EXPERIMENTAL AND THEORETICAL STUDIES OF VARIOUS GLASS MATERIALS AND ITS ORIENTATION FOR OPTIMUM HEAT GAIN AND OPTIMUM DAY LIGHTING IN BUILDINGS

Thesis

Submitted in partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY

by

G. KIRANKUMAR

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA
SURATHKAL, MANGALORE – 575025
FEBRUARY, 2019

DECLARATION

by the Ph.D. Research Scholar

I hereby *declare* that the Research Thesis entitled “Experimental and Theoretical Studies of Various Glass Materials and its Orientation for Optimum Heat Gain and Optimum Day lighting in Buildings” which is being submitted to the National Institute of Technology Karnataka, Surathkal in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Mechanical Engineering is a bonafide report of the research work carried out by me. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

G. KiranKumar
Reg. No. ME12F01
Department of Mechanical Engineering

Place: NITK - Surathkal
Date:

CERTIFICATE

This is to certify that the Research Thesis entitled "Experimental and Theoretical Studies of Various Glass Materials and its Orientation for Optimum Heat Gain and Optimum Day lighting in Buildings" *submitted by Mr. G. KiranKumar (Register Number* ME12F01) as *record of the research work carried out by him, is accepted as the Research Thesis submission in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy.*

Dr. T. P. Ashok Babu

Research Guide and Professor,

Department of Mechanical Engineering

Chairman DRPC

Department of Mechanical Engineering

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ABSTRACT

The commercial buildings use glass as main building material. The extensive use of glass in buildings increase cooling load of the buildings. This report presents the key findings, conclusions and recommendations of a study that was conducted to control heat gain through various tinted and reflective glasses. The optimum orientation and tilt of the window glasses have been proposed in the report to control heat gain in the buildings. The radiation passing through glass depends on solar optical properties such as solar transmittance, reflectance and absorbance. This report presents spectral characteristics of clear, bronze, green, grey, bronze-reflective, green-reflective, grey-reflective, opal blue reflective, sapphire blue reflective and gold reflective glasses which are measured experimentally by double beam ratio Perkin Elmer Lambda 950 spectrophotometer. These spectral characteristics are used to find the visible optical properties in the visible spectrum wavelength region (380nm-780nm) and solar optical properties in the total solar spectrum wavelength region (300nm-2500nm) as per British standards. The results of the report propose following best glass in single and double glazing window combinations to reduce total solar heat gain through glass windows in buildings, energy and cost saving annually for various climatic zones. The heat gain and adequate daylight factor were computed for different building of composite climatic zone (New Delhi) using various reflective window glasses like single and double glass windows in Design Builder and Energy Plus simulation tools. From the results, it is noticed that the green reflective glass window observed to be the best in summer and bronze reflective glass window is best in winter in single reflective glass windows and double gold reflective glass windows is observed to be energy efficient in both summer & winter seasons due to its optimum heat gain and adequate daylight factor in buildings. From the results it is also noticed that best shading device along with window to allow optimum heat and daylight factor levels inside the different buildings to meet the requirements as per standards. The results of the report propose the best energy efficient single and multiple pane glasses, optimum orientation and tilt of the glasses for energy efficient solar passive building construction.

Keywords: Spectral characteristics, Solar optical properties, Adequate day light factor, Reflective glasses, Cooling and heating load, Double window glass and Window glass tilt.

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CONTENTS

`

CHAPTER 3

CHAPTER-4

CHAPTER-5

`

`

`

`

`

CHAPTER-6

CHAPTER7

`

`

CHAPTER-9

`

`

LIST OF FIGURES

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LIST OF TABLES

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NOMENCLATURE

A1	Solar radiation in absence of atmosphere (W/m^2)
A_G	Area of the glazing (m^2)
A_{VIS}	Visible absorbance (%)
A_{SOL}	Solar absorbance (%)
B1	Atmospheric extinction coefficient [-]
C1	Sky radiation coefficient [-]
C_g	Thermal resistance of the air gap (m^2)
d_{ia}	Declination angle (Deg)
L1	Thickness of the outer glazing (mm)
L2	Thickness of the inner glazing (mm)
h	Hour angle (Deg)
h_i	Inside heat transfer coefficient (W/m^2K)
h_o	Outside heat transfer coefficient (W/m^2K)
k	Angle of window glazing from vertical (Deg)
K1	Thermal conductivity of outside glazing (W/m K)
K2	Thermal conductivity of inside glazing (W/m K)
l	Latitude (Deg)
n_d	Number of days (Jan 1st)
DF	Daylight factor (%)
E_i	Illumination indoors at the point of observation (lux)
E_o	Illumination outdoors from an unobstructed sky hemisphere (lux)
D_λ	Relative spectral distribution of illuminant D65

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R_{SOL} Solar reflectance (%)

R_{se} Outside surface resistance coefficient (m^2K/W)

R_{si} Inside surface resistance coefficient (m^2K/W)

R_{VIS} Visible reflectance (%)

t_{ag} Thickness of the air gap (m)

T_{SOL} Solar transmittance (%)

T_{VIS} Visible transmittance (%)

U1 Thermal transmittance of the single glazing (W/m^2K)

U2 Thermal transmittance of the double glazing (W/m^2K)

$V(\lambda)$ Spectral luminous efficiency for photopic vision defining the standard observer for photometry (Dimensionless)

w_{ag} Width of the air gap (m)

S_λ Relative spectral distribution of the solar radiation (W/m^2)

Greek Letters

α_s Solar absorbance of the glazing (%)

ρ_s Solar reflectance of the glazing (%)

τ_s Solar transmittance of the glazing (%)

$\alpha (\lambda)$ Spectral absorbance of the glazing (%)

$\rho (\lambda)$ Spectral reflectance of the glazing (%)

$\tau (\lambda)$ Spectral transmittance of the glazing (%)

τ_V Visible transmittance of the glazing (%)

ρ_V Visible reflectance of the glazing (%)

α_V Visible absorbance of the glazing (%)

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Δλ	Wavelength interval (nm)
β	Solar altitude angle
θ	Solar incidence angle
Φ	Solar azimuth angle
γ	Surface solar azimuth angle

Abbreviations

ES	East summer
EW	East winter
GC1	Bronze reflective glass window–Air gap10mm– Bronze reflective glass window
GC2	Bronze reflective glass window –Air gap10mm– Green reflective glass window
GC3	Bronze reflective glass window –Air gap10mm– Grey reflective glass window
GC4	Bronze reflective glass window –Air gap10mm– Opal blue reflective glass window
GC5	Bronze reflective glass window –Air gap10mm–Sapphire blue reflective glass window
GC6	Bronze glass window–Air gap10mm– Gold reflective glass window
GC7	Green reflective glass window –Air gap10mm– Green reflective glass window
GC8	Green reflective glass window –Air gap10mm– Grey reflective glass window
GC9	Green reflective glass window –Air gap10mm–Opal blue reflective glass window
GC10	Green reflective glass window –Air gap10mm– Sapphire blue reflective glass window
GC11	Green reflective glass window –Air gap10m– Gold reflective glass window
GC12	Green reflective glass window –Air gap10mm– Bronze reflective glass window
GC13	Grey reflective glass window–Air gap10m– Opal blue reflective glass window
GC14	Grey reflective glass window –Air gap10mm– Sapphire blue reflective glass window
GC15	Grey reflective glass window –Air gap10mm– Gold reflective glass window

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GC16 Grey reflective glass window –Air gap10mm– Bronze reflective glass window

GC17 Grey reflective glass window –Air gap10mm– Green reflective glass window

GC18 Grey reflective glass window –Air gap10mm– Grey reflective glass window

GC19 Opal blue reflective glass window –Air gap10mm– Opal blue reflective glass window

GC20 Opal blue reflective glass window –Air gap10mm– Sapphire blue reflective glass window

GC21 Opal blue reflective glass window –Air gap10mm– Gold reflective glass window

GC22 Opal blue reflective glass window –Air gap10mm– Bronze reflective glass window

GC23 Opal blue reflective glass window –Air gap10mm– Green reflective glass window

GC24 Opal blue reflective glass window –Air gap10mm– Grey reflective glass window

GC25 Sapphire blue reflective glass window –Air gap10mm– Sapphire blue reflective glass window

GC26 Sapphire blue reflective glass window –Air gap10mm– Gold reflective glass window

GC27 Sapphire blue reflective glass window –Air gap10mm– Bronze reflective glass window

GC28 Sapphire blue reflective glass window –Air gap10mm– Green reflective glass window

GC29 Sapphire blue reflective glass window –Air gap10mm– Grey reflective glass window

GC30 Sapphire blue reflective glass window –Air gap10mm– Opal blue reflective glass window

GC31 Gold reflective glass window –Air gap10mm– Gold reflective glass window

GC32 Gold reflective glass window –Air gap10mm– Bronze reflective glass window

GC33 Gold reflective glass window –Air gap10mm– Green reflective glass window

GC34 Gold reflective glass window –Air gap10mm– Grey reflective glass window

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GC35 Gold reflective glass window –Air gap10mm– Opal blue reflective glass window

GC36 Gold reflective glass window –Air gap10mm– Sapphire blue reflective glass window

BZGW Bronze glass window

BZRGW Bronze reflective glass window

CLGW Clear glass window

GGW Green glass window

GLDRGW Gold reflective glass window

GRGW Green reflective glass window

GrGW Grey glass window

GrRGW Grey reflective glass window

NIR Near Infra red

NS North summer,

NW North winter

OPBRGW Opal blue reflective glass window

SPBRGW Sapphire blue reflective glass window

SS South summer

SW South winter

UV Ultra violet

VIS Visible

WS West summer

WW West winter

CHAPTER-1

INTRODUCTION

1.1 OVERVIEW

Buildings are responsible for about 40% of the total energy used in the world. Glass has been a major building component for centuries. Glass has today, transformed architecture across the globe. It gives a plethora of design options that use light and space effectively. It is used as a material for structural glasses or curtain wall of the building. It has truly become a symbol of futuristic architecture. Nowadays, all commercial buildings are using a maximum of 70-80% of glass as a building envelope. The building sector represents about 33% of power consumption in India, with the commercial sector and the residential sector accounting for 8% and 25%, respectively (ECBC 2009). Buildings are also responsible for carbon dioxide emissions with a consequential impact on global warming. Climate responsive design of buildings becomes an extremely important aspect in the process of constructing an energy efficient building. Though, India has a large variety of climate types, it is predominantly a country with tropical climate (NBC 2005). Approximately, 90% of the area has hot-dry, warm-humid, and composite climate. Therefore, climate responsive buildings are designed to avoid the heat gain, and at the same time allow adequate daylight into the living space. Most of the buildings that are presently being designed and used in India are far from being green or sustainable (GRIHA 2011 3rd edition). The energy consumption and imposition of the buildings on natural resources are massive. In order to reduce energy demand of space conditioning, an energy efficient design of building envelopes is needed. The building envelopes or enclosures, such as walls and roofs should be designed in such a way that, the internal built environment must be in a comfortable condition, even when the outside ambient conditions are out of the comfort range. The building envelope is the physical barrier that separates the interior of the building from the outdoor environment. The purpose of the envelope of a building is to act as a passive climate modifier, which helps in maintaining an indoor environment more suitable for habitation than the outdoors. Building materials serve as thermal mass in passive building design. The energy efficient and environment friendly building and insulating materials, have become an extremely important aspect of energy efficient building construction. Figure 1.1 shows a schematic diagram of solar-passive building design.

The type and design of a glass window are important variables affecting energy performance in a building. Glass and frame types will have an impact on the building's heating, cooling and lighting, as well as relating it to the natural environment in terms of access to daylight, ventilation and views.

Glass is used in building envelopes to provide day lighting, either through side lighting or top lighting, where the first is the most familiar approach to day lighting. The quantity of light admitted from the side opening depends on width, height of the opening above the working plane, type of glass and control elements such as blinds or louvers.

The heat transmission through the glass window occurs through the conduction/convection mode and the radiation mode. The portion of the incident solar radiation on the glass window that enters the room depends on the optical properties of the glass (transmittance and absorbance). The transmitted radiation becomes instantaneous room heat gain while the absorbed radiation in the glass window becomes the delayed heat gain (sometimes called heat gain from the long wave radiation). The absorbed radiation will cause the glass temperature to increase and the heat will then, be transferred into the room from the higher glass surface temperature to the lower room air temperature. Glass window affects the building not only in terms of heat transmission but also in terms of thermal comfort. Solar energy efficient glass can reduce 70% of direct heat from the sun, thus reducing air conditioning and lighting costs (http://www.efficientglazing.net/efficientglazing.aspx, Accessed Jan 28 2018).

A good solar control glass for a green building, must deliver effectively on energy efficiency. The glass must take care of the heat gain from direct Sunlight, and also able to reduce the heat gain differences on both the inside and outside surfaces of the window glass of a building.

Buildings consume a substantial amount of energy for air conditioning and day lighting. The construction rate in India is increasing rapidly, which accounts for massive consumption of fossil fuels that result in a lot of environmental damages. Thus, it is imperative to pay attention to the crucial aspect of energy efficiency in the design of the building itself. According to the US green building council, buildings are consuming about 40% of the total energy use in the world and they are responsible for 40% of greenhouse gas emissions (https://www.usgbc.org/articles/green-building-facts, Accessed Dec 29 2018, Published April 01 2016).

Day light is a natural source of light, which meets all the requirements of good lighting while enhancing user efficiency and productivity. In India, daylight is available in plenty under clear sky conditions, and can be used for satisfactory indoor illumination during the day. By designing windows properly, in terms of their orientation, size and shape, one can eliminate the use of artificial lighting in most buildings during daytime. Building spaces with poor daylight availability and spaces with night time usage can be provided with supplementary artificial lighting, as it is not desirable from the viewpoint of lighting quality. It can create problems of harsh shadows and severe brightness imbalances, resulting in glare. Direct Sunlight also results in undesirable heat in summer. Therefore, shading devices (overhang, louver, egg crate, roller and venetian blinds) are recommended, not only for thermal comfort but also for visual comfort.

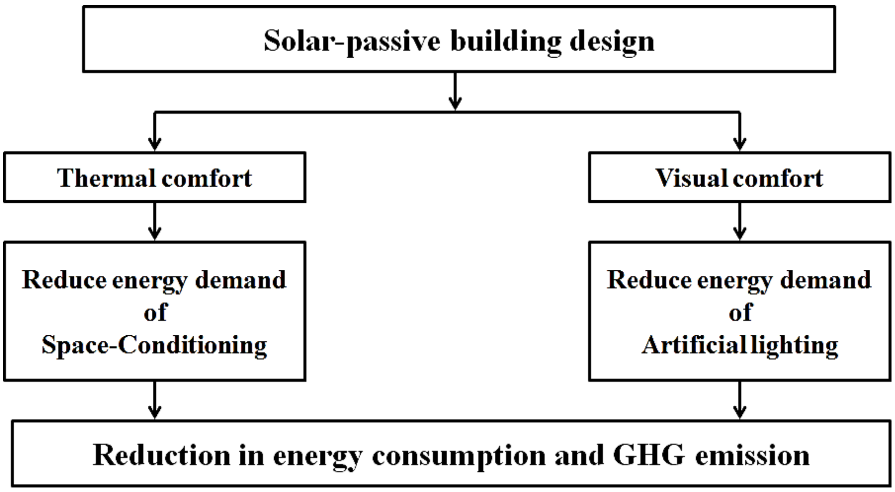


Figure 1.1 Schematic diagram of solar-passive building design (GRIHA 2011)

1.2 OPTIMUM ORIENTATION

The orientation of the building plays a very significant role in the design of solar passive buildings. The optimum orientation of buildings is essential to maintain comfortable indoor conditions. The total incident radiation falling on the surface of the building changes with the orientation of the building. To achieve cooling, the passive building should be designed so that it should receive less radiation in summer and maximum radiation in winter. The information relating to peak summer/winter conditions and thermal properties of building materials are significant in the designing of passive buildings. Figure 1.2 shows the long facades of the building facing least radiation.

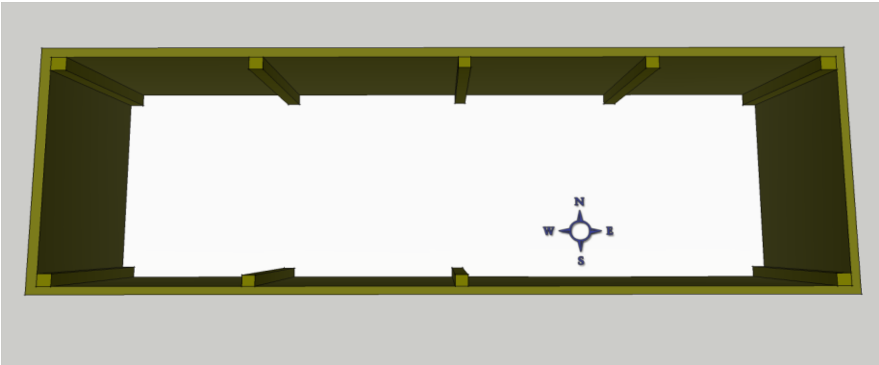


Figure 1.2 Orientation of the building

1.3 ROOM SPACE ARRANGEMENT (THERMAL BUFFER ZONE OR BUFFER SPACES)

The living room should be shielded by the thermal buffer zones or buffer space such as staircases, lifts, corridors, toilets, rest rooms, store rooms, balconies and other service areas to reduce heat gain during the summer seasons. With the help of these buffer zones, solar radiation through the walls of the living room can be reduced or eliminated. These concepts should be incorporated during the building design stage itself. Figure 1.3 depicts the buffer space arrangement in building envelopes.

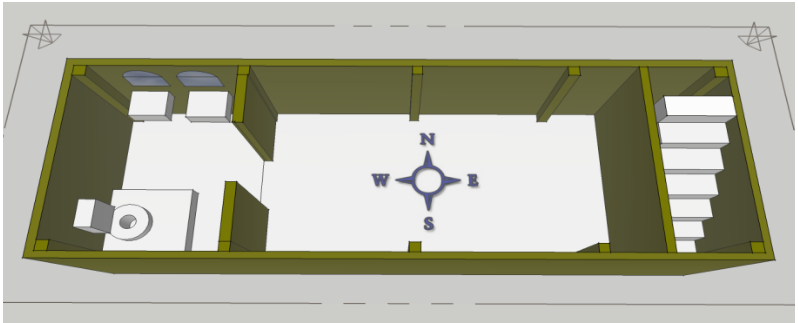


Figure1.3 Buffer spaces arrangement in building envelopes

1.4 PLACING OF BUILDING OPENINGS

The right placement of building openings helps in further reduction of heat gain in the buildings. The building openings must be placed on the facades with the minimum insolation. The openings of the buildings must be placed so that they allow adequate day lighting with comfortable indoor conditions without increasing cooling loads.

1.5 SHADING DESIGN

There are two shading design types (i) Facade shading (ii) Fenestration shading for reducing heat gain or for reducing cooling loads into the buildings.

1.5.1 Shading of facades

Solar radiation passes into the building through roofs, floor, walls and window glass materials. Maximum amount of solar radiation passes through window glasses as it is transparent and it also depends on longitude, latitude and the motion of the sun at a particular location. If the critical surfaces such as roofs, east walls and west walls are shaded externally, then cooling loads can be reduced drastically. Due to the lower altitude position of the Sun i.e., the Sun rays make a position in a vertical plane between the Sun rays and the projection of the Sun rays on the horizontal plane, east and west walls are gaining more solar radiation which passes into buildings. Hence, shading devices help to cut down the maximum heat gain into the buildings.

1.5.2 Shading of fenestration

The openings are the major source of heat gain into the buildings. Hence, the openings require external shading devices for effectively preventing unwanted heat gain into the buildings. They should be designed so that, they keep summer Sunlight out and allow winter Sunshine.

1.6 CLIMATE ZONES OF INDIA

India has a large variety of climatic conditions ranging from extremely hot to severe cold conditions. There are 233 automatic weather stations located currently across India, to record monthly mean data of incident solar radiation, ambient temperature, air humidity, precipitation, wind and sky conditions and rainfall in different climatic conditions. India has five climatic zones namely; (i) Hot and Dry (ii) Warm and Humid (iii) Composite (iv) Cold (v) Moderate. Figure 1.4 shows the climatic zones of India.

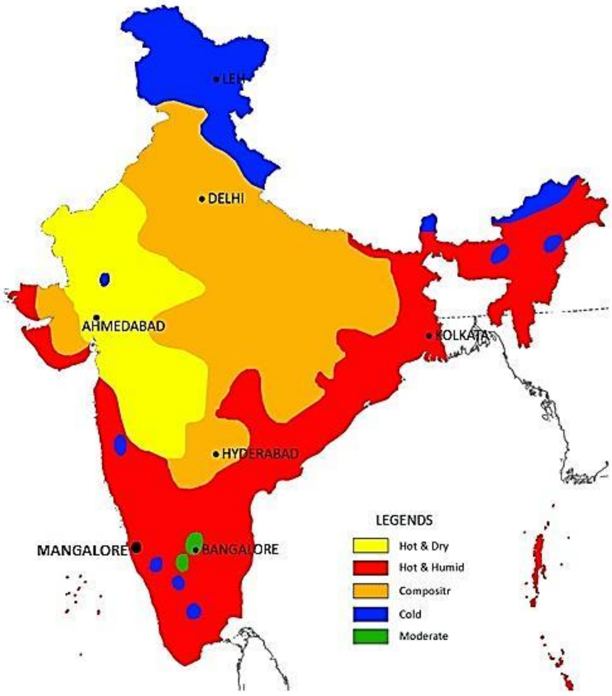


Figure 1.4 Climatic classification of India (Source: IREDA India)

The total solar radiation (direct plus diffused radiation) incident on various surfaces of the buildings during summer in Indian latitudes is shown in Figure 1.5. This graph presents the total incident solar radiation for 21st June, which is representative of the summer solstice. From Figure 1.5, it is clear that during summer, the total incident solar radiation is maximum on horizontal surfaces such as roof, terrace, and so on. Among the facades, west and east orientations are significant in summer for maximum solar radiation as compared to south and north orientations.

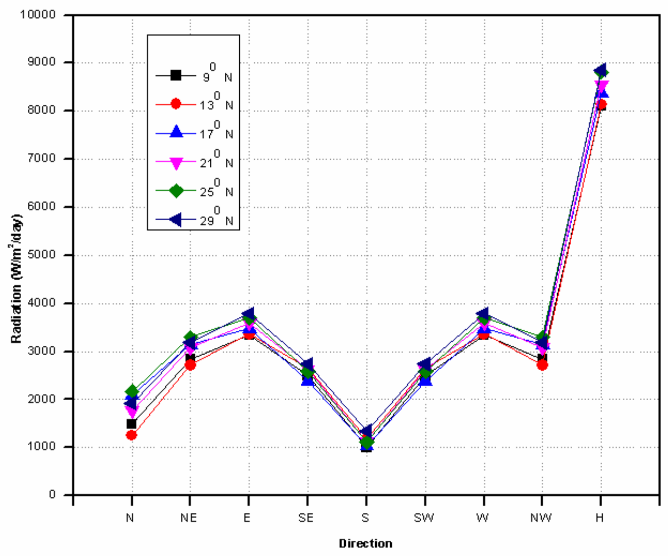


Figure 1.5 Incident solar radiation in different orientations for 9^0, 13^0, 17^0, 21^0, 25^0 and 29^0 latitudes during summer season (NBC 2005)

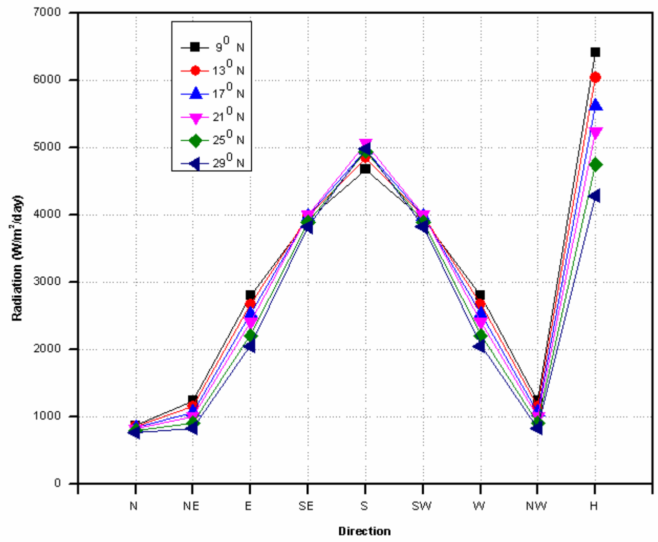


Figure 1.6 Incident solar radiation in different orientations for 9^0, 13^0, 17^0, 21^0, 25^0 and 29^0 latitudes during winter season (NBC 2005)

The total solar radiation (direct plus diffused radiation) incident on various surfaces of the buildings during winter in Indian latitudes is shown in Figure 1.6. This graph presents the total incident solar radiation for 21st December, which is representative of winter solstice. From this, it is clear that during winter, the total incident solar radiation is more on the south surface and horizontal surfaces, which can be allowed inside the room to maintain comfortable conditions in winter. Table 1, shows the details about number of climatic zones studied in this work and for these climatic zones find the total solar radiation at summer and winter solstices.

Table 1. Number of climate zones studied

Place	Climatic zones	Latitude	Longitude
Bangalore	Temperate	12.97^0N	77.59^0E
Jodhpur	Hot & Dry	26.30^0N	73.02^0E
Kolkata	Warm & Humid	22.65^0N	88.45^0E
Mangalore	Warm & Humid	12.91^0N	74.85^0E
New Delhi	Composite	28.58^0N	77.12^0E

1.7 ORGANIZATION OF DISSERTATION

This dissertation consists of ten chapters and a list of references.

Chapters one and two are the introduction and literature review, chapter three presents the mathematical correlation to find solar heat gain through a glass window and Chapter four presents experimental measurement of spectral characteristics of ten glass materials using Perkin Elmer Lambda 950 spectrophotometer. Chapters five to nine, deal with the current research objectives. The summary for each chapter is presented below.

Chapter two gives the review of literature on the work carried out by various researchers in the related field. This chapter summarizes the past work carried out on finding the solar optical properties of different glass materials and also finding the solar radiation through different glasses like single, double and triple. The objectives of the present work are listed at the end of this chapter.

Chapter three presents the procedure to find solar heat gain through window glass with the help of equations as per ASHARE standards.

Chapter four presents the experimental measurement of nine glass windows using Perkin Elmer Lambda 950 spectrophotometer followed by American standards (ASTM E424 1971). A MATLAB code has been developed to evaluate visible and solar optical properties using equations as per British and International standards (BS EN410 1998 & ISO 2003). Another MATLAB code was also developed to find the analytical computation for solar heat gain through glass.

Chapter five explains the theoretical studies of various solar control window glasses for the reduction of cooling and heating loads in buildings across three different climatic regions in India. This chapter also deals with the cost and energy saving analysis using various solar reflective double glass window combinations on heat gain into buildings for the composite climatic zone of India.

Chapter six discusses the heat gain in buildings through different glass windows at different window area to wall area ratios in various Indian climatic zones. This chapter also deliberates the heat gain in buildings, through different glass windows at different window to wall ratios, in various Indian climatic zones in south orientation.

Chapter seven replicates the effects of single, double, triple and quadruple window glasses of various glass types, on heat gain in buildings at summer season and also, deals with finding the minimum heat gain in buildings, through different double glass window combinations at 40% window area to wall area ratios of different Indian climatic zones in summer season.

Chapter eight reveals the effect of reflective glass materials by placing them like single and double in different placements, to find which is suitable for various buildings in order to provide thermal as well as visual comfort inside the buildings for composite climatic zonesof India during both peak winter and summer days.

Chapter nine takes care of the effect of various external shading devices on four glasses like clear, bronze, green and grey glass windows for optimum heat gain and optimum day lighting in buildings of composite climatic zones in India during both peak winter and summer days.

The conclusions of the dissertation and the scope for future work are presented in chapter ten.

CHAPTER-2

REVIEW OF LITERATURE

2.1 INTRODUCTION

Worldwide concern about depletion of energy resources has stressed the need of energy conservation strategies. The impact of the building industry is significant in energy consumption. Buildings annually consume more than 20% of the electricity used in India. The need of conserving primary resources, has led to an increased awareness of the need of energy saving in cooling and heating of the buildings. Buildings consist of wall, floor, roof and windows. In general, solar radiation takes place through the walls, floor and the roof. Most of the solar radiation and day lighting enter through windows because of its transparency and causes the higher load. Hence it is necessary to decrease the solar radiation and heat transfer through the glass without obstructing the day light into the buildings. Glass is having three optical properties like transmittance, reflectance and absorbance. Depending on the glass material these properties will vary. Heat gain through glass windows depends on these three solar optical properties. This chapter presents a survey of the past work, done in the field of different windows and shading devices on windows to achieve this objective. Table 2.1.1 gives the literature review on various glasses used for windows.

Table 2.1.1 The literature review on different glass windows

No.	Author/Year	Summary
1.	Agrawal, A. et al. (2016)	• This work, analyzed the cooling load required by the enterprise data center, which was about 180 ton, with the help of transient energy analysis software TRNSYS by following ASHRAE climatic data of seventeen climatic zones in the world. • Cooling strategies were applied to water side economizer, indirect evaporative cooler and air cooled chillers in all climatic zones. • Significant energy saving of up to 30% was achieved by using indirect evaporative cooler compared to air cooled chillers in climatic zones 3 and 7, and 25% of energy saving was achieved by using water side economizer in climatic zones 4 and 5.
2.	Aguilar, J.O. et al. (2015)	• The aim of this work was to investigate the effect of different glasses like float, reflective by placing them in windows as double pane glasses with an air gap and to find the heat transfer through these windows for different climates in Mexican city. • Energy saving were improved from 10.5% to 28.5% for different climates with these window glasses

3.	Alibaba, H. (2016)	• In this study, heat loss and heat gain through a standard glass window of a university office building at different window to wall ratios was done, by using dynamic thermal simulations with EDSL T_{as} software. • This study was carried out in Eastern Mediterranean University, Mersin latitude of Turkey country, which is a hot and dry climatic region.
4.	Amaral, A.R. et al. (2016)	• In this work, a detailed study of window type, orientation, size and shadow effect on buildings of Coimbra in Portugal climatic condition, and thermal assessment was carried out. • It was found that triple layer glazing windows are much better than single, double glazing windows in north orientation, and in northeast and northwest orientations it was giving inferior results when compared with all other orientations.

5.	Chelbi, M. et al. (2015)	• Five angstrom regression models such as linear, cubic, quadratic, logarithmic and exponential were studied and compared, for the estimation of global solar radiation on horizontal surfaces in Tunisia territory. • These models were studied and calibrated using data from four metrological stations of global radiation and Sunshine. Cubic regression model gave better results than other regression models. • From the results, it was concluded that global monthly mean daily solar radiation on horizontal surfaces, ranges from 15.7 to 19.4 MJ/m^2/day and increases from north to south.
6.	Costantine, G. et al. (2018)	• In this work, hemp concrete material, which is used as an envelope of buildings located in north east France to act as insulation within the wall material and improves hygro-thermal comfort was studied. • Study of building was done for several months to measure the parameters like indoor temperatures, relative humidity, and thermal heat flux on the building roof. Numerical model was developed with SPARK simulation tool and the study found that the above parameters gave closure with experimental results.

7.	Datta, G. (2001)	• The aim of this work was to investigate the effect of various geometries of horizontal louver shading devices on windows. • Energy performance simulations were carried out by TRNSYS software, to find the optimum shading design in both summer and winter seasons, in four different climatic regions of Italy.
8.	Fasi, M.A. and Budaiwi, I.M. (2015)	• In this paper, various double glazing windows, which were placed in office buildings, were studied, to check the energy performance of windows and energy consumption of buildings in Saudi Arabian country climatic region. • Thermal analysis and day lighting were carried out with Design builder simulation to find the energy performance and daylight illuminance levels inside the buildings. • It was found that, double glazed clear windows reduce 14% of energy consumption whereas double glazed Low E-windows reduce 16.5% of energy consumption.

9.	Freewan, A.A.Y. (2014)	• In this paper, various external shading devices like vertical fins, diagonal fins and egg-crate fins were studied, to check the energy performance of windows and energy consumption of south-west orientation window, for an office building of Jordan University of Science and Technology. • Thermal analysis and day lighting were carried out with IES/Sun-Cast and Radiance simulation to find the energy performance of the window. • It was found that, it is reducing most of the direct Sunlight and providing adequate daylight illuminance levels in office buildings.
10.	Gomes, M.G. et al. (2014)	• In this work, detailed study on windows with roller and venetian blind shading devices, thermal performance, day lighting through fenestration in both experimental and numerical study was carried out for different weather conditions. • The result showed that, overcast conditions are better than clear sky conditions.
11.	Huang, Y. et al. (2014)	• In this work, a series of window designs and shading devices were placed as building envelopes, to evaluate the energy performance of a building in Hong Kong latitude conditions, by using computer simulation studies. • It was observed that, the Low-E glazing windows were giving better energy efficiency than windows with double layer glazing shadings, and also that, its energy performance was affected by the place and orientation of the window.

12.	Inanici, M.N. and Demirbilek, F.N. (2000)	• In this investigative study, the net annual energy consumption was found for south windows orientated at different residential building aspects, with various windows at optimum sizes, which was done by thermal analysis program SUNCODE-PC in five different cities of Turkey country.
13.	Ishwar, C. and Shree, K. (2011)	• This paper focused on how much direct solar radiation goes through clear glass window at different tilt positions in different window orientations. • It was found that, in south direction at 6^0 tilt, direct solar radiation is zero for composite climatic region (New Delhi).
14.	Khandelwal, A. et al. (2011)	• In this paper, use of advanced evaporative cooling systems to reduce annual energy consumption, of a typical three floor library building, which is located in IIT New Delhi having central air conditioning equipment was studied • TRNSYS simulation software was used to find heat load, dynamic calculations and annual energy consumption by applying simple evaporative, regenerative evaporative cooling and both combined (simple and regenerative) cooling systems. • The results showed that, coupled regenerative cooling systems give significant energy saving from 12.09% to 15.69% annually.

15.	Kim, S.H. et al. (2015)	• The aim of this study, was to control the maximum amount of solar radiation with different shading devices on windows, which were examined at different climatic seasons and was done by building a simulation model. With the help of overhang shading devices, energy saved up to 13% and with Venetian interior blinds energy saved up to 24% was determined.
16.	Kinoshita, T. et al. (2008)	• Detailed study of window orientation, azimuth position, and arbitrary positions in order to find minimum solar radiation passing into buildings was done in this study. The seasonal accumulated solar heat gain required, for estimating the energy performance of windows was calculated using a detailed methodology and a simplified method, for different latitudes of Japan Country.
17.	Kontoleon, K.J. (2015)	• The aim of this study was to calculate the distribution of incoming solar radiation in Mediterranean climatic conditions. A new methodology was used i.e., Sunlight was introduced at different window orientations, to find the diffuse and reflected solar radiation by using computer program simulations.
18.	Lai, C.M. and Wang, Y.H. (2011)	• Aim of this work was to reduce the annual energy consumption of the building by using various window glasses like float and low-E glass in Taiwan country climatic conditions. • It was found that with float glass, 13.6% of energy consumption was reduced and with low-E glass, 15.1% of energy consumption was reduced.

19.	Lee, J.W. et al. (2013)	• The aim of this work was the study of different window glasses like single, double, triple float, tinted and low-E glasses used for buildings at different window to wall ratios in five typical Asian climatic conditions. • Building simulation software was used to find optimum heating, cooling and lighting energy consumption at different window to wall ratios for buildings in different climatic conditions of Korean country.
20.	Maestre, I.R. et al. (2015)	• The aim of this study was to inspect the overhang and side fin shading devices on windows of buildings, to reduce the cooling loads on air conditioned buildings, by using new computer simulation programs and also by comparing with previous program simulations. • It was found that, change of the result depends on latitudes of location and size of the windows. South oriented overhangs, showed daily deviations of incident solar energy up to 0.48 kWh/m^2, with a relative error of 17%, having hourly errors as high as 26%.
21.	Oleskowicz-Popiel, C. and Sobczak, M. (2014)	• In this paper, study of internal and external roller blind shading devices on double glazing windows, to increase the heating loads on buildings at night in central European climatic regions was investigated. • From the results, internal roller blinds can save about 33% and external roller blinds can save about 45% heat loss. Relative energy saving were obtained in which internal and external roller blinds can save 29% and 44%, respectively.

22.	Palmero-Marrero, A.I. and Oliveira, A.C. (2010)	• In this paper, external shading devices were studied to check the energy performance of windows and energy consumption of buildings. • Thermal analysis was carried out with Energy Equation Solver with TRNSYS simulation, to find the energy performance of the window. • It was found that, windows having louver shading device gave good results compared to windows without shading device.
23.	Pal, S. et al. (2009)	• In this work, the aim was to find the solar optical properties of float glass and to measure the temperature of the glass surface. • Aim was also to find the solar radiation through window glass for warm and humid climatic regions of India. Experimental study was performed in a room with float glass window and this was compared with simulation of mathematical model and the results error was ± 5%.
24.	Parishwad, G.V. et al. (1997)	• In this work, the aim of the authors was to develop a procedure to find the direct, diffuse and global radiation on horizontal surfaces, in different locations of India by using measured solar radiation data. • The hourly solar radiation of six different Indian cities by method of statistical analysis was found by using ASHRAE constants and with the help of constants obtained for India using the measured data. Results obtained were compared with measured data and ASHRAE values, and it was seen to be below ±5% for any location of India.

25.	Parishwad, G.V. et al. (2011)	• In this work, the authors aimed to develop software, to find the direct, diffuse, and global radiation on horizontal and vertical surfaces. The study considered window overhangs in two climatic regions of India at different orientations. • The hourly solar radiation of six different Indian cities by using software was done. ASHRAE constants and constants obtained for India using the measured data were used. • Results obtained were compared with measured data and ASHRAE values, and it was seen to be below $\pm$7% for New Delhi and Pune climatic zones of India.
26.	Sharma, S. et al. (2016)	• This work, introduces an experimental evaluation of phase change materials to improve performance of low-concentration Building-Integrated Concentrated Photovoltaic (BICPV) system through thermal regulation and it discusses the electrical parameters while using PCM in BICPV system. • A new analytical model was suggested and applied within the house, which controlled the experiments. Paraffin wax based RT42 was used within the house, designed and fabricated PCM containment. • Results revealed that electrical efficiency was increased by 7.7% and the reduction of average temperature of the center of the house was 3.80 deg, when compared with naturally ventilated system without PCM material.

27.	Singh, I. and Bansal, N.K. (2011)	• This work dealt with the study of various glasses like clear and bronze by placing them as windows for buildings. • The objective was to determine the effect of these glasses when used as double and triple glasses, with an air gap of 10mm, to find the minimum solar radiation through the buildings for different Indian climatic zones by using TRNSYS software.
28.	Taleb, A.M. and Al-Wattar, A.J.H. (1988)	• Study of inward glass tilt for windows to reduce solar beam radiation, transmitted into buildings through clear and brown windows in summer and winter season, in Baghdad city in Iraq was conducted. Objective was to find the optimum glass tilt which was at 15^0 to reduce maximum solar radiation inside the building through glass windows.
29.	Waewsak, J. et al. (2014)	• This work focuses on an alternative approach to evaluate global solar radiation, by using Artificial Neural Networks collected with observed meteorological data of Bangkok in the time period of 2001 to 2010. • Three combinations of observed monthly mean meteorological data, mean temperatures, relative humidity, rainfall amount and Sunshine hours were used with 3, 5 and 6 parameters as the model input for the ANN training to forecast the solar radiation over the territory. Three algorithms were used, to find the monthly mean Sunshine hours, monthly mean global solar radiation with root mean square, and mean bias error results, which was helpful and has significant importance.

The building enclosures such as walls and roofs should be designed so that, the internal built environment must be in a comfortable condition even when the outside ambient conditions are outside the comfort range. In buildings, the maximum incident heat gain occurs through the roof and the walls. The incident solar radiation is more on roofs as compared to the walls (NBC 2005). Hence it is imperative to pay attention to the building roofs to reduce heat gain into the building. Table 2.1.1 gives the literature review on window shading and day lighting in buildings through glass windows.

Table 2.1.2 Literature review on window shading and day lighting in buildings through glass windows

No.	Author/Year	Summary
1.	Acosta, I. et al. (2016)	• This work focused on the study of different window model designs, geometry and position in residential buildings, to provide day lighting to reduce the energy consumption of buildings. • It was concluded that, daylight autonomy is proportional to the glass surface and reflectance of surfaces at the back of the room. Windows located higher up, result in higher illuminance at the back of the room than those in centered locations.
2.	Athienitis, A.K. and Tzempelikos, A. (2002)	• This paper presents a methodology for comprehensive day lighting numerical simulation of an office space with an advanced window system, and calculation of dimming levels for electric lights to provide the additional illuminance required, so as to minimize electric energy consumption for lighting.

3.	Atzeri, A. et al. (2014)	• This paper investigates the effect of internal and external roller shades on different windows like single, double and triple, in an open office building in Rome latitude. • It was found that, external roller shades on windows gave long term energy saving and also provided thermal comfort as well as visual comfort compared to other internal roller shading devices.
4.	Chen, Y. et al. (2014)	• This work investigates two different types of shading devices i.e., fixed and motorized, and it evaluates the thermal and daylight performance of an Open-plan office building of the Research Support Facility, at the National Renewable Energy Laboratory in USA. • Different windows like double and triple, having low SHGC at window to wall ratios to these buildings were tried. • The study concluded that, motorized shading devices give better results than fixed shading devices in both summer and winter seasons, to provide thermal comfort and visual comfort to an open plan office building.

5.	Dhariwal, J. and Banerjee, R. (2017)	• In this research, the authors proposed a model to find annual cooling, heating and lighting energy of a three storey air conditioned office building, which is located in New Delhi climatic zone, by using surrogate modeling and fractional factorial designs instead of design of experiments. • The surrogate model shows an order of magnitude faster than the simulation model, by approximating the simulation model behavior. • Optimization with genetic algorithms using these surrogate models, leads to quick analyses of single and multi-objective optimization scenarios, resulting in a better solution than a genetic algorithm directly coupled to the simulation model. • The authors suggest this model in urban areas, to design the buildings in a quicker manner than previous models.
6.	Koo, S.Y. et al. (2010)	• In this work, a new control method was proposed for an automated venetian blind, controlled for thermal comfort of occupants inside the buildings, which also maximizes the daylight penetrations in perimeter zone. • Compared to previous control methods it is the best, as it offers thermal comfort as well as day lighting not only to the defined zone, but it is also applicable to multiple perimeter zones to control glare, provide thermal comfort and decrease the cooling loads.

7.	Lee, E.S. et al. (1998)	• This work aimed to test an automated Venetian blind, which was operated in synchronization with a dimmable electric lighting system to block direct Sun to provide illuminance on work plane of an office building, which has a south east orientation window located in Oakland climatic latitude region at different weather conditions. • It was concluded that cooling load energy saving were 7% to 32% at different blind positions, lighting energy saving were nearly 22% to 28% at static blind position and these calculations were used by computer simulations.
8.	Li, D.H.W. et al. (1999)	• In this paper, the daylight factor for a building is studied, by considering the effect of a high storey building which stood beside, and as an obstruction to the original building, studied for Hong Kong and Britain country climatic conditions at different seasons. • For kitchen rooms, 0.5% daylight factor and for bed rooms, 3.5% daylight factor was found, when obstruction position is in between 22^0 to 40^0. • It was also concluded that, when the obstruction position is greater than 60^0, no daylight factor comes into buildings.

9.	Li, D.H.W. and Lam, J.C. (2000)	• This study measured the three year illuminance data, which was hourly available, in the outdoor environment of Hong Kong, to find the illuminance inside the office buildings through different glass windows. • Aim was to find the indoor illuminance through three window glasses i.e., clear, tinted and reflective glasses, at four orientations namely North, South, West and East of an office building. A methodology was applied to save energy with reflective glass, which was nearly 40 to 60 kWh/m^2 per year.
10.	Li, D.H.W. (2007)	• This study inspects, the effect of various building obstruction shadings on 40 storey office building, to reduce the energy consumption by using computer simulation software with Energy plus. • Regression analysis was used to find the energy saving by using correlations.Energy consumption was reduced by varying the obstruction position between 25^0 to $30^{0.}$ The energy reduced was nearly 25–28 kWh/m^2.
11.	Li, D.H.W. et al. (2010)	• This work aimed to define the daylight illuminance on a vertical plane under non-overcast sky conditions. • A method was proposed, to evaluate the comparison of daylight illuminance results with simulation results like RADIANCE lighting software and other measurement results, under clear sky conditions. • It was found that, the daylight illuminance results estimated by proposed method gave good results and closure, when compared to the RADIANCE results and measured results.

12.	Meresi, A. (2016)	• This work checks the daylight performance of south facing class rooms having light shelves external blind shading devices at different positions, in Athens climatic region. • In this work, double glazing reflective glass and other building envelope reflectivity factors were taken from RADIANCE software tool, in order to find the daylight performance of south facing class rooms. • An external light shelf from the floor at a distance 2.00 m and width 0.80 m, and an inclination of blinds between 10^0 to 20^0 gives best performance, protecting glare as well as daylight distribution in class rooms.
13.	Mohelnikova, J. (2010)	• In this work, the comparison and study of float, solar control clear and solar control tinted glasses, and the daylight performance evaluation of an open office building (with and without interior furniture) was done. • Daylight computer simulations were performed on these glasses at single, double and triple windows, and checked, to find which glass is suitable at different climatic conditions. • Ordinary window glasses with automatic shading devices were more effective than other special tinted glass windows as per daylight calculations.

