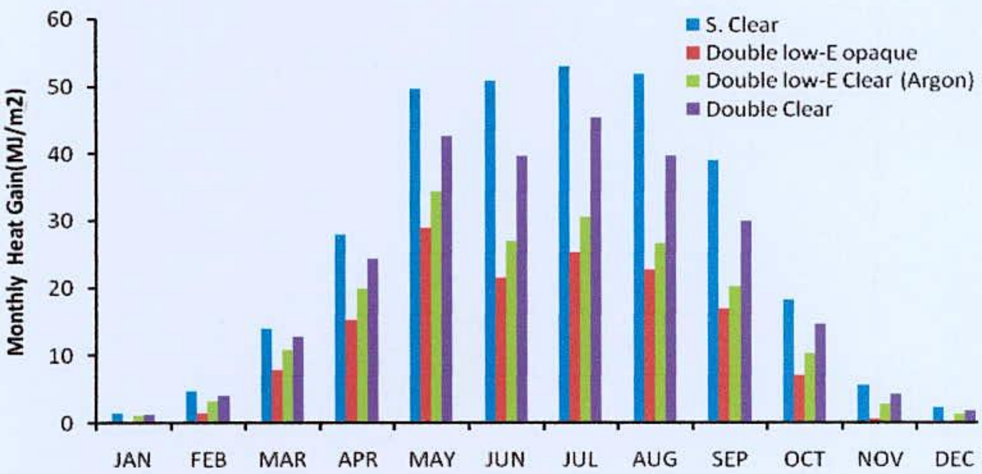


Fig. 5.14: Monthly heat gain per window area for different glazing system for north facing window

In Fig. 5.14 the monthly heat gain for double low-E opaque is lowest compare with other glazing system. So the energy consumption for double low-E opaque glazing would be lowest. In addition, the monthly heat gains for double clear and double low-E clear (argon) are lower compare with single clear glazing system.

Fig. 5.15: Energy Consumption for Advance glazing

In Fig. 5.15, It can be scrutinized that energy consumption is the lowest for the north facing window of the building as well as highest energy consumption is required for west facing window in all glazing system. Energy consumption is lower for double low-E opaque as well as for double low-E clear (Argon).

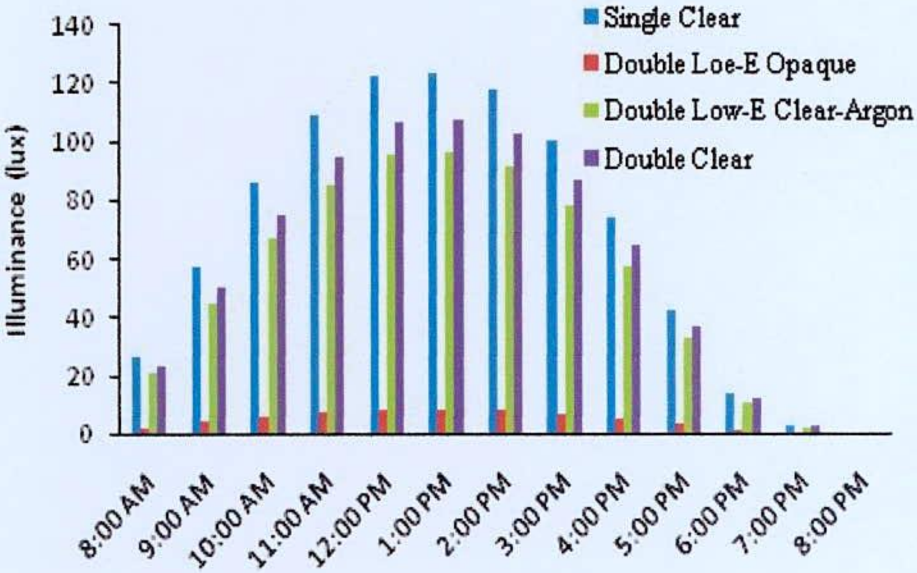


Fig. 5.16: Daily daylight for advance glazing in north facing window

The daylight scheme values for different glazing system are presented in the Fig. 5.16. Here, It can regarded that the illuminance value (lux) of daylight is lowest for the window with double low-E opaque glazing. But Double low-E clear (Argon) glazing give a comfort level light.