14.	Ochoa, C.E. and Capeluto, I.G. (2006)	• In this study, three various systems were analyzed, i.e., window without any protection, window having horizontal light shelf, and Anidolic concentrator mounted on window, by using RADIANCE computer simulation program of high illuminance latitude in climatic region of Israel at different seasons. • The results concluded that, horizontal light shelves give better and sufficient daylighting compared to other systems, in latitudes where high daylight illuminance was available.
15.	Olbina, S. and Hu, J. (2012)	• This work, deals with the study and design of automated split blind controls at different positions, and aims to find the day lighting and thermal performance of buildings, and energy saving in Gainesville climatic region by using Energy plus computer simulations. • The results conclude that split blinds, both optimum and predicted, had an improved day lighting performance and cause low energy consumption.
16.	Perez-Burgos, A. et al. (2010)	• This study measured the illuminance levels on both horizontal and vertical surfaces, in all four directions of Castilla-Leon region near Valladolid city of Spain country on a Sunny clear day. • The study aimed to analyze the illuminance measurements and to find the relation between global vertical and horizontal illuminance, and also to find if there is no direct Sunlight on surfaces.

17.	Shen, H. and Tzempelikos, A. (2014)	• The objective of this work, was to develop a new control method to reduce direct Sunlight and maximize the daylight illuminance in office buildings in West Lafayette, Indiana, USA. • For this work, internal roller shading devices were used for buildings, to conduct experiments and validate new algorithms developed by Energy Plus simulation software. • It was concluded that, by using new control glare method, we can reduce more amount of direct Sun light and control daylight glare compared with previous work.
18.	Sudan, M. et al. (2015)	• This article states that, daylight factor model (DFM) has been developed for daylight aperture, which has been experimentally validated for east oriented wall window under clear sky condition of composite climatic region in India. It was observed that, south oriented window has maximum daylight factor than a north oriented window. Also, if the window is in the upper position of the room, it allows higher illuminance when compared to a wall window toward the bottom of the room.
19.	Sudan, M. and Tiwari, G.N. (2016)	• In this work, a new daylight performance metric, daylight illuminance ratio was developed for an atrium space which is in square shape. • Daylight performance of each inner surface, by theoretical and experimental hourly daylight illuminance values, under clear sky conditions at Varanasi climatic region in India was found. • The results were compared between theoretical and experimental results.

20.	Sudan, M. et al. (2017)	• The energy saving and day lighting performance of a building, with parameters like energy payback time and life cycle conversion efficiency, of a composite climatic zone (Varanasi) was studied annually. • It was found that, the energy payback time and life cycle conversion efficiency increased at clear sky conditions than intermediate sky conditions in the day time and was compared with experimental results.
21.	Voll, H. and Seinre, E. (2014)	• In this study, two different areas of rooms were tested in a laboratory of Tallinn University of Northern Europe, to provide optimum day lighting to reduce cooling and heating loads in offices. • Different window designs were designed for the two rooms, to analyze the daylight and thermal performance of an office building. • It concludes that, thermal and daylight performance depends on window parameters.
22.	Yoon, Y.B. et al. (2014)	• Study and comparison of two day lighting algorithms of double glazed clear glass window by using Energy plus and DE light program simulations was conducted. • It was found that, DE light Radiosity algorithm is used for windows without shading and Energy plus split flux algorithm is used for windows with shading for better accuracy.

From the available literature, it is conclude that there are no significant studies on thermal performance of float, tinted and reflective window glasses, as well as, the net cost saving from the cooling and heating loads by utilizing these glasses. To find these gaps, this present study focuses on the heat transfer through window glasses with single, double, triple and quadruple arrangement, for reducing heating and cooling costs. The direction of the window also affects the heat gain, and hence directions have been considered for different Indian climatic zones.

2.2 OBJECTIVES OF THE PRESENT STUDY

From the review of literature, the objectives of the current study are as follows:

- Experimental determination of optical properties of glass materials.
- Theoretical study to understand the heat gain/loss of a space, with a window fitted with single, double number of glasses, for different Indian climatic conditions and optimum direction.
- To study the effect of glass tilt position in a window for the heat gain in buildings with a single glass window and optimum direction.
- To study window area to wall area ratio for the optimum heat gain in buildings.
- Conduct simulation studies of heat gain in buildings with single, double, triple and quadruple window glass arrangements, for different Indian climatic conditions.
- To observe the effect of different reflective glasses on day lighting and heat gain.
- To study the effect of external shading devices on windows, and to provide optimum heat gain and optimum day lighting for the buildings.

CHAPTER-3

PROCEDURE TO CALCULATE SOLAR RADIATION THROUGH THE WINDOW GLASS

INTRODUCTION

To calculate the solar heat gain through the glass, it is required to find the Earth, Sun and solar derived angles. The terminology and correlations used are given below (ASHRAE 2001).

3.1. Standard equations to evaluate total solar radiation through the glass

- **Hour position (h):** It expresses the time of the day with respect to solar noon.

$$h = -15x(12 - t) \quad (3.1)$$

- **Declination position ($\mathbf{d_{ia}}$):** The declination of the Sun is the position between the equator and a line drawn from the center of the earth to the center of the Sun.

$$d_{ia} = 23.45\sin\frac{360(284 + n)}{365} \quad (3.2)$$

Where n= number of days counting from Jan 1st

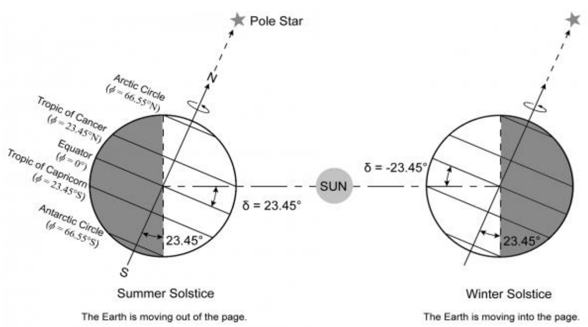


Figure 3.1 Declination position (R.C. Arora 2011)

- **Altitude position (β):** It is the position in a vertical plane between the Sun rays and the projection of the Sun rays on the horizontal plane.

$$\sin\beta = \cos l \cos d . \cosh + \sin l . \sin d \quad (3.3)$$

- **Solar Azimuth position** (ϕ)**:** It is the position in the horizontal plane measured from south to the horizontal projection of the Sun rays.

$$\cos\phi = \frac{\sin\beta\sin l - \sin d}{\cos\beta\cos l} \quad (3.4)$$

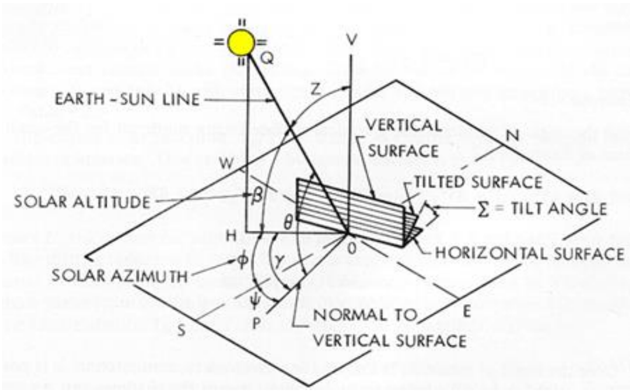


Figure 3.2 Solar positions for horizontal and vertical surface (ASHRAE 2001)

- **Surface solar Azimuth position (**γ**):** It is the position between the horizontal projection of the solar rays and the horizontal projection of the normal surface.

$$(\gamma) = \phi - \Psi \quad (3.5)$$

Table 3.1 Surface orientations and azimuths, measured from south (ASHRAE 2001)

orientation	N	NE	E	SE	S	SW	W	NW
Surface azimuth Ψ	180^0	-135^0	-90^0	-45^0	0^0	45^0	90^0	135^0

- **Position of incidence(**θ**):** The position of incidence for any surface is defined as the position between the incoming solar rays and a line normal to that surface of an object.

$$\cos\theta = \cos\beta\cos\gamma\cos k + \sin\beta\sin k \quad (3.6)$$

At the earth's surface on a clear day solar irradiance at clear atmosphere is given by

$$I_{DN} = \frac{A1}{\exp(B1/\sin\beta)} \quad (3.7)$$

Table 3.2 shows the hourly solar radiation values for 21st of every month for different climatic regions in India. These values are used to find the direct, diffuse and ground reflected radiation values on any surface.

Table 3.2 Values of Constants A1, B1 and C1 Obtained for Predicting Hourly Solar Radiation in India (Parishwad, 1997 & 2011)

Day	**A1 (W/m^2)** Solar radiation in absence of atmosphere	**B1** Atmospheric extinction coefficient	**C1** Sky radiation coefficient
Jan. 21	610.00	0.000	0.242
Feb. 21	652.20	0.010	0.249
Mar. 21	667.86	0.036	0.299
Apr. 21	613.35	0.121	0.395
May. 21	558.39	0.200	0.495
Jun. 21	340.71	0.428	1.058
Jul. 21	232.87	0.171	1.611
Aug. 21	240.80	0.148	1.624
Sep. 21	426.21	0.074	0.688
Oct. 21	584.73	0.020	0.366
Nov. 21	616.60	0.008	0.253
Dec. 21	622.52	0.000	0.243

- **Intensity of Direct Solar Radiation (I_{DR}):**

  $I_{DR} = I_{DN}\cos\theta$………. kWh/day. m^2 (3.8)

- **Diffuse solar radiation (I_{dR}):**

  $I_{dR} = C1.\, I_{DN}.\frac{1-\sin k}{2}$……….. kWh/day. m^2 (3.9)

- **Ground reflected solar radiation (I_{GR}):**

  $I_{GR} = (C1 + \sin\beta) I_{DN} \rho_g \frac{1-\sin k}{2}$………. kWh/day. m^2 (3.10)

- **Total solar radiation falling on the glass (Q_{TS}):** It is the radiation gained by the space when the direct Sun rays, diffuse sky rays and ground reflected rays through the glass.

  $Q_{TS} = q_{dS} = q_{dW} = (I_{DR} + I_{dR} + I_{GR})$……… kWh/day. m^2 (3.11)

- **Thermal transmittance of the single glazing (U1):**

$$U1 = \frac{1}{\left(\frac{1}{h_o} + \frac{1}{h_i} + \frac{L}{K}\right)} \tag{3.12}$$

- **Total solar radiation through the single glass window (Q_1):**

$$Q_1 = (I_{DR} + I_{dR} + I_{GR}).\left(T_{SOL} + \frac{U1}{h_o} A_{SOL}\right).A_G \ \ldots\ldots \text{ kWh/day} \tag{3.13}$$

- **Total solar radiation through the double glass window (Q_2):**

$$Q_2 = (I_D + I_d + I_G).\left(T_{SOL} + U2(\frac{\alpha_i + \alpha_o}{h_o} + \alpha_i x C_g)\right).A_G \tag{3.14}$$

Where,

U2 (Thermal transmttance of the double glazing)

$$= 1/\left(1/h_o + L1/K1 + C_g + L2/K2 + 1/h_i\right)$$

$$C_g = 1 \Bigg/ \left(1.25 + \left(2.32x\left(\sqrt{\left(1 + \left(\frac{{t_{ag}}^2}{{w_{ag}}^2}\right)\right)} - \frac{t_{ag}}{w_{ag}}\right)\right)\right) \tag{3.15}$$

The following assumptions are made in this study to find out the outside and inside heat transfer coefficients (CIBSE 2006)

1. For outside surface wind velocity was taken as normal condition i.e. C_s=5m/s and inside surface wind velocity was taken as stand still condition i.e. C_s=0.1 m/s.
2. Emissivity's of the inside and outside surfaces are 0.9.
3. Room geometry (Cubical geometry) constant was taken as k1=1.

Calculations

Outside heat transfer coefficient

$E = k1.\varepsilon$

$E = 1\times 0.9 = 0.9$

Convective heat transfer coefficient at external surface

$h_c = 5.8 + 4.1C_s$

$= 26.3\ W/m^2\ K$

Radiative heat transfer coefficient, $h_r = 4\sigma T_s^3$

The Radiative heat transfer coefficient depends upon the absolute temperatures of radiating surface and environment receiving the radiation. It should be considered that, for night time clear skies, the difference between the wall surface temperature and the sky temperature will be very large and causing an underestimation of h_c in these circumstances. This should be incorporated into the calculations.

$$h_r = 4 \times \sigma \times T_s^3$$
$$= 4 \times 5.67 \times 10^{-8} \times (273)^3$$
$$= 4.61\ W/m^2\ K^4$$

Where, T_s = mean temperature of surfaces in 'K'

σ = Stefan Boltzmann constant ($5.67 \times 10^{-8}\ W/m^2K^4$)

$R_{se} = \frac{1}{h_c + Eh_r} = \frac{1}{26.3+4} = 0.033 \approx 0.04\ m^2.K/W$

$h_o = 1/R_{se} = 25\ W/m^2.K$

Inside heat transfer coefficient

h_c Considered as 2.5 W/m^2K (Horizontal heat flow)

$R_{si} = \frac{1}{(1.2Eh_r + h_c)} = \frac{1}{(1.2 \times 4 + 2.5)} = 0.137 \approx 0.13\ m^2.K/W$

$h_i = 1/R_{si} = 7.69\ W/m^2.K$

In this work only two seasons like summer and winter are considered to find the solar radiation through glass windows in buildings for different climatic zones. In summer season solar heat gain in buildings is high because the Sun travelling path is more when compared with winter season i.e. duration of the day length is more than night. In winter season solar heat gain in buildings is low because the Sun travelling path is less when compared with summer season i.e. duration of the night length is more than the day, like spring and autumn Sun travelling path is in between summer and winter seasons i.e. duration of the day length is equal to length of the night.

In this work summer months are considered from April to August and winter months are considered from September to March. As per NBC standards (National Building Code 2005) peak summer and peak winter can be determined based on the latitude ranges. For latitudes ranges from 9^0 to 17^0 the maximum solar radiation will fall in the month of April, for 17^0 to 25^0 latitudes will fall in the month of May and beyond 25^0 latitudes will fall in the month of June. In winter irrespective of any latitude minimum solar radiation will fall in the month of December, as Sun radiation is directly falling on the above considered latitudes due to their declination position.

CHAPTER-4

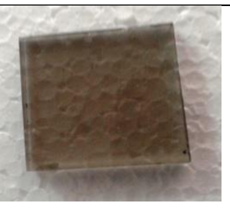
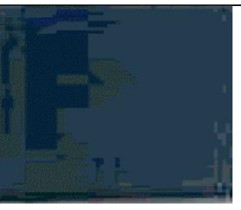
EVALUATION OF OPTICAL PROPERTIES OF THE GLASS MATERIALS

4.1 INTRODUCTION

Glass is a transparent material and has optical properties such as transmittance, reflectance, and absorbance. The extent of heat gain or loss through a building window glass mainly depends on the solar optical properties of the glass. To evaluate the solar optical properties of ten different glasses, spectral optical data are required.

Ten different types of glasses as listed in Table 4.1.1 have been selected for heat gain and daylight calculations. The spectral characteristics of these ten glasses were not found in the available literature. Hence the spectral characteristics of glasses were measured using Perkin-Elmer lambda 950 double beam monochromator spectrophotometer, with 150 mm integrating sphere detector module, which is available in Indian Nanoelectronics Users Program center at IIT Bombay. Perkin Elmer Lambda 950 spectrophotometer specifications are Wavelength range: 175 nm – 3300 nm; Resolution: 0.05 nm (UV-VIS) 0.2 nm (NIR); Wavelength accuracy: ±0.08 nm (UV-VIS) and ±0.3 nm (NIR)). Pre-aligned deuterium (UV region) and tungsten-halogen (VIS-NIR) lamps were used as the light source in the spectrophotometer. Figure 4.1.1, shows a schematic diagram of the experimental setup. A photomultiplier type R-6872 is used as a detector for UV-VIS range while peltier cooled PbS detector is used as a NIR range detector. To measure transmittance, a glass sample (size 30 mm × 30 mm with 5 mm thickness) was loaded into the transmittance sample holder located at the entrance of the sphere. The glass sample should be placed, to completely cover the slit window. A sample beam should then pass through the sample transmission port with the reflectance port covered with white standard plate. The total transmission can be detected by both photomultiplier (R-687) and PbS detectors. To assess the reflectance of a glass sample, a glass sample was placed in a reflectance sample holder at the rear end of the sphere with the transmission port open. The sample beam is reflected back and collected by the sphere.

Table 4.1.1 Glass materials studied for this work

S.No	Glass window	Abbreviation	Image
1	Clear glass	CLGW	
2	Bronze glass	BZGW	
3	Bronze-reflective glass	BZRGW	
4	Green glass	GGW	
5	Gold reflective glass	GLDRGW	
6	Grey glass	GrGW	

Continued…………

7	Green reflective glass	GRGW	
8	Grey reflective glass	GrRGW	
9	Opal blue reflective glass	OPBRGW	
10	Sapphire blue reflective glass	SPBRGW	

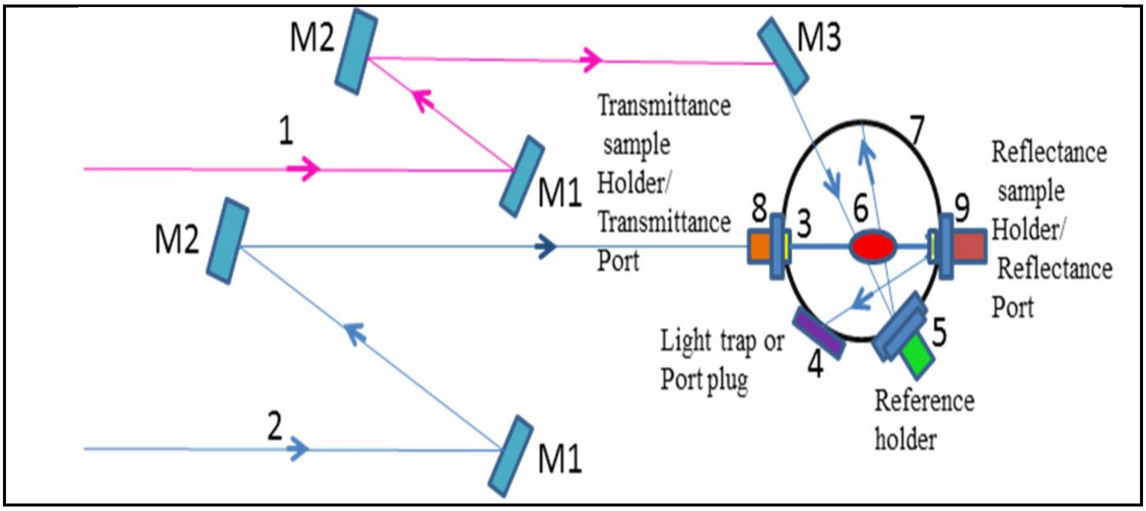


Figure 4.1.1 Schematic diagram of experimental set up: (a) Reference beam (b) Sample beam (c) Sample (d) Port plug (e) Reference holder (f) Detector (g) Integrated sphere (h) Transmittance sample holder (i) Reflectance sample holder and (j) M1, M2 and M3 Mirrors

The optical properties are not available in the literature for the glass materials studied. The definitions of the optical properties of glass materials are given below as per British standards (BS EN 410 1998).

4.2 VISIBLE OPTICAL PROPERTIES OF VARIOUS GLASS MATERIALS (BS EN 410 1998)

Visible Light Transmittance (T_{VIS}):

The percentage of light in the visible spectrum, 380 to 780 nanometers, that is transmitted through the glass.

$$T_{VIS} = \frac{\sum_{\lambda=380}^{\lambda=780} D_\lambda \tau(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380}^{\lambda=780} D_\lambda V(\lambda) \Delta\lambda} \qquad (4.2.1)$$

Visible Light Reflectance (R_{VIS}):

The percentage of light in the visible spectrum, 380 to 780 nanometers, that is reflected from the glass.

$$R_{VIS} = \frac{\sum_{\lambda=380}^{\lambda=780} D_\lambda \rho(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380}^{\lambda=780} D_\lambda V(\lambda) \Delta\lambda} \qquad (4.2.2)$$

Visible Light Absorbance (A_{VIS}):

The percentage of light in the visible spectrum, 380 to 780 nanometers, that is absorbed by the glass. Visible light absorbance of the window glass will be finding by knowing the transmittance and reflectance of the glass with Eqn. (4.2.3).

$$A_{VIS} = 100 - \frac{\sum_{\lambda=380}^{\lambda=780} D_\lambda \tau(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380}^{\lambda=780} D_\lambda V(\lambda) \Delta\lambda} - \frac{\sum_{\lambda=380}^{\lambda=780} D_\lambda \rho(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380}^{\lambda=780} D_\lambda V(\lambda) \Delta\lambda} \qquad (4.2.3)$$

Spectral characteristics such as transmission, reflection and absorption, have been measured for ten glass materials for wavelength range from 380 nm to 780 nm are taken at 2 nm wavelength intervals to find visible optical properties. Figure 4.2.1 and Figure 4.2.2 show the spectral characteristics of nine glass materials in ultra violet and visible wavelength region. Table 4.2.1 shows spectral characteristics data of bronze glass material in visible wavelength region. These properties are utilized to find daylight calculations through glass windows. Spectral data of ten glass materials are recorded from the experiments. The sample data of bronze glass material from 380 nm wavelength to 780 nm wavelength data are listed in Appendix I.

Table 4.2.1 Spectral characteristics of bronze glass in visible wavelength region

Wavelength(nm)	Transmission (%)	Reflection (%)	Absorption (%)
380	40.85	5.56	53.59
382	41.76	5.60	52.65
384	43.46	5.69	50.86
386	45.67	5.80	48.53
388	47.92	5.88	46.19
390	49.92	5.99	44.09
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
770	62.23	6.34	31.42
772	62.25	6.31	31.44
774	62.02	6.28	31.69
776	61.70	6.28	32.01
778	61.61	6.27	32.11
780	61.64	6.27	32.10

Table 4.2.2 Visible optical properties of glass materials

Window Glass	Code	T_{VIS} [%]	R_{VIS} [%]	A_{VIS} [%]
Clear glass window	CLGW	90	9	1
Bronze glass window	BZGW	55	6	39
Bronze-reflective glass window	BZRGW	20	20	60
Green glass window	GGW	72	7	21
Gold reflective glass window	GLDRGW	36	51	13
Grey glass window	GrGW	22	5	73
Green reflective glass window	GRGW	30	34	36
Grey reflective glass window	GrRGW	8	6	86
Opal blue reflective glass window	OPBRGW	26	24	50
Sapphire blue reflective glass window	SPBRGW	25	10	65

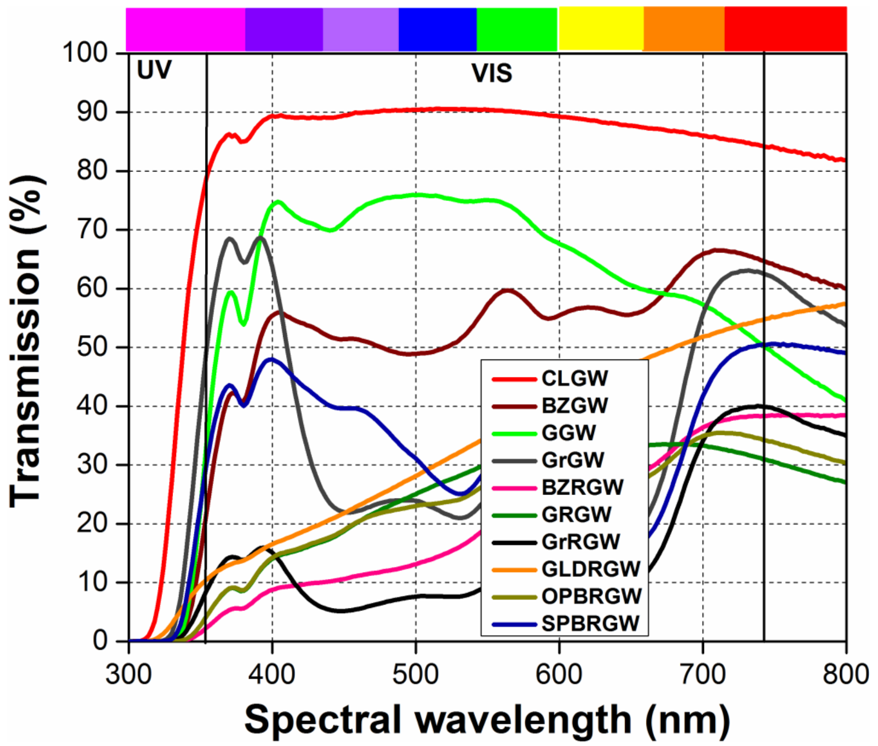


Figure 4.2.1 Spectral transmission of glass materials in Ultra violet and visible wavelength region

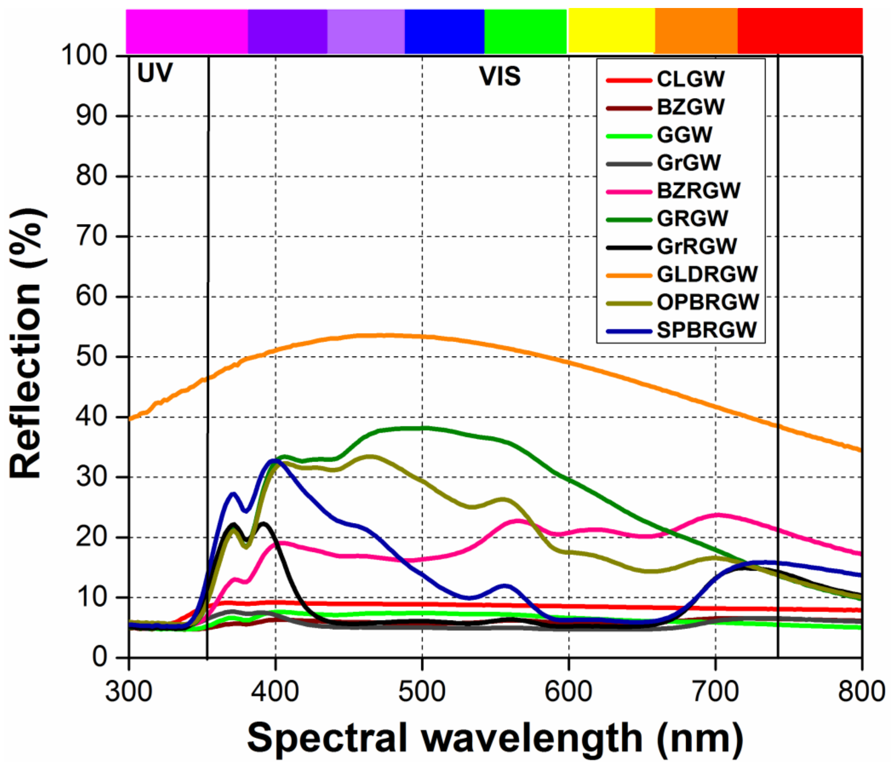


Figure 4.2.2 Spectral reflection of glass materials in Ultra violet and visible wavelength region

4.3 SOLAR OPTICAL PROPERTIES OF VARIOUS GLASS MATERIALS (BS EN 410 1998)

Solar Energy Transmittance (T_{SOL}):

The percentage of the solar spectrum energy (ultra violet, visible and near infrared) from 300 nm to 2500 nm that is directly transmitted by a glass product

$$T_{SOL} = \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \tau(\lambda)\Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \tag{4.3.1}$$

Solar Energy Reflectance (R_{SOL}):

The percentage of the solar spectrum energy (ultra violet, visible and near infrared) from 300 nm to 2500 nm that is reflected by a glass product.

$$R_{SOL} = \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \rho(\lambda)\Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \tag{4.3.2}$$

Solar Energy Absorbance (A_{SOL}):

The percentage of the solar spectrum energy (ultra violet, visible and near infrared) from 300 nm to 2500 nm that is absorbed by a glass product. Solar energy absorbance of the window glass will be finding by knowing the transmittance and reflectance of the glass with Eqn. (4.3.3).

$$A_{SOL} = 100 - \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \tau(\lambda)\Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} - \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \rho(\lambda)\Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \tag{4.3.3}$$

Spectral characteristics transmission, reflection and absorption have been measured for ten glass materials, wavelength range from 300 nm to 2500 nm taken at each 2 nm wavelength interval to find solar optical properties. Figures 4.3.1 and 4.3.2 shows the spectral characteristics of ten glass materials in total spectrum wavelength region. These properties are utilized to find solar radiation through glass windows. Spectral data of nine glass materials are recorded from the experiments. Table 4.3.1 shows spectral characteristics data of bronze glass material in total spectrum wavelength region. A MATLAB code was developed to calculate solar optical properties using the Eqn. from (4.3.1) to (4.3.3). The sample data of bronze glass from 300 nm wavelengths to 2500 nm wavelength is shown in Appendix II.

Table 4.3.1 Spectral characteristics of bronze glass in solar spectrum wavelength region

Wavelength(nm)	**Transmission (%)**	**Reflection (%)**	**Absorption (%)**
300	0.02	4.96	95.02
302	0.02	4.93	95.06
304	0.04	4.94	95.02
306	0.02	4.88	95.10
308	0.02	4.82	95.16
310	0.01	4.87	95.12
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
2490	69.74	6.97	23.29
2492	69.47	6.25	24.28
2494	69.98	7.15	22.87
2496	68.89	5.88	25.24
2498	69.60	7.14	23.26
2500	68.96	6.73	24.31

Table 4.3.2 solar optical properties of glass materials

Window Glass	**Code**	T_{SOL} [%]	R_{SOL} [%]	A_{SOL} [%]
Clear glass window	CLGW	82	08	10
Bronze glass window	BZGW	56	06	38
Bronze-reflective glass window	BZRGW	37	14	49
Green glass window	GGW	47	06	47
Gold reflective glass window	GLDRGW	55	32	13
Grey glass window	GrGW	41	06	53
Green reflective glass window	GRGW	29	14	57
Grey reflective glass window	GrRGW	26	08	66
Opal blue reflective glass window	OPBRGW	29	13	58
Sapphire blue reflective glass window	SPBRGW	42	11	47

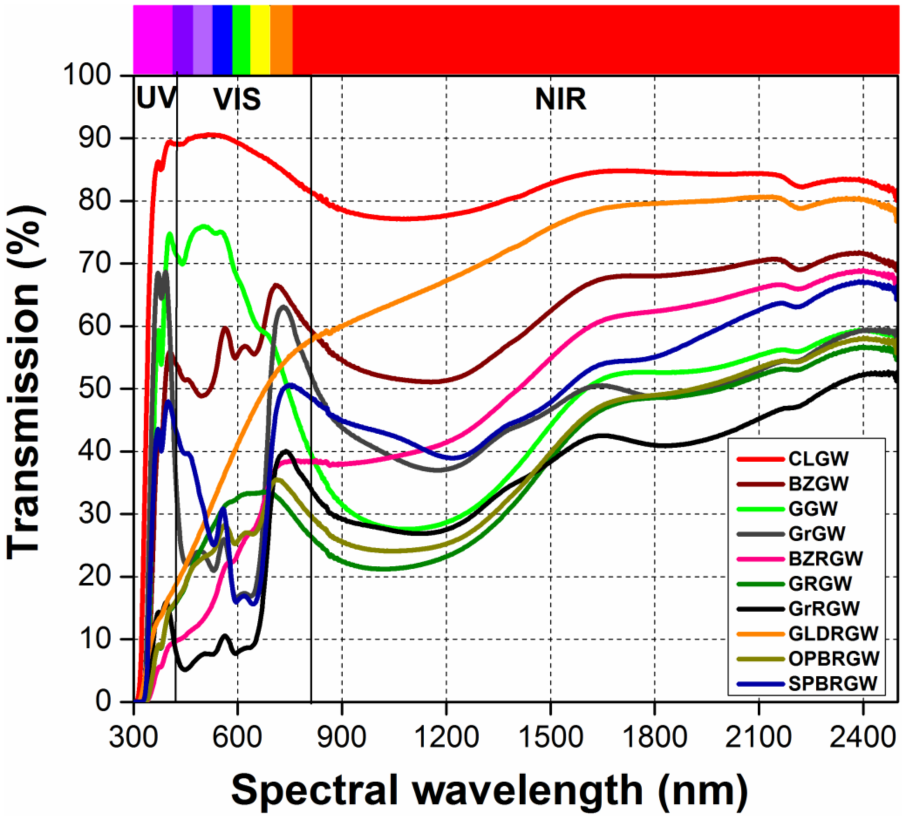


Figure 4.3.1 Spectral transmission of glass materials in total solar wavelength region

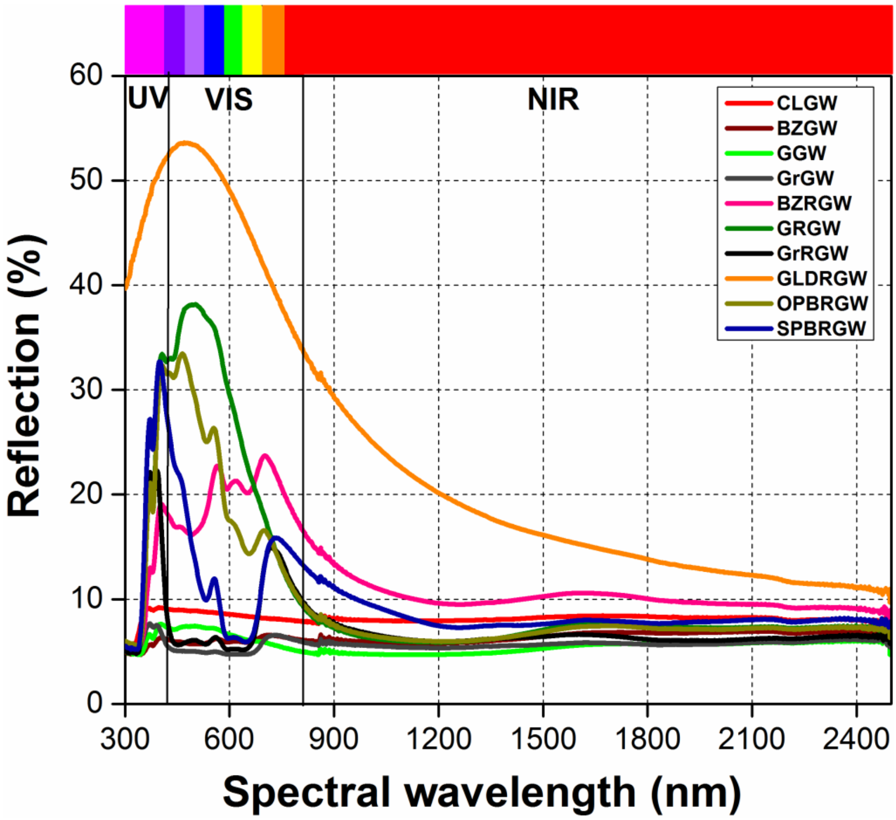


Figure 4.3.2 Spectral reflection of glass materials in total solar wavelength region

CHAPTER-5

THEORETICAL CALCULATIONS OF HEAT GAIN IN BUILDINGS THROUGH SINGLE AND DOUBLE GLASS WINDOWS

5.1 INTRODUCTION

Glass is one of the major elements of the outer building envelope. The energy efficient glass is one that allows ample daylight while reducing heat gain inside the building. The use of appropriate window glasses can significantly reduce cooling/heating loads inside the building. Conventionally, clear glasses were used as common window glasses. These glasses generally have very high transmission of light and solar radiation. Usually, tints are added to control the solar heat gain coefficient and glare of window glasses. The clear glasses are tinted by the addition of metal oxides into molten glass. The variations in the tint can be achieved by varying the type of metal oxides. For instance, oxides of several metals (e.g., iron, manganese, chromium, and vanadium) were identified to be responsible for the color of tinted glass. The addition of iron oxide into molten glass leads to glass colors of green and brown. In contrast, the metal oxides of manganese, chromium, and vanadium lead to color tints of purple, emerald green, and blue, respectively. The tinted glasses were seen to reduce the cooling loads by blocking some of the sun's energy and by diminishing energy transmission. Apart from mixing of glass with metals, the metal coatings can also be applied to the sides of the glasses, in order to increase the light reflection. These glasses are termed as reflective glasses. A thin film coating of metals displayed considerable effect on the optical properties of window glasses. Table 5.1.1, shows the details about the number of glass types and combinations studied in this work for heat gain in buildings.

The following Assumptions are made:

1. The solar heat gain in buildings is found at clear sky conditions.

2. Solar heat gain through glass window (Frame not considered) was taken only and solar heat gain through walls, floor and roof into buildings was not taken into consideration.
3. The heat transfer through glass due to outside and inside temperatures across the glass is not considered.
4. Infiltration load is not taken into account.
5. Internal loads of the space are not considered.

Table 5.1.1 Number of glass combinations studied for heat gain in buildings

Place	Number of single glasses	Single glass tilt (0, -2, -4 and -6) in summer	Single glass tilt (0, 2, 4 and 6) in winter	Double glass combinations in summer and winter	Orientations
Jodhpur	9	9×4=36	9×4=36	6×6=36 (Summer) 6v6=36 (Winter)	8
Kolkata	9	9×4=36	9×4=36	-	8
New Delhi	9	9×4=36	9×4=36	-	8

For validation purpose, a MATLAB code was developed to find direct solar radiation results of New Delhi climatic region using 3mm clear glass window and is validated with Ishwar et al (2011). The deviation is less than 1% and these results are listed in Table 5.1.2. Therefore, the developed MATLAB code is reliable and hence it can be used for the computation of solar heat gain for different glasses.

Table 5.1.2 Validation of calculated values with Ishwar et al. (2011) for New Delhi climatic region on a peak summer day of June 21st

S. No	Orientation	MATLAB program results	Ishwar et al (2011)	Absolute deviation (%)
1	North (N)	178	178.36	0.20
2	North East (NE)	1292	1289.98	0.15
3	East (E)	1952	1953.83	0.09
4	South East (SE)	1272	1273.55	0.12
5	South (S)	184	184.27	0.14
6	South West (SW)	1272	1273.55	0.12
7	West (W)	1952	1953.83	0.09
8	North West (NW)	1292	1289.98	0.15

5.2 SOLAR HEAT GAIN IN BUILDINGS THROUGH NINE SINGLE GLASS WINDOWS IN THREE DIFFERENT CLIMATIC REGIONS

The aim of this work is to find the total solar heat gain in building with dimensions 3.5 m × 3.5 m × 3.5 m, through nine different single glass windows, from eight different orientations i.e., north, northeast, east, southeast, south, southwest, west and northwest, at 40% window area to wall area ratio. The dimensions of the glass window considered were 2.45 m × 2 m. The heat gain was calculated on a peak summer day and on a peak winter day in three different climatic regions (Jodhpur, Kolkata and New Delhi) of India. It also aims to find the energy and cost saving annually. Table 5.2.1, shows the details about the number of single glass windows studied. Figure 5.2.1(a) shows the building model and Figure 5.2.1(b) shows the building with a window. The window was provided to the only one wall of the cubical room. But the cubical building model was rotated as per the requirement to face the window to the different orientations such as E, W, N, NE, NW, SE, SW and S to find the heat gain in buildings through glass window in different orientations of the room.

Table 5.2.1 Total single glass combination studied for heat gain in buildings

Number of glasses	Climatic zones	Glass arrangement	Number of orientations	Number of glass combinations in orientations
9	Jodhpur, Kolkata and New Delhi	Single	8	9×8=72 in each climate zone

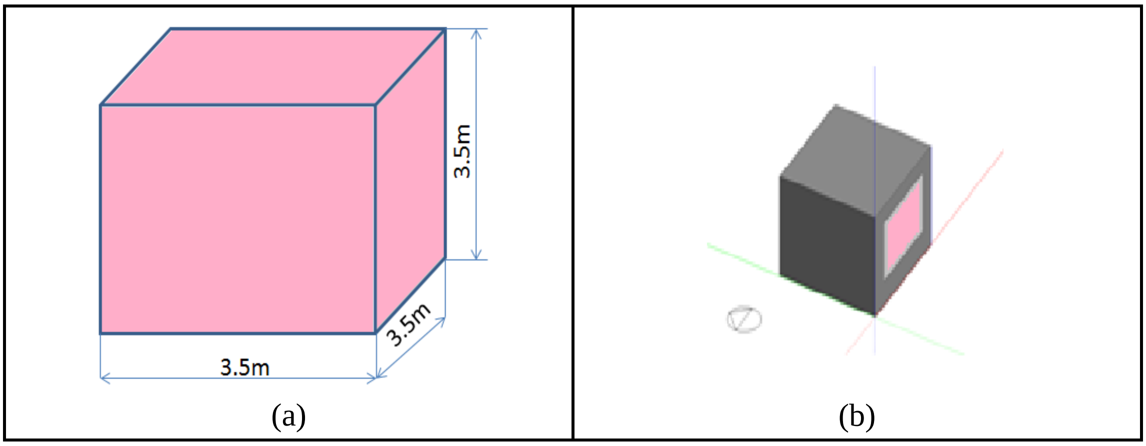


Figure 5.2.1 (a) Building dimensions 3.5m × 3.5 m × 3.5m (b) Building model having glass window

The net annual cooling and heating cost saving of nine window glasses in eight orientations were determined across three different climatic conditions. For the computation of net annual cost saving, the procedure followed as (Cengel, Y.A. and Ghajar, A.J. 2010).

The average daily total solar radiation falling on the surface of any place can be computed using Eqn. (3.11) in summer and winter respectively. In the present study, such computation was made by focusing on two seasons: 1) winter season (September to March) and 2) summer season (April to August), by using average daily solar radiation and the number of days in each month, the total solar radiation falling on the glass for each season was computed. For summer the solar radiation was computed from 6:00 A.M to 6:00 P.M and for winter the solar radiation was computed from 7:00 A.M to 5:00 P.M as per Indian standards (IS 11907).

The total solar radiation falling on the glass during summer season ($Q_{solar,summer}$) is given by Eq. (5.2.1).

$$Q_{solar,summer} = (q_{ds} \times 30)_{April} + (q_{ds} \times 31)_{May} + (q_{ds} \times 30)_{June} + (q_{ds} \times 31)_{July} + (q_{ds} \times 31)_{August} \ldots\ldots\ldots\ldots\ldots \text{ kWh/year} \quad (5.2.1)$$

Where q_{ds} is the daily average total solar radiation falling on glass in summer (Direct + Diffuse + Reflected from ground).

The total solar radiation falling on the glass during winter season ($Q_{solar,winter}$) is given by Eq. (5.2.2).

$$Q_{solar,winter} = (q_{dw} \times 30)_{September} + (q_{dw} \times 31)_{October} + (q_{dw} x30)_{November} + (q_{dw} \times 31)_{December} + (q_{dw} \times 31)_{January} + (q_{dw} \times 29)_{February} + (q_{dw} \times 31)_{March} \ldots\ldots\ldots\ldots\ldots \text{ kWh/year} \quad (5.2.2)$$

Where q_{dw} is daily average total solar radiation falling on glass in winter (Direct + Diffuse + Reflected from ground).

Next, the decrease in the annual cooling load and annual heating loads were computed from Eqn. 5.2.3 and 5.2.4, respectively.

In this work, the unit cost of the electricity and natural gas was taken as ₹6/kWh and ₹1.09/kWh, respectively. The coefficient of performance of the cooling system and efficiency of the furnace are taken as 2.5 and 0.8, respectively from (Cengel, Y.A. and Ghajar, A.J. 2010).

$$\text{Cooling load decrease} = Q_{solar,summer} \times A_G \times (SHGC_{CGW} - SHGC_{selected\ glass}) \ldots\ldots\ldots\ldots\ldots\ldots \text{ kWh/year} \quad (5.2.3)$$

$$\text{Heating load Increase} = Q_{solar,winter} \times A_G \times (SHGC_{CGW} - SHGC_{selected\ glass)}) \ldots. \text{ kWh/year} \quad (5.2.4)$$

$$\text{Decrease in cooling costs} = \frac{((\text{cooling load decrease})(\text{unit cost of electricity}))}{(\text{COP})} \quad (5.2.5)$$

$$\text{Increase in heating costs} = \frac{((\text{heating load increase})(\text{unit cost of fuel}))}{(\text{Efficiency})} \quad (5.2.6)$$

$$\text{The net annual cost saving} = \text{Decrease in cooling costs} - \text{increase in heating costs} \quad (5.2.7)$$

Where, $Q_{solar,summer}$ is total solar radiation falling on glass in summer months in a year, $Q_{solar,winter}$ is total solar radiation falling on glass in winter months in a year, A_G is glass area, $SHGC_{CGW}$ is solar heat gain coefficient of the clear glass window, and $SHGC_{selected\ glass}$ is solar heat gain coefficient of the selected glass window. Figure 5.2.2, shows flow chart to find solar heat gain in buildings through single glass window.

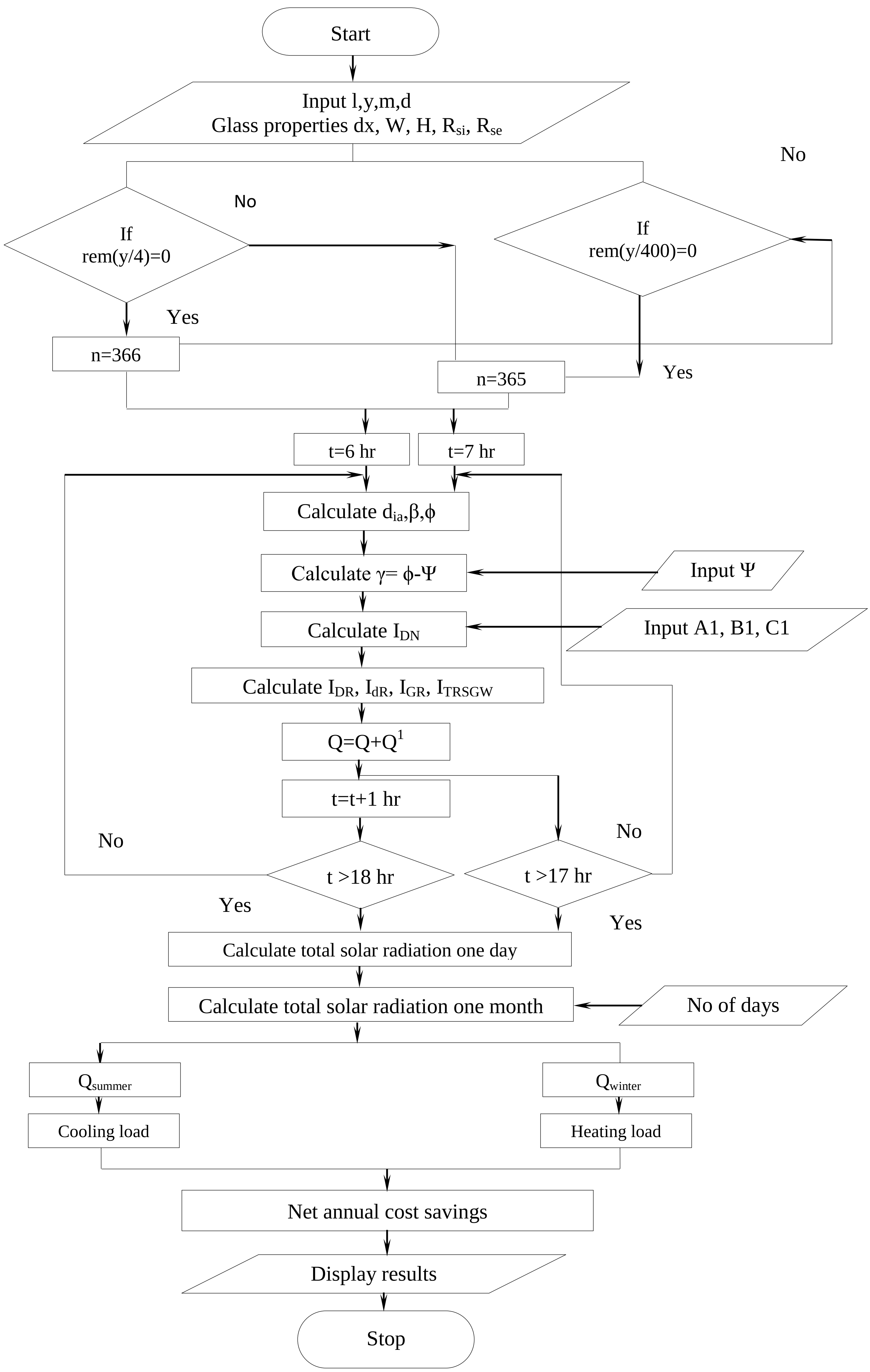


Figure 5.2.2 Flow chart for calculating solar heat gain through single glass window

5.2.1 Thermal and cost analysis of buildings using various glass windows in the climatic region of Jodhpur (Hot & Dry), during summer and winter seasons

Figures 5.2.3, 5.2.4 and Tables 5.2.2, 5.2.3 show the total solar heat gain in building through nine glass windows at peak summer and winter days for Jodhpur climatic region. From Figure 5.2.3, it is observed that grey reflective glass window allow minimum heat 3.04 kWh and from Figure 5.2.4, it is observed that bronze glass window allow more heat 17.87 kWh in buildings from south orientation compare with other orientations. The south oriented window, reduces the cooling loads and heating loads, during summer and winter, respectively. Hence, it is the optimum position for placing a window. The decreasing order of preference of orientation in both summer and winter seasons is as follows S<N<SE<SW<E<W<NE<NW. In winter season, solar heat gain in buildings based on the orientations is shown from increasing order to decreasing order as follows S>SE>SW>E>W>NE>NW>N.

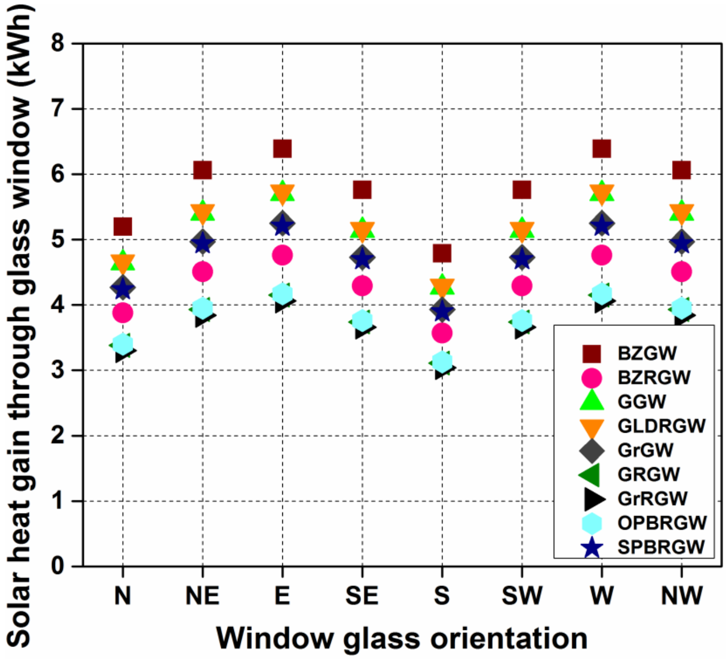


Figure 5.2.3 Total solar heat gain in buildings through glass windows at peak summer day for Jodhpur region

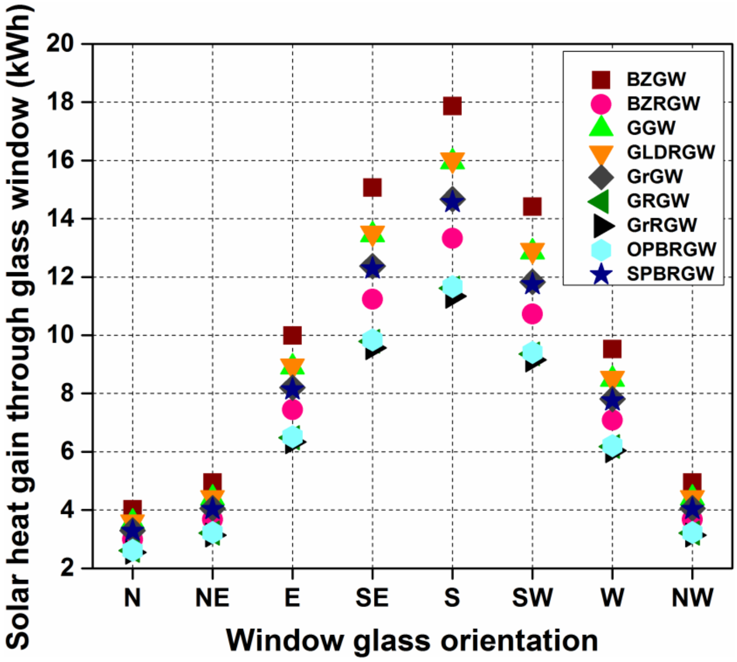


Figure 5.2.4 Total solar heat gain in buildings through glass windows at peak winter day for Jodhpur region

Table 5.2.2 Total solar heat gain in buildings through glass windows at peak summer day for Jodhpur region

	Heat gain in buildings through glass windows at peak summer day							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	5.2	6.06	6.39	5.76	4.79	5.76	6.39	6.06
BZRGW	3.88	4.51	4.76	4.29	3.57	4.29	4.76	4.51
GGW	4.64	5.4	5.7	5.14	4.27	5.14	5.7	5.4
GLDRGW	4.66	5.43	5.73	5.16	4.29	5.16	5.73	5.43
GrGW	4.27	4.97	5.25	4.73	3.93	4.73	5.25	4.97
GRGW	3.38	3.93	4.15	3.74	3.11	3.74	4.15	3.93
GrRGW	3.3	3.84	4.06	3.66	3.04	3.66	4.06	3.84
OPBRGW	3.4	3.95	4.17	3.76	3.13	3.76	4.17	3.95
SPBRGW	4.24	4.94	5.21	4.7	3.9	4.7	5.21	4.94

Table 5.2.3 Total solar heat gain in buildings through glass windows at peak winter day for Jodhpur region

	Heat gain in buildings through glass windows at peak winter day							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	4.02	4.94	9.99	15.07	17.87	14.41	9.52	4.94
BZRGW	2.99	3.68	7.44	11.23	13.32	10.73	7.09	3.68
GGW	3.59	4.41	8.91	13.45	15.95	12.86	8.49	4.41
GLDRGW	3.60	4.43	8.95	13.51	16.02	12.92	8.53	4.43
GrGW	3.30	4.06	8.20	12.37	14.67	11.83	7.81	4.06
GRGW	2.61	3.21	6.48	9.79	11.61	9.36	6.18	3.21
GrRGW	2.55	3.14	6.34	9.57	11.34	9.15	6.04	3.14
OPBRGW	2.62	3.23	6.52	9.84	11.67	9.41	6.21	3.23
SPBRGW	3.28	4.03	8.14	12.29	14.57	11.75	7.76	4.03

5.2.2 Annual cooling load decrease and heating load increase in buildings using various glass windows in comparison with clear glass window for Jodhpur climatic region

Figures 5.2.5 and 5.2.6 indicate the annual cooling load decrease and heating load increase in buildings using various types of glass windows in comparison with clear glass window in eight orientations for Jodhpur climatic region. From Figure 5.2.5, it can be clearly seen that all glass windows are reducing more cooling load in south orientation in summer season.

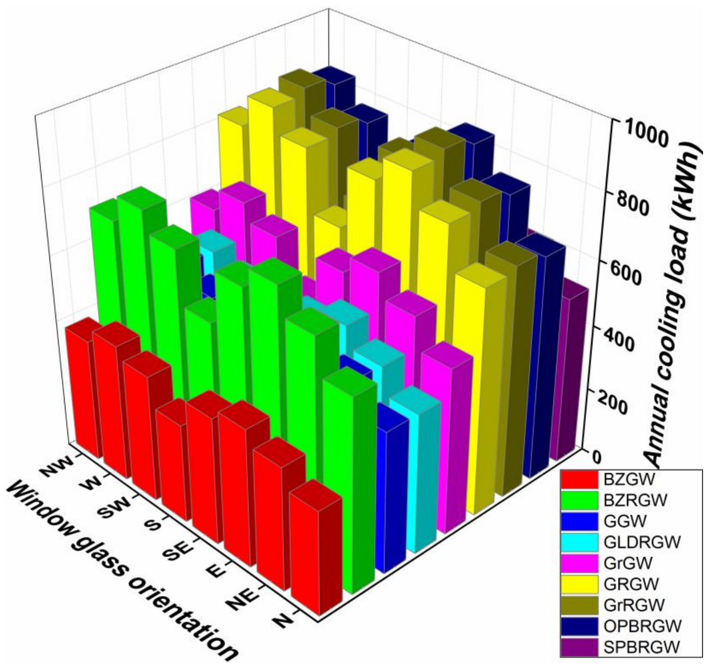


Figure 5.2.5 Annual cooling load decrease in buildings using various glass windows in comparison with clear glass window in summer season

Grey reflective glass window is observed to reduce more cooling load i.e. 670.73 kWh in south orientation in summer season. From the Figure 5.2.6, it can be clearly seen that all glass windows increase more heating load in south orientation at winter season. The bronze glass window is observed to increase more heating load inside the building i.e. 954.78 kWh.

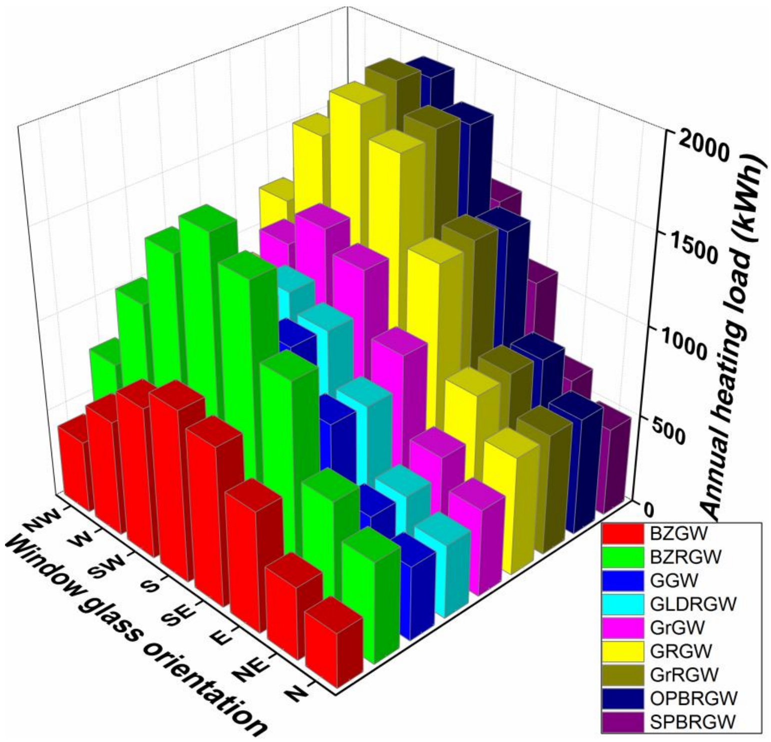


Figure 5.2.6 Annual heating load increase in buildings using various glass windows in comparison with clear glass window in winter season

Figure 5.2.7 and Table 5.2.4 show the net annual cost saving of nine glass windows compared with clear glass window, in the climatic region of Jodhpur. From Figure 5.2.7, it is observed that grey reflective glass window (GrRGW) saves the highest net cost among the nine tested glasses. Moreover, the best orientations for placing window glasses are south-east, south-west and south orientations, respectively.

Table 5.2.4 Net annual cost saving of buildings using nine glass windows compared with clear glass window in the climatic region of Jodhpur [Rupees]

	Annual cost saving of buildings for Jodhpur region							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	218.4	237.4	55.4	2134.0	2072.8	2082.3	12.2	237.4
BZRGW	401.7	436.8	102.0	3926.1	3813.4	3830.9	22.4	436.8
GGW	295.6	321.4	75.0	2889.0	2806.2	2819.0	16.5	321.4
GLDRGW	292.8	318.3	74.3	2861.5	2779.5	2792.2	16.3	318.3
GrGW	347.1	377.4	88.1	3392.4	3295.1	3310.2	19.4	377.4
GRGW	470.4	511.4	119.4	4597.1	4465.4	4485.7	26.3	511.4
GrRGW	481.0	522.9	122.1	4700.2	4565.5	4586.3	26.8	522.9
OPBRGW	467.8	508.6	118.7	4572.4	4441.3	4461.6	26.0	508.6
SPBRGW	328.6	351.8	138.9	3497.6	3396.1	3419.5	67.2	351.8

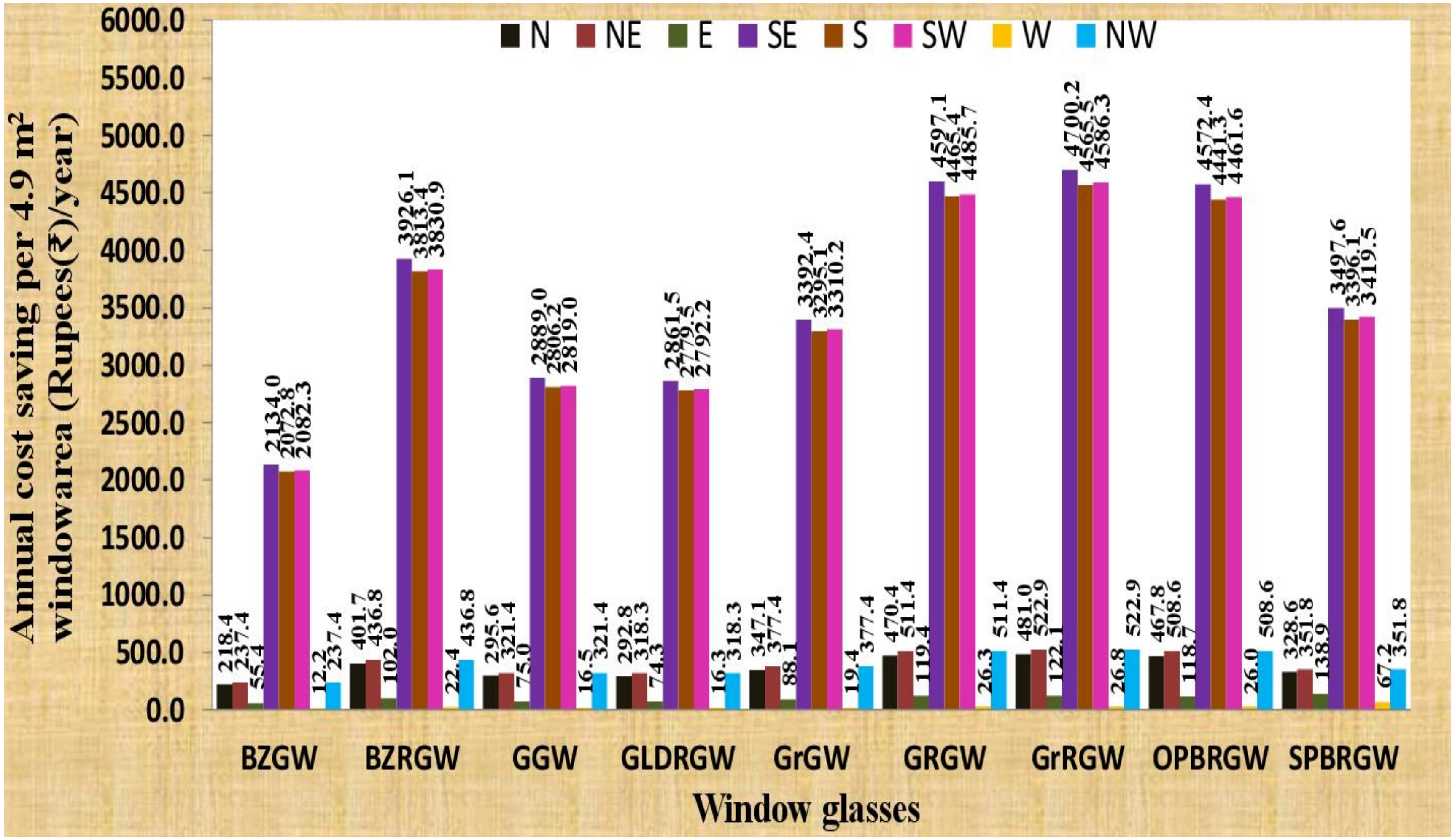


Figure 5.2.7 Annual cost saving of buildings in the climatic region of Jodhpur using various types of window glasses

5.2.3 Thermal and cost analysis of buildings using glass windows during summer and winter seasons in the climatic condition of Kolkata

The warm and humid climatic conditions of Kolkata (22.65^0 N, 88.45^{0}E), during summer and winter seasons were analyzed for thermal and cost analysis using different glass windows. Figures 5.2.8, 5.2.9 and Tables 5.2.5, 5.2.6 show the total solar heat gain in a building through nine types of glass windows on peak summer and winter days.

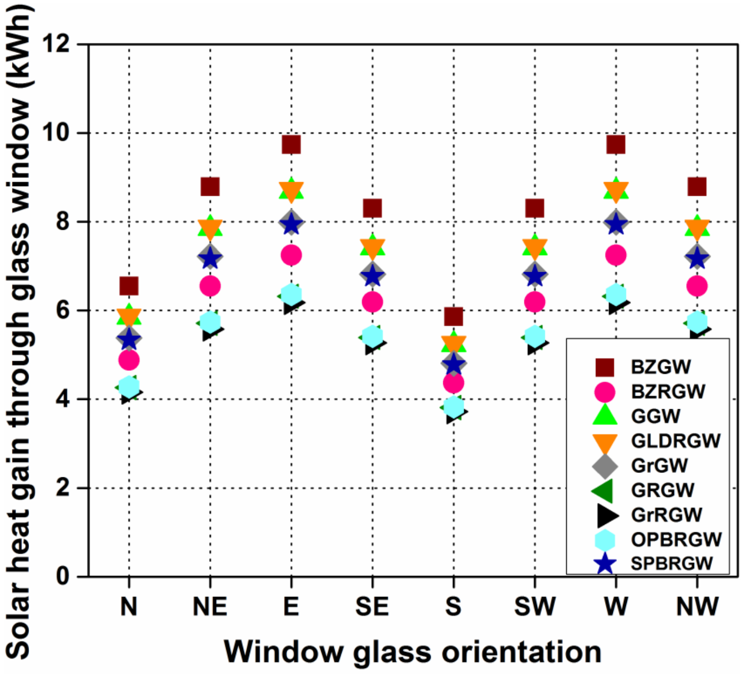


Figure 5.2.8 Total solar heat gain in buildings through glass windows at peak summer day for Kolkata region

From Figure 5.2.8, it is observed that grey reflective glass window allows minimum heat of 2.93 kWh, and from Figure 5.2.9, it is observed that bronze glass window allows maximum heat of 17.39 kWh in buildings, during summer and winter respectively, from south orientation when compared with other orientations.

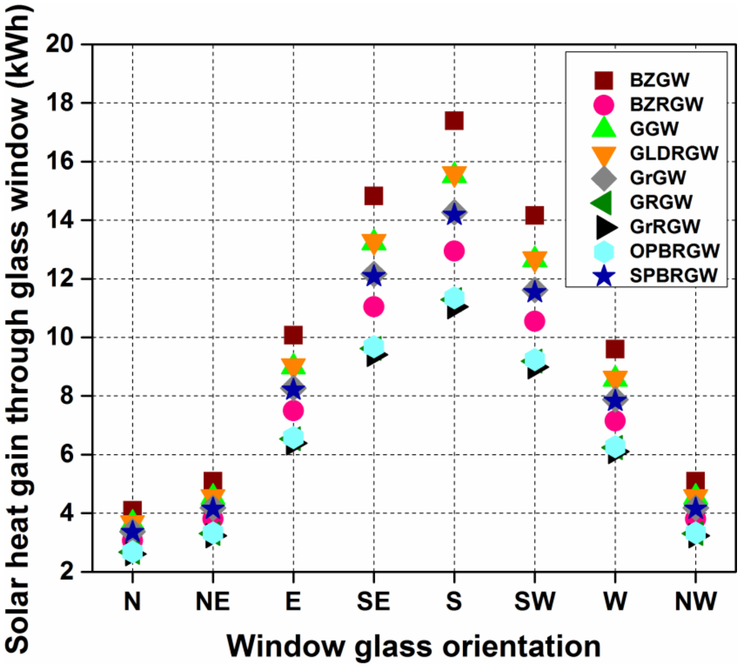


Figure 5.2.9 Total solar heat gain in buildings through glass windows at peak winter day for Kolkata region

Table 5.2.5 Total solar heat gain in buildings through glass windows in the climatic region of Kolkata at peak summer day

	Heat gain in buildings through glass windows at peak summer day							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	5.33	6.03	6.26	5.54	4.62	5.54	6.26	6.03
BZRGW	3.97	4.49	4.66	4.12	3.44	4.12	4.66	4.49
GGW	4.75	5.39	5.59	4.94	4.13	4.94	5.59	5.39
GLDRGW	4.77	5.41	5.61	4.96	4.14	4.96	5.61	5.41
GrGW	4.37	4.95	5.14	4.54	3.79	4.54	5.14	4.95
GRGW	3.46	3.92	4.07	3.59	3.00	3.59	4.07	3.92
GrRGW	3.38	3.83	3.97	3.51	2.93	3.51	3.97	3.83
OPBRGW	3.48	3.94	4.09	3.61	3.02	3.61	4.09	3.94
SPBRGW	4.34	4.92	5.10	4.51	3.77	4.51	5.10	4.92

Table 5.2.6 Total solar heat gain in buildings through glass windows in the climatic region of Kolkata at peak winter day

	Heat gain in buildings through glass windows at peak winter day							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	4.10	5.09	10.07	14.82	17.39	14.16	9.60	5.09
BZRGW	3.06	3.80	7.50	11.04	12.95	10.55	7.15	3.80
GGW	3.66	4.55	8.99	13.23	15.52	12.64	8.57	4.55
GLDRGW	3.68	4.57	9.03	13.28	15.59	12.69	8.61	4.57
GrGW	3.37	4.18	8.27	12.16	14.27	11.62	7.88	4.18
GRGW	2.67	3.31	6.54	9.62	11.29	9.19	6.24	3.31
GrRGW	2.61	3.23	6.39	9.41	11.04	8.99	6.10	3.23
OPBRGW	2.68	3.33	6.58	9.68	11.35	9.24	6.27	3.33
SPBRGW	3.35	4.15	8.21	12.08	14.18	11.54	7.83	4.15

5.2.4 Annual cooling load decrease and heating load increase in buildings using various types of glass windows in comparison with clear glass window in the climatic region of Kolkata

Figures 5.2.10, 5.2.11 indicate the annual cooling load decrease and heating load increase in buildings using nine different types of glass windows compared with clear glass window for Kolkata climatic region in all orientations. From Figure 5.2.5, it is clearly seen that all glass windows are reducing more cooling load in south orientation at summer season.

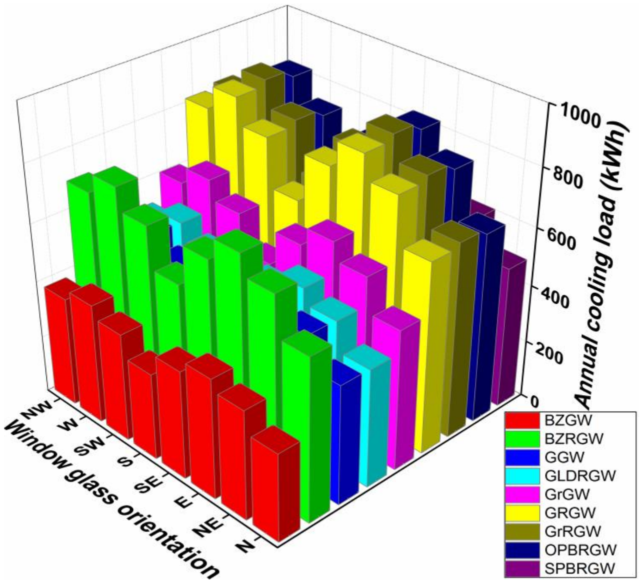


Figure 5.2.10 Annual cooling load decrease in buildings using various glass windows in comparison with clear glass window in summer season

Grey reflective glass window is observed to reduce more cooling load i.e. 664.69 kWh in south orientation in summer season. From the Figure 5.2.6, it can be clearly seen that all glass windows increase more heating load in south orientation in winter season. The bronze glass window is observed to increase more heating load inside the building i.e. 918.15 kWh.

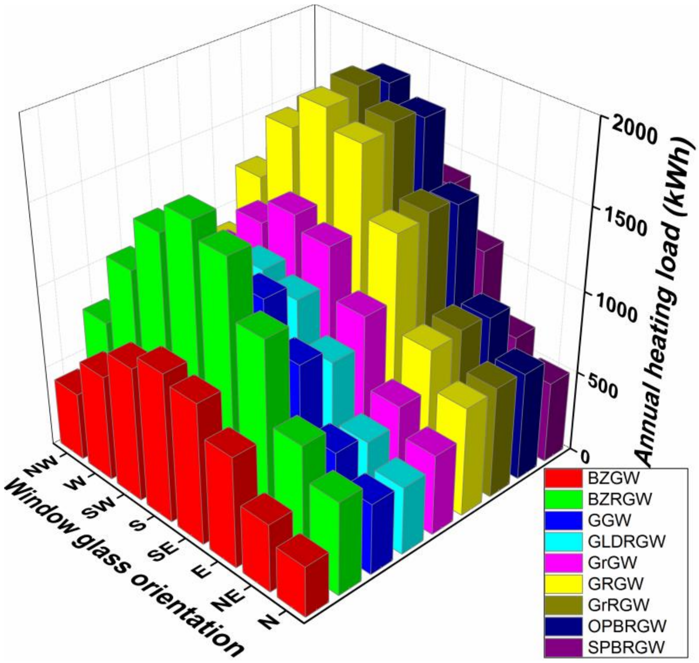


Figure 5.2.11 Annual heating load increase in buildings using various glass windows in comparison with clear glass window in winter season

Figure 5.2.12 and Table 5.2.7 are shows the net annual cost saving of buildings, using nine different types of glass windows compared with clear glass window, in the climatic region of Kolkata. From Figure 5.2.12, it is observed that grey reflective glass window (GrRGW) saves the highest net cost among the nine tested glasses. Moreover, the best orientations for placing window glasses are south-east, south-west and south orientations, respectively.

Table 5.2.7 Net annual cost saving of buildings using various glass windows compared with clear glass window for Kolkata climatic region [Rupees]

	Annual cost saving of glasses of Kolkata region							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	215.9	222.8	78.0	2078.8	1988.1	2017.6	34.7	222.8
BZRGW	397.2	409.8	143.6	3824.4	3657.4	3711.7	63.9	409.8
GGW	292.3	301.5	105.6	2814.3	2691.4	2731.4	47.0	301.5
GLDRGW	289.5	298.7	104.7	2787.5	2665.7	2705.4	46.6	298.7
GrGW	343.1	354.1	124.0	3304.6	3160.4	3207.3	55.2	354.1
GRGW	465.1	479.9	168.0	4478.1	4282.6	4346.2	74.8	479.9
GrRGW	475.5	490.6	171.8	4578.6	4378.7	4443.8	76.5	490.6
OPBRGW	462.5	477.3	167.1	4454.0	4259.6	4322.8	74.4	477.3
SPBRGW	347.2	358.2	125.5	3343.4	3197.5	3245.0	55.8	358.2

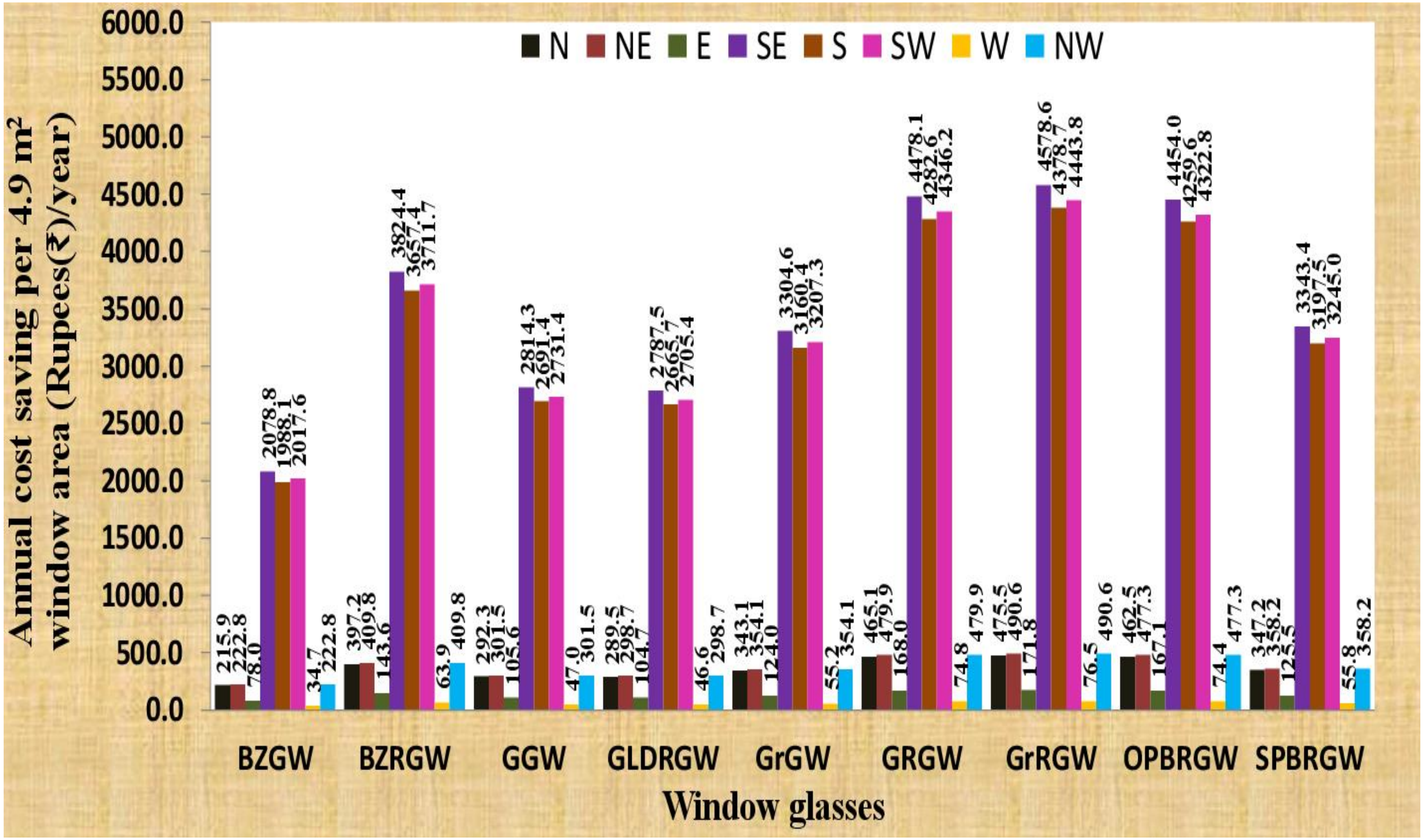


Figure 5.2.12 Annual net cost saving of buildings using various types of glass windows in the climatic region of Kolkata

5.2.5 Thermal and cost analysis of buildings using various types of glass windows in the climatic region of New Delhi during summer and winter seasons

The third region selected for thermal and cost analysis of glass windows was New Delhi. The climatic conditions during both summer and winter seasons were tested for solar heat gain. Figures 5.2.13, 5.2.14 and Tables 5.2.8, Table 5.2.9 show the total solar heat gain in buildings through glass windows on peak summer and winter days. From Figure 5.2.13, it is observed that grey reflective glass window allows minimum heat of 3.14 kWh, and from Figure 5.2.14, it is observed that bronze glass window allows maximum heat of 18.15 kWh in buildings, during summer and winter respectively, from south orientation when compared with other orientations.

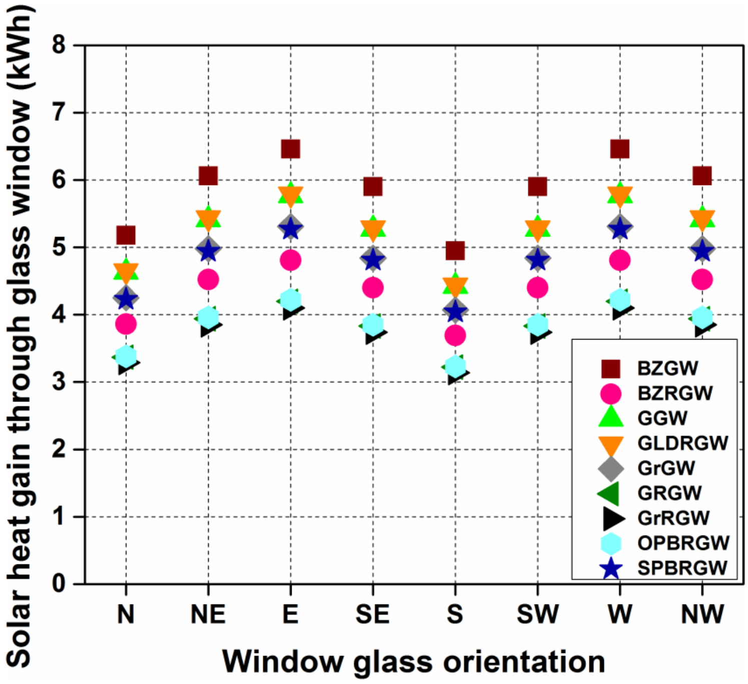


Figure 5.2.13 Total solar heat gain in buildings through glass windows at peak summer day for New Delhi region

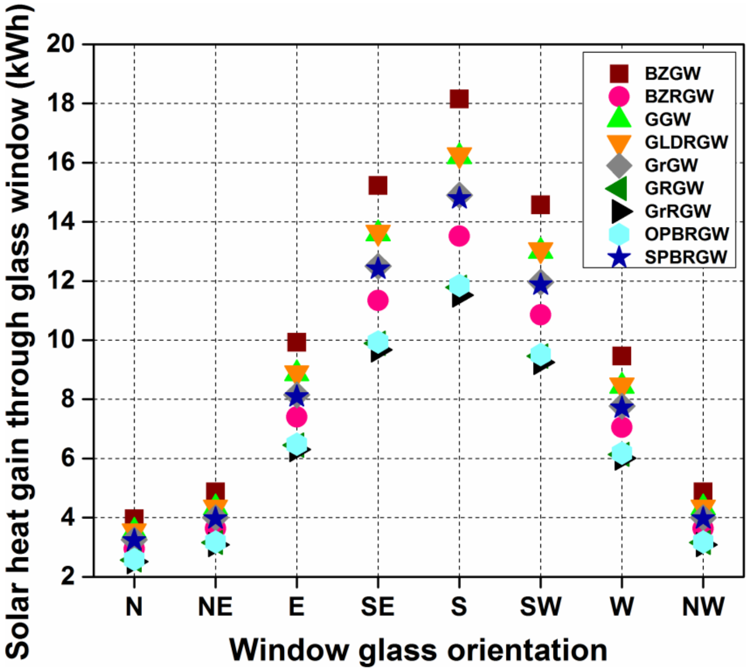


Figure 5.2.14 Total solar heat gain in buildings through glass windows at peak winter day for New Delhi region

Table 5.2.8 Total solar heat gain in buildings through glass windows in the climatic region of New Delhi at peak summer day

	Heat gain in buildings through glass windows at peak summer day							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	5.18	6.06	6.46	5.90	4.95	5.90	6.46	6.06
BZRGW	3.86	4.52	4.81	4.40	3.69	4.40	4.81	4.52
GGW	4.63	5.41	5.77	5.27	4.42	5.27	5.77	5.41
GLDRGW	4.65	5.44	5.79	5.29	4.44	5.29	5.79	5.44
GrGW	4.25	4.98	5.31	4.84	4.07	4.84	5.31	4.98
GRGW	3.37	3.94	4.20	3.83	3.22	3.83	4.20	3.94
GrRGW	3.29	3.85	4.10	3.74	3.14	3.74	4.10	3.85
OPBRGW	3.38	3.96	4.22	3.85	3.23	3.85	4.22	3.96
SPBRGW	4.23	4.94	5.27	4.81	4.04	4.81	5.27	4.94

Table 5.2.9 Total solar heat gain in buildings through glass windows in the climatic region of New Delhi at peak winter day

	Heat gain in buildings through glass windows at peak winter day							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	3.96	4.87	9.93	15.23	18.15	14.57	9.46	4.87
BZRGW	2.95	3.63	7.40	11.34	13.52	10.85	7.05	3.63
GGW	3.54	4.34	8.86	13.59	16.20	13.00	8.44	4.34
GLDRGW	3.55	4.36	8.90	13.65	16.27	13.06	8.48	4.36
GrGW	3.25	4.00	8.15	12.50	14.90	11.96	7.77	4.00
GRGW	2.57	3.16	6.45	9.89	11.78	9.46	6.14	3.16
GrRGW	2.51	3.09	6.30	9.67	11.52	9.25	6.01	3.09
OPBRGW	2.59	3.18	6.48	9.94	11.85	9.51	6.18	3.18
SPBRGW	3.23	3.97	8.09	12.41	14.79	11.87	7.71	3.97

5.2.6 Annual cooling load decrease and heating load increase in buildings using various glass windows compared with clear glass window in the climatic region of New Delhi

Figures 5.2.15, 5.2.16 indicates that the annual cooling load decreases and heating load increases in buildings using various types of glass windows in comparison with clear glass window for New Delhi climatic region in eight orientations. From Figure 5.2.15, it is clearly seen that all glass windows are reducing more cooling load in south orientation. Grey reflective glass window is observed to reduce more cooling load i.e. 669.46 kWh in south orientation in summer season. From the Figure 5.2.16, it can be clearly seen that all glass windows increase more heating load in south orientation in winter season. The bronze glass window is observed to increase more heating load inside the building i.e. 975.59 kWh.

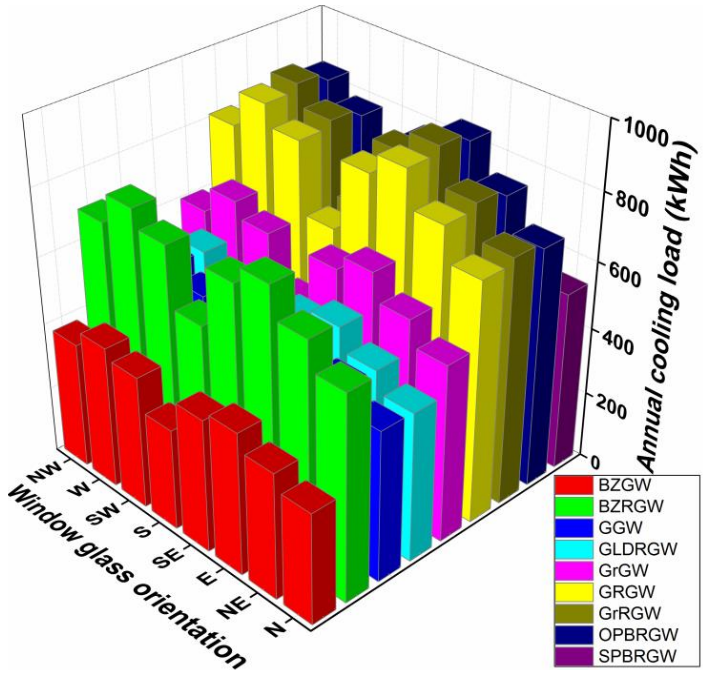


Figure 5.2.15 Annual cooling load decrease in buildings using various glass windows in comparison with clear glass window in summer season

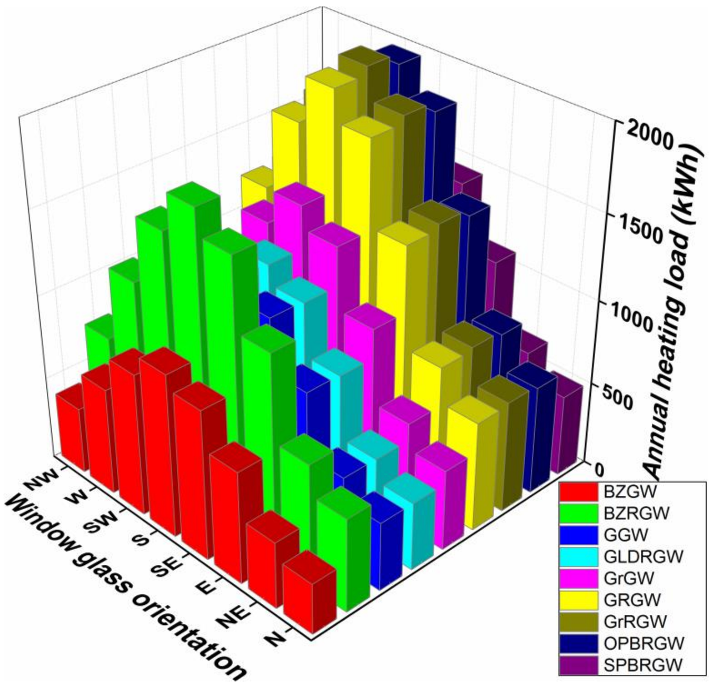


Figure 5.2.16 Annual heating load increase in buildings using various glass windows in comparison with clear glass window in winter season

Figure 5.2.17 and Table 5.2.10 are showing the net annual cost saving in rupees/year, of nine different types of glass windows compared with clear glass window, in the climatic region of New Delhi. From Figure 5.2.15, it is observed that grey reflective glass window (GrRGW) saves the highest net cost saving among the nine tested glasses. Moreover, the best orientations for placing window glasses are south-east, south-west and south orientations, respectively.