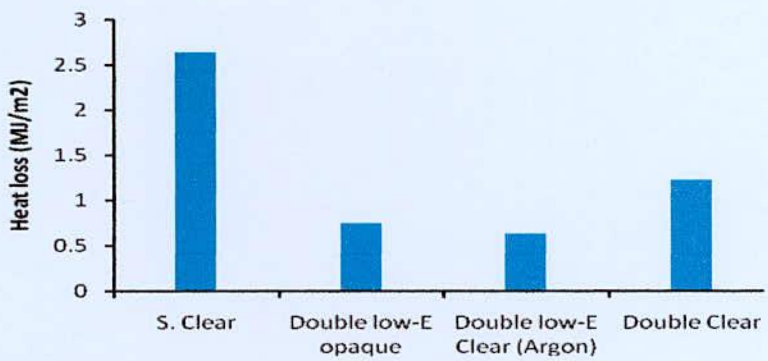


Fig. 5.17: Heat loss during heating period

In Fig. 5.17, the heat loss during heating period is shown with different type of glazing system. Heat loss is minimum for double low-E clear (Argon) as well as maximum for single clear. The heat loss from room to outdoor of building of single clear glazing is four times higher than the double low-E clear (argon).

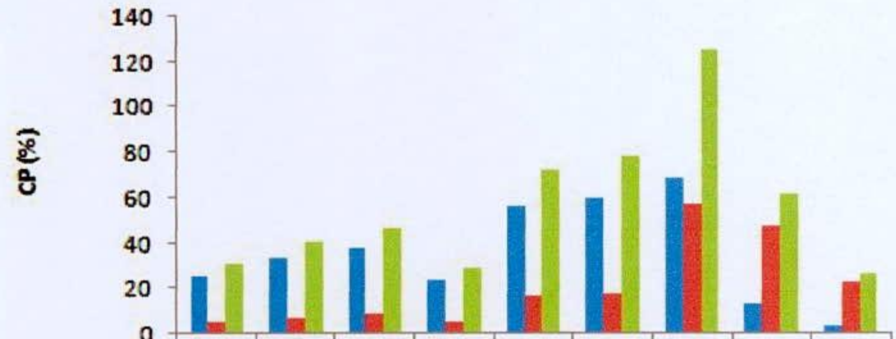
In present study, window energy transfer (E) has been used for the declaration of the results and has been determinate from the following equation.

$$E = | \text{Windows heat gain} - \text{Windows heat loss} | \qquad 5.1$$

Hourly windows annual heat gain (or loss) has been calculated by EnergyPlus program and they have been declared as follow:
Window Heat Gain Energy, the total heat flow to the zone from the glazing, frame and divider of an exterior window when the total heat flow is positive. The total window heat flow is the sum of the solar and conductive gain from the window glazing.
Window Heat Loss Energy, the absolute value of the total heat flow through an exterior window when the total heat flow is negative. Also, the *cp* (coefficient of performance) index has been used for evaluating the shading effect and using of advanced glazing window that it has been determined from the following equation (5.2).

$$cp = 100 \times \frac{E_a - E_b}{E_a} \qquad 5.2$$

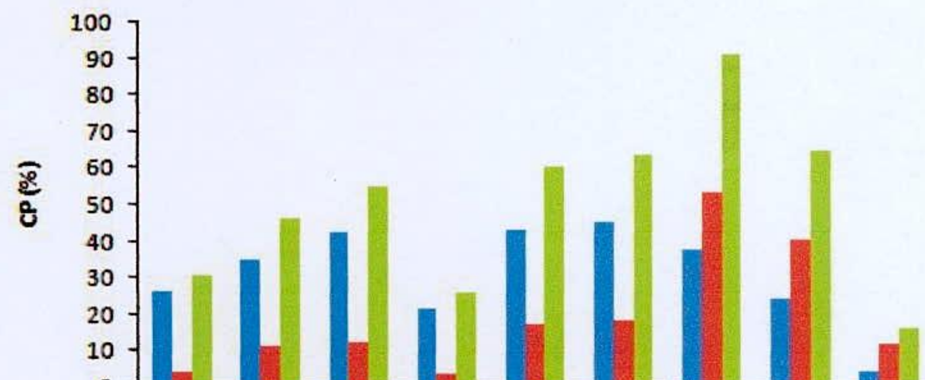
E_a is the total energy that it is transferred into the building from the single clear pane glazing window without overhangs or side fins (reference model). Also E_b is the total energy that it is transferred into the building from the window (new model). In this new model the type of window, overhang and side fin are different with the reference one. Results have been shown in Table 4.1 for all Models. The overhangs and side fins have been applied only at single clear glazing windows. Also the *cp* index for heating, cooling periods or for the year has been calculated. Taking into consideration the formula of the *cp*, it can be concluded that, increasing the *cp* index, leads to a decrease of the total energy transferred into the building from window. An assumption was made that all zones were ideally controlled by thermostats such that the zone temperatures would be kept steadily at 23^0C in the year.



	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	D.L.O.	D.L.C.	D. Clear
Heating Period	25.39	33.48	37.53	23.68	56.16	60.03	68.44	13.57	3.747
Cooling Period	5.676	7.280	8.694	4.980	16.40	17.93	56.93	47.97	22.91
Annual	31.06	40.76	46.22	28.66	72.57	77.96	125.3	61.55	26.66

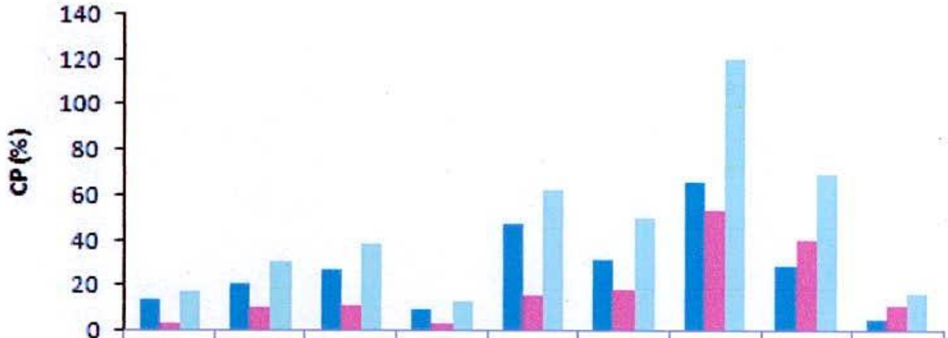
Fig. 5.19: Results for north window

For the north window (Fig. 5.19), the best performance is obtained in the case 6. With taking into consideration the cases 1–6, it can be concluded that using overhangs increase the annual average *cp* index (lower than south window).



	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	D.L.O.	D.L.C.	D. Clear
Heating Period	26.420	35.067	42.383	21.672	43.188	45.011	37.658	24.377	4.3240
Cooling Period	4.0628	11.163	12.320	3.9880	17.188	18.167	53.413	40.235	11.79
Annual	30.483	46.230	54.704	25.660	60.377	63.179	91.071	64.612	16.114

Fig. 5.20: Results for east window



	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	D.L.O.	D.L.C.	D. Clear
Heating Period	14.057	21.042	27.598	9.8528	47.240	31.445	66.463	29.216	4.9111
Cooling Period	3.3428	10.173	11.352	3.4607	15.430	18.683	54.057	40.302	11.603
Annual	17.400	31.216	38.951	13.313	62.670	50.129	120.52	69.519	16.514

Fig. 5.21: Results for west window

For the east window (Fig. 5.20), the best performance application case of overhangs is the case 6. With attention to cases 1–6, it can be indicated that using of overhangs increase the annual average *cp* index (lower than south and north window)

For the west window (Fig. 5.21), the best performance has been obtained in the case 5 (overhang with 2 m width, 0.75 m depth without distance above the window and a side fin in the right side of the window and 2.25 m^2 area). And With attention to cases 1–6, it can be concluded that using of overhangs and side fins, the *cp* index has lowest value during the heating or cooling periods.