Table 5.2.10 Net annual cost saving of buildings using various glass windows in New Delhi climatic region [Rupees]

	Annual cost saving of buildings for New Delhi region							
Window glass	N	NE	E	SE	S	SW	W	NW
BZGW	221.9	246.2	41.6	2166.3	2105.2	2139.9	1.7	246.2
BZRGW	408.3	453.0	76.4	3985.5	3873.0	3936.9	3.1	453.0
GGW	300.4	333.4	56.2	2932.8	2850.1	2897.1	2.2	333.4
GLDRGW	297.6	330.2	55.7	2904.9	2822.9	2869.5	2.2	330.2
GrGW	352.8	391.5	66.1	3443.8	3346.6	3401.8	2.7	391.5
GRGW	478.0	530.5	89.6	4666.8	4535.1	4609.9	3.6	530.5
GrRGW	488.8	542.4	91.6	4771.5	4636.9	4713.4	3.7	542.4
OPBRGW	475.5	527.6	89.0	4641.6	4510.6	4585.1	3.6	527.6
SPBRGW	356.9	396.0	66.8	3484.3	3385.9	3441.9	2.7	396.0

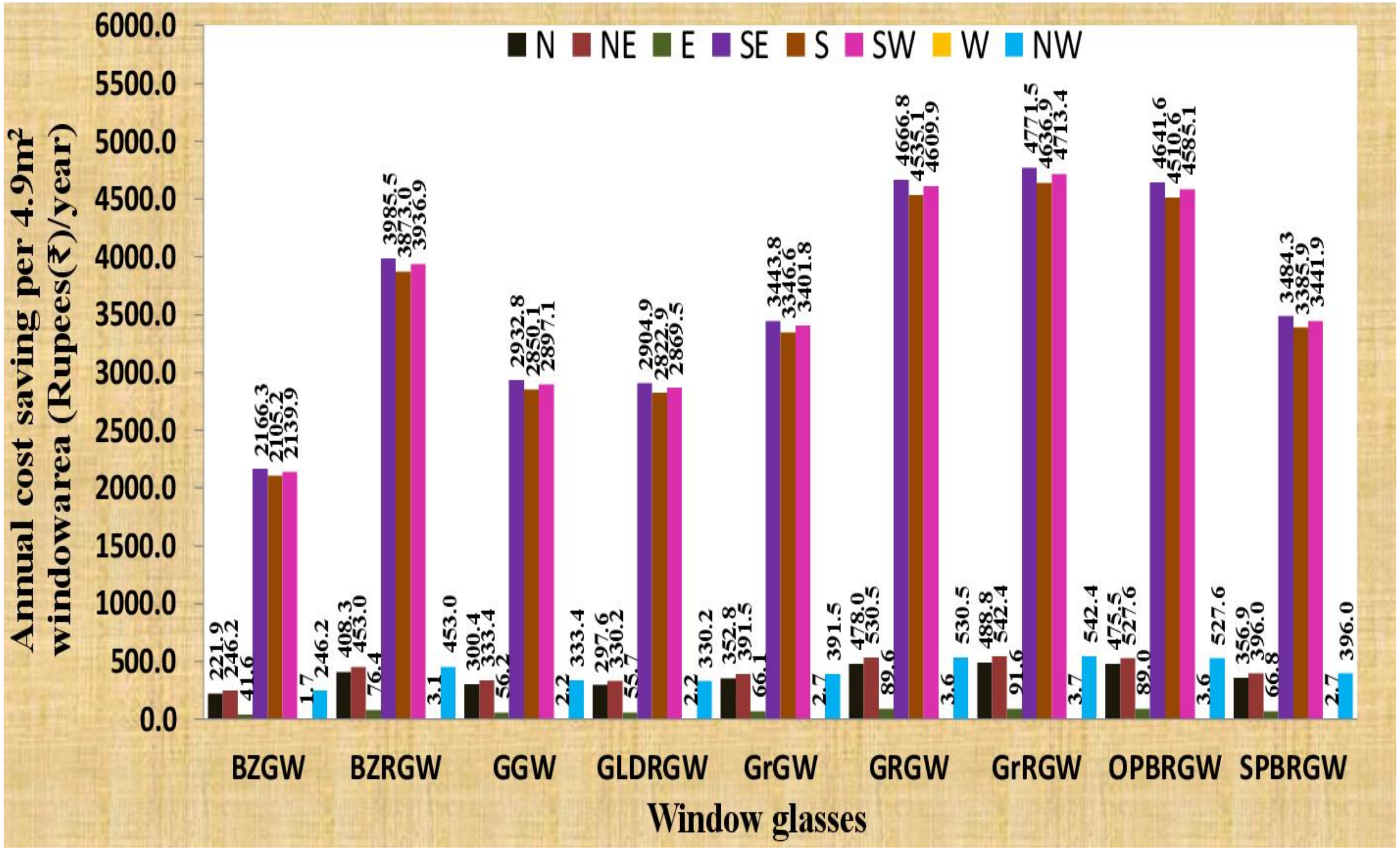


Figure 5.2.17 Annual net cost saving of buildings using window glasses in the climatic region of New Delhi

5.3 STUDY THE EFFECT OF GLASS TILT POSITION IN WINDOWS FOR HEAT GAIN IN BUILDINGS WITH SINGLE GLASS WINDOW AND OPTIMUM DIRECTION

In this study, nine glass materials were considered to find heat gain in a building of dimensions 3.5 m × 3.5 m × 3.5 m, at four window tilt positions. Various tilt positions in window were of 0^0, 2^0, 4^0 and 6^0 (Facing to the Earth) studied during summer season. And in winter, the four tilt positions were of 0^0, 2^0, 4^0 and 6^0 (Facing to the Sky) studied. The present work is to find at which tilt position of window glass, the total solar radiation through glass window is optimum in eight orientations of various Indian climatic zones in both summer and winter seasons. Table 5.3.1 shows the details of nine single glass windows studied in this work.

Table 5.3.1 Number of glass materials studied

Number of glasses	Number of climatic zones	Glass arrangement	Number of orientations	Glass tilt position from vertical direction (deg)	Number of glass combinations
9	3	Single	8	summer (0,2, 4 and 6) facing to the Earth winter (0,2, 4 and 6) facing to the Sky	9×4=36 in each climatic zone

Figure 5.3.1 shows the flow chart for solar heat gain through single glass window at four window tilt positions.

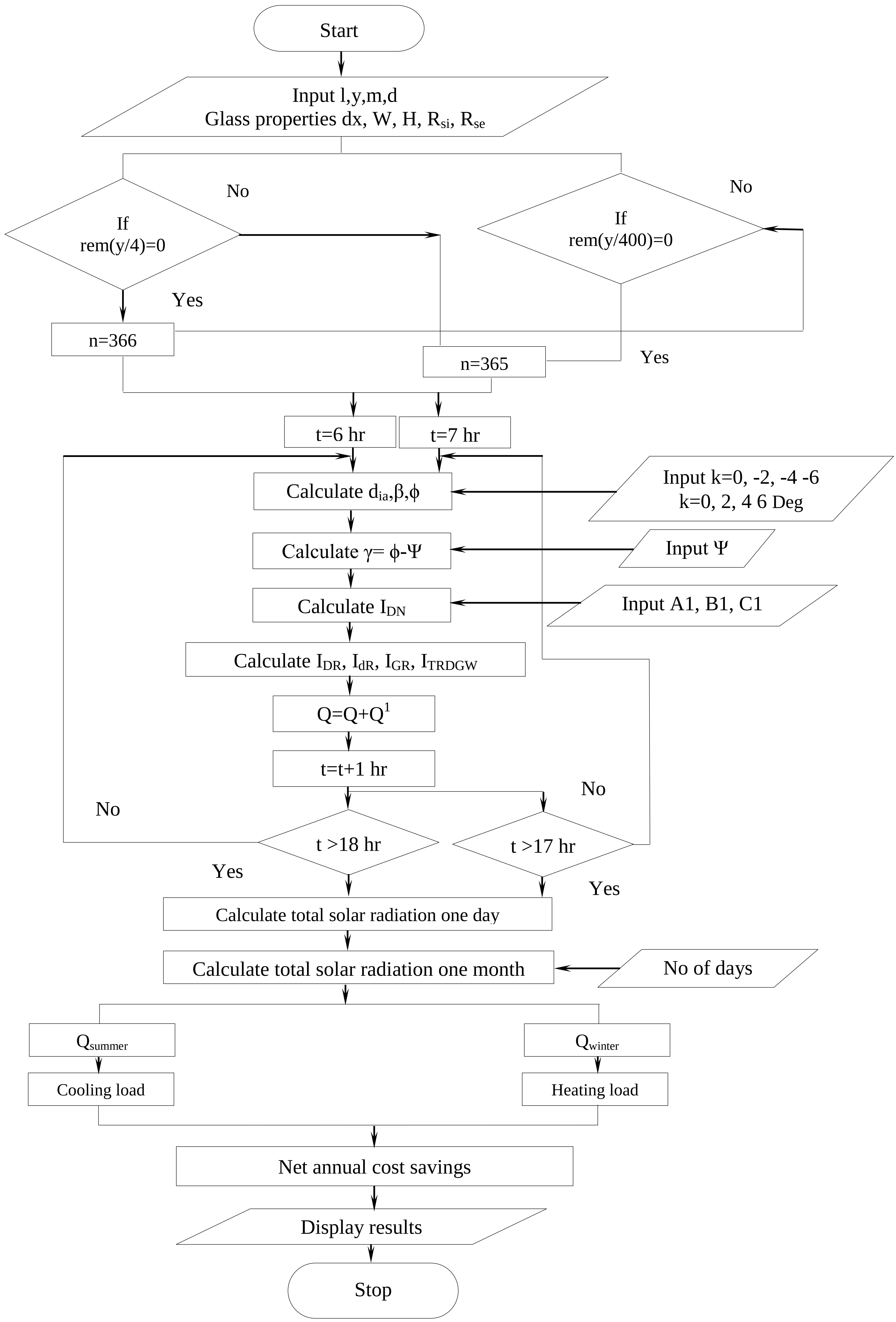


Figure 5.3.1 Flow chart for calculating total solar heat gain in buildings through single glass window at four window glass tilt positions

5.3.1 Solar heat gain in buildings through glass windows on peak summer day at four window tilt positions in the climatic region of Jodhpur

Figures 5.3.2, 5.3.3, 5.3.4 and 5.3.5 show the total solar heat gain in buildings through glass window at four window tilt positions such as 0^0, 2^0, 4^0 and 6^0 (Facing to the Earth) for Jodhpur climatic region during peak summer day. From the results heat gain in buildings decreases when, the window tilt position changes from 0^0 to -6^0 through all glass windows in south orientation when compared with other orientations.

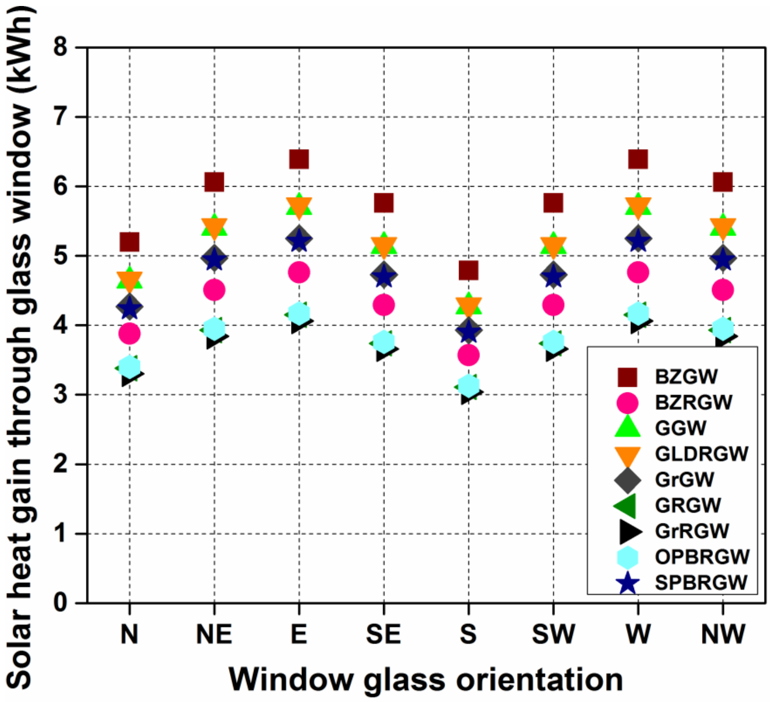


Figure 5.3.2 Total solar heat gain in buildings through glass windows at zero deg window tilt position at peak summer day for Jodhpur region

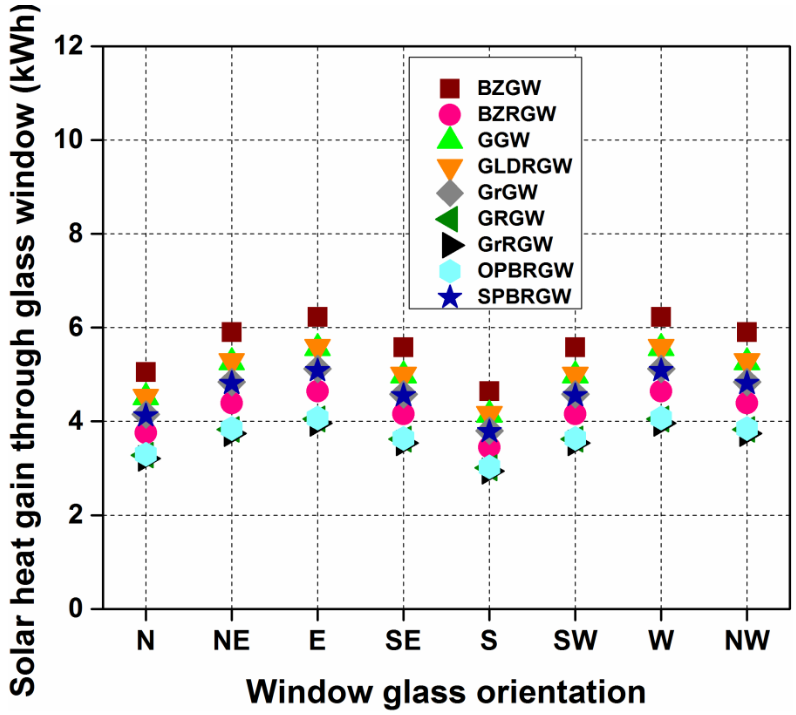


Figure 5.3.3 Total solar heat gain in buildings through glass windows at two deg window tilt position towards Earth at peak summer day for Jodhpur region

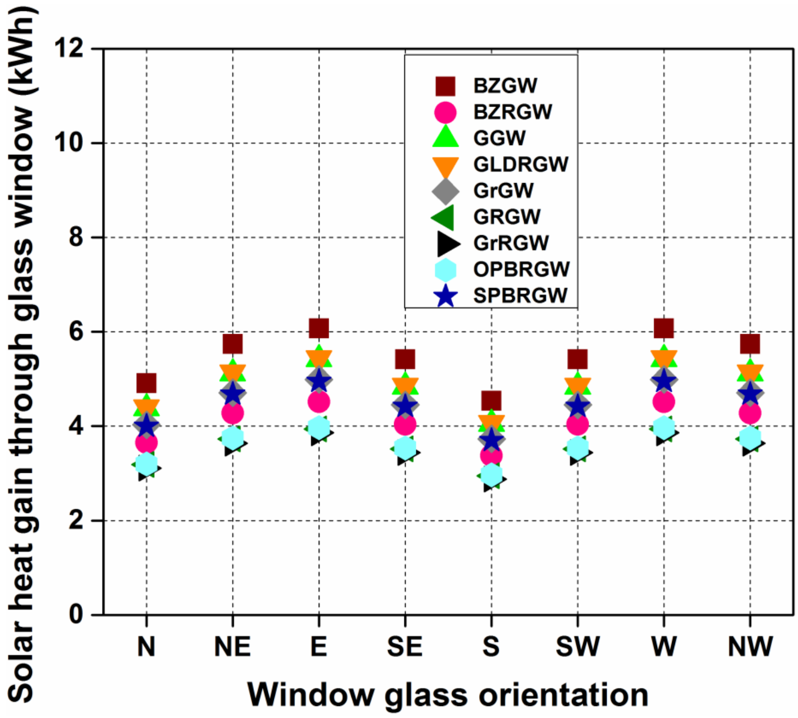


Figure 5.3.4 Total solar heat gain in buildings through glass windows at four deg window tilt position towards Earth at peak summer day for Jodhpur region

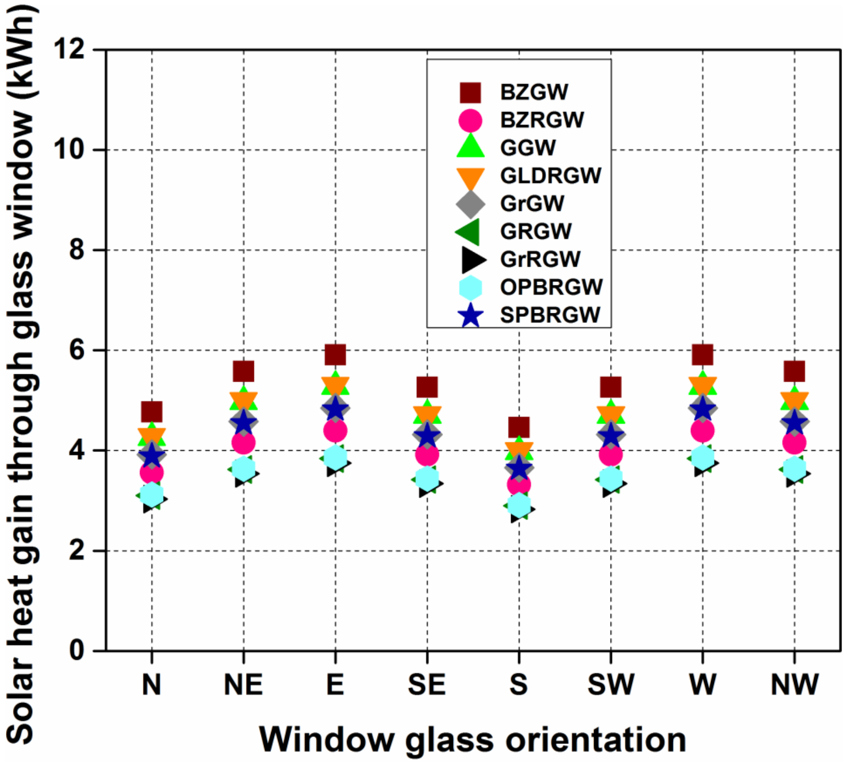


Figure 5.3.5 Total solar heat gain in buildings through glass windows at six deg window tilt position towards Earth at peak summer day for Jodhpur region

5.3.2 Solar heat gain in buildings through glass windows on peak winter day at four window tilt positions in the climatic region of Jodhpur

Figures 5.3.6, 5.3.7, 5.3.8 and 5.3.9 show the total solar heat gain in buildings through glass windows at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Sky) for Jodhpur climatic condition during peak winter day. From the results, heat gain in buildings increases when the window tilt position changes from 0^0 to 6^0 through all glass windows in south orientation when compared with other orientations.

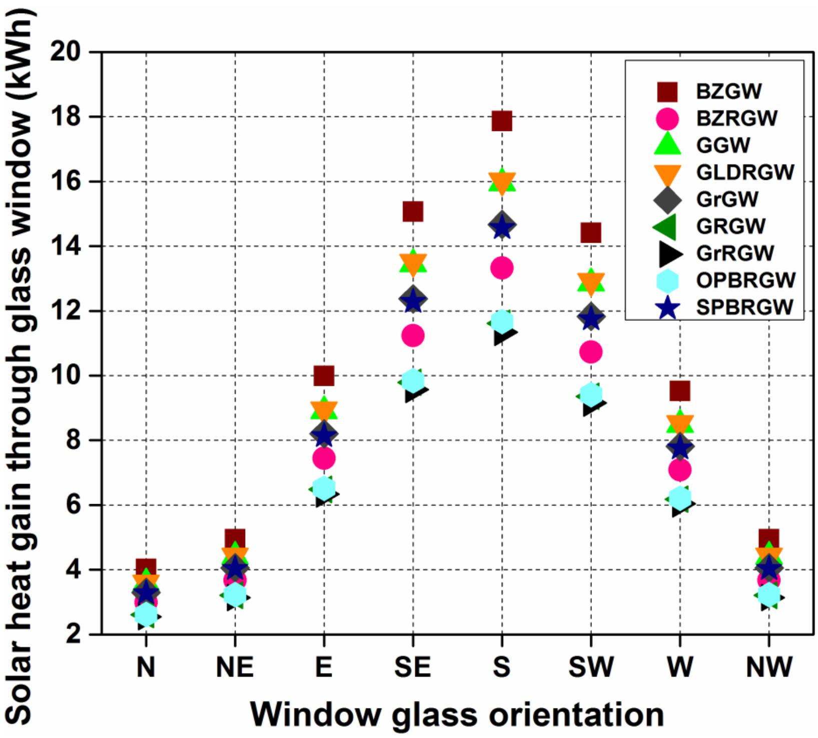


Figure 5.3.6 Total solar heat gain in buildings through glass windows at zero deg window tilt position at peak winter day for Jodhpur region

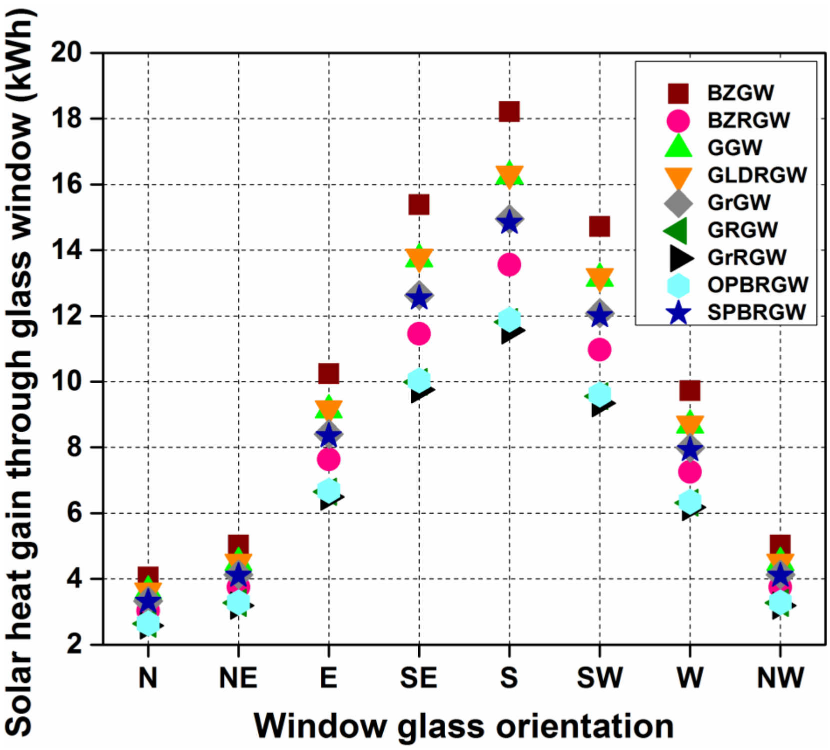


Figure 5.3.7 Total solar heat gain in buildings through glass windows at two deg window tilt position towards Sky at peak winter day for Jodhpur region

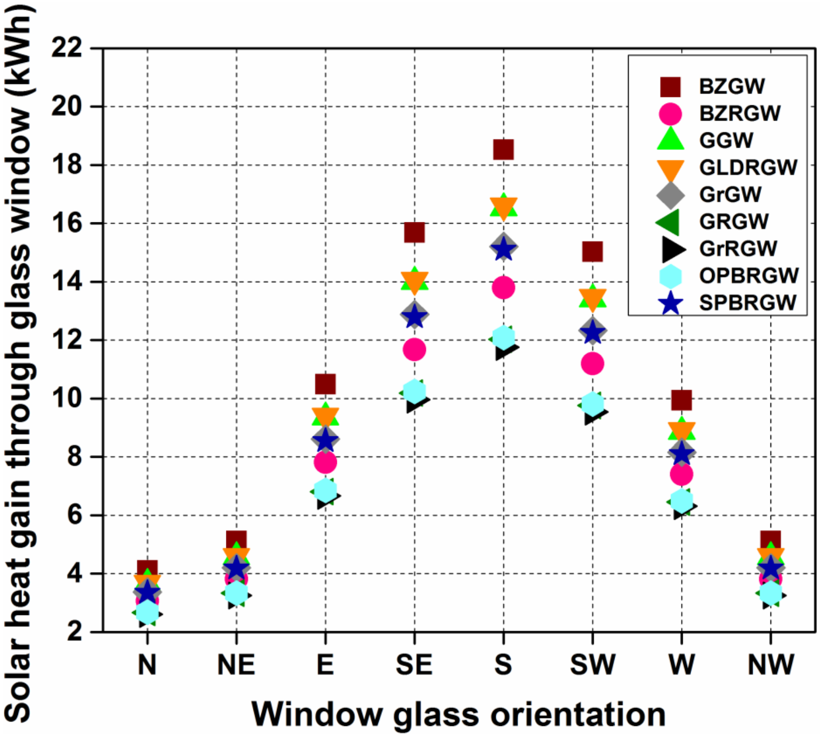


Figure 5.3.8 Total solar heat gain in buildings through glass windows at four deg window tilt position towards Sky at peak winter day for Jodhpur region

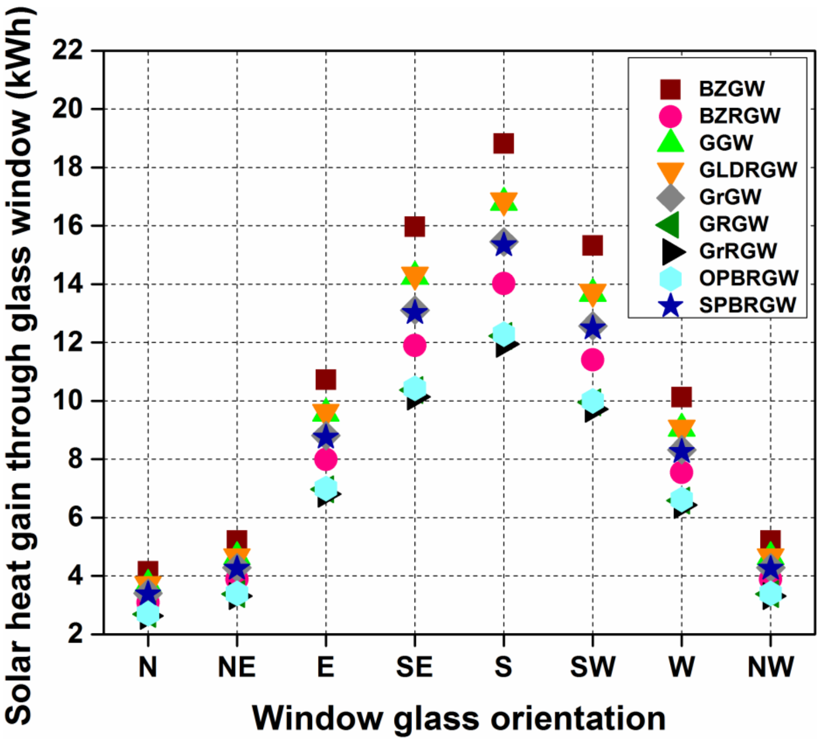


Figure 5.3.9 Total solar heat gain in buildings through glass windows at six deg window tilt position towards Sky at peak winter day for Jodhpur region

5.3.3 Annual cooling load decrease in buildings using various types of glass windows in comparison with clear glass window at four window tilt positions in the climatic region of Jodhpur

Figures 5.3.10, 5.3.11, 5.3.12 and 5.3.13 show the graph between annual cooling load decrease in buildings using different types of glass windows compared with clear glass window, at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Earth) for Jodhpur region, in eight orientations. From the Figures, it is clearly seen that, all glass windows are reducing more cooling load in south orientation at all window tilt positions. Grey reflective glass window is observed to decrease the highest cooling load 625.78 kWh at -6 Deg tilt position in the south direction.

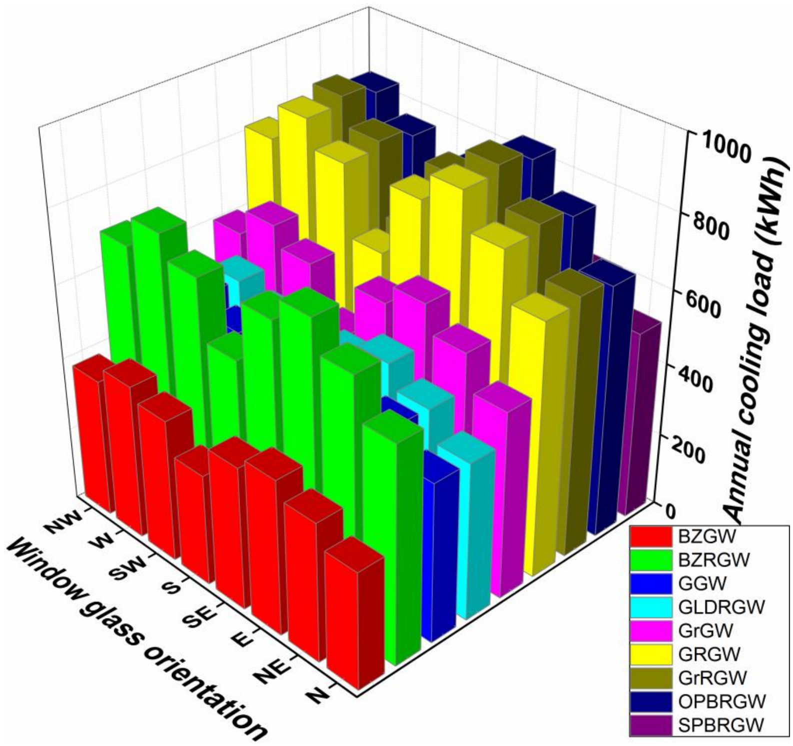


Figure 5.3.10 Annual cooling load decrease in buildings at zero deg window tilt position for Jodhpur region

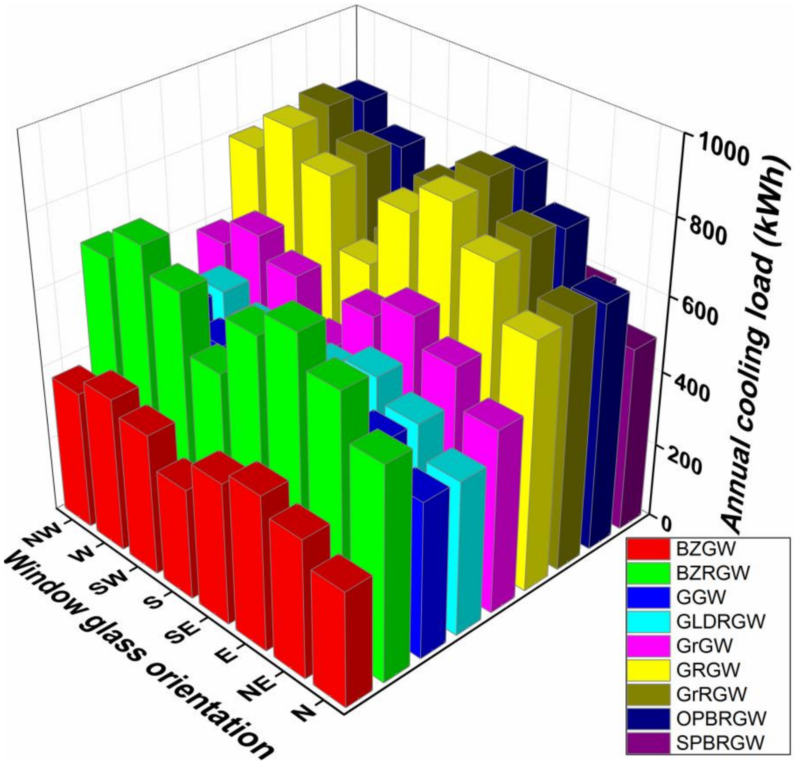


Figure 5.3.11 Annual cooling load decrease in buildings at two deg window tilt position towards Earth for Jodhpur region

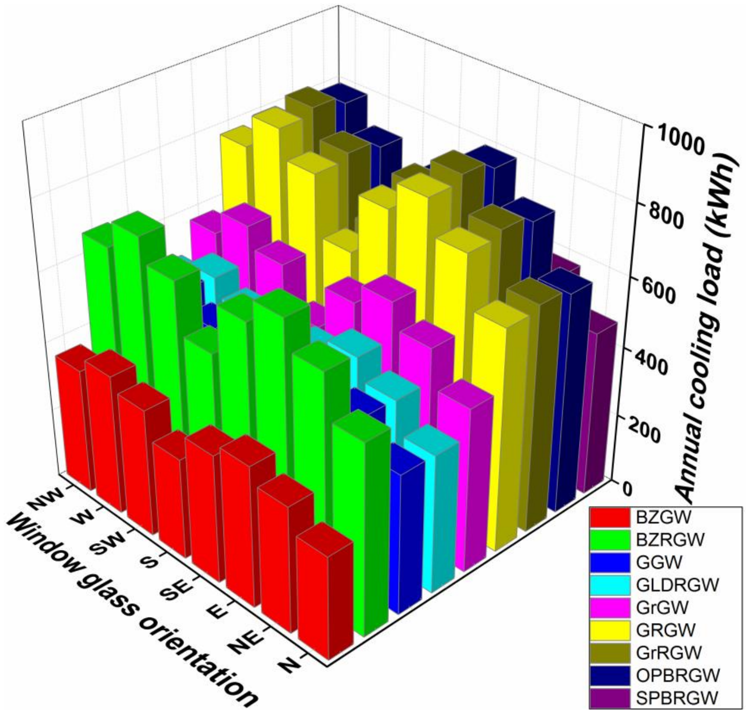


Figure 5.3.12 Annual cooling load decrease in buildings at four deg window tilt position towards Earth for Jodhpur region

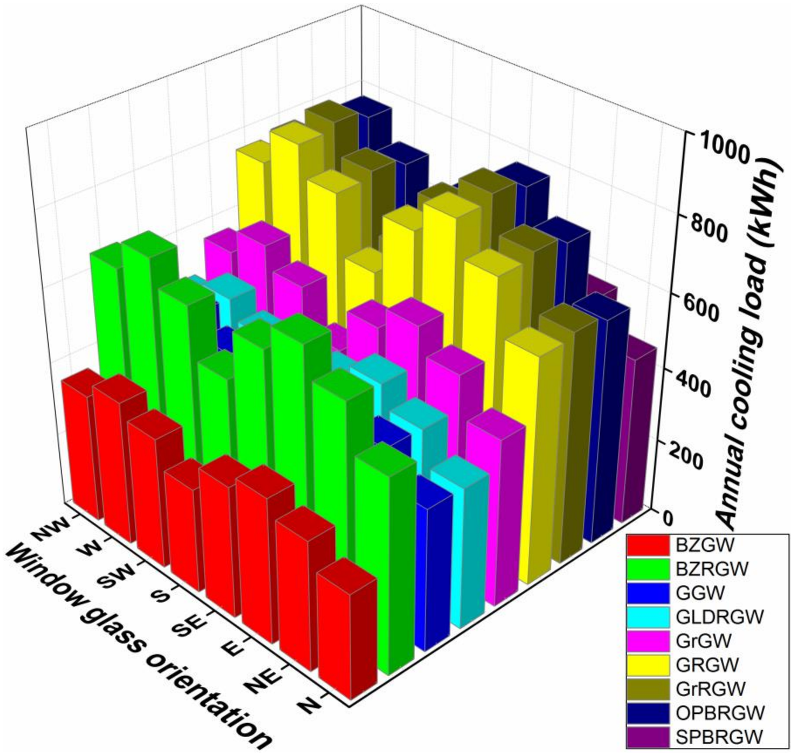


Figure 5.3.13 Annual cooling load decrease in buildings at six deg window tilt position towards Earth for Jodhpur region

5.3.4 Annual heating load decrease in buildings using various types of glass windows in comparison with clear glass window at four window tilt positions in the climatic region of Jodhpur

Figures 5.3.14, 5.3.15, 5.3.16 and 5.3.17 show the graph between annual heating load increase in buildings using different types of glass windows compared with clear glass window, at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Sky) in the climatic region of Jodhpur, in eight orientations. From Figures, it is clearly seen that, all glass windows are increasing more heating load in south orientation at all window tilt positions. The bronze glass window is observed to increase the highest heating load 1029.23 kWh at 6 Deg tilt position in the south direction.

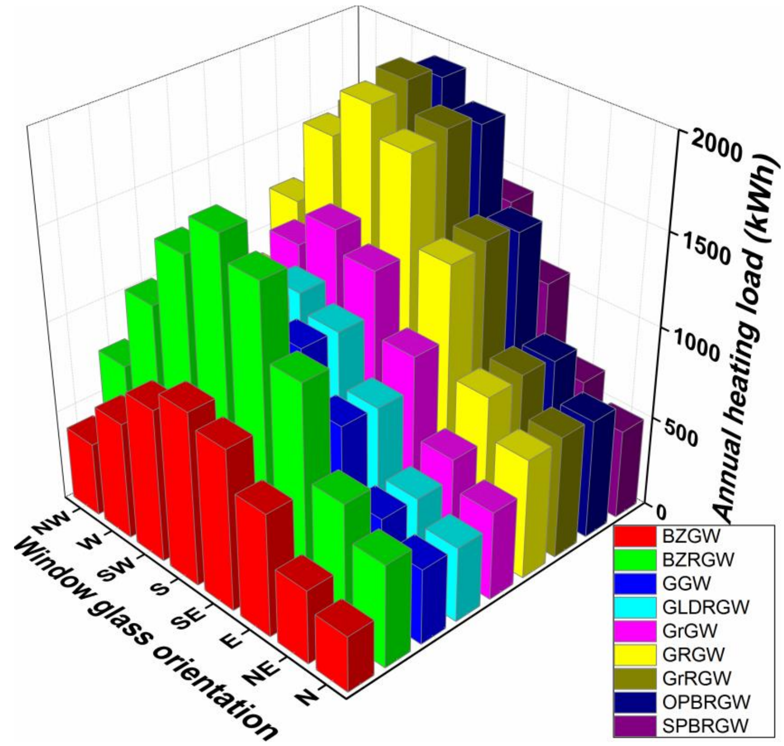


Figure 5.3.14 Annual heating load increase in buildings at zero deg window tilt position for Jodhpur region

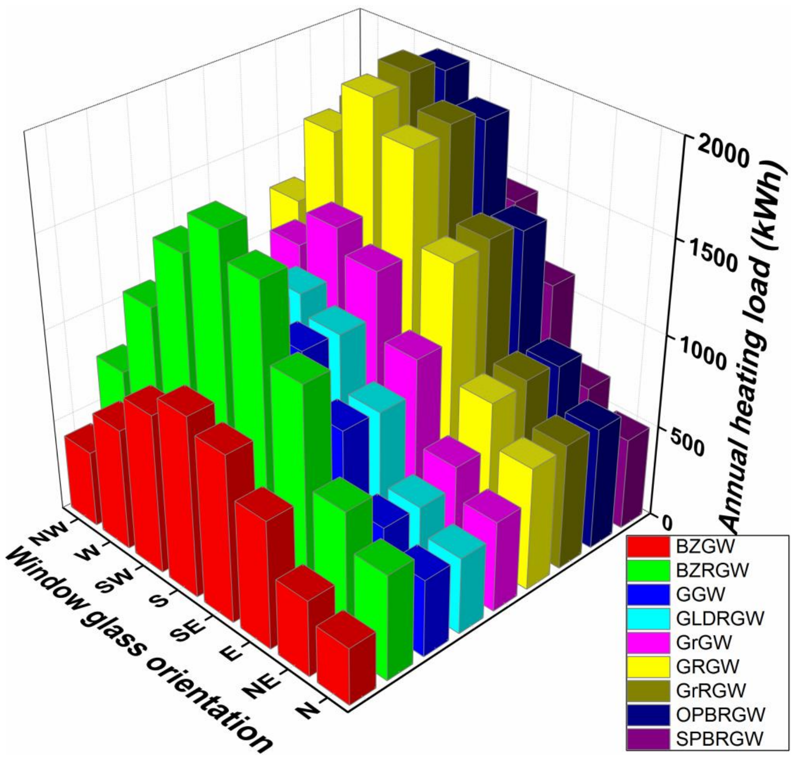


Figure 5.3.15 Annual heating load increase in buildings at two deg window tilt position towards Sky for Jodhpur region

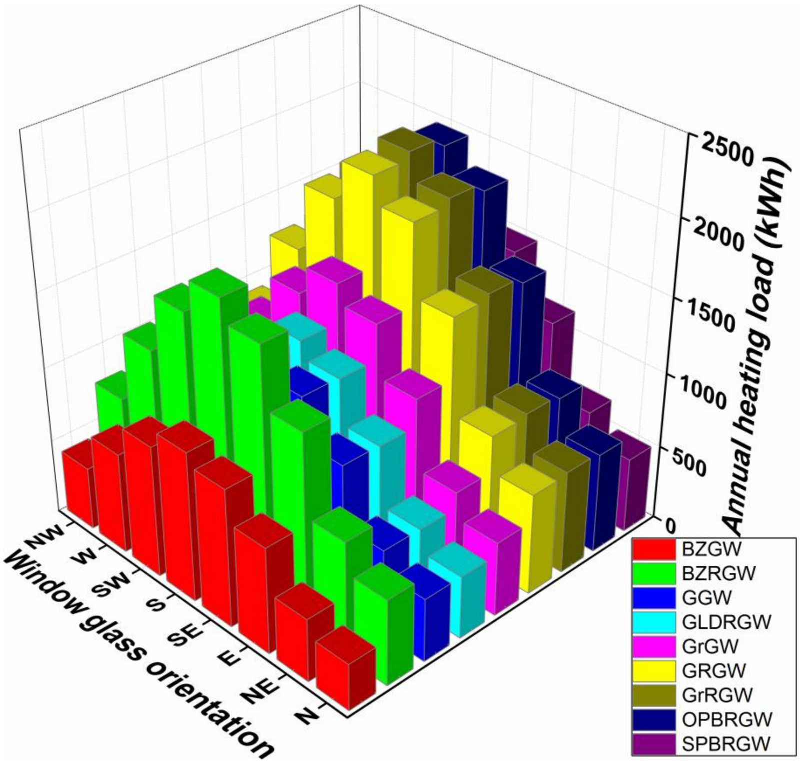


Figure 5.3.16 Annual heating load increase in buildings at four deg window tilt position towards Sky for Jodhpur region

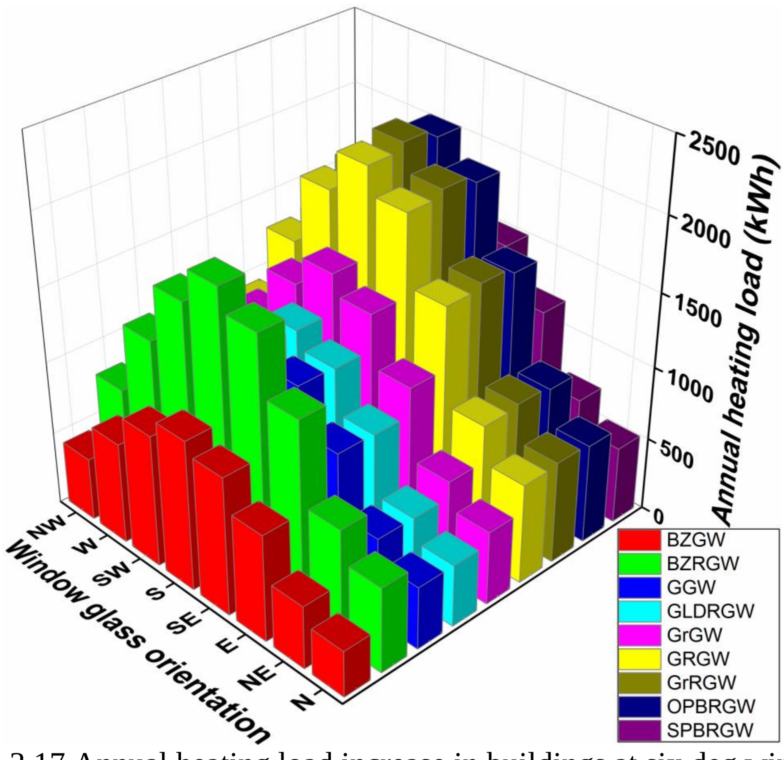


Figure 5.3.17 Annual heating load increase in buildings at six deg window tilt position towards Sky for Jodhpur region

5.3.5 Annual cost saving for buildings using various types of glass windows compared with clear glass window at 6 Deg window tilt position in the climatic region of Jodhpur

Figure 5.3.18, shows the graph between nine glass windows and annual cost saving in rupees in eight orientations of Jodhpur climatic region. From the graph it is clearly observed that grey reflective glass window is saving more cost when compared with all glass windows in south orientation and it is saving 4599.8 (Rupees/year), when compared with other glass windows for Jodhpur climatic region.