Using of advanced glazing systems i.e., Double low-E Opaque glazing (D.L.O), Double low-E Clear (Argon) glazing (D.L.C), Double clear glazing (D.Clear) window, the cp index increase for each direction of the windows but Double low-E Opaque glazing (D.L.O) give highest *cp* index for south facing window and also save more energy.

In this study, the heat gain and energy consumption for north facing window are the lowest among others facing window. The consumption of energy for the Case 6 (overhang with side fin in left side) for north facing window is lowest. In addition, in coefficient of performance study, it is possible to reduce more energy consumption for south window compare with other facing window and for case 6, energy consumption is lowest. In advance glazing Double low-E Opaque glazing reduces more energy consumption compare with other advance glazing system. Therefore, double low-E opaque is more useful But with respect to illuminance double low-E clear (Argon) is best.

Chapter VI

Conclusion

Effect of external shading and window glazing has been investigated in this study using building simulation software EnergyPlus. Four types of window glazing (single clear, double low-E opaque, double layer argon gapping, and double clear glazing) and six types of window shading (with different dimensions of overhang and fin) have been investigated for residential building in this project considering climate condition of Jessore, Bangladesh. From this study following conclusions can be drawn:

- For the south facing windows of a single clear glazing window with an overhang (with adding the width) and side fin window is the best solution for case 6. Also, it can be noticed that using of appropriate overhang and side fin will lead to similar performance to the advanced glazing windows and a reduction of the energy consumption with respect to south reference model.
- For the north facing windows, using of overhangs or side fins (the case 6 especially) has lowest heat gain in comparison to other window and also useful in heating, cooling periods but cp index is slightly lower than south facing window. Additionally, it can be concluded that use of appropriate overhang and side fin will lead to similar performance to the advanced glazing, in addition the effect on energy consumption with overhang and side fin for east and west facing windows also considerable.
- Therefore, in Bangladeshi climate condition, the north-facing window with overhang and side fin in left side is effective with considering energy consumption and generously shaded like case 6 south-facing window can also be used for residential building with considering cp index i.e., the energy consumption can be reduced by proper window shading
- Using of the most appropriate overhang or side fin that has been established for the single clear pane glazing is more useful for any direction of window compare with the advanced glazing windows. As well as Double low-E opaque glazing consumes lowest energy. But with considering illuminance and energy consumption Double low-E clear (Argon) is best selection for Bangladeshi climate.

Recommendation for future work

- If this work can do in experimental method then more precise explanation can be obtained.
- Therefore, find out a suitable method to do this work experimentally.

Chapter VII

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Appendix

Annual Heat Gain (MJ/m^2-yr) per window area for different cases (Fig. 5.1)

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
South	442.3246	402.1794	380.5263	438.7274	341.3821	315.8018
North	276.6095	269.919	265.3806	278.5491	239.9587	236.2002
East	421.124	387.5675	376.1227	423.7259	356.4304	320.3404
West	453.4571	419.4383	406.4238	456.5812	355.6543	374.65