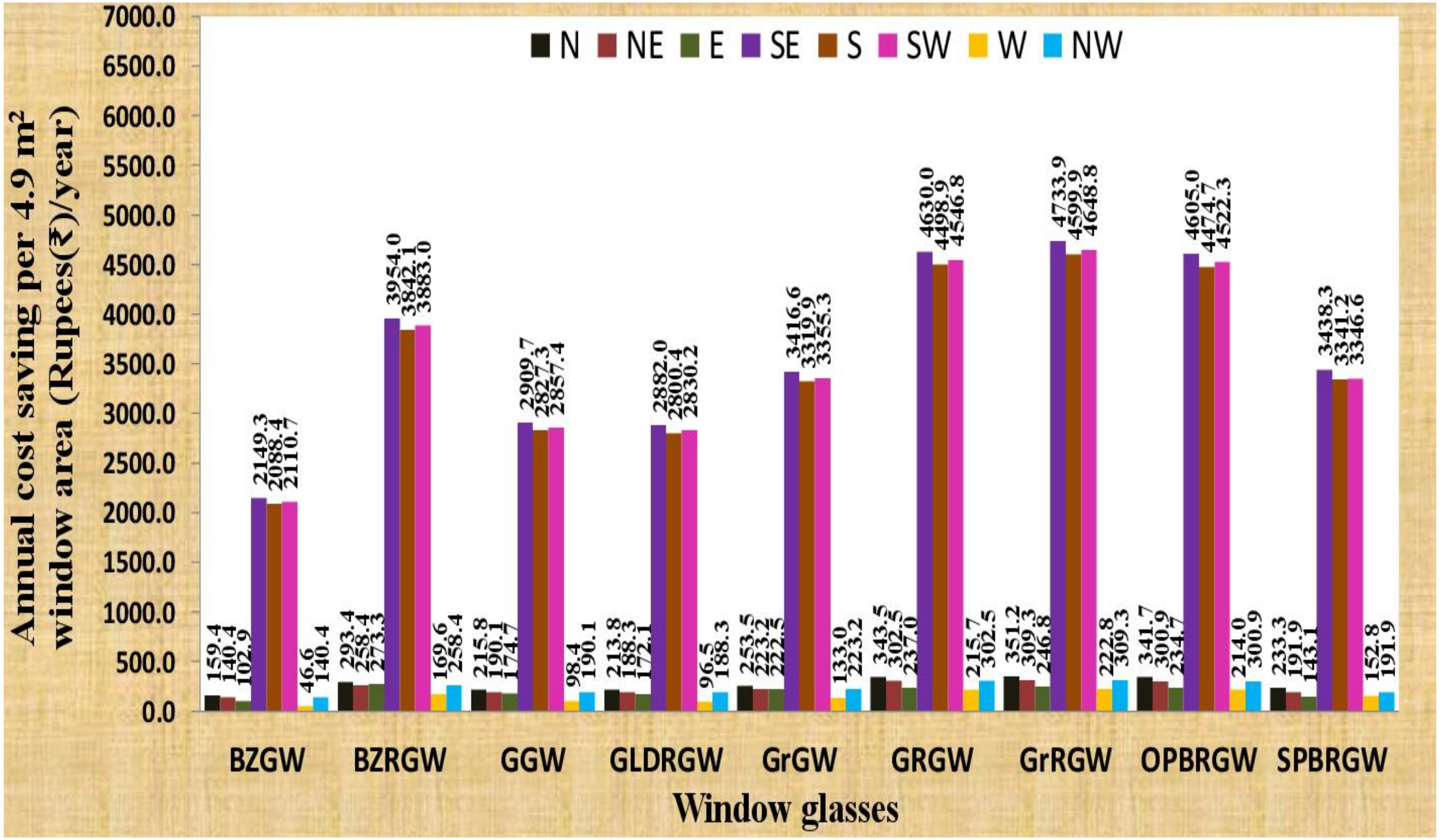


Figure 5.3.18 Annual cost saving of buildings using various glass windows at 6 Deg window tilt position in the climatic region of Jodhpur

5.3.6 Solar heat gain in buildings through glass windows on peak summer day at four window tilt positions in the climatic region of Kolkata

Figures 5.3.19, 5.3.20, 5.3.21 and 5.3.22 show the total solar heat gain in buildings through glass window at four window tilt positions from vertical at 0^0, 2^0, 4^0 and 6^0 (Facing to the Earth) for Kolkata climatic condition during peak summer day. From the results heat gain in buildings decreases when, the window tilt position changes from 0^0 to -6^0 through all glass windows in south orientation when compared with other orientations.

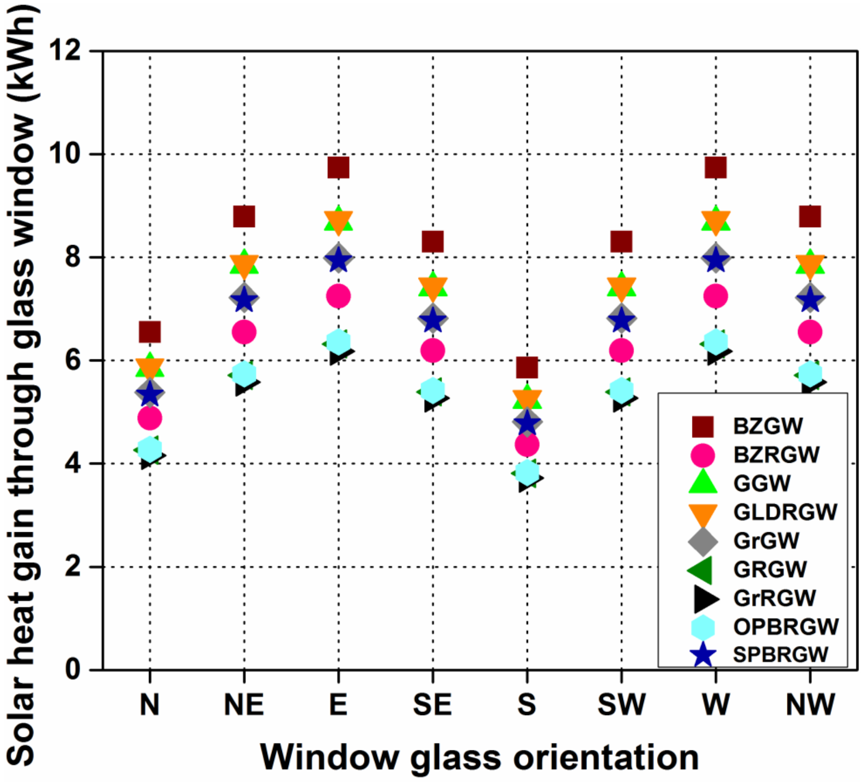


Figure 5.3.19 Total solar heat gain in buildings through glass windows at zero deg window tilt position at peak summer day for Kolkata region

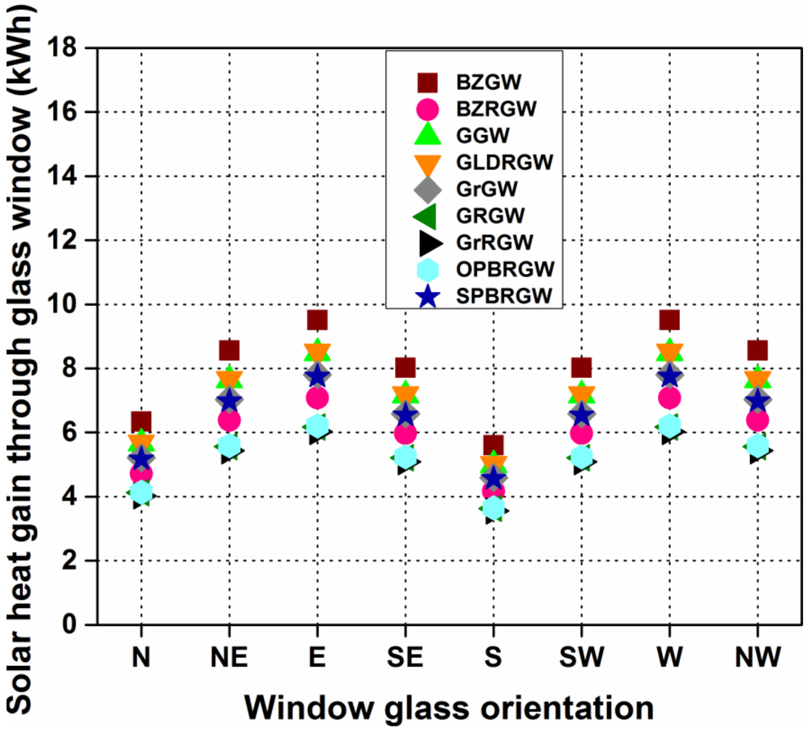


Figure 5.3.20 Total solar heat gain in buildings through glass windows at two deg window tilt position towards Earth at peak summer day for Kolkata region

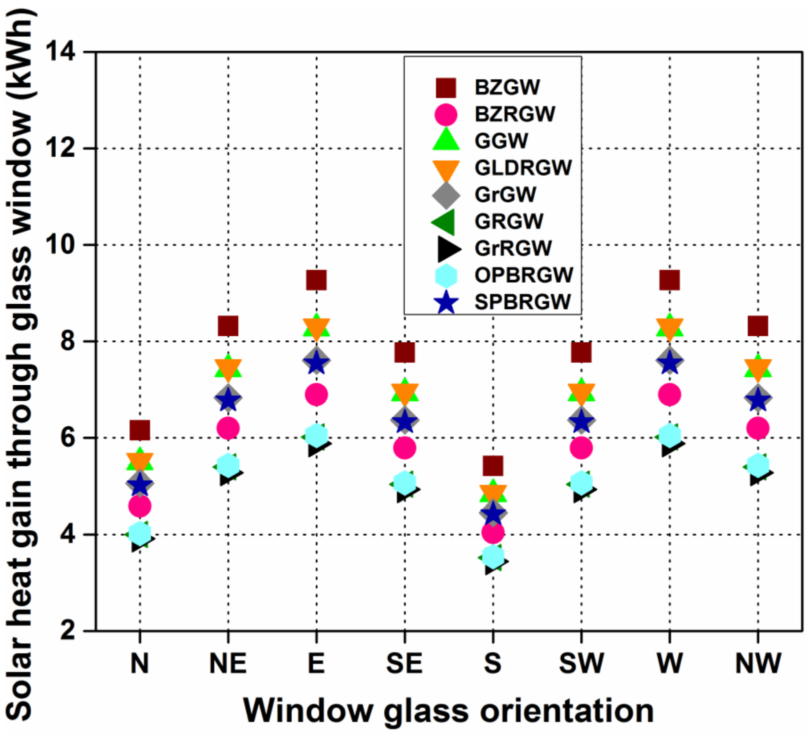


Figure 5.3.21 Total solar heat gain in buildings through glass windows at four deg window tilt position towards Earth at peak summer day for Kolkata region

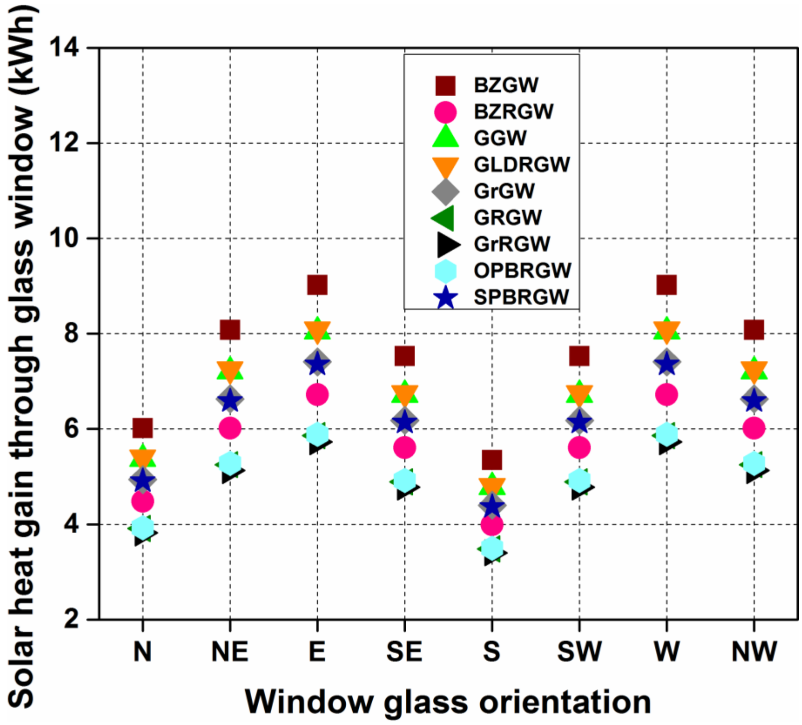


Figure 5.3.22 Total solar heat gain in buildings through glass windows at six deg window tilt position towards Earth at peak summer day for Kolkata region

5.3.7 Solar heat gain in buildings through glass windows at four window tilt positions on peak winter day in the climatic region of Kolkata

Figure 5.3.23, 5.3.24, 5.3.25 and 5.3.26 show the total solar heat gain in buildings through glass window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Sky) for Kolkata climatic condition during peak winter day. From the results heat gain in buildings decreases when, the window tilt position changes from 0^0 to -6^0 through all glass windows in south orientation when compared with other orientations.

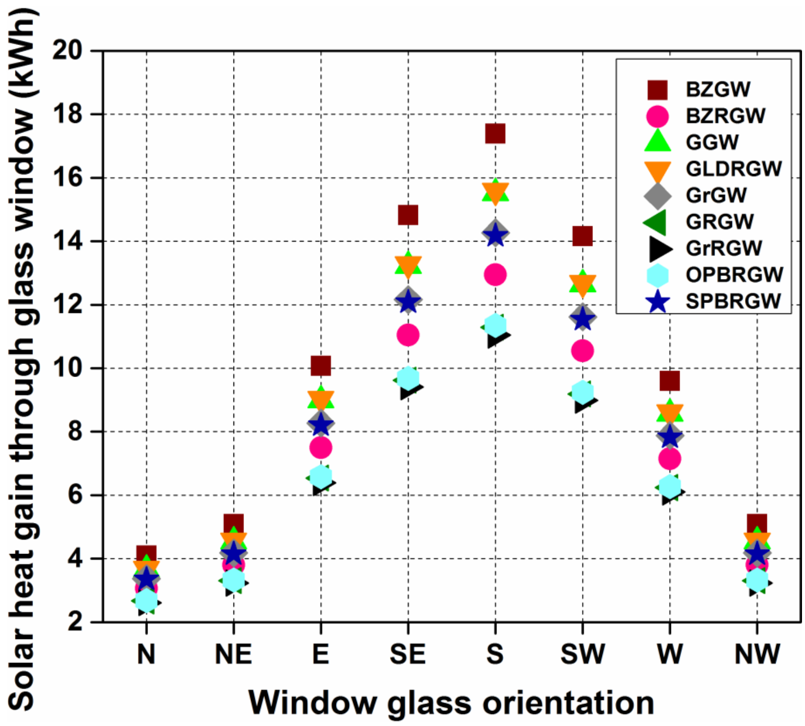


Figure 5.3.23 Total solar heat gain in buildings through glass windows at zero deg window tilt position at peak winter day for Kolkata region

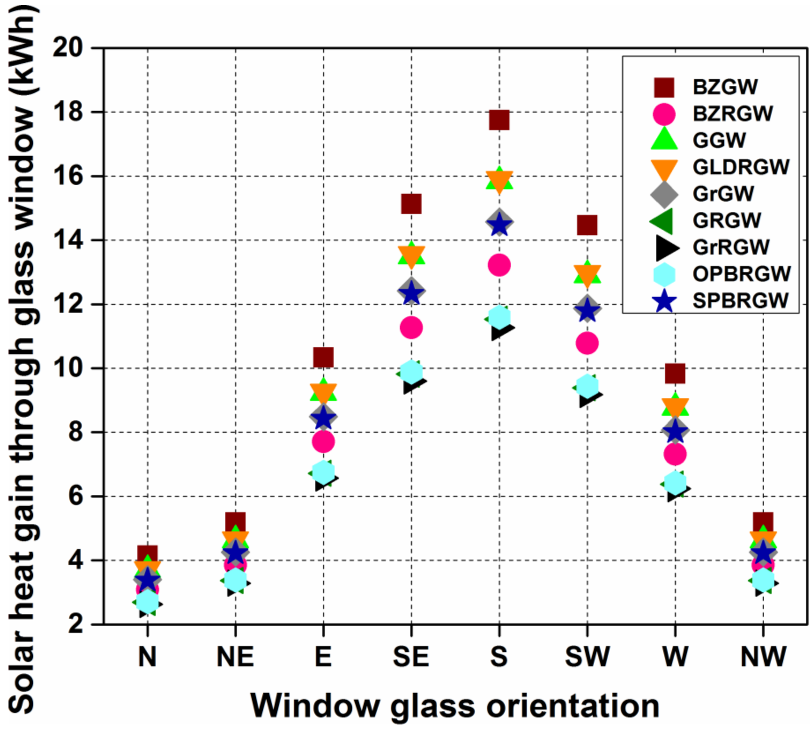


Figure 5.3.24 Total solar heat gain in buildings through glass windows at two deg window tilt position towards Sky at peak winter day for Kolkata region

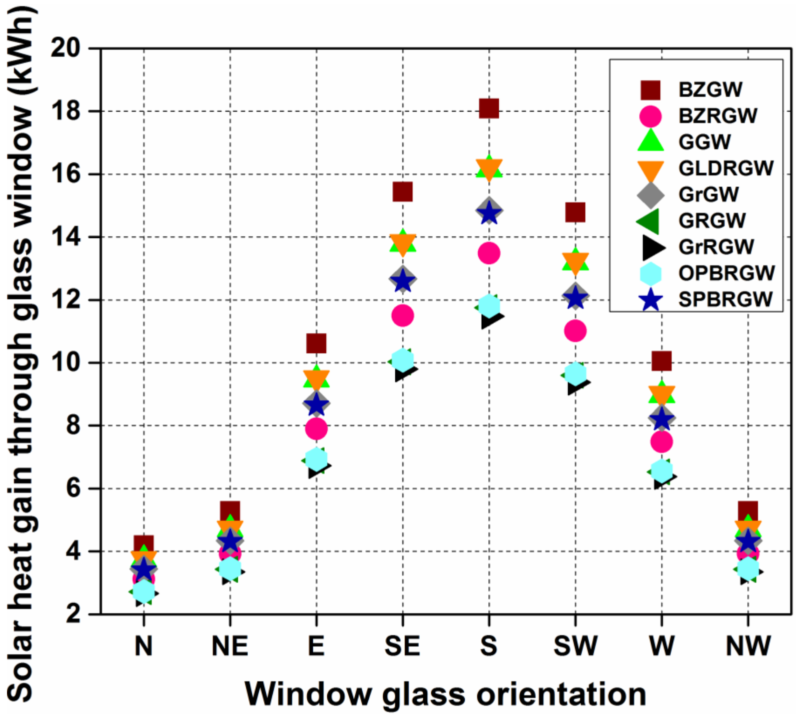


Figure 5.3.25 Total solar heat gain in buildings through glass windows at four deg window tilt position towards Sky at peak winter day for Kolkata region

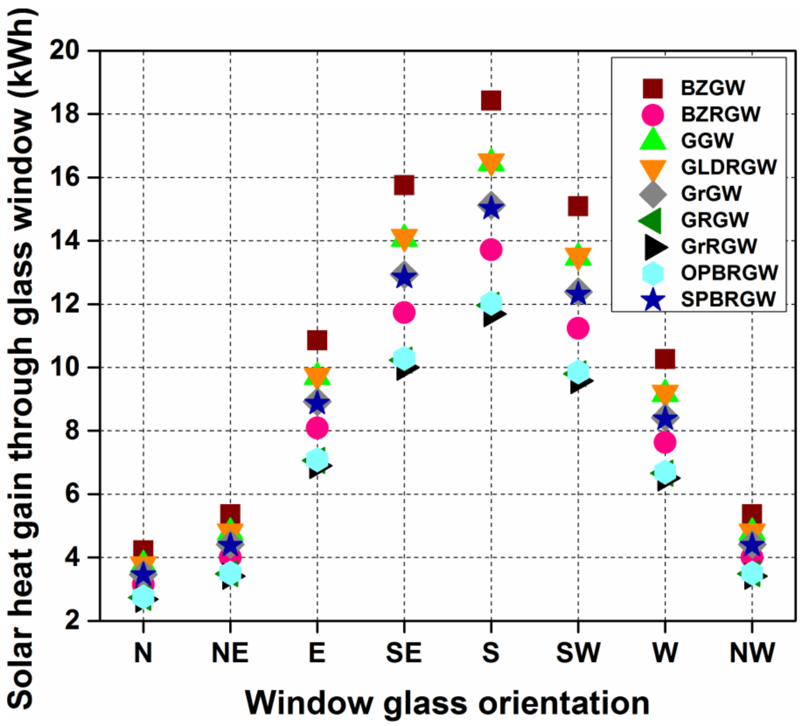


Figure 5.3.26 Total solar heat gain in buildings through glass windows at six deg window tilt position towards Sky at peak winter day for Kolkata region

5.3.8 Annual cooling load decrease in buildings using various types of glass windows in comparison with clear glass window at four window tilt positions in the climatic region of Kolkata

Figures 5.3.27, 5.3.28, 5.3.29 and 5.3.30 show the graph between annual cooling load decrease in buildings using different types of glass windows compared with clear glass window, at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Earth) in the climatic region of Kolkata, in eight orientations. From the Figures, it is clearly observed that, all glass windows are reducing more cooling load in south orientation at all window tilt positions. Grey reflective glass window is observed to reduce the highest cooling load 600.9 kWh at -6 Deg tilt position in the south direction.

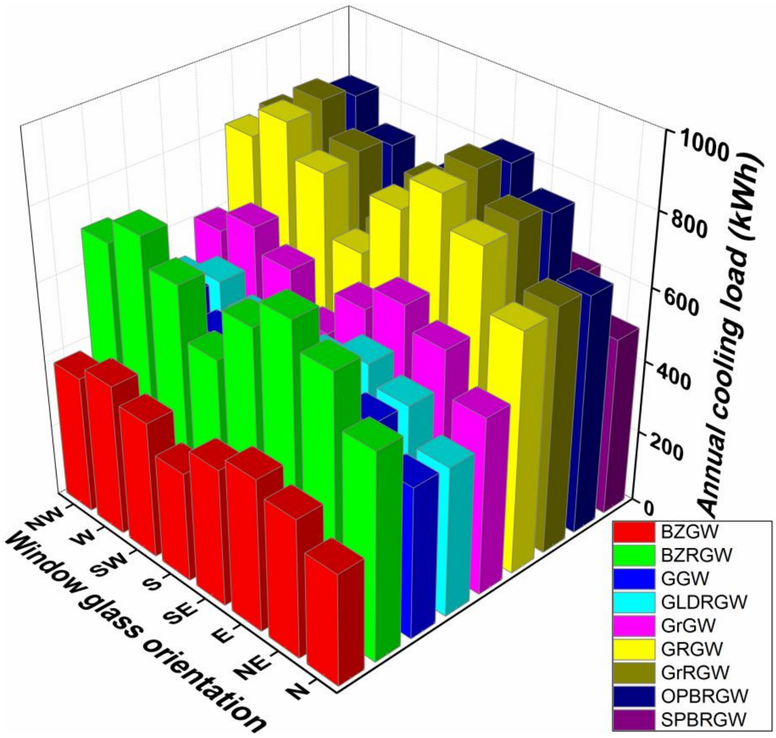


Figure 5.3.27 Annual cooling load decrease in buildings at zero deg window tilt position for Kolkata region

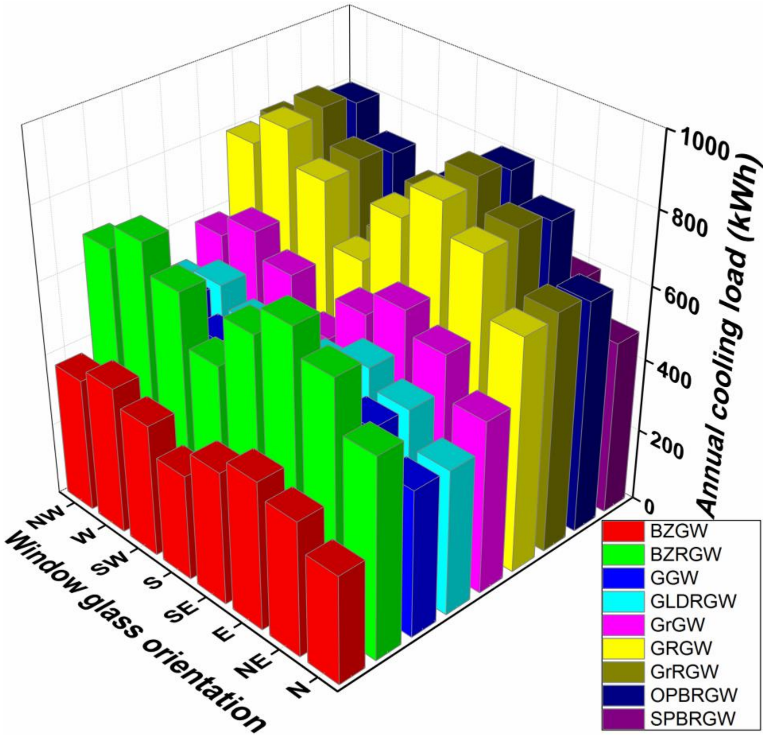


Figure 5.3.28 Annual cooling load decrease in buildings at two deg window tilt position towards Earth for Kolkata region

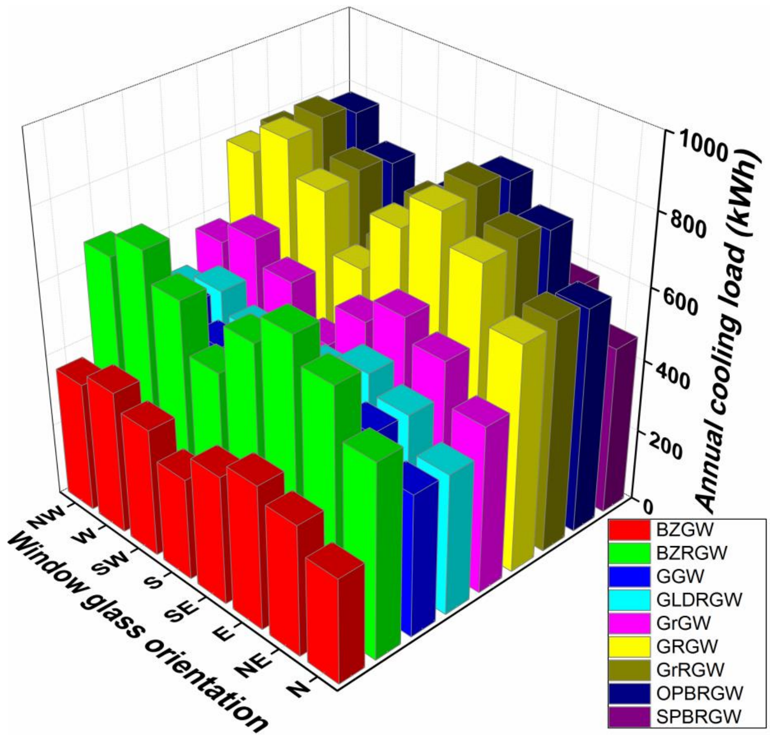


Figure 5.3.29 Annual cooling load decrease in buildings at four deg window tilt position towards Earth for Kolkata region

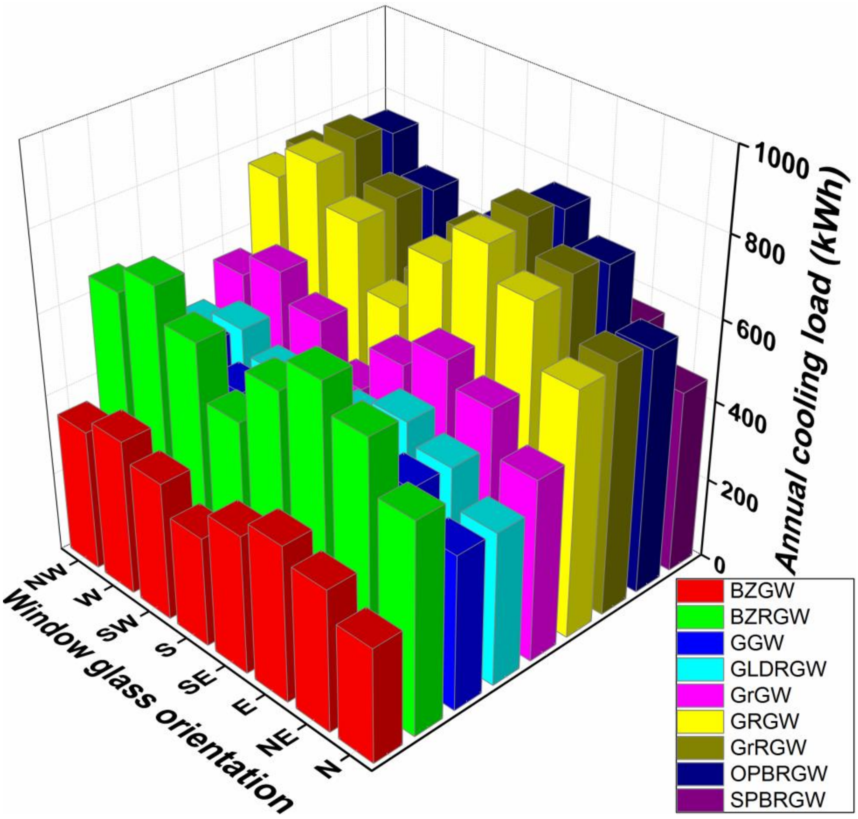


Figure 5.3.30 Annual cooling load decrease in buildings at six deg window tilt position towards Earth for Kolkata region

5.3.9 Annual heating load increase in buildings using various types of glass windows in comparison with clear glass window at four window tilt positions in the climatic region of Kolkata

Figures 5.3.31, 5.3.32, 5.3.33 and 5.3.34 show the graph between annual heating load increase in buildings using different types of glass windows compared with clear glass window, at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Sky) in the climatic region of Kolkata, in eight orientations. From the Figures, it is clearly observed that, all glass windows are increasing more heating load in south orientation at all window tilt positions. The bronze glass window is observed to increase the highest heating load 996.74 kWh at 6 Deg tilt position in the south direction.

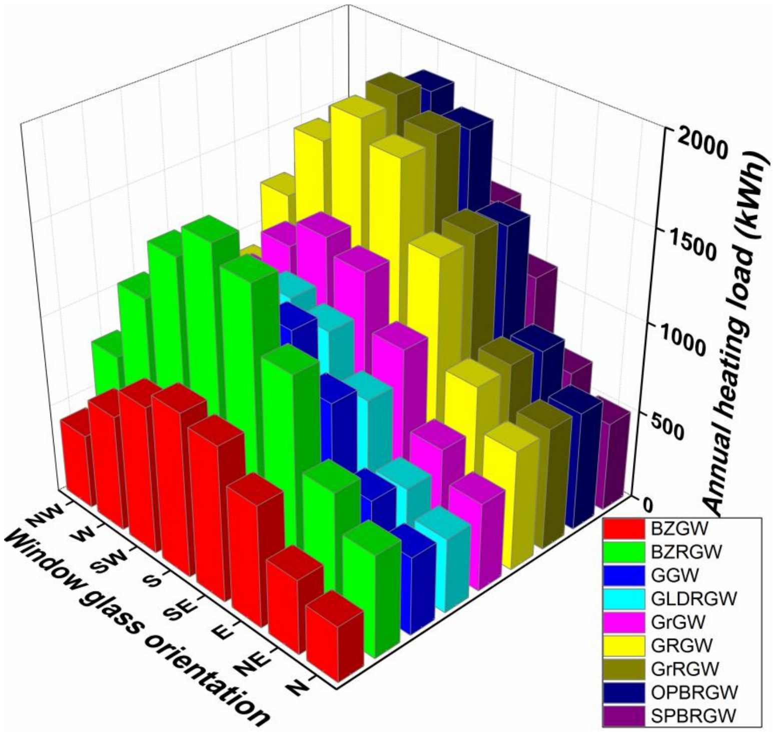


Figure 5.3.31 Annual heating load increase in buildings at zero deg window tilt position for Kolkata region

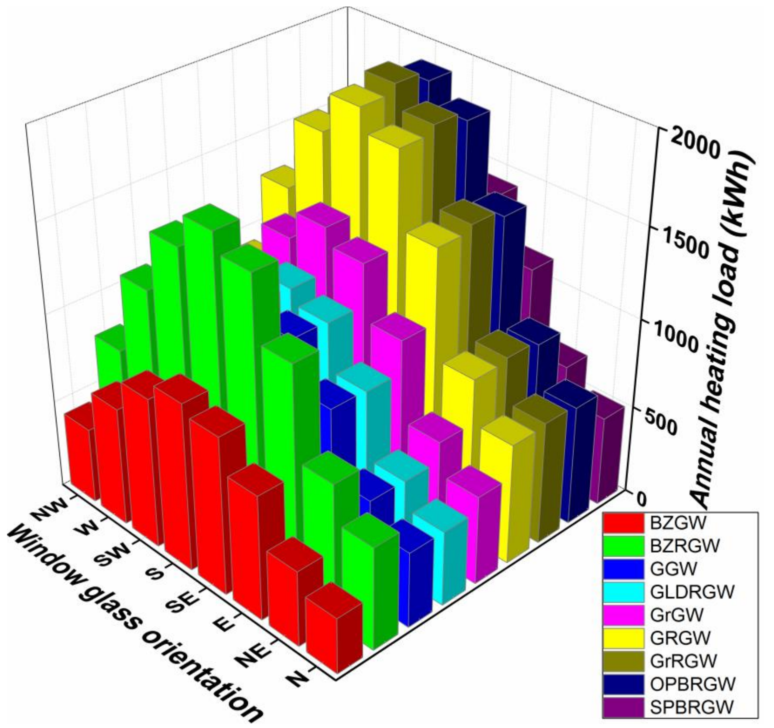


Figure 5.3.32 Annual heating load increase in buildings at two deg window tilt position towards Sky for Kolkata region

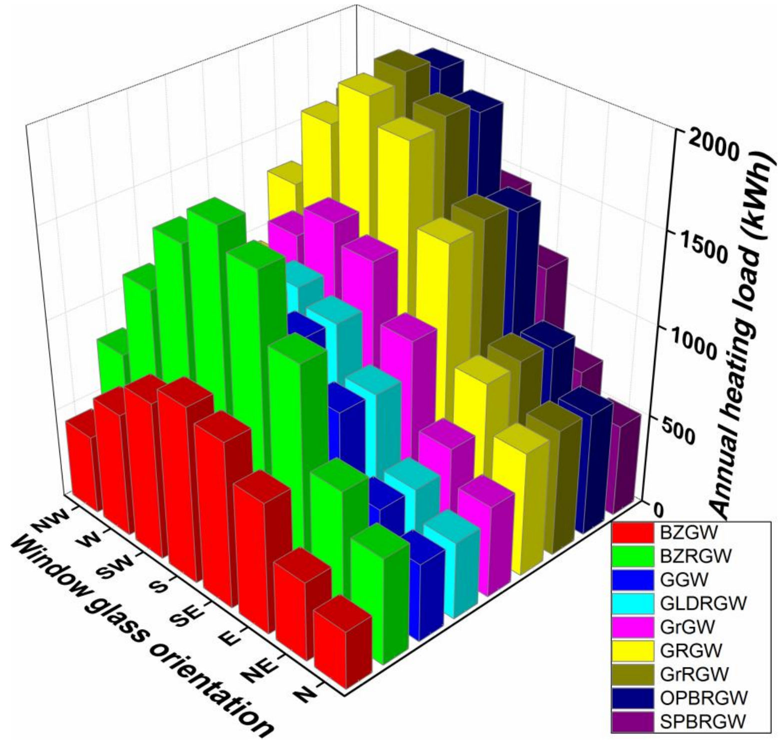


Figure 5.3.33 Annual heating load increase in buildings at four deg window tilt position towards Sky for Kolkata region

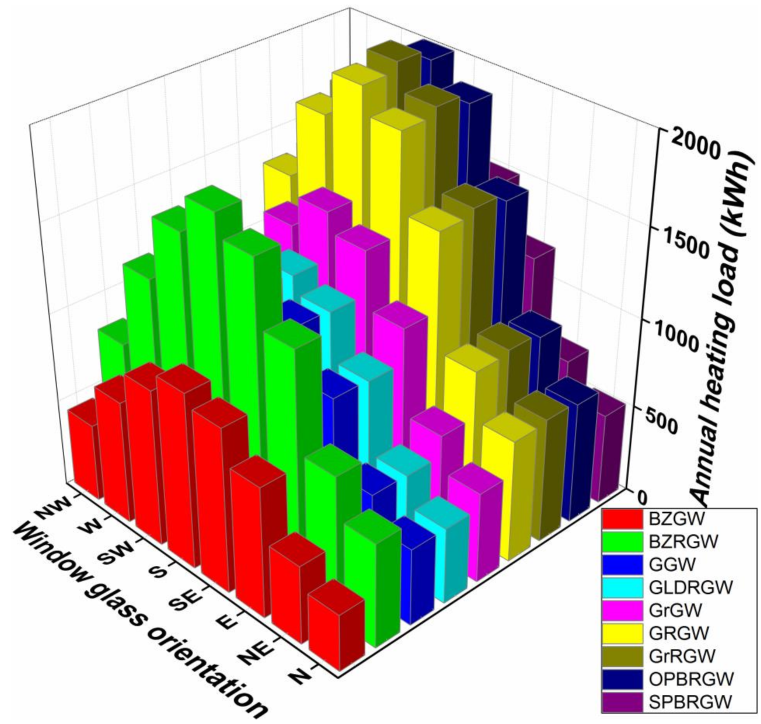


Figure 5.3.34 Annual heating load increase in buildings at six deg window tilt position towards Sky for Kolkata region

5.3.10 Annual cost saving for buildings using various types of glass windows compared with clear glass window at 6 Deg window tilt position in the climatic region of Kolkata

Figure 5.3.35, shows the graph between nine glass windows and annual cost saving in rupees in eight orientations of Kolkata climatic region. From the graph it is clearly shown that grey reflective glass window is saving more cost when compared with all glass windows and in that south orientation is saving 4490.9 (Rupees/year), when compared with other glass windows of Kolkata climatic region.

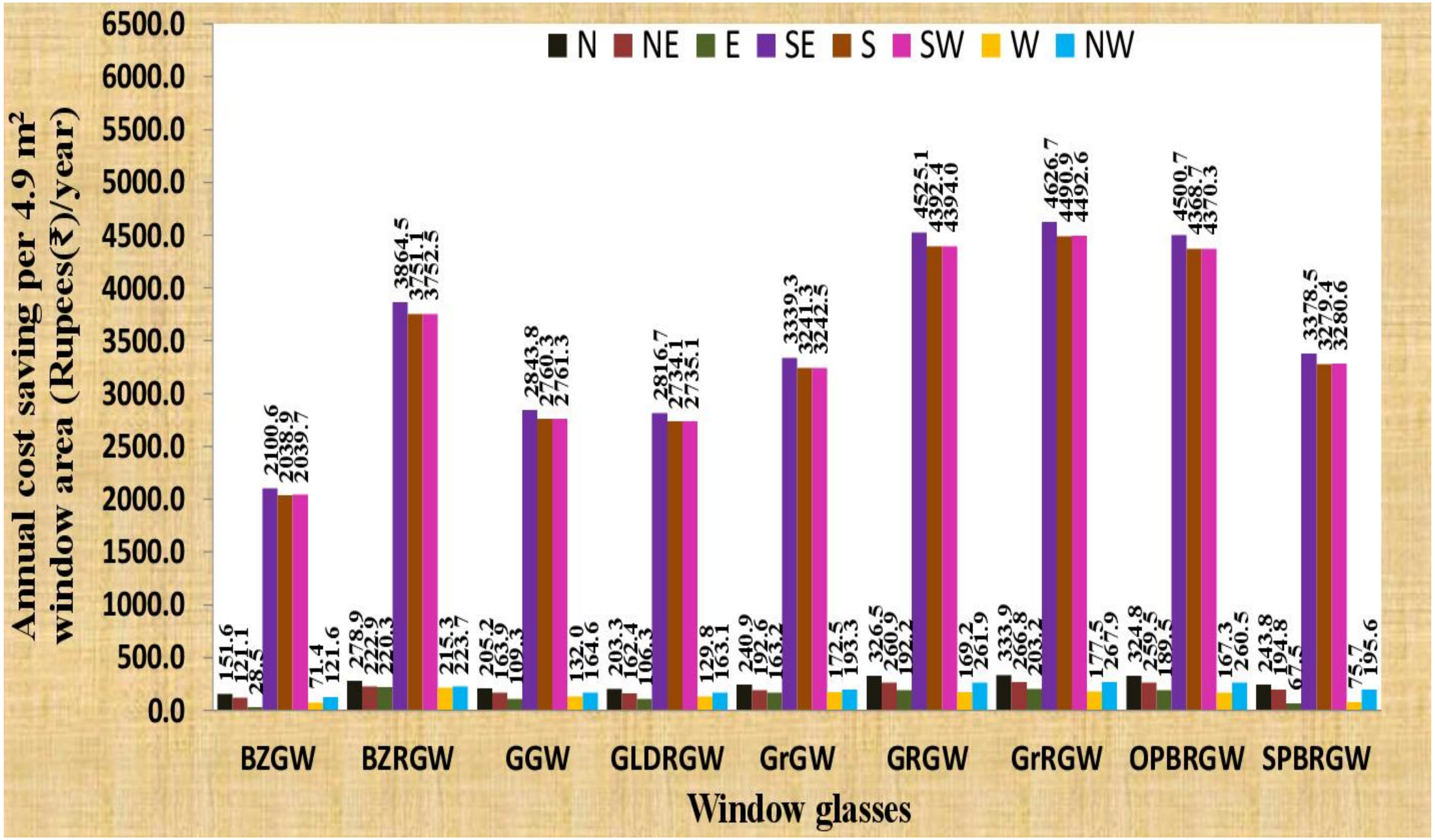


Figure 5.3.35 Annual cost saving of buildings using various glass windows at 6 Deg window tilt position in the climatic region of Kolkata

5.3.11 Solar heat gain in buildings through glass windows on peak summer day at four window tilt positions for New Delhi climatic region

Figures 5.3.36, 5.3.37, 5.3.38 and 5.3.39 show the total solar heat gain in buildings through glass window at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Earth) for New Delhi climatic condition during peak summer day. From the results heat gain in buildings decreases when, the window tilt position changes from 0^0 to -6^0 through all glass windows in south orientation when compared with other orientations.