Monthly Heat Gain (MJ/m^2) per window area for different cases in north facing (Fig. 5.3)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Case 1	1.059	3.761	12.60	25.53	46.59	47.124	55.54	49.54	37.93	16.77	3.46	2.5
Case 2	0.97	3.48	12.17	24.7	45.6	46.24	54.58	48.76	36.18	16.22	3.151	2.3
Case 3	0.939	3.351	11.957	24.33	44.98	45.30	53.76	48.24	36.19	16.06	2.997	2.3
Case 4	1.07	3.81	12.649	25.63	46.866	47.65	55.92	49.73	37.11	16.84	3.53	2.5
Case 5	0.710	2.749	10.82	22.138	41.07	40.29	49.24	45.38	34.02	14.48	2.125	1.9
Case 6	0.66	2.62	10.62	21.98	41.2	39.62	48.16	44.637	33.67	14.19	1.94	1.8

Average shading factor for 1-4 cases of south facing window (Fig. 5.6)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Case 1	0.8732	0.7524	0.71	0.5123	0.25	0.182	0.211	0.351	0.634	0.7924	0.871	0.872
Case 2	0.8245	0.704	0.635	0.35	0.25	0.182	0.211	0.301	0.523	0.6954	0.812	0.81
Case 3	0.753	0.612	0.541	0.3	0.22	0.01	0.21	0.26	0.412	0.642	0.749	0.7
Case 4	0.8346	0.712	0.634	0.355	0.251	0.183	0.212	0.312	0.531	0.701	0.823	0.82

Annual Energy consumption (MJ/m^2-yr) per window area for different cases (Fig. 5.7)

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
South	325.6414	324.2778	323.1125	324.8893	320.6247	320.2208
North	318.9997	318.6374	318.0587	319.1824	316.7767	313.3008
East	328.0038	326.1806	325.3731	327.4916	323.7744	322.6165
West	359.88	355.9905	354.6609	359.9013	349.0609	352.2161

Monthly daylight for different cases (Fig. 5.8)

Illuminance (lux)	Without overh+fin	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
South	439.37	358.35	317.74	307.13	355.24	270.76	262.75
North	196.95	175.19	159.24	158.7	175.44	137.61	136.41
East	367.05	305.58	267.25	262.31	306.29	247.51	217.9
West	367.77	316.98	286.94	281.02	316.59	246.46	269.08

Annual Heat Gain (MJ/m^2-yr) per window area for advance glazing (Fig. 5.13)

	S. Clear	Double low-E opaque	Double low-E Clear (Argon)	Double Clear
South	578.0345793	238.3526	322.7651	462.8703
North	297.868082	123.0952	161.7592	234.2331
East	509.9121455	195.7957	283.7836	407.3398
West	547.100217	208.2812	299.4358	433.0802

Total Energy consumption (MJ/m2-yr) per window area for advance glazing (Fig. 5.15)

	S. Clear	Double low-E opaque	Double low-E Clear	Double Clear
South	331.6676	319.1467	323.0628	327.6918
North	320.7794	310.1626	316.2992	317.0864
East	332.7191	318.4145	326.4327	328.2184
West	368.9191	337.6592	351.4869	358.7948

Daylight Illuminance (lux) for advance glazing (Fig. 5.16)

	S. Clear	Double low-E opaque	Double low-E Clear	Double Clear
South	36.61417	2.414167	28.5275	31.86417
North	16.4125	0.4925	12.67167	14.28167
East	30.5875	0.918333	23.63833	26.62
West	30.6475	0.92	23.6825	26.6725

Heat loss for advance glazing (Fig. 5.17)

	S. Clear	Double low-E opaque	Double low-E Clear (Argon)	Double Clear
Heat loss (MJ/m^2)	2.639952	0.74844	0.630504	1.220184

Result for north window (Fig. 19)

cp value	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	D.L.O.	D.L.C.	D. Clear
Heating Period	25.53121	37.54749	41.50789	21.92803	49.26866	60.73995	66.04335	37.2912	14.393776
Cooling Period	15.64432	17.22133	19.28661	16.21703	24.56652	25.45744	53.64102	48.22205	23.160526
Annual	41.17553	54.76883	60.7945	38.14506	73.83518	86.19739	119.6844	85.51325	37.554301