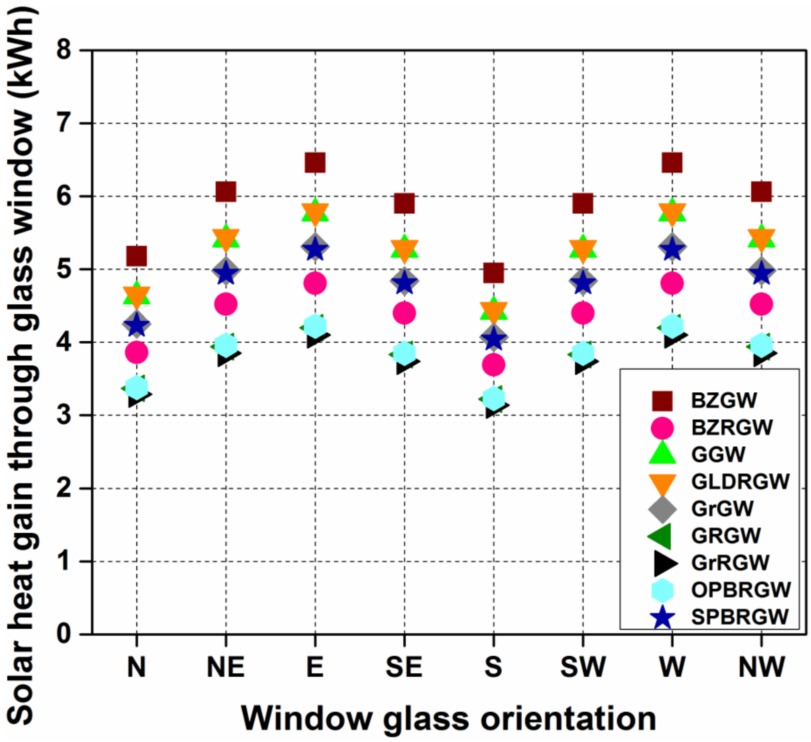


Figure 5.3.36 Total solar heat gain in buildings through glass windows at zero deg window tilt position at peak summer day for New Delhi region

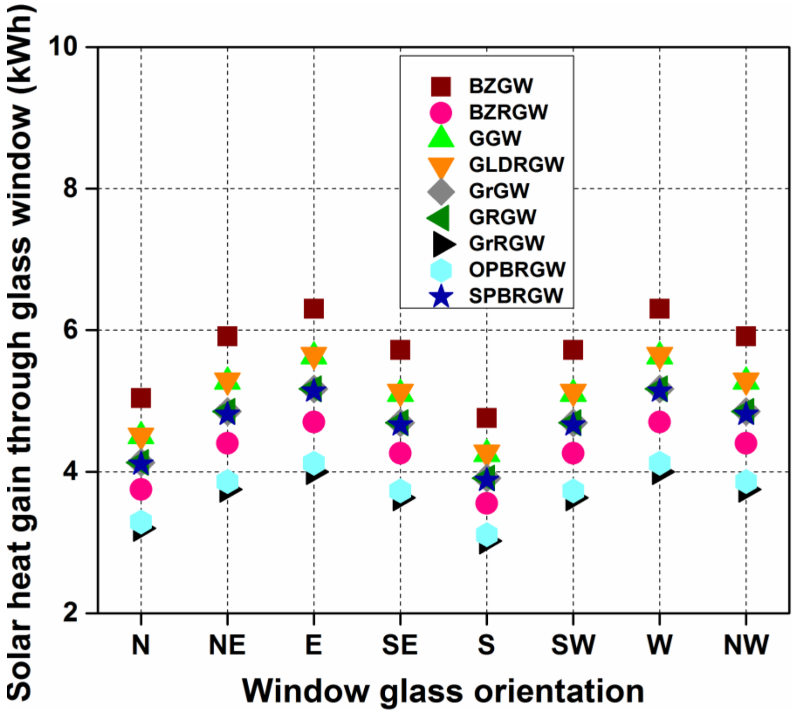


Figure 5.3.37 Total solar heat gain in buildings through glass windows at two deg window tilt position towards Earth at peak summer day for New Delhi region

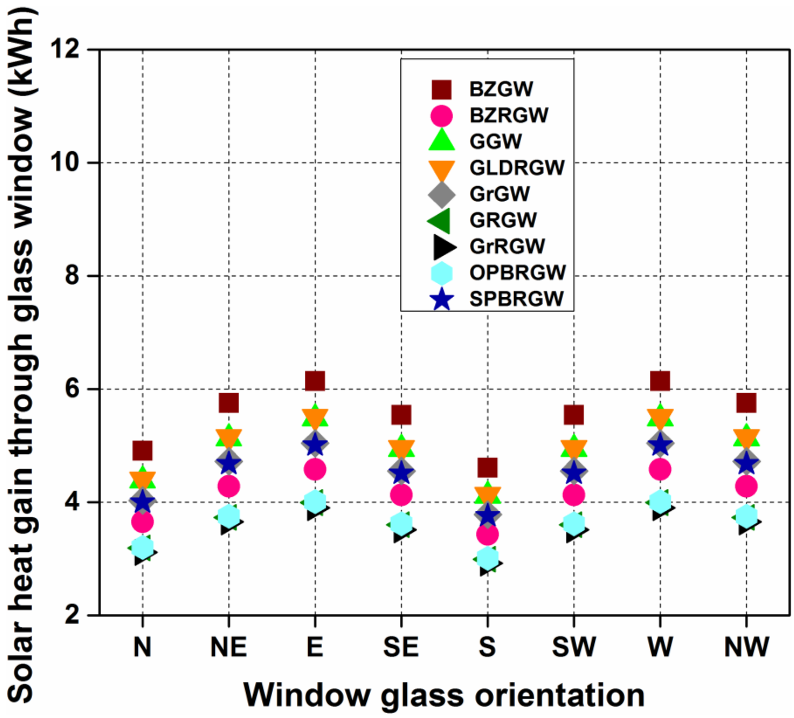


Figure 5.3.38 Total solar heat gain in buildings through glass windows at four deg window tilt position towards Earth at peak summer day for New Delhi region

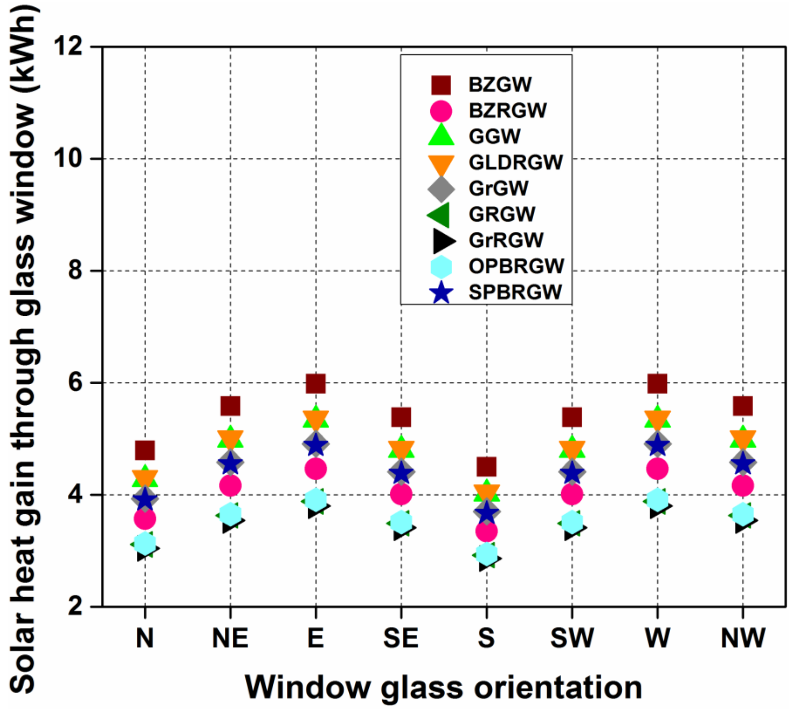


Figure 5.3.39 Total solar heat gain in buildings through glass windows at six deg window tilt position towards Earth at peak summer day for New Delhi region

5.3.12 Solar heat gain in buildings through glass windows on peak winter day at four window tilt positions for New Delhi climatic region

Figures 5.3.40, 5.3.41, 5.3.42 and 5.3.43 show the total solar heat gain in buildings through glass window at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Sky) for New Delhi climatic condition during peak winter day. From the results heat gain in buildings decreases when, the window tilt position changes from 0^0 to 6^0 through all glass windows in south orientation when compared with other orientations.

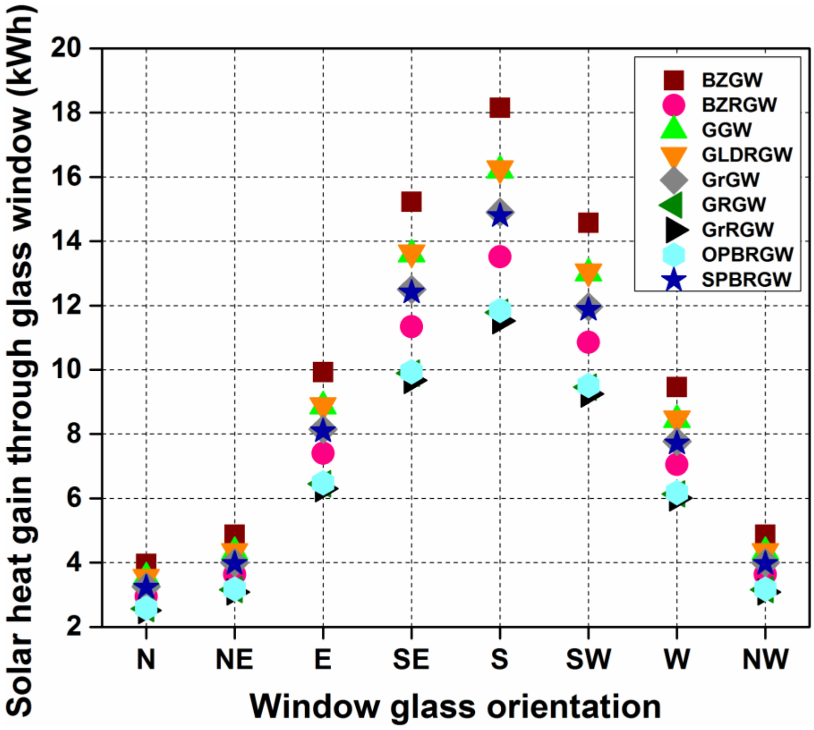


Figure 5.3.40 Total solar heat gain in buildings through glass windows at zero deg window tilt position at peak winter day for New Delhi region

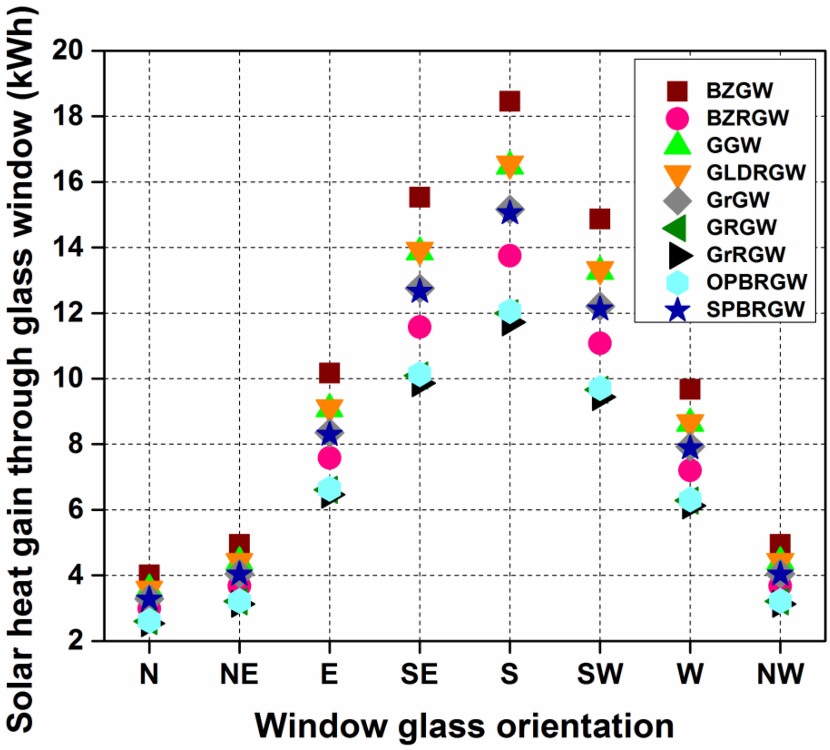


Figure 5.3.41 Total solar heat gain in buildings through glass windows at two deg window tilt position towards Sky at peak winter day for New Delhi region

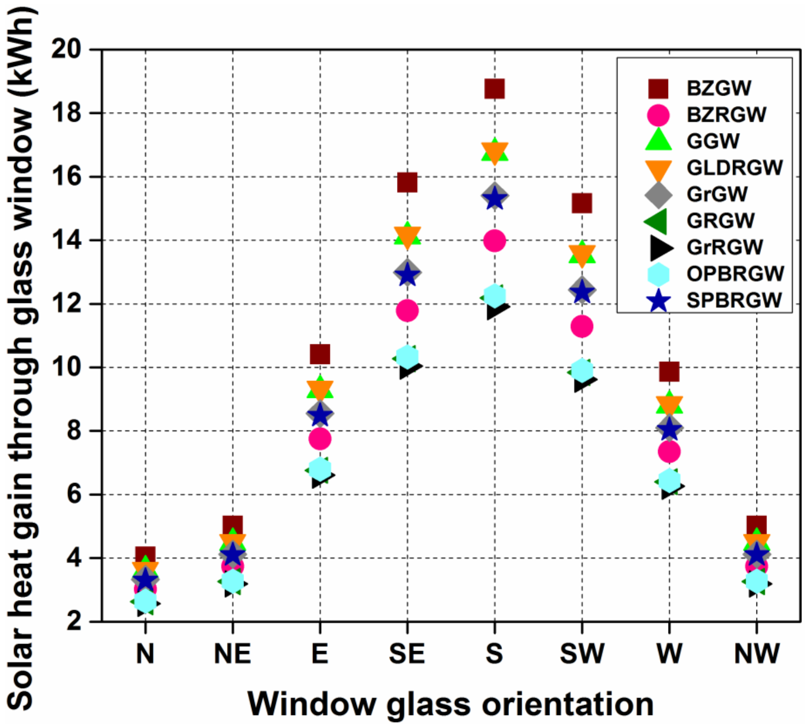


Figure 5.3.42 Total solar heat gain in buildings through glass windows at four deg window tilt position towards Sky at peak winter day for New Delhi region

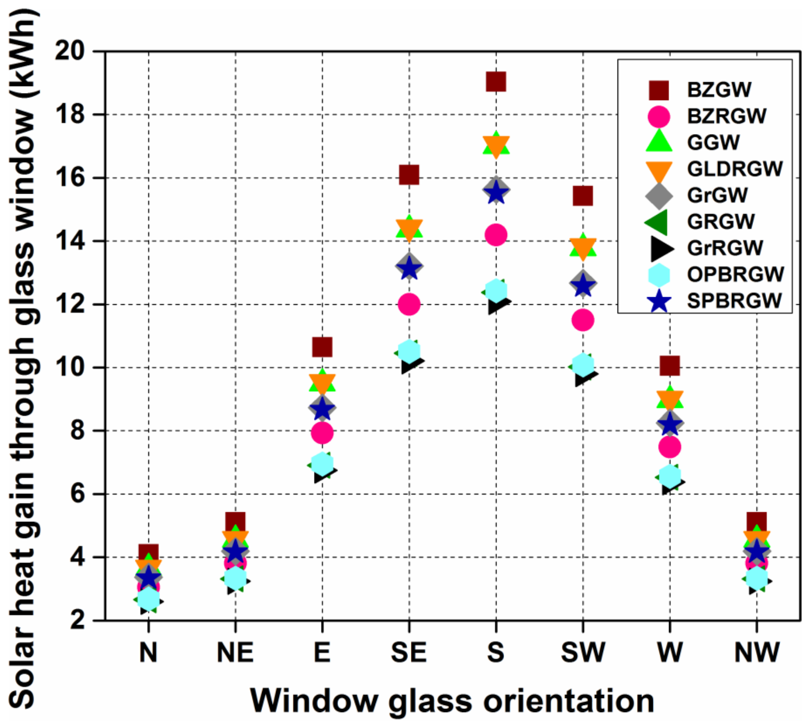


Figure 5.3.43 Total solar heat gain in buildings through glass windows at six deg window tilt position towards Sky at peak winter day for New Delhi region

5.3.13 Annual cooling load decrease in buildings using various types of glass windows in comparison with clear glass window at four window tilt positions in the climatic region of New Delhi

Figures 5.3.44, 5.3.45, 5.3.46 and 5.3.47 show the graph between annual cooling load decrease in buildings using different types of glass windows compared with clear glass window, at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Earth) in the climatic region of New Delhi, in eight orientations. From the Figures, it is clearly observed that, all glass windows are reducing more cooling load in south orientation at all window tilt positions. Grey reflective glass window is observed to reduce the highest cooling load 626.11 kWh at -6 Deg tilt position in the south direction.

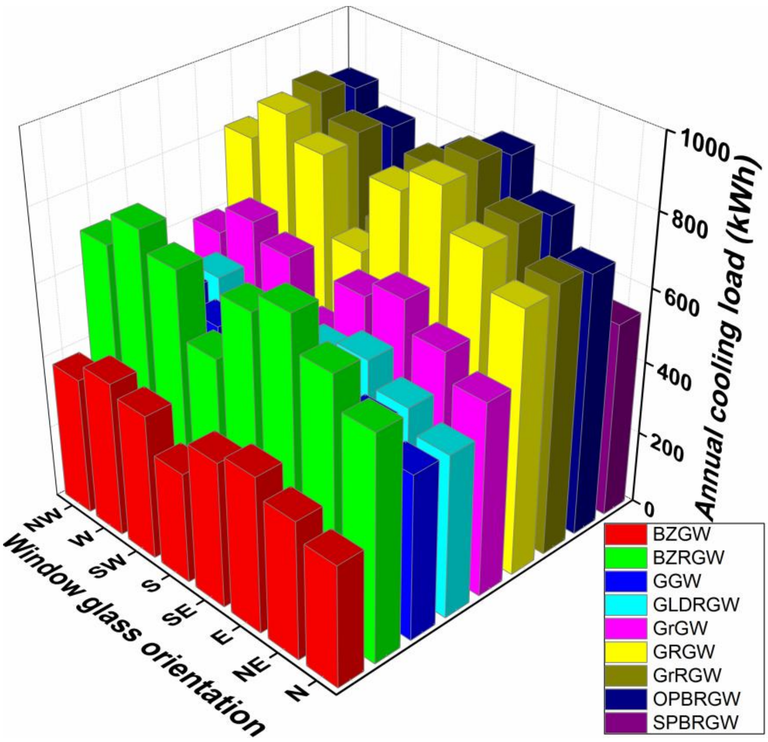


Figure 5.3.44 Annual cooling load decrease in buildings at zero deg window tilt position for New Delhi region

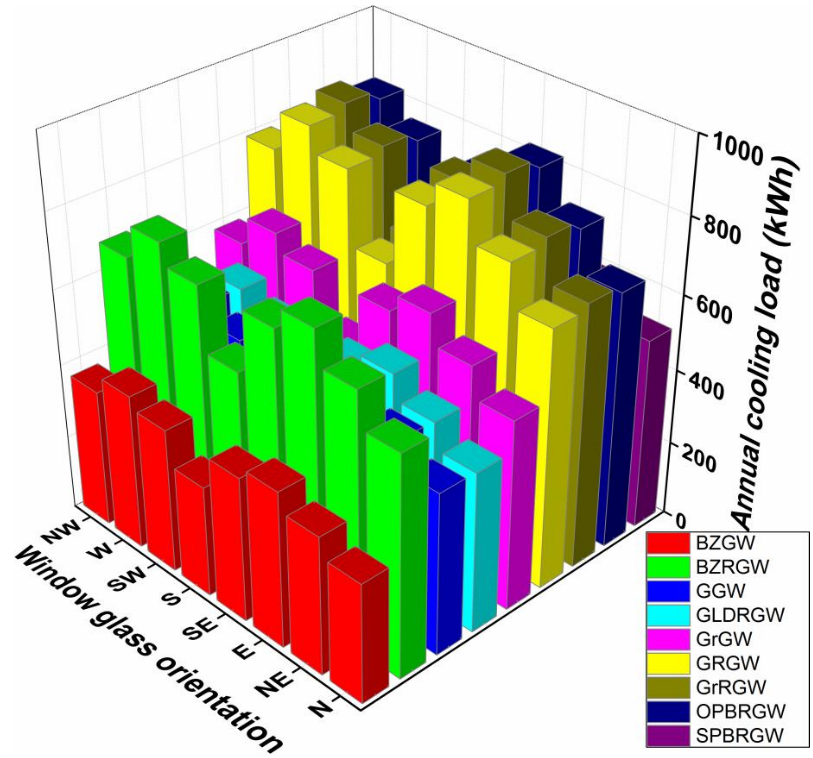


Figure 5.3.45 Annual cooling load decrease in buildings at two deg window tilt position towards Earth for New Delhi region

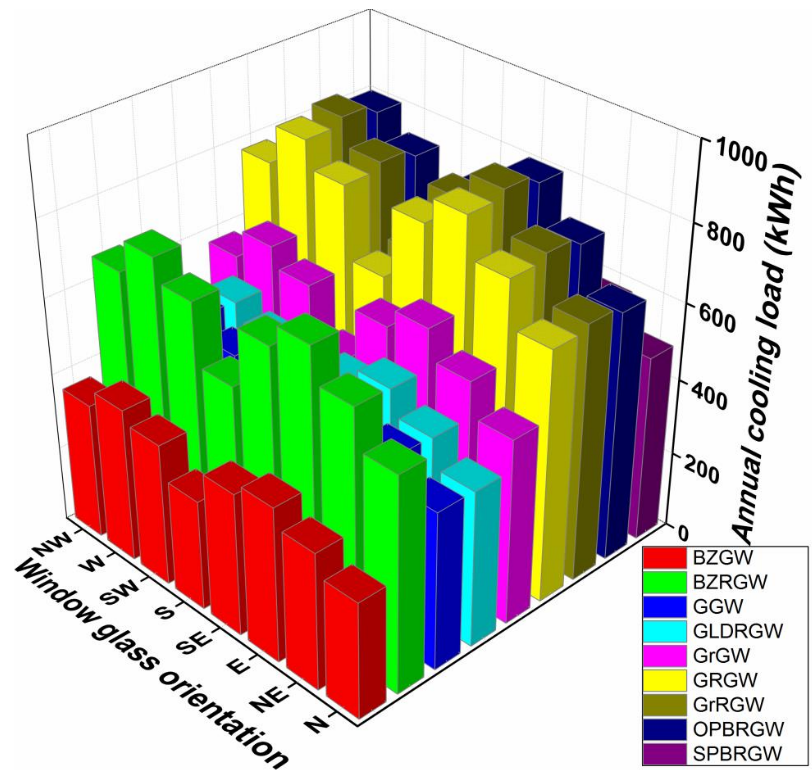


Figure 5.3.46 Annual cooling load decrease in buildings at four deg window tilt position towards Earth for New Delhi region

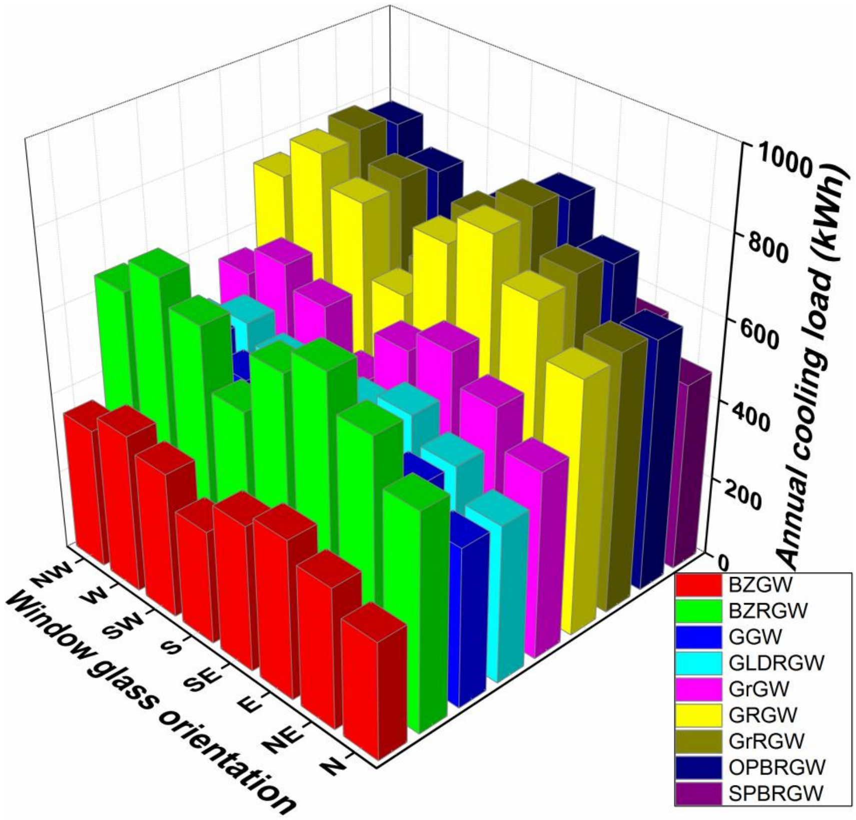


Figure 5.3.47 Annual cooling load decrease in buildings at six deg window tilt position towards Earth for New Delhi region

5.3.14 Annual heating load increase in buildings using various types of glass windows in comparison with clear glass window at four window tilt positions in the climatic region of New Delhi

Figures 5.3.48, 5.3.49, 5.3.50 and 5.3.51 show the graph between annual heating load increase in buildings using different types of glass windows compared with clear glass window, at four window tilt positions at 0^0, 2^0, 4^0 and 6^0 (Facing to the Sky) in the climatic region of New Delhi, in eight orientations. From the Figures, it is clearly observed that, all glass windows are increasing more heating load in south orientation at all window tilt positions. Bronze glass window is observed to increase the highest heating load 1047.32 kWh at 6 Deg tilt position in the south direction.

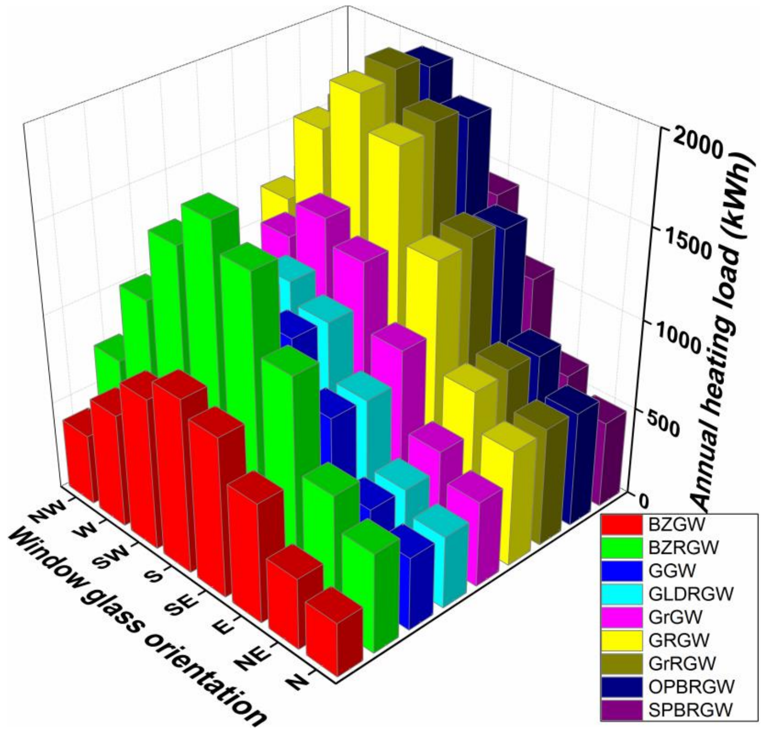


Figure 5.3.48 Annual heating load increase in buildings at zero deg window tilt position for New Delhi region

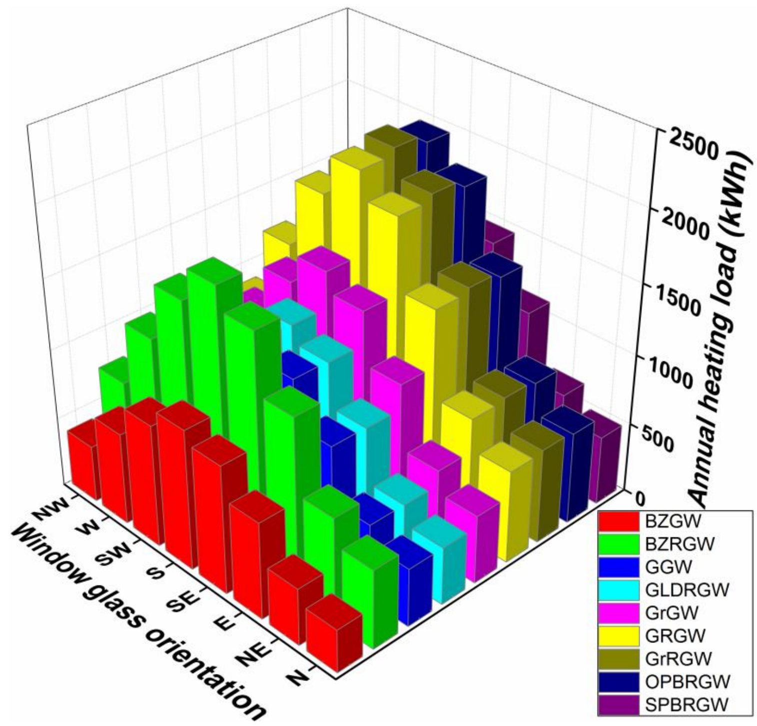


Figure 5.3.49 Annual heating load increase in buildings at two deg window tilt position towards Sky for New Delhi region

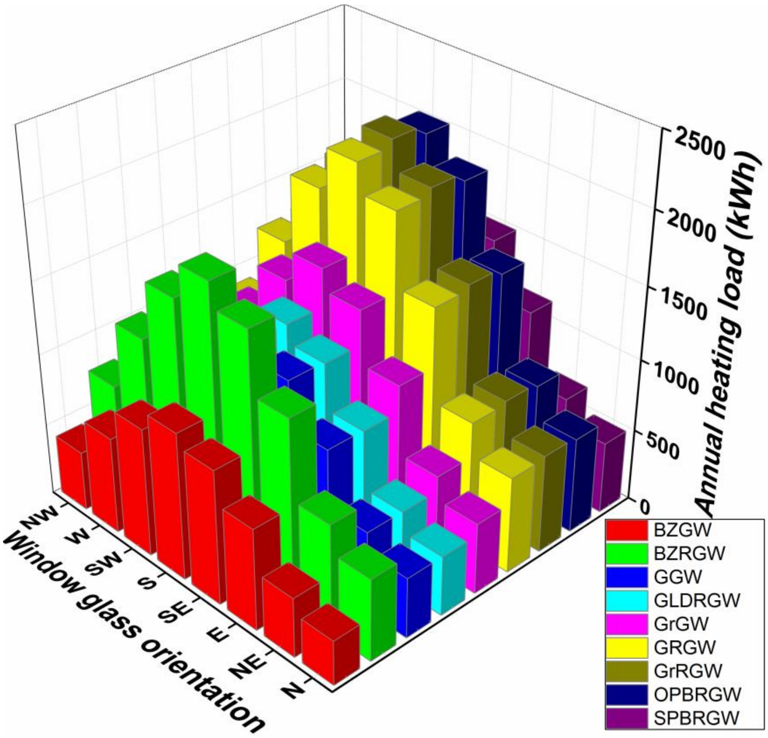


Figure 5.3.50 Annual heating load increase in buildings at four deg window tilt position towards Sky for New Delhi region

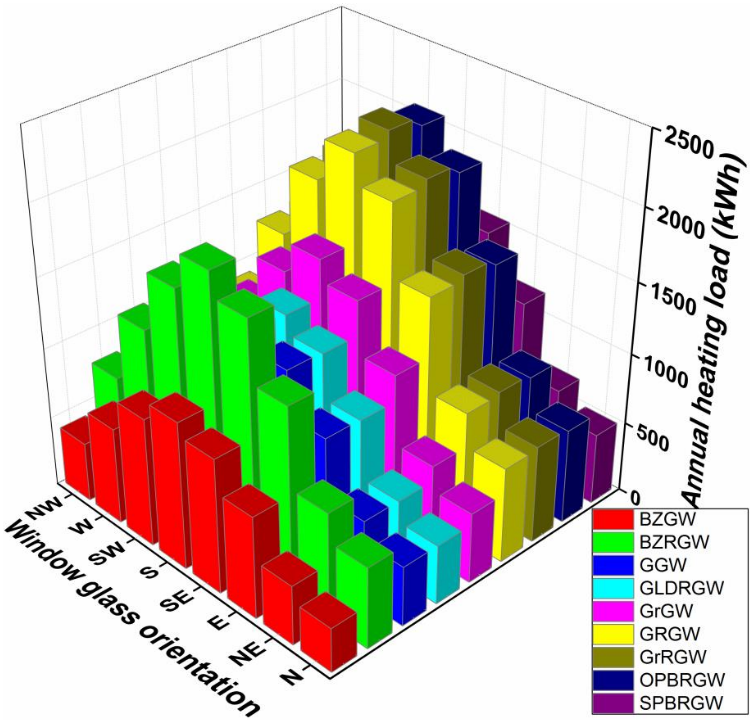


Figure 5.3.51 Annual heating load increase in buildings at six deg window tilt position towards Sky for New Delhi region

5.3.15 Annual cost saving for buildings using various glass windows compared with clear glass window at 6 Deg window tilt position for New Delhi climatic region

Figure 5.3.16, shows the graph between nine glass windows and annual cost saving in rupees in eight orientations of New Delhi climatic region. From the graph it is clearly shown that grey reflective glass window is saving more cost when compared with all glass windows and in that south orientation is saving 4662.2 (Rupees/year), when compared with other glass windows of New Delhi climatic region.

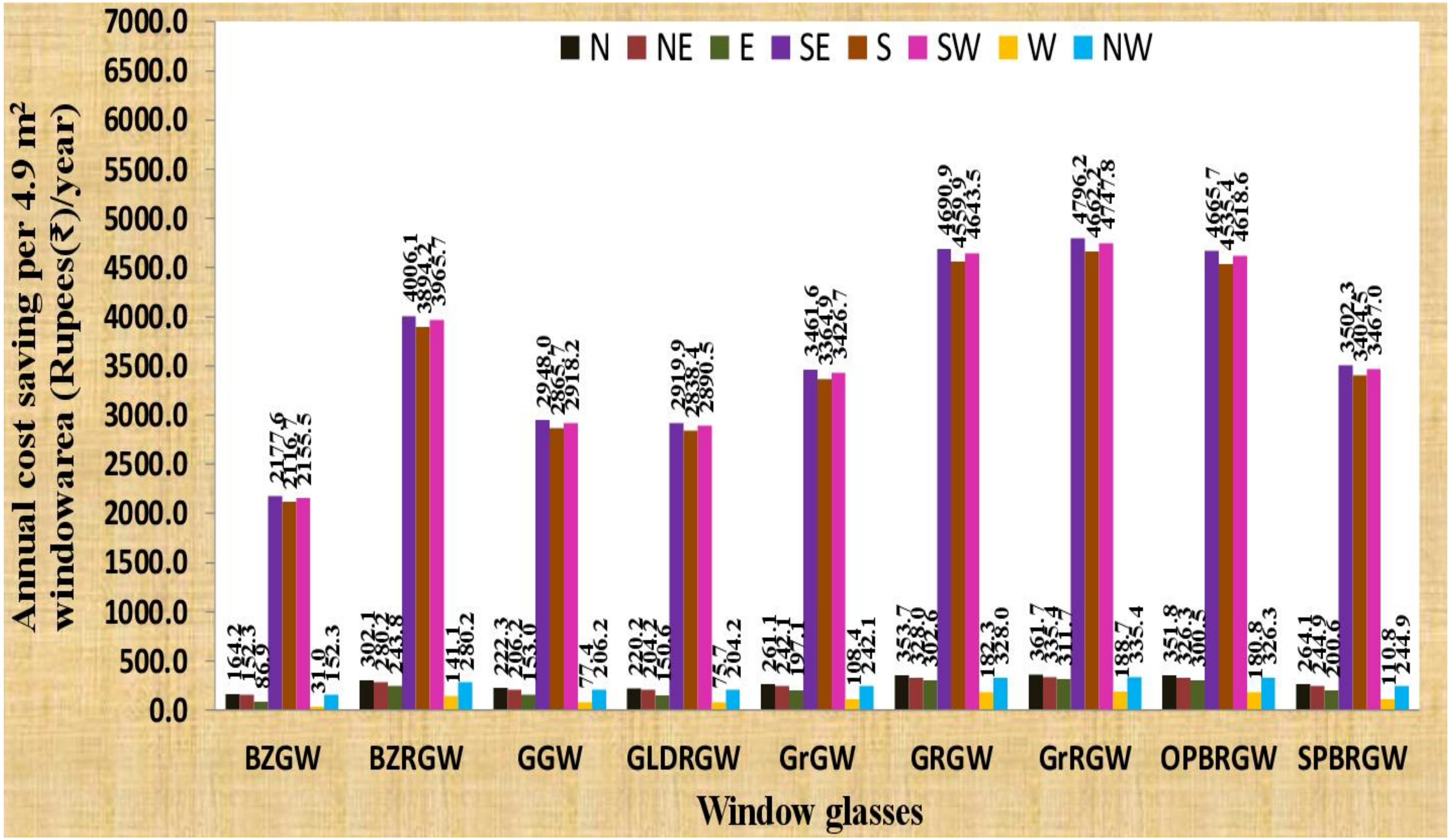


Figure 5.3.52 Annual cost saving of buildings using various glass windows at 6 Deg window tilt position in the climatic region of New Delhi

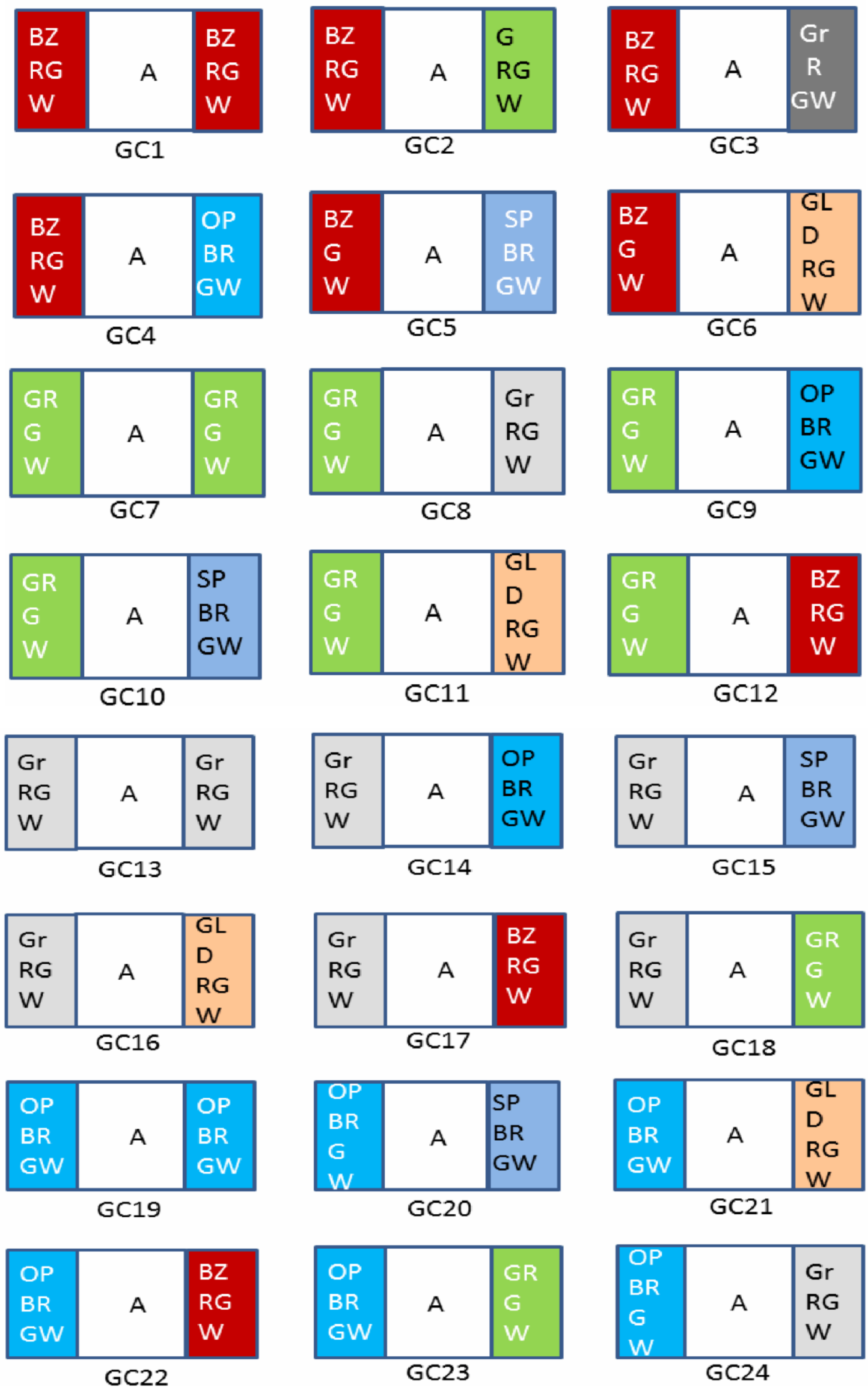
5.4 EFFECT OF VARIOUS DOUBLE REFLECTIVE GLASS WINDOW COMBINATIONS ON ENERGY SAVING IN BUILDINGS

In this study, six reflective glass materials, namely bronze, green, grey, opal blue, sapphire blue and gold reflective glasses are placed as double window glass. Table 5.4.1, shows the details about the number of double window combinations studied, to find solar heat gain in buildings in eight orientations on peak summer and peak winter days of hot & dry climatic zone (Jodhpur) in India.

Table 5.4.1 Glass materials studied

Number of glasses	Climatic zone	Glass arrangement	Number of orientations	Number of glass combinations
6	Jodhpur	Double glass	8	6×6=36

To find the total solar heat gain entering into the buildings through glass windows for particular climatic condition, several factors are to be considered like hour position, declination position, solar altitude, solar azimuth position, surface solar azimuth position and position of incidence. In this work, to find the total solar heat gain through double reflective glass window combinations with an unventilated air gap of 10mm between glasses, in hot and dry climatic zone from morning 6:00hrs to evening 18:00hrs on a peak summer day and on a peak winter day, from morning 7:00hrs to evening 17:00hrs, (selected as per Indian standards) in eight orientations. In this work, hot and dry climatic region of the Indian city Jodhpur (26.30^{0}N, 73.02^{0}E) was selected for computation of the total solar heat gain through all double reflective glass window combinations. Building model of dimensions 3.5 m × 3.5 m × 3.5 m with 40% window area to wall area ratio was considered. Dimensions of double window glass were taken as 2.45 m × 2 m. Total solar heat gain was computed in eight orientations by varying the double reflective window glass combinations one by one such that total of thirty six types of window combinations were considered from GC1 to GC36 as shown in Figure 5.4.1. Figure 5.4.2, shows the flow chart of solar heat gain through double glass window.


BZ RG W
A
BZ RG W
GC1
BZ RG W
A
G RG W
GC2
BZ RG W
A
Gr R GW
GC3
BZ RG W
A
OP BR GW
GC4
BZ G W
A
SP BR GW
GC5
BZ G W
A
GL D RG W
GC6
GR G W
A
GR G W
GC7
GR G W
A
Gr RG W
GC8
GR G W
A
OP BR GW
GC9
GR G W
A
SP BR GW
GC10
GR G W
A
GL D RG W
GC11
GR G W
A
BZ RG W
GC12
Gr RG W
A
Gr RG W
GC13
Gr RG W
A
OP BR GW
GC14
Gr RG W
A
SP BR GW
GC15
Gr RG W
A
GL D RG W
GC16
Gr RG W
A
BZ RG W
GC17
Gr RG W
A
GR G W
GC18
OP BR GW
A
OP BR GW
GC19
OP BR G W
A
SP BR GW
GC20
OP BR GW
A
GL D RG W
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A
Gr RG W
GC24

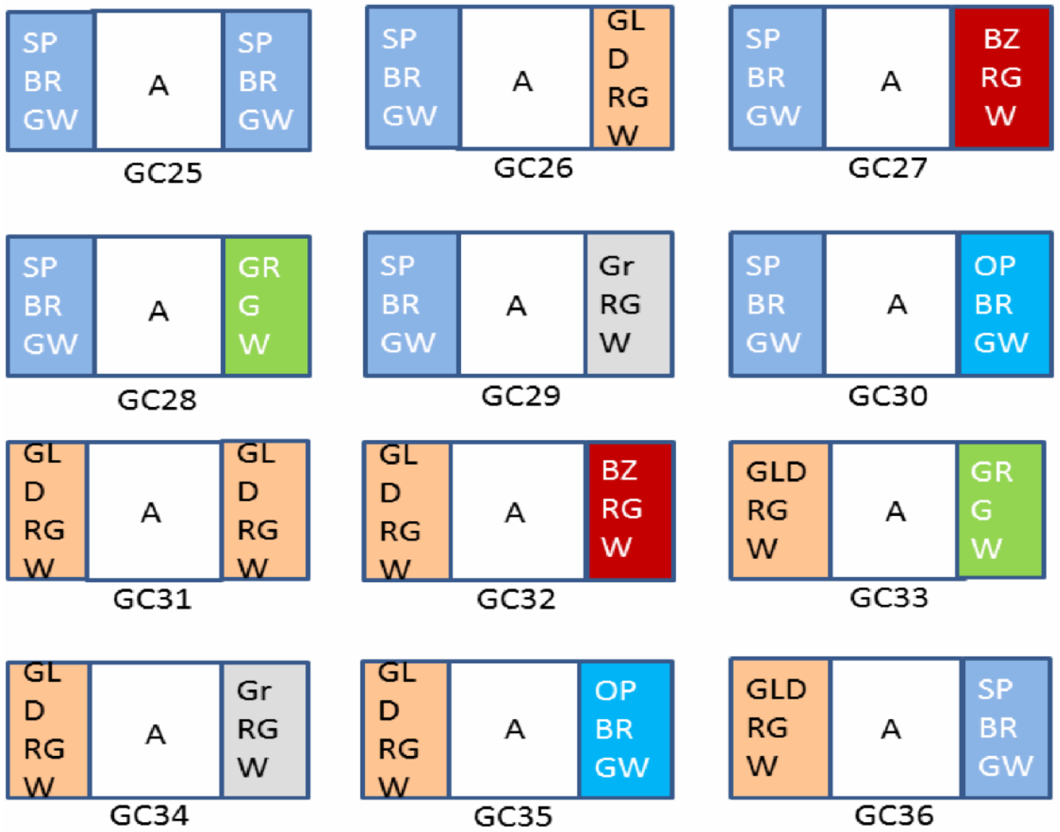


Figure 5.4.1 Double reflective glass window combinations with an air gap of 10mm

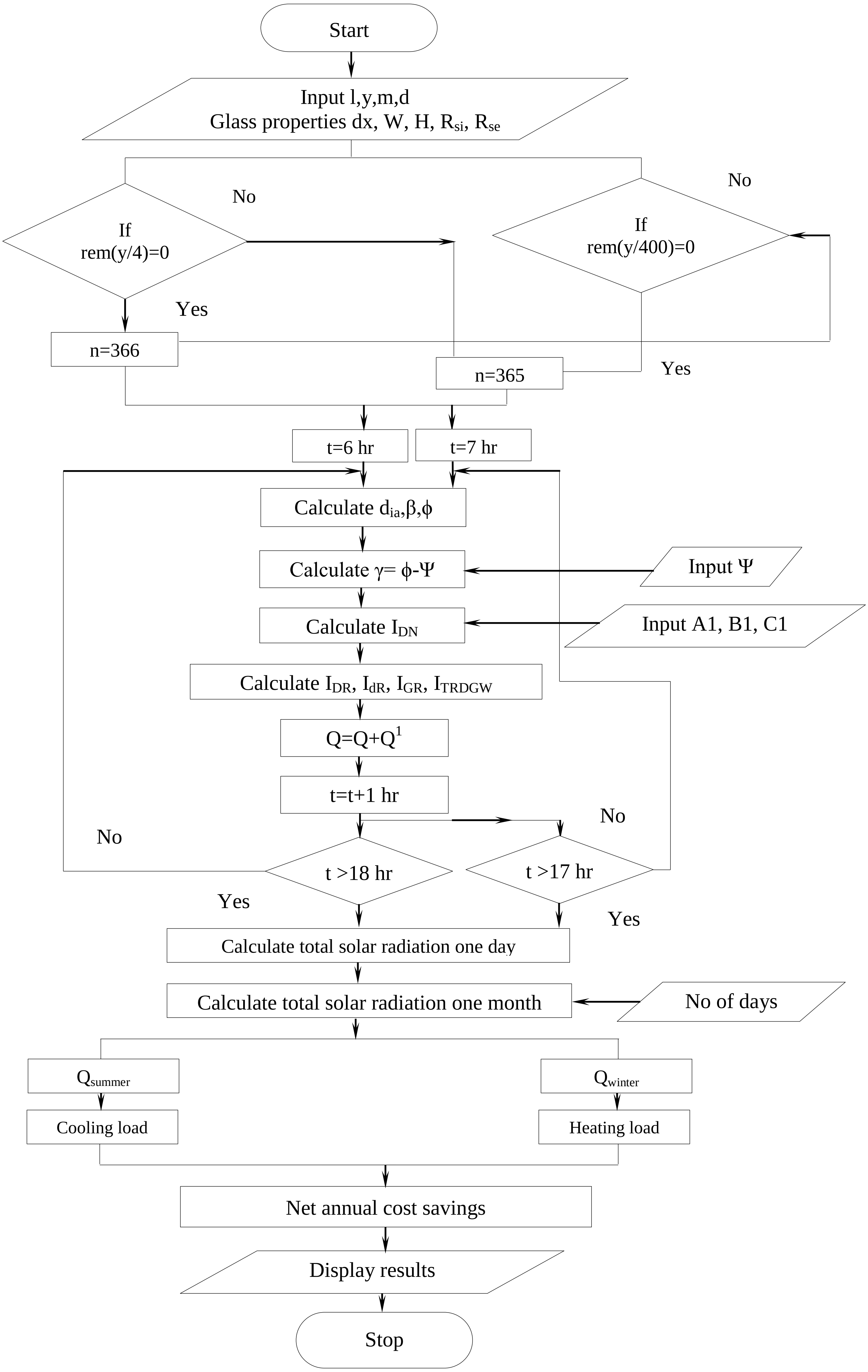


Figure 5.4.2 Flow chart for solar heat gain in buildings through double glass window

5.4.1 Solar heat gain in buildings through bronze reflective glass window combinations (Bronze reflective glass was placed outside and other reflective glasses was placed inside) at both peak summer and winter days

Figure 5.4.3, shows the arrangement of bronze reflective glass window combinations GC1 to GC6 for building. Tables 5.4.2, 5.4.3 and Figures 5.4.4, 5.4.5 show the total solar heat gain in buildings through these six combinations from eight orientations of the building on both peak summer and winter days for Jodhpur climatic region. From the graphs, it is clearly observed that in south orientation, all bronze reflective glass window combinations are gaining less heat at peak summer day and gaining more heat at peak winter day in buildings when compared with other orientations.

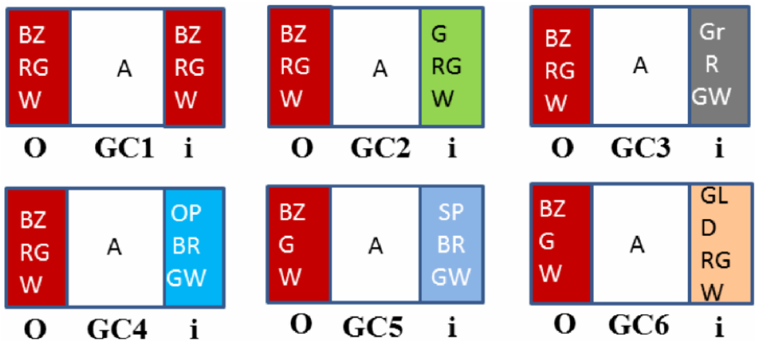


Figure 5.4.3 Bronze reflective glass window combinations GC1 to GC6 with an air gap of 10mm, O-Outdoor, i-Indoor

Table 5.4.2 Total solar heat gain in buildings through bronze reflective glass window combinations at peak summer day

	Bronze reflective glass window combinations					
Direction	GC1	GC2	GC3	GC4	GC5	GC6
North	2.52	2.44	2.51	2.46	2.61	2.38
North East	2.93	2.84	2.93	2.86	3.04	2.77
East	3.09	3.00	3.09	3.02	3.21	2.92
South East	2.79	2.71	2.79	2.72	2.89	2.64
South	2.32	2.25	2.31	2.26	2.40	2.19
South West	2.79	2.71	2.79	2.72	2.89	2.64
West	3.09	3.00	3.09	3.02	3.21	2.92
North West	2.93	2.84	2.93	2.86	3.04	2.77

Table 5.4.3 Total solar heat gain in buildings through bronze reflective glass window combinations at peak winter day

	Bronze reflective glass window combinations					
Direction	GC1	GC2	GC3	GC4	GC5	GC6
North	1.94	1.89	1.94	1.90	2.02	1.84
North East	2.39	2.32	2.39	2.34	2.48	2.26
East	4.83	4.69	4.83	4.72	5.01	4.57
South East	7.29	7.08	7.29	7.12	7.57	6.89
South	8.65	8.39	8.64	8.45	8.98	8.18
South West	6.97	6.76	6.97	6.81	7.24	6.59
West	4.60	4.47	4.60	4.50	4.78	4.35
North West	2.39	2.32	2.39	2.34	2.48	2.26

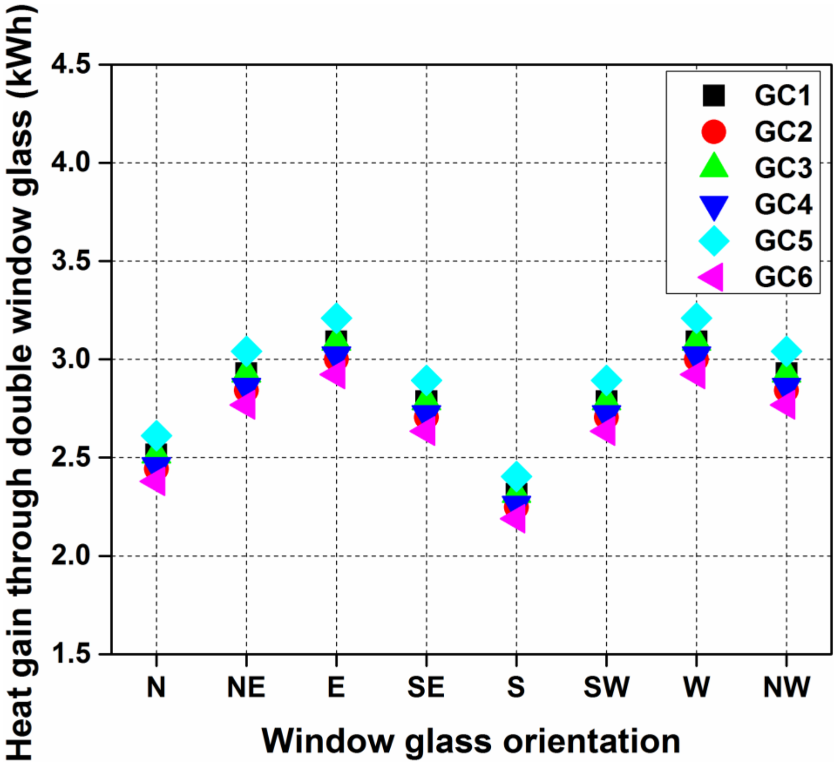


Figure 5.4.4 Total solar heat gain in buildings through bronze reflective glass window combinations at peak summer day

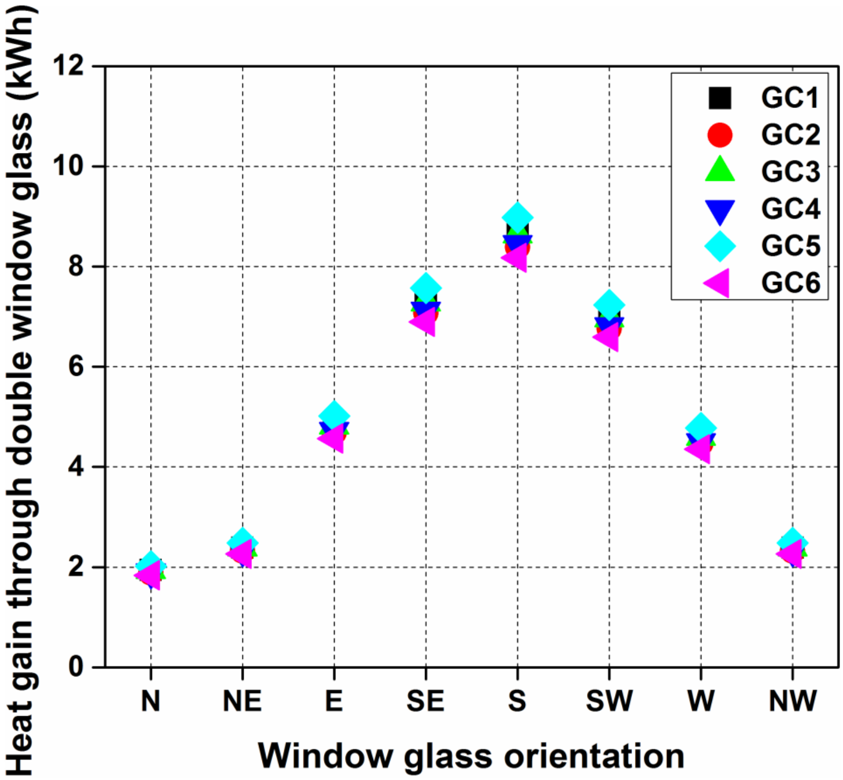


Figure 5.4.5 Total solar heat gain in buildings through bronze reflective glass window combinations at peak winter day

5.4.2 Annual cooling load decrease and heating load increase in buildings using bronze reflective glass window combinations in comparison with double clear glass window in summer and winter seasons

Figures 5.4.6, 5.4.7, indicate the graph between annual cooling load decrease and heating load increase in buildings using bronze reflective glass window combinations compared with double clear glass window in eight orientations. From the Figure 5.4.6, it is clearly observed that, all bronze reflective glass window combinations are reducing more cooling load in south orientation. Among which GC6 combination glass window reduces the highest cooling load 693.95 kWh inside the building in summer season. From the Figure 5.4.7, it is observed that, all bronze reflective glass window combinations are increasing more heating load in south orientation. Among which GC5 combination glass window increases the highest heating load 2034.89 kWh inside the building in winter season.

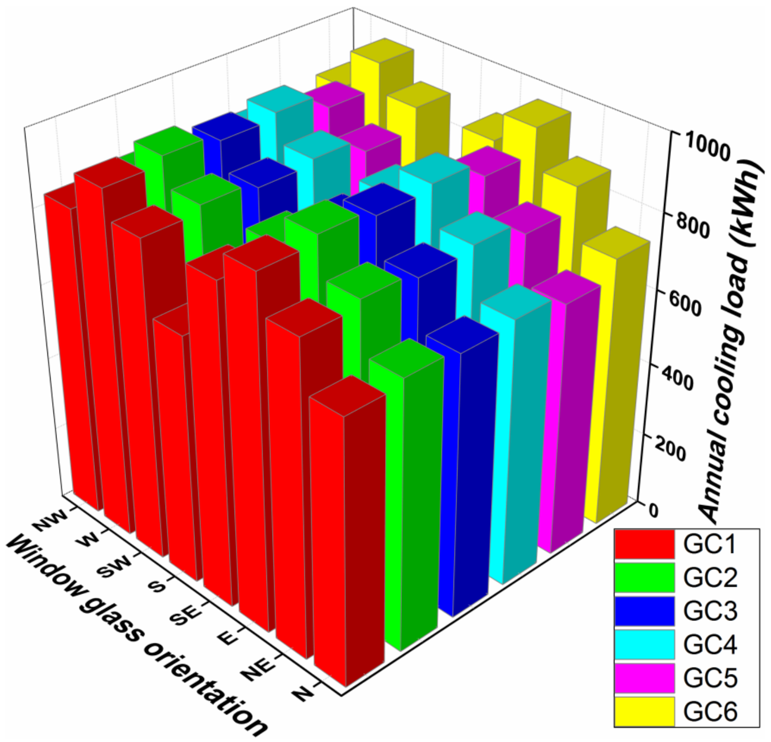


Figure 5.4.6 Annual cooling load decrease in buildings using bronze reflective glass window combinations in summer season

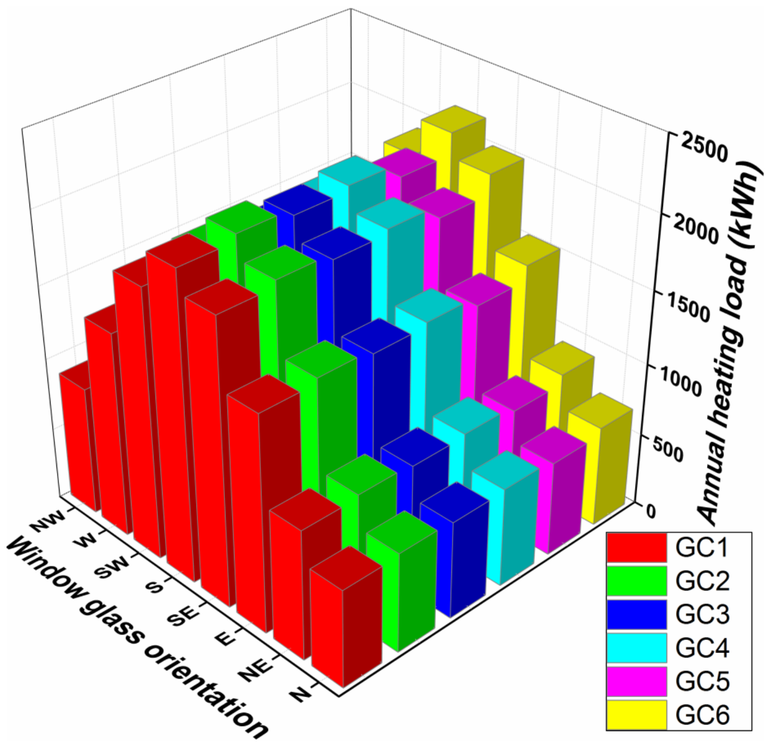


Figure 5.4.7 Annual heating load increase in buildings using bronze reflective glass window combinations in winter season

5.4.3 Annual cost saving of buildings using bronze reflective glass window combinations compared with double clear glass window

Figure 5.4.8, shows the annual cost saving of buildings using bronze reflective glass window combinations in eight orientations of Jodhpur climatic region. From the graph, it is clearly observed that GC6 bronze reflective glass window combination is the most energy efficient and also, it saves more cost when compared with all other bronze reflective glass window combinations. In south east orientation, GC6 combination glass window saves 4862.9 (Rupees/year), in south west orientation it saves 4745.1 (Rupees/year) and in south orientation it saves 4723.5 (Rupees/year), for Jodhpur climatic region.

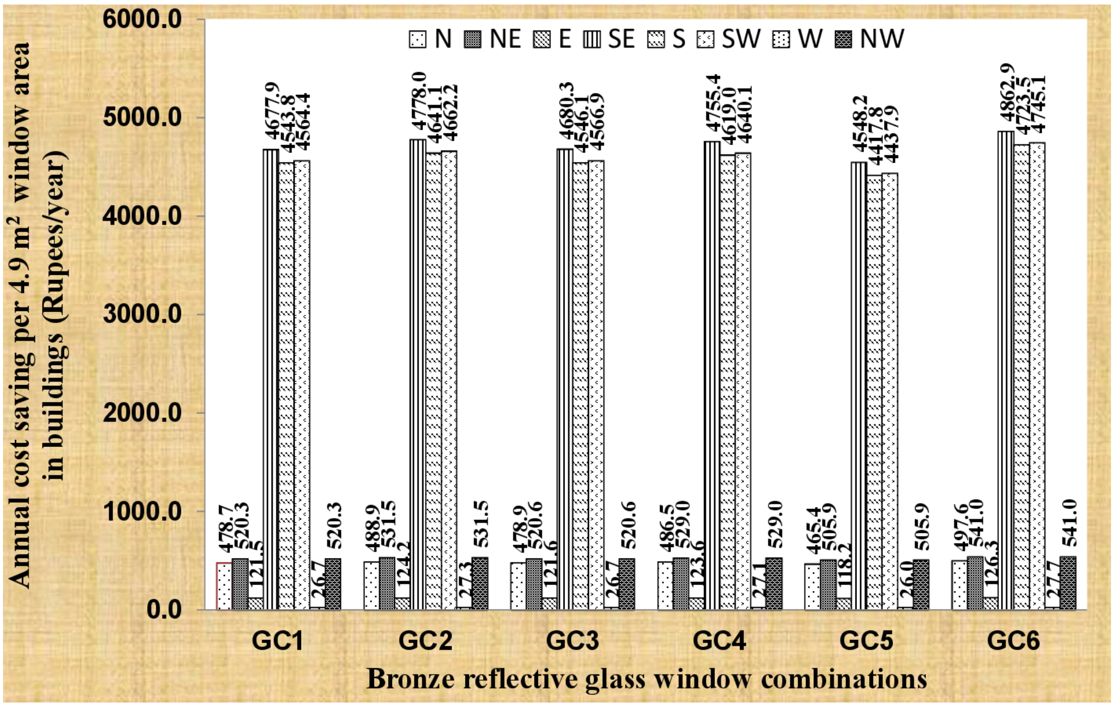


Figure 5.4.8 Annual cost saving of buildings using bronze reflective glass window combinations compared with double clear glass window

5.4.4 Solar heat gain in buildings through green reflective glass window (Green reflective glass was placed outside and other reflective glasses was placed inside) combinations at both peak summer and winter days

Figure 5.4.9, shows the arrangement of green reflective glass window combinations GC7 to GC12 for building. Tables 5.4.4, 5.4.5 and Figures 5.4.10, 5.4.11 show the total solar heat gain in buildings through these six combinations from eight orientations of the building on both peak summer and winter days. From the graphs, it is clearly observed that in south orientation, all green reflective glass window combinations are gaining less heat at peak summer day and gaining more heat in buildings at peak winter day when compared with other orientations.

Figure 5.4.9 Green reflective glass window combinations GC7 to GC12 with an air gap of 10mm, O-Outdoor, i-Indoor

Table 5.4.4 Total solar heat gain in buildings through green reflective glass window combinations at peak summer day

	Green reflective glass window combinations					
Direction	GC7	GC8	GC9	GC10	GC11	GC12
North	2.03	2.10	2.06	2.16	2.00	2.09
North East	2.36	2.45	2.40	2.52	2.33	2.43
East	2.49	2.58	2.53	2.66	2.46	2.56
South East	2.25	2.33	2.28	2.39	2.22	2.31
South	1.87	1.93	1.89	1.99	1.84	1.92
South West	2.25	2.33	2.28	2.39	2.22	2.31
West	2.49	2.58	2.53	2.66	2.46	2.56
North West	2.36	2.45	2.40	2.52	2.33	2.43

Table 5.4.5 Total solar heat gain in buildings through green reflective glass window combinations at peak winter day

	Green reflective glass window combinations					
Direction	GC7	GC8	GC9	GC10	GC11	GC12
North	1.58	1.62	1.59	1.68	1.55	1.63
North East	1.94	2.00	1.96	2.07	1.90	2.00
East	3.93	4.03	3.95	4.18	3.84	4.04
South East	5.93	6.09	5.97	6.31	5.79	6.10
South	7.03	7.22	7.07	7.49	6.87	7.23
South West	5.67	5.82	5.70	6.04	5.54	5.83
West	3.74	3.85	3.77	3.99	3.66	3.85
North West	1.94	2.00	1.96	2.07	1.90	2.00

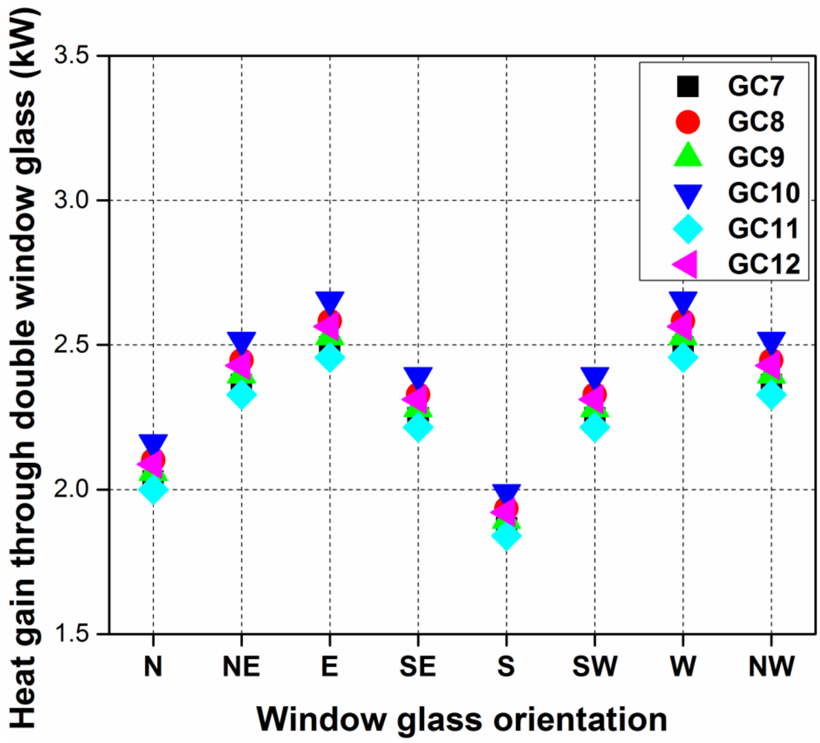


Figure 5.4.10 Total solar heat gain in buildings through green reflective glass window combinations at peak summer day

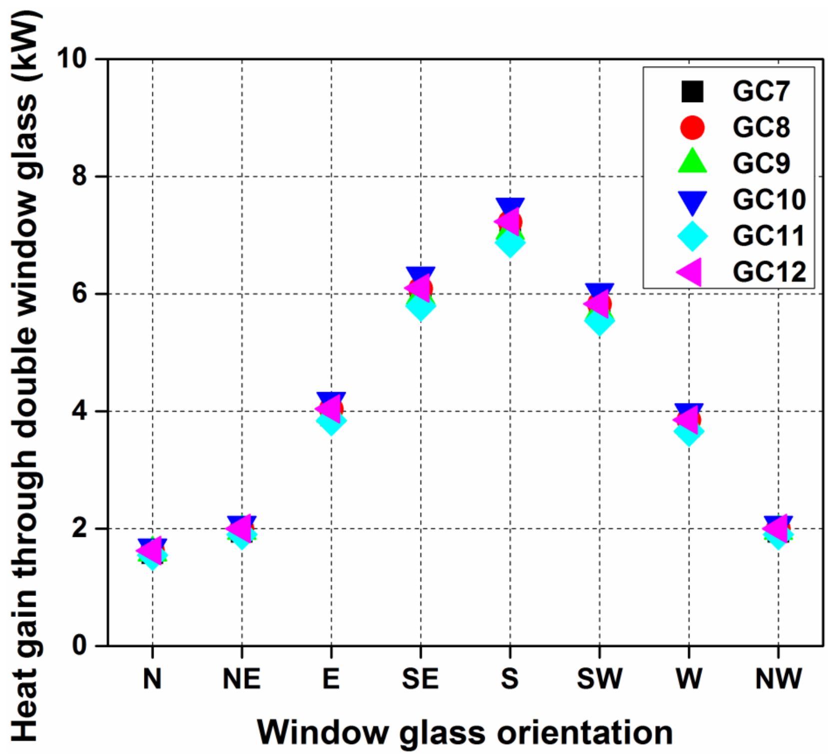


Figure 5.4.11 Total solar heat gain in buildings through green reflective glass window combinations at peak winter day

5.4.5 Annual cooling load decrease and heating load increase in buildings using green reflective glass window combinations in comparison with double clear glass window in summer and winter seasons

Figures 5.4.12, 5.4.13 indicate the graph between annual cooling load decrease and heating load increase in buildings using green reflective glass window combinations compared with double clear glass window in eight orientations. From the Figure 5.4.12, it is clearly observed that, all green reflective glass window combinations are reducing more cooling load in south orientation. Among which, GC11 combination glass window reduces the highest cooling load 767.07 kWh inside the building in summer season. From the Figure 5.4.13, it is observed that, all green reflective glass window combinations are increasing more heating load in south orientation. Among which GC10 combination glass window increases the highest heating load 2296.78 kWh inside the building in winter season.

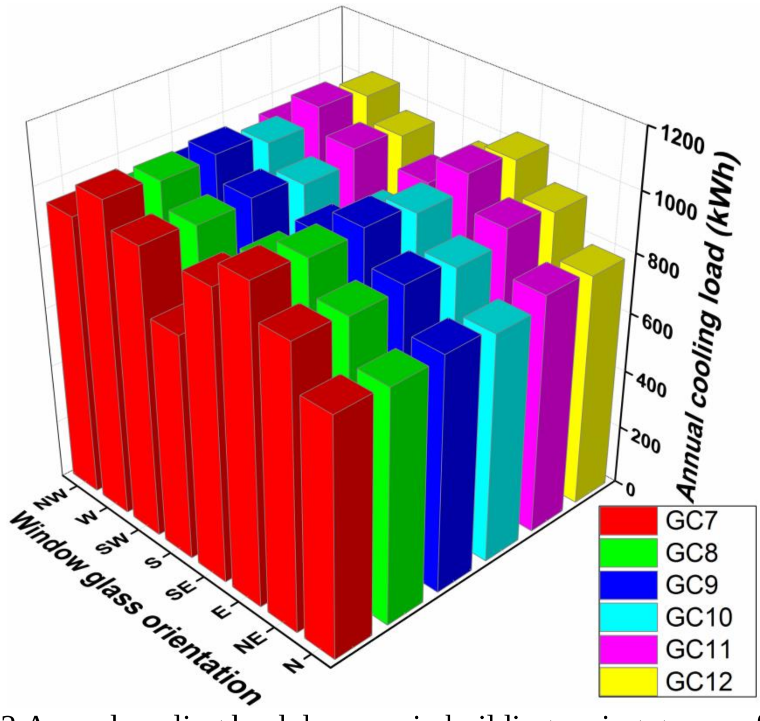


Figure 5.4.12 Annual cooling load decrease in buildings using green reflective glass window combinations in summer season

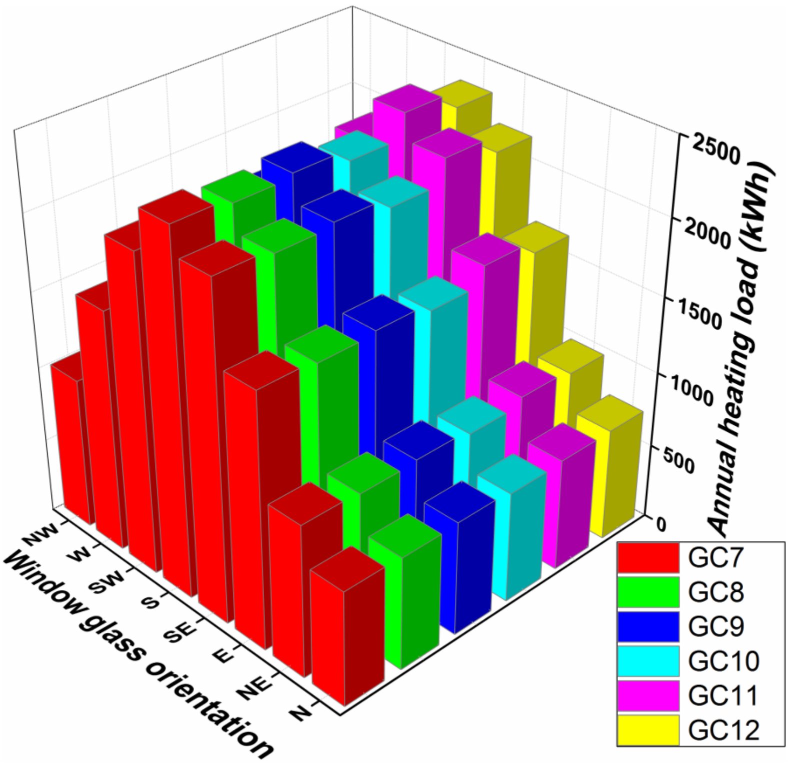


Figure 5.4.13 Annual heating load increase in buildings using green reflective glass window combinations in winter season

5.4.6 Annual cost saving of buildings using green reflective glass window combinations compared with double clear glass window

Figure 5.4.14, shows the annual cost saving of buildings using green reflective glass window combinations in eight orientations of Jodhpur climatic region. From the graph, it is clearly shown that GC11 green reflective glass window combination is the most energy efficient glass window and also, it saves more cost when compared with all other double reflective glass window combinations. In south east orientation GC11 combination glass window saves 5448.9 (Rupees/year), in south west orientation it saves 5304.6 (Rupees/year) and in south orientation it saves 5285.5 (Rupees/year), for Jodhpur climatic region.

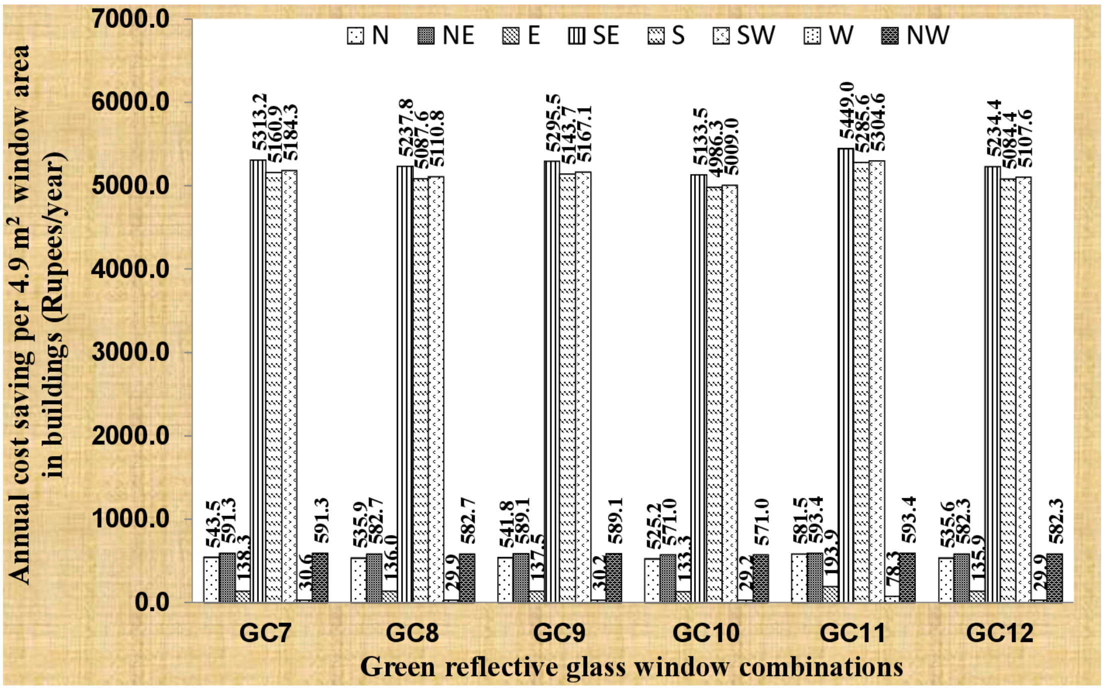


Figure 5.4.14 Annual cost saving of buildings using green reflective glass window combinations compared with double clear glass window

5.4.7 Solar heat gain in buildings through grey reflective glass window (Grey reflective glass was placed outside and other reflective glasses was placed inside) combinations in both summer and winter seasons

Figure 5.4.15, shows the arrangement of grey reflective glass window combinations GC13 to GC18 for building. Tables 5.4.6, 5.4.7 and Figures 5.4.16, 5.4.17 show the total solar heat gain in buildings through these six combinations from eight orientations of the building on both peak summer and winter days. From the graphs, it is clearly observed that in south orientation, all green reflective glass window combinations are gaining less heat at peak summer day and gaining more heat in buildings at peak winter day when compared with other orientations.

Figure 5.4.15 Grey reflective glass window combinations GC13 to GC18 with an air gap of 10mm, O-Outdoor, i-Indoor

Table 5.4.6 Total solar heat gain in buildings through grey reflective glass window combinations at peak summer day

	Grey reflective glass window combinations					
Direction	GC13	GC14	GC15	GC16	GC17	GC18
North	1.98	1.92	2.03	1.87	1.98	1.93
North East	2.31	2.24	2.37	2.18	2.30	2.24
East	2.44	2.36	2.50	2.30	2.43	2.37
South East	2.20	2.13	2.25	2.08	2.19	2.14
South	1.82	1.77	1.87	1.72	1.82	1.77
South West	2.20	2.13	2.25	2.08	2.19	2.14
West	2.44	2.36	2.50	2.30	2.43	2.37
North West	2.31	2.24	2.37	2.18	2.30	2.24

Table 5.4.7 Total solar heat gain in buildings through grey reflective glass window combinations at peak winter day

	Grey reflective glass window combinations					
Direction	GC13	GC14	GC15	GC16	GC17	GC18
North	1.53	1.50	1.58	1.45	1.53	1.49
North East	1.88	1.84	1.95	1.78	1.88	1.83
East	3.80	3.72	3.93	3.60	3.80	3.70
South East	5.74	5.62	5.94	5.43	5.74	5.59
South	6.81	6.67	7.04	6.44	6.80	6.62
South West	5.49	5.37	5.67	5.19	5.48	5.34
West	3.63	3.55	3.75	3.43	3.62	3.53
North West	1.88	1.84	1.95	1.78	1.88	1.83

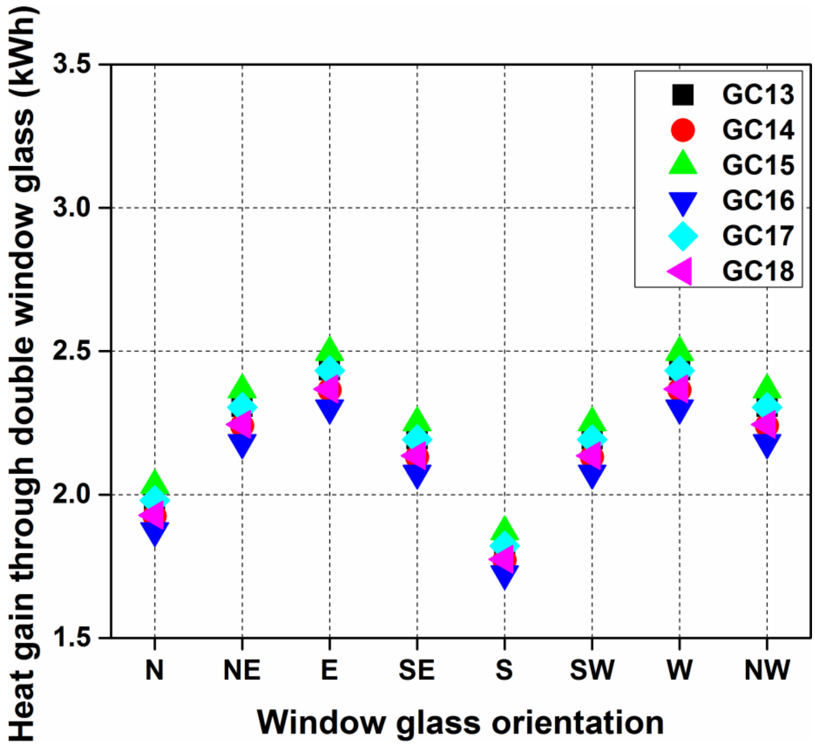


Figure 5.4.16 Total solar heat gain in buildings through grey reflective glass window combinations at peak summer day

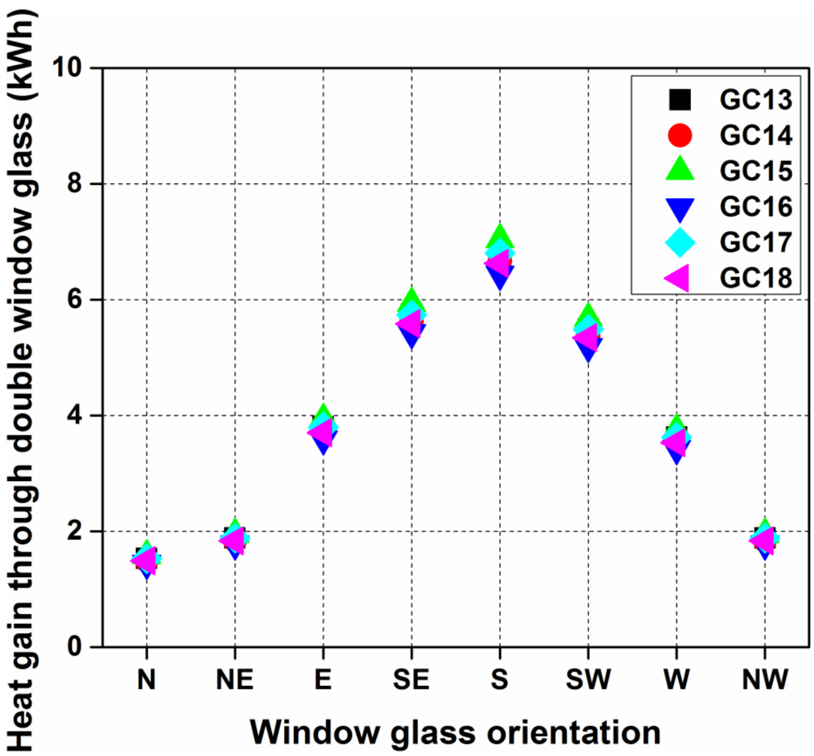


Figure 5.4.17 Total solar heat gain in buildings through grey reflective glass window combinations at peak winter day

5.4.8 Annual cooling load decrease and heating load increase in buildings using grey reflective glass window combinations in comparison with double clear glass window in summer and winter seasons

Figures 5.4.18, 5.4.19 indicate the graph between annual cooling load decrease and heating load increase in buildings using grey reflective glass window combinations compared with double clear glass window in eight orientations. From the Figure 5.4.18, it is clearly observed that, all grey reflective glass window combinations are reducing more cooling load in south orientation. Among which GC16 combination glass window reduces the highest cooling load 791.36 kWh inside the building in summer season. From the Figure 5.4.19, it is clearly observed that, all grey reflective glass window combinations are increasing more heating load in south orientation. Among which GC13 combination glass window increases the highest heating load 2415.76 kWh inside the building in winter season.

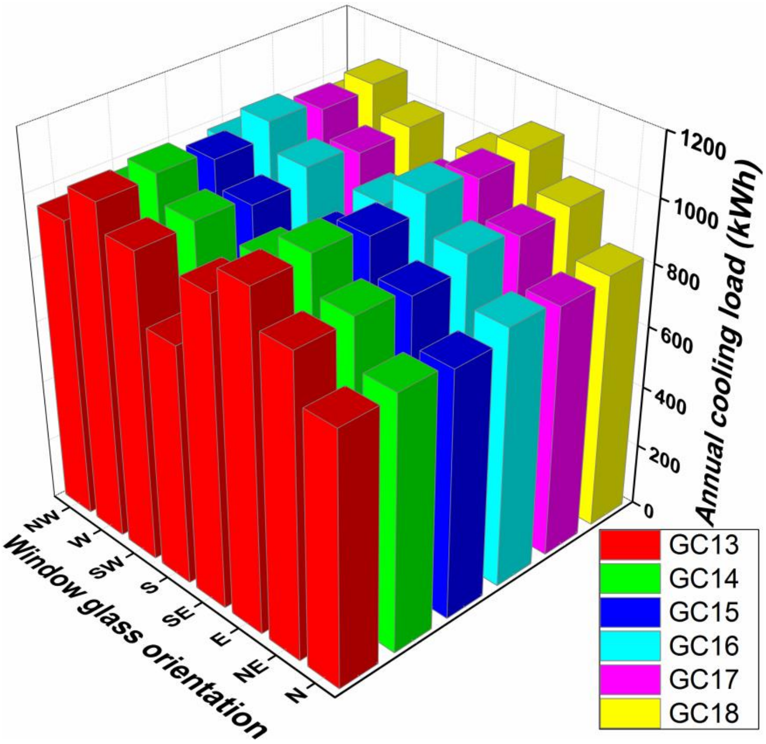


Figure 5.4.18 Annual cooling load decrease in buildings using grey reflective glass window combinations in summer season

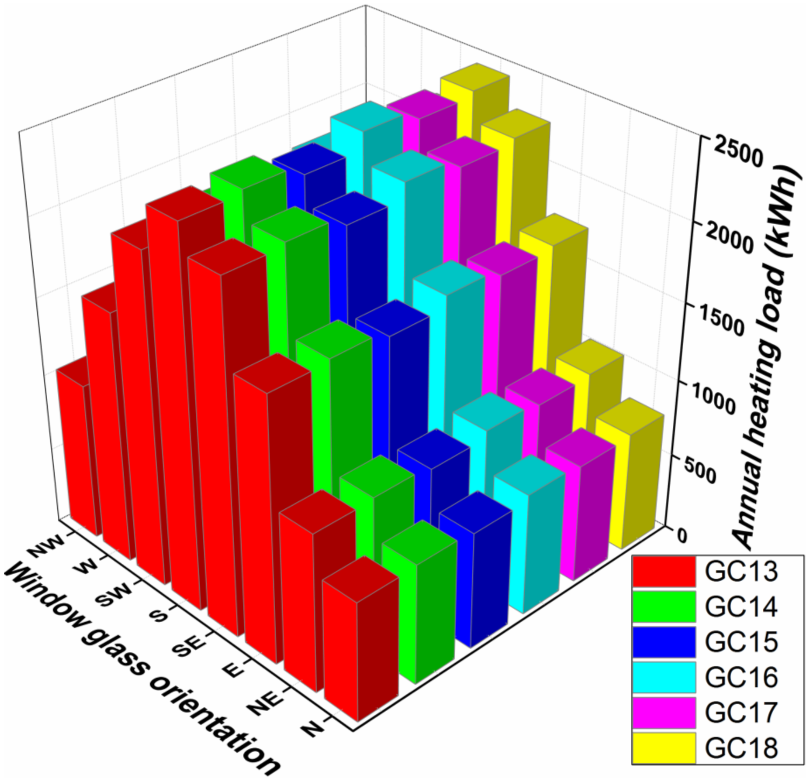


Figure 5.4.19 Annual heating load increase in buildings using grey reflective glass window combinations in winter season

5.4.9 Annual cost saving of buildings using grey reflective glass window combinations compared with double clear glass window

Figure 5.4.20, shows the annual cost saving of buildings using grey reflective glass window combinations in eight orientations of Jodhpur climatic region. From the graph, it is clearly shown that GC16 grey reflective glass window combination is the most energy efficient and also that, it saves more cost when compared with all other double reflective glass window combinations. In south east orientation, GC16 window combination saves 5545.5 (Rupees/year), in south west orientation it saves 5411.2 (Rupees/year), and in south orientation it saves 5386.5 (Rupees/year), in Jodhpur climatic region.

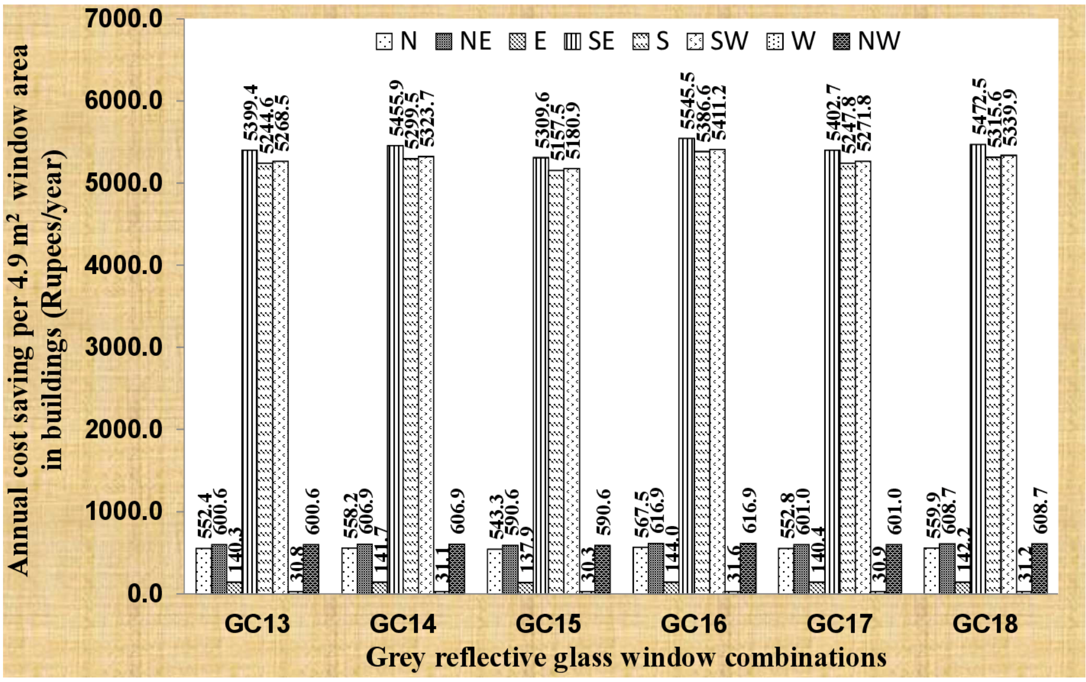


Figure 5.4.20 Annual cost saving of buildings using grey reflective glass window combinations compared with double clear glass window

5.4.10 Solar heat gain in buildings through double opal blue reflective glass window (Opal blue reflective glass was placed outside and other reflective glasses was placed inside) combinations at both peak summer and winter days

Figure 5.4.21, shows the arrangement of opal blue reflective glass window combinations GC19 to GC24 for building. Tables 5.4.8, 5.4.9 and Figures 5.4.22, 5.4.23 show the total solar heat gain in buildings through these six combinations from eight orientations of the building on both peak summer and winter days. From the graphs, it is clearly observed that in south orientation, all opal blue reflective glass window combinations are gaining less heat at peak summer day and gaining more heat in buildings at peak winter day when compared with other orientations.

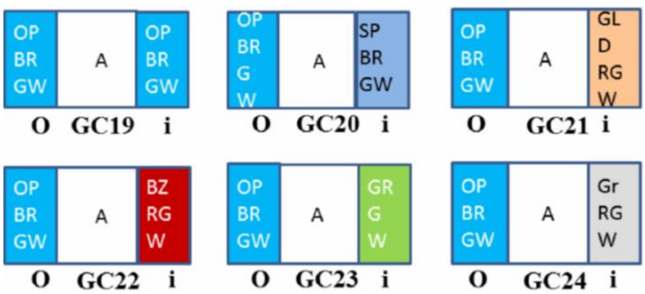


Figure 5.4.21 Opal blue reflective glass window combinations GC19 to GC24 with an air gap of 10mm, O-Outdoor, i-Indoor

Table 5.4.8 Total solar heat gain in buildings through opal blue reflective glass window combinations at peak summer day

	Opal blue reflective glass window combinations					
Direction	GC19	GC20	GC21	GC22	GC23	GC24
North	2.06	2.18	2.00	2.11	2.05	2.11
North East	2.40	2.54	2.33	2.46	2.39	2.45
East	2.54	2.68	2.46	2.59	2.52	2.59
South East	2.29	2.42	2.22	2.34	2.27	2.33
South	1.90	2.01	1.84	1.94	1.89	1.94
South West	2.29	2.42	2.22	2.34	2.27	2.33
West	2.54	2.68	2.46	2.59	2.52	2.59
North West	2.40	2.54	2.33	2.46	2.39	2.45

Table 5.4.9 Total solar heat gain in buildings through opal blue reflective glass window combinations at peak winter day

	Opal blue reflective glass window combinations					
Direction	GC19	GC20	GC21	GC22	GC23	GC24
North	1.59	1.69	1.55	1.63	1.58	1.63
North East	1.96	2.08	1.90	2.00	1.95	2.00
East	3.96	4.19	3.84	4.05	3.94	4.05
South East	5.98	6.33	5.80	6.11	5.94	6.11
South	7.09	7.50	6.88	7.25	7.05	7.24
South West	5.72	6.05	5.55	5.84	5.68	5.84
West	3.78	4.00	3.66	3.86	3.75	3.86
North West	1.96	2.08	1.90	2.00	1.95	2.00

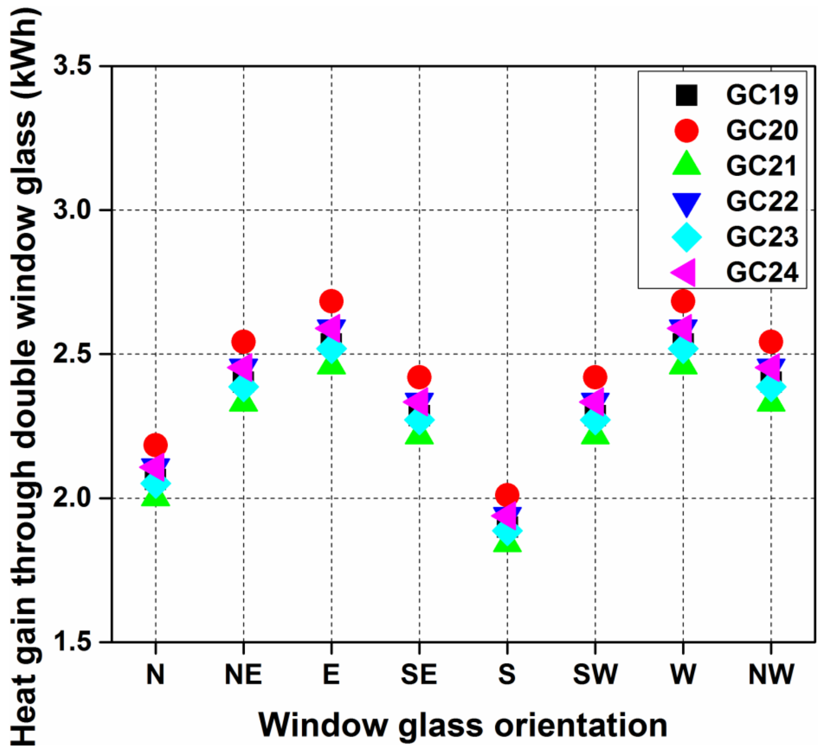


Figure 5.4.22 Total solar heat gain in buildings through opal blue reflective glass window combinations at peak summer day

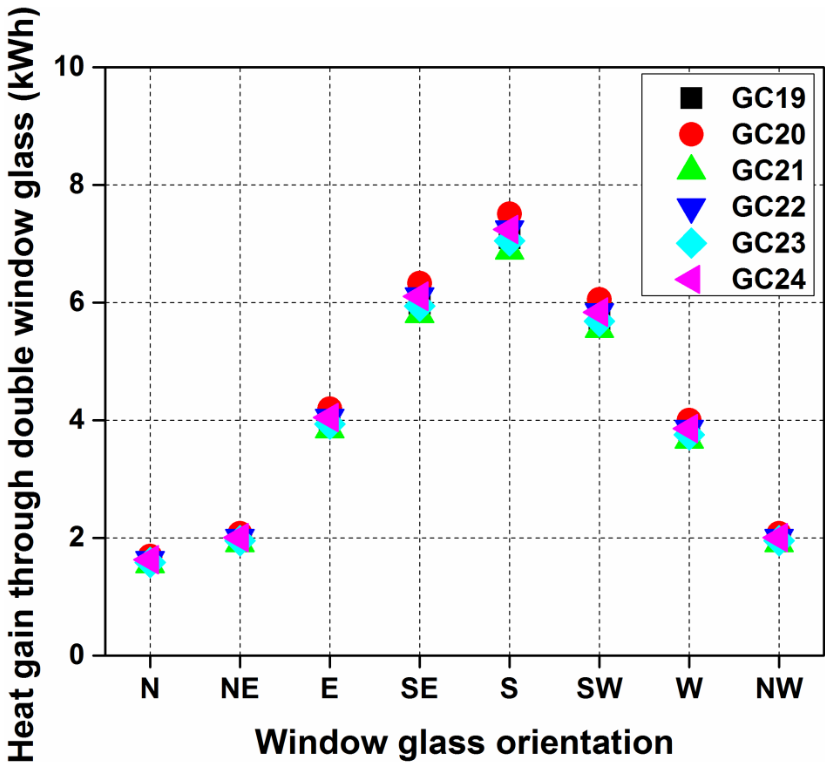


Figure 5.4.23 Total solar heat gain in buildings through opal blue reflective glass window combinations at peak winter day

5.4.11 Annual cooling load decrease and heating load increase in buildings using opal blue reflective glass window combinations in comparison with double clear glass window in summer and winter seasons

Figures 5.4.24, 5.4.25 indicate the graph between annual cooling load decrease and heating load increase in buildings using opal blue reflective glass window combinations compared with double clear glass window, in eight orientations. From the Figure 5.4.24, it is clearly observed that, all opal blue reflective glass window combinations are reducing more cooling load in south orientation. Among which GC21 combination glass window decreases the highest cooling load 766.63 kWh inside the building in summer season. From the Figure 5.4.25, it is clearly seen that, all opal blue reflective glass window combinations are increasing more heating load. Among which GC20 combination glass window increases the highest heating load 2293.64 kWh inside the building in winter season.

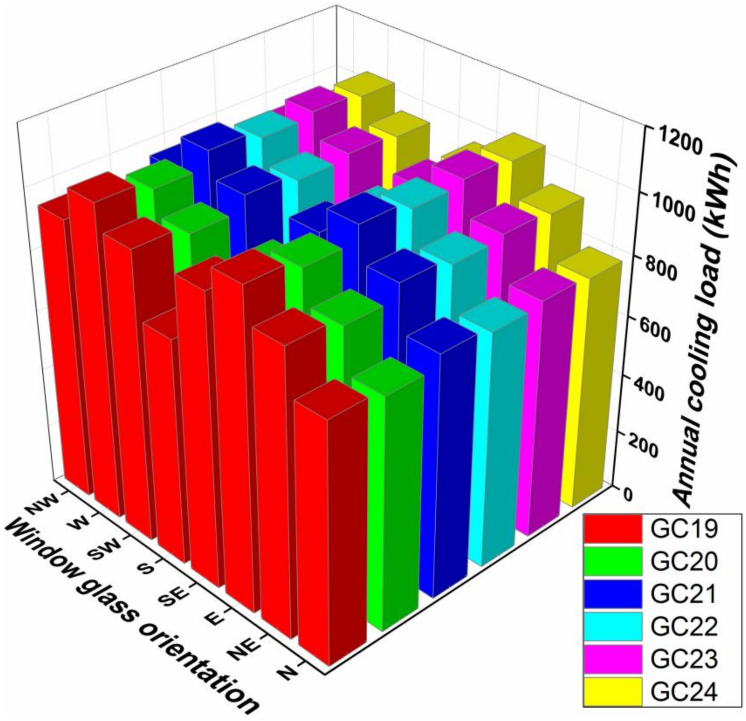


Figure 5.4.24 Annual cooling load decrease in buildings using opal blue reflective glass window combinations in summer season

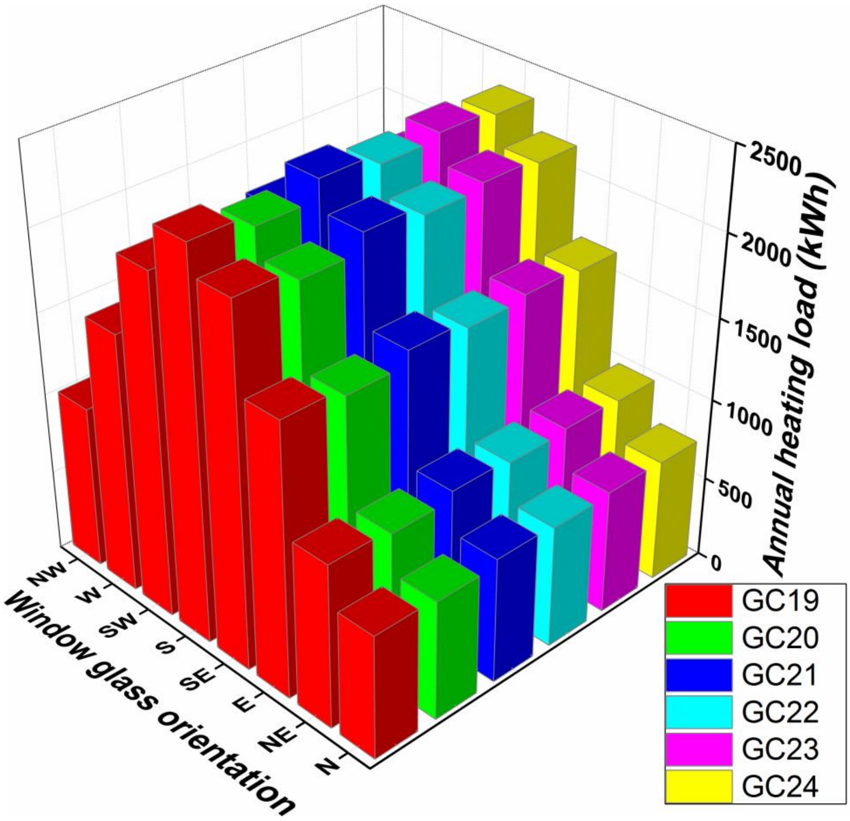


Figure 5.4.25 Annual heating load increase in buildings using opal blue reflective glass window combinations in winter season

5.4.12 Annual cost saving of buildings using opal blue reflective glass window combinations for buildings compared with double clear glass window

Figure 5.4.26, shows the annual cost saving of buildings using opal blue reflective glass window combinations in eight orientations of Jodhpur climatic region. From the graph, it is clearly shown that GC21 opal blue reflective glass window combination is the most energy efficient, and also that, it saves more cost when compared with all other double reflective glass window combinations. In south east orientation, GC21 glass window combination saves 5372.2 (Rupees/year), in south west orientation it saves 5242.1 (Rupees/year) and in south orientation it saves 5218.3 (Rupees/year), for Jodhpur climatic region.

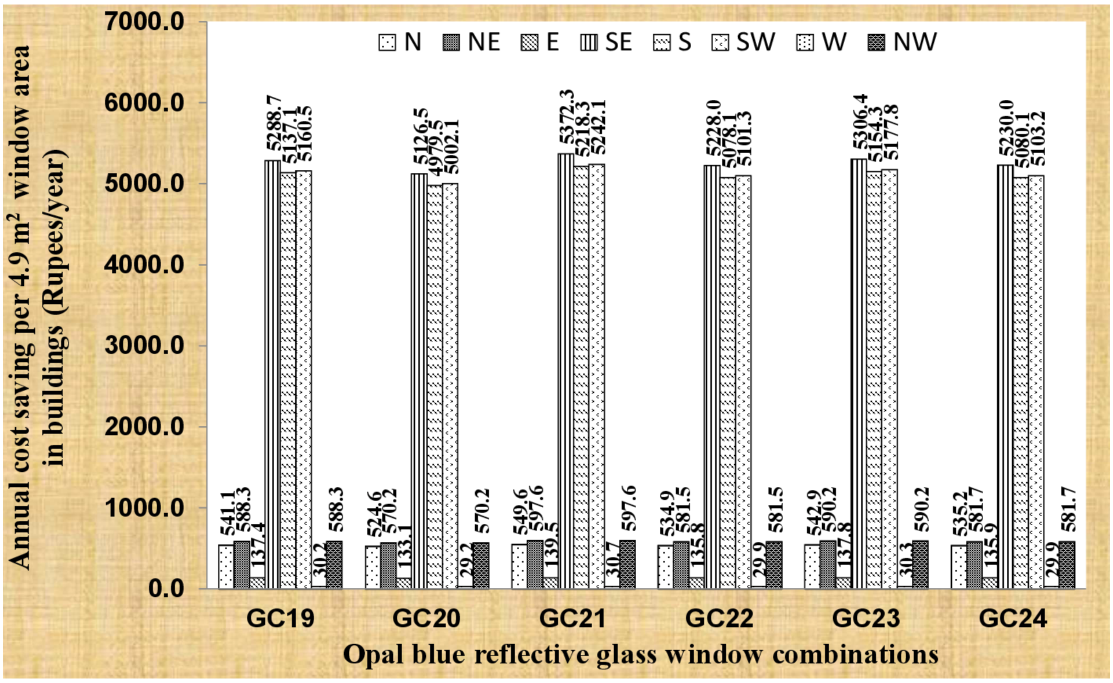


Figure 5.4.26 Annual cost saving of buildings using opal blue reflective glass window combinations compared with double clear glass window

5.4.13 Solar heat gain in buildings through sapphire blue reflective glass window (Sapphire blue reflective glass was placed outside and other reflective glasses was placed inside) combinations in both summer and winter seasons

Figure 5.4.27, shows the arrangement of sapphire blue reflective glass window combinations GC25 to GC30 for building. Tables 5.4.10, 5.4.11 and Figures 5.4.28, 5.4.29 show the total solar heat gain in buildings through these six combinations from eight orientations of the building on both peak summer and winter days. From the graphs, it is clearly observed that in south orientation, all sapphire blue reflective glass window combinations are gaining less heat at peak summer day and gaining more heat in buildings at peak winter day when compared with other orientations.

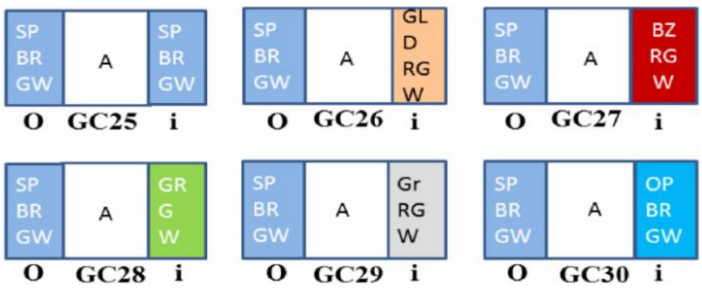


Figure 5.4.27 Sapphire blue reflective glass window combinations GC25 to GC30 with an air gap of 10mm, O-Outdoor, i-Indoor

Table 5.4.10 Total solar heat gain in buildings through sapphire blue reflective glass window combinations at peak summer day

	Sapphire blue reflective glass window combinations					
Direction	GC25	GC26	GC27	GC28	GC29	GC30
North	2.90	2.62	2.79	2.70	2.79	2.72
North East	3.37	3.05	3.24	3.14	3.25	3.17
East	3.56	3.21	3.42	3.32	3.43	3.34
South East	3.21	2.90	3.08	2.99	3.09	3.01
South	2.67	2.41	2.56	2.49	2.57	2.50
South West	3.21	2.90	3.08	2.99	3.09	3.01
West	3.56	3.21	3.42	3.32	3.43	3.34
North West	3.37	3.05	3.24	3.14	3.25	3.17

Table 5.4.11 Total solar heat gain in buildings through sapphire blue reflective glass window combinations at peak winter day

	Sapphire blue reflective glass window combinations					
Direction	GC25	GC26	GC27	GC28	GC29	GC30
North	2.24	2.02	2.15	2.09	2.15	2.10
North East	2.75	2.49	2.65	2.57	2.65	2.59
East	5.56	5.02	5.35	5.18	5.35	5.22
South East	8.39	7.58	8.07	7.83	8.08	7.88
South	9.95	8.99	9.57	9.28	9.58	9.35
South West	8.02	7.25	7.71	7.48	7.72	7.54
West	5.30	4.79	5.10	4.94	5.10	4.98
North West	2.75	2.49	2.65	2.57	2.65	2.59

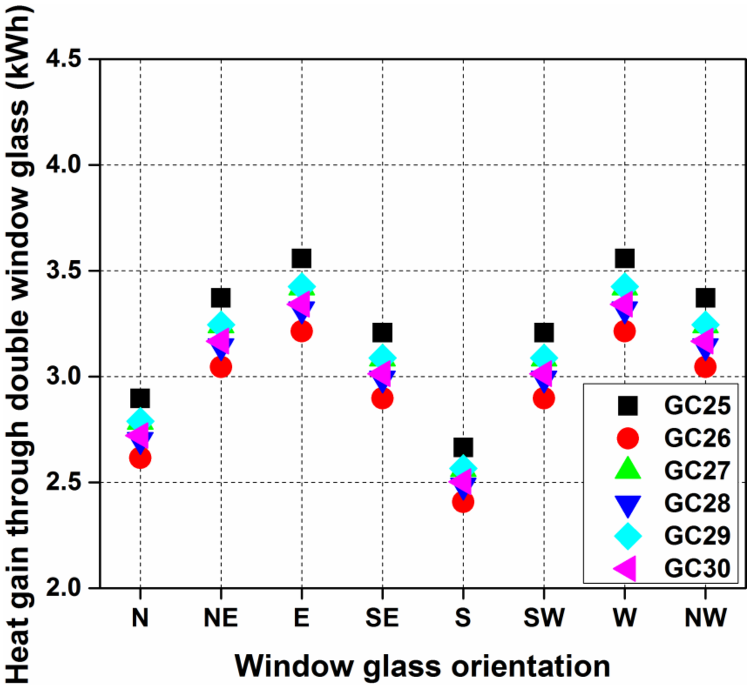


Figure 5.4.28 Total solar heat gain in buildings through sapphire blue reflective glass window combinations at peak summer day

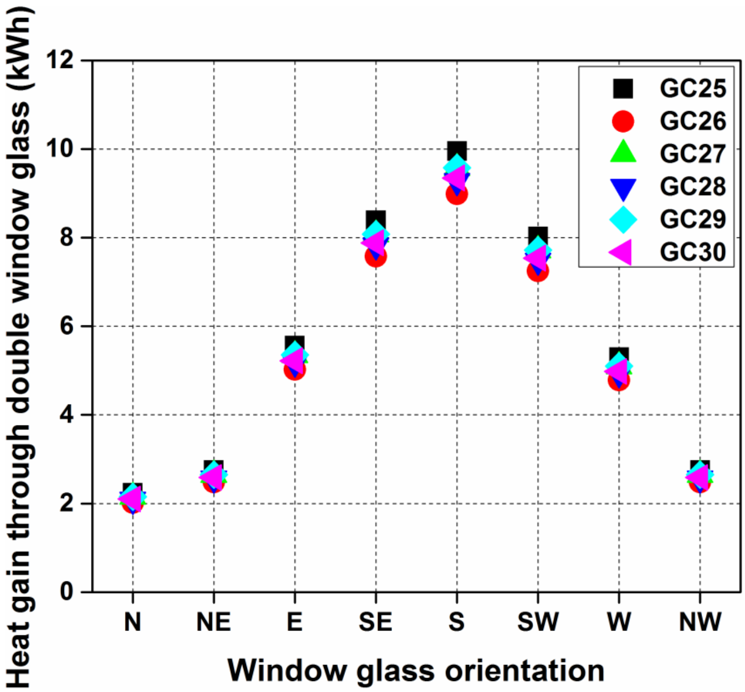


Figure 5.4.29 Total solar heat gain in buildings through sapphire blue reflective glass window combinations at peak winter day

5.4.14 Annual cooling load decrease and heating load increase in buildings using sapphire blue reflective glass window combinations in comparison with double clear glass window in summer and winter seasons

Figure 5.4.30, 5.4.31 indicate the graph between annual cooling load decrease and heating load increase in buildings and sapphire blue reflective glass window combinations compared with double clear glass window, in eight orientations. From the Figure 5.4.30, it is clearly observed that, all sapphire blue reflective glass window combinations are reducing more cooling load in south orientation. Among which GC26 combination glass window reduces the highest cooling load 648.38 kWh inside the building in summer season. From the Figure 5.4.31, it is clearly observed that, all sapphire blue reflective glass window combinations are increasing more heating load in south orientation. Among which GC25 combination glass window increases the highest heating load 1863.49 kWh inside the building in winter season.

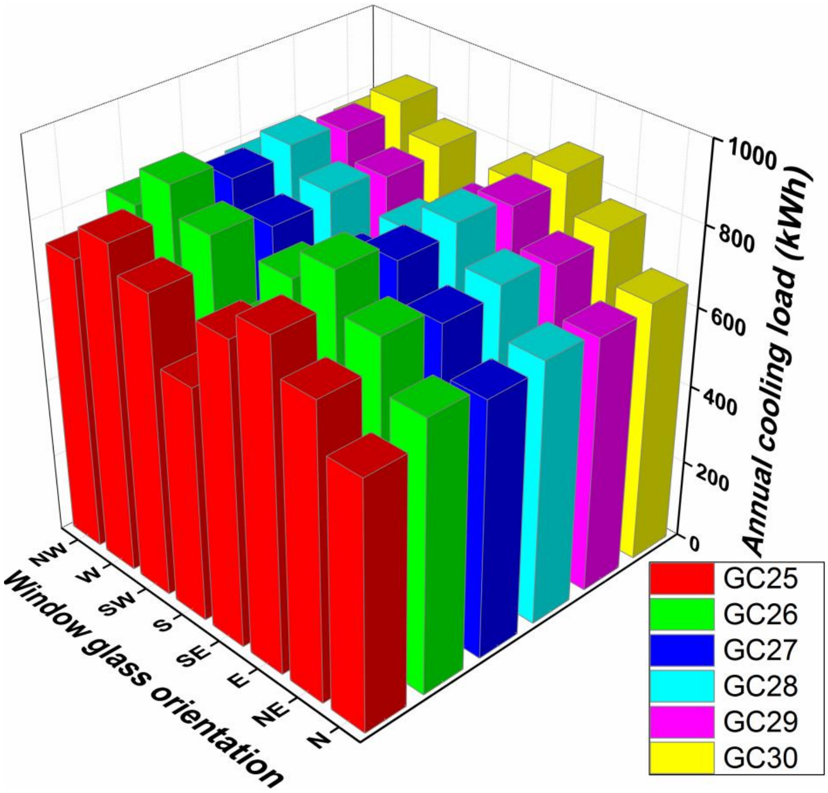


Figure 5.4.30 Annual cooling load decrease in buildings using sapphire blue reflective glass window combinations in summer season

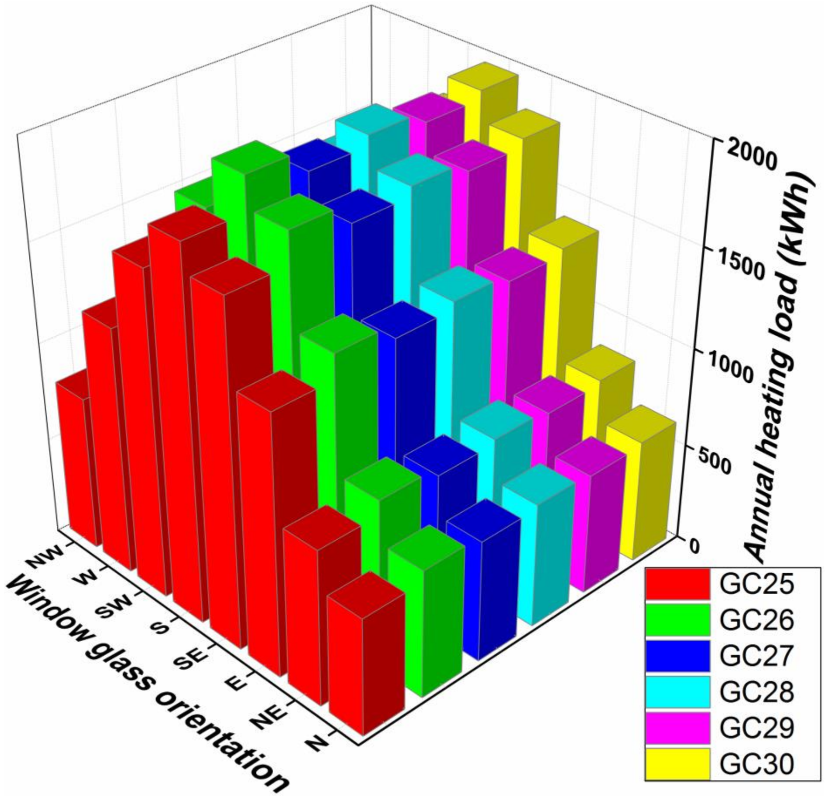


Figure 5.4.31 Annual heating load increase in buildings using sapphire blue reflective glass window combinations in winter season

5.4.15 Annual cost saving of buildings using sapphire blue reflective glass window combinations compared with double clear glass window

Figure 5.4.32, shows the annual cost saving of buildings using sapphire blue reflective glass window combinations in eight orientations of Jodhpur climatic region. From the graph, it is clearly shown that, GC26 sapphire blue reflective glass window combination is most energy efficient and also that, it saves more cost when compared with all other double glass window combinations. In south east orientation, GC26 glass window combination saves 4543.6 (Rupees/year), in south west orientation it saves 4433.5 (Rupees/year) and in south orientation it saves 4413.3 (Rupees/year), for Jodhpur climatic region.

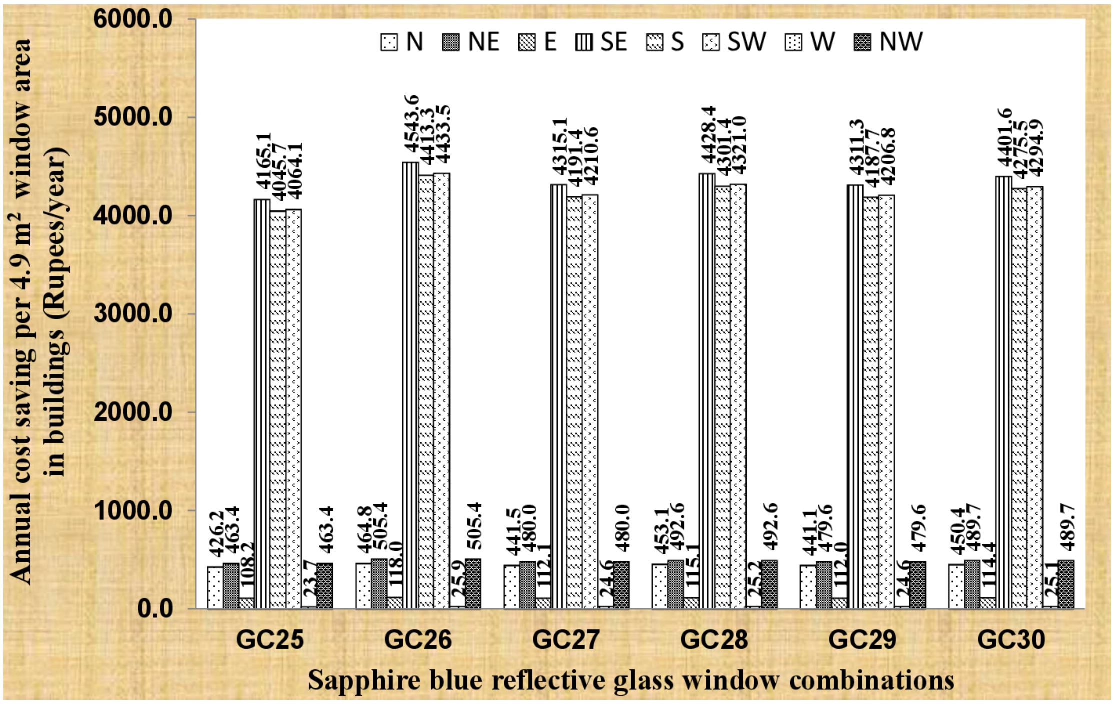


Figure 5.4.32 Annual cost saving of buildings using sapphire blue reflective glass window combinations compared with double clear glass window

5.4.16 Solar heat gain in buildings through gold reflective glass window (Gold reflective glass was placed outside and other reflective glasses was placed inside) combinations at both peak summer and winter days

Figure 5.4.33 shows the arrangement of gold reflective glass window combinations GC19 to GC24 for building. Tables 5.4.12 and 5.4.13 and Figures 5.4.34 and 5.4.35 show the total solar heat gain in buildings through these six combinations from eight orientations of the building on both peak summer and winter days of Jodhpur climatic region. From the graphs, it is clearly observed that in south orientation, all gold reflective glass window combinations are gaining less heat at peak summer day and gaining more heat in buildings at peak winter day when compared with other orientations.

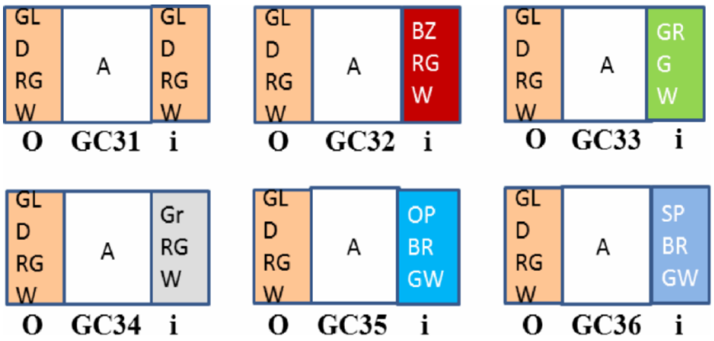


Figure 5.4.33 Gold reflective glass window combinations GC31 to C36 with an air gap of 10mm, O-Outdoor, i-Indoor

Table 5.4.12 Total solar heat gain in buildings through gold reflective glass window combinations at peak summer day

	Gold reflective glass window combinations					
Direction	GC31	GC32	GC33	GC34	GC35	GC36
North	3.27	3.39	3.28	3.36	3.30	3.52
North East	3.80	3.94	3.81	3.91	3.84	4.10
East	4.01	4.16	4.02	4.12	4.05	4.32
South East	3.62	3.75	3.63	3.72	3.65	3.90
South	3.00	3.12	3.01	3.09	3.03	3.24
South West	3.62	3.75	3.63	3.72	3.65	3.90
West	4.01	4.16	4.02	4.12	4.05	4.32
North West	3.80	3.94	3.81	3.91	3.84	4.10

Table 5.4.13 Total solar heat gain in buildings through gold reflective glass window combinations at peak winter day

	Gold reflective glass window combinations					
Direction	GC31	GC32	GC33	GC34	GC35	GC36
North	2.52	2.62	2.53	2.59	2.55	2.72
North East	3.10	3.22	3.11	3.19	3.13	3.35
East	6.27	6.50	6.29	6.44	6.33	6.76
South East	9.46	9.82	9.49	9.73	9.55	10.20
South	11.22	11.64	11.25	11.54	11.33	12.09
South West	9.04	9.39	9.07	9.30	9.13	9.75
West	5.97	6.20	5.99	6.14	6.03	6.44
North West	3.10	3.22	3.11	3.19	3.13	3.35

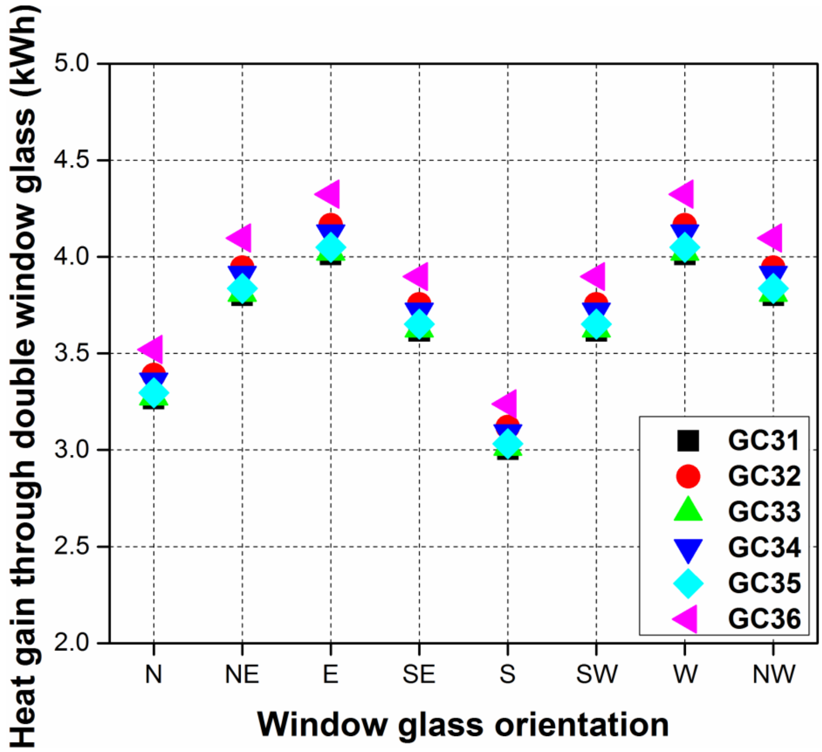


Figure 5.4.34 Total solar heat gain in buildings through gold reflective glass window combinations at peak summer day

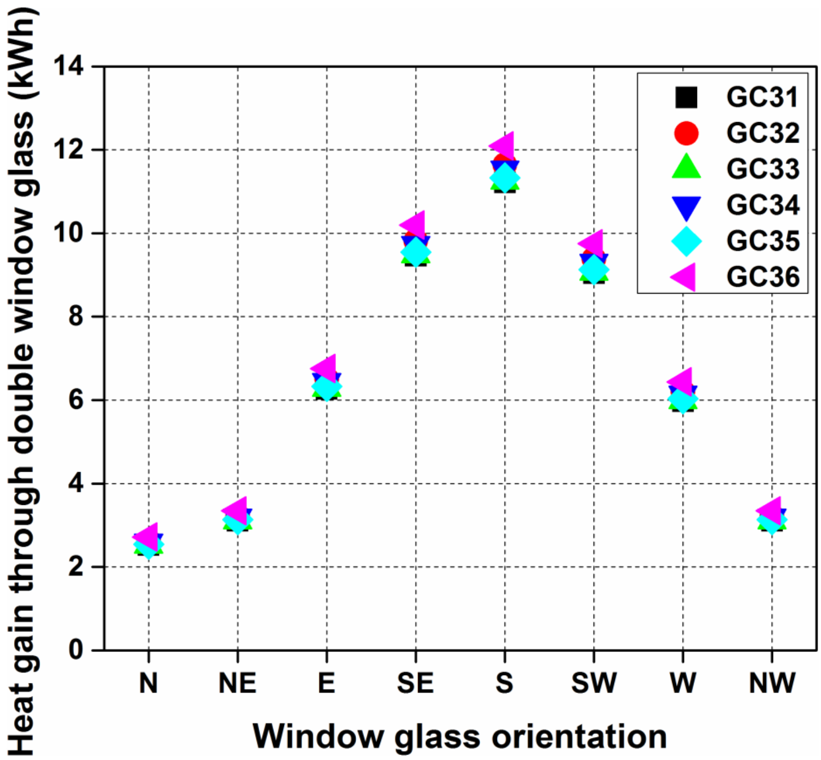


Figure 5.4.35 Total solar heat gain in buildings through gold reflective glass window combinations at peak winter day

5.4.17 Annual cooling load decrease and heating load increase in buildings using gold reflective glass window combinations in comparison with double clear glass window in summer and winter seasons

Figures 5.4.36, 5.4.37 indicate the graph between annual cooling load decrease and heating load increase in buildings and gold reflective glass window combinations compared with double clear glass window, in eight orientations. From the Figure 5.4.36 it is clearly observed that, all gold reflective glass window combinations are reducing more cooling load in south orientation. Among which GC31 combination window reduces the highest cooling load 523.26 kWh inside the building in summer season. From the Figure 5.4.37, it is clearly observed that, all gold reflective glass window combinations are increasing more heating load in south orientation. Among which GC36 combination glass window increases the highest heating load 1486.58 kWh inside the building in winter season.

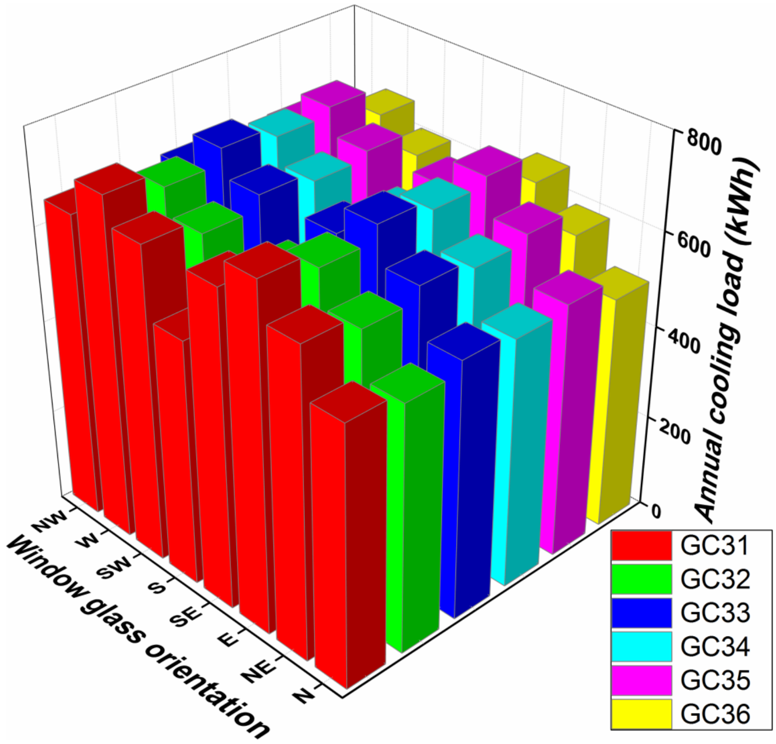


Figure 5.4.36 Annual cooling load decrease in buildings using gold reflective glass window combinations in summer season

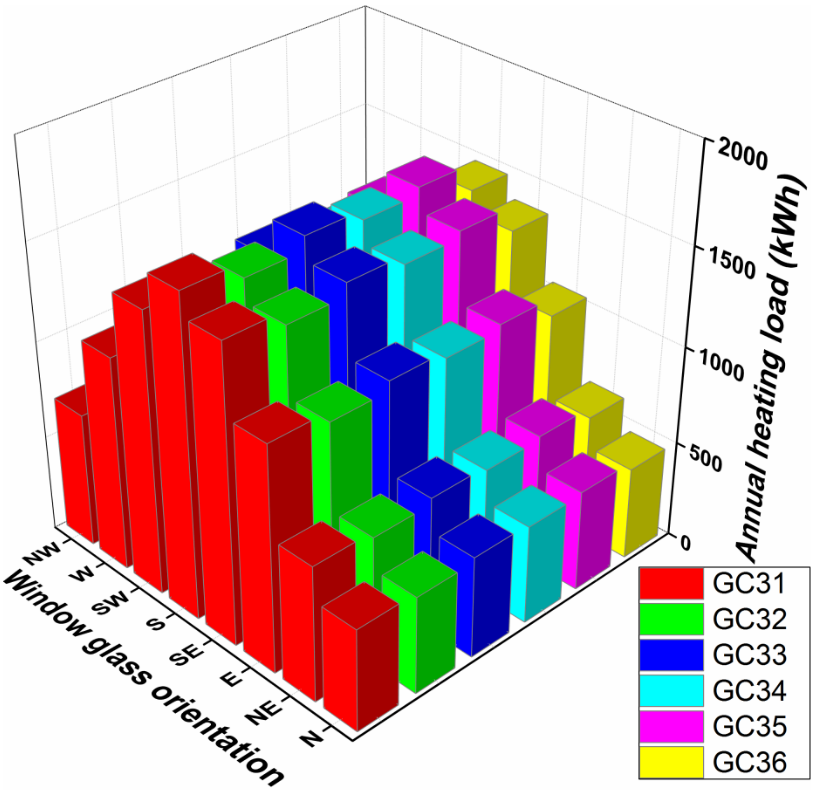


Figure 5.4.37 Annual heating load increase in buildings using gold reflective glass window combinations in winter season

5.4.18 Annual cost saving of buildings using gold reflective glass window combinations for buildings compared with double clear glass window

Figure 5.4.38, shows the annual cost saving of buildings using gold reflective glass window combinations in eight orientations of Jodhpur climatic region. From the graph, it is clearly shown that, GC31 gold reflective glass window combination is most energy efficient, and also that, it saves more cost when compared with all other double glass window combinations. In south east orientation, GC31 combination window saves 3666.8 (Rupees/year), in south west orientation it saves 3577.9 (Rupees/year) and in south orientation it saves 3561.7 (Rupees/year), for Jodhpur climatic region.

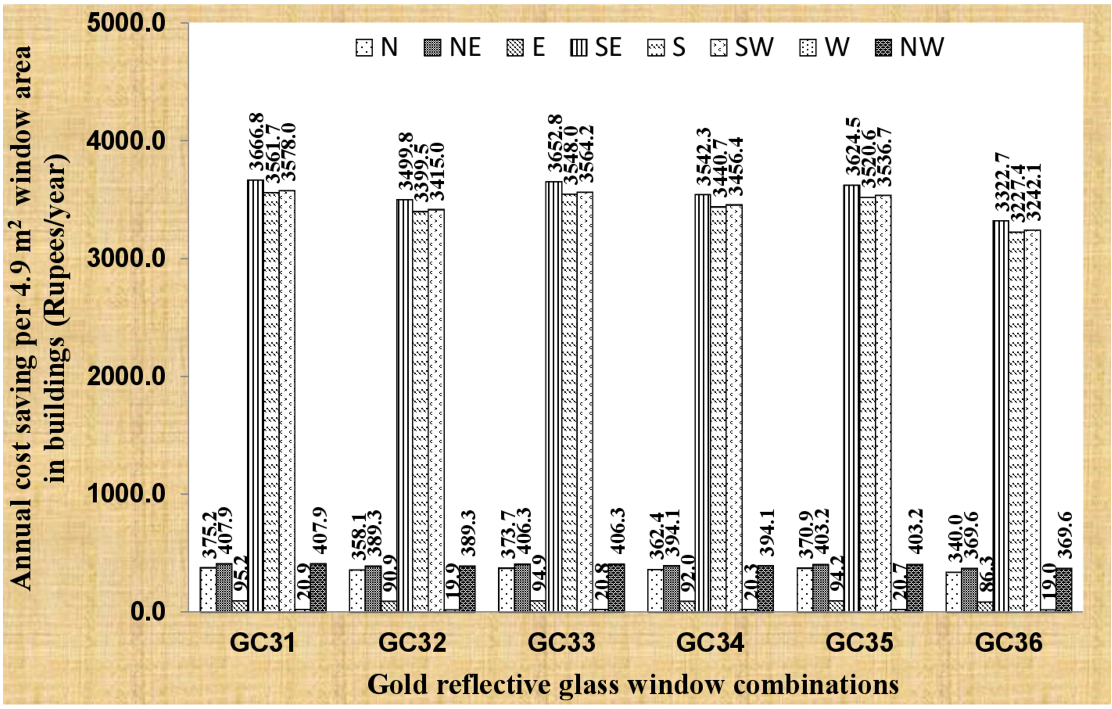


Figure 5.4.38 Annual cost saving of buildings using gold reflective glass window combinations compared with double clear glass window

5.4.19 Annual energy saving of buildings using double reflective glass window combinations compared with double clear glass window in summer season in south orientation

Figure 5.4.39, shows that the annual energy saving of various double reflective glass window combinations compared with double clear glass window combination in south orientation, of Jodhpur climatic region at summer season. From the results, GC16 glass window combination (Grey reflective glass window + Air gap 10mm + Gold reflective glass window) is saving 68.67% of energy compared to double clear window glazing combination compared with double clear window glazing combination.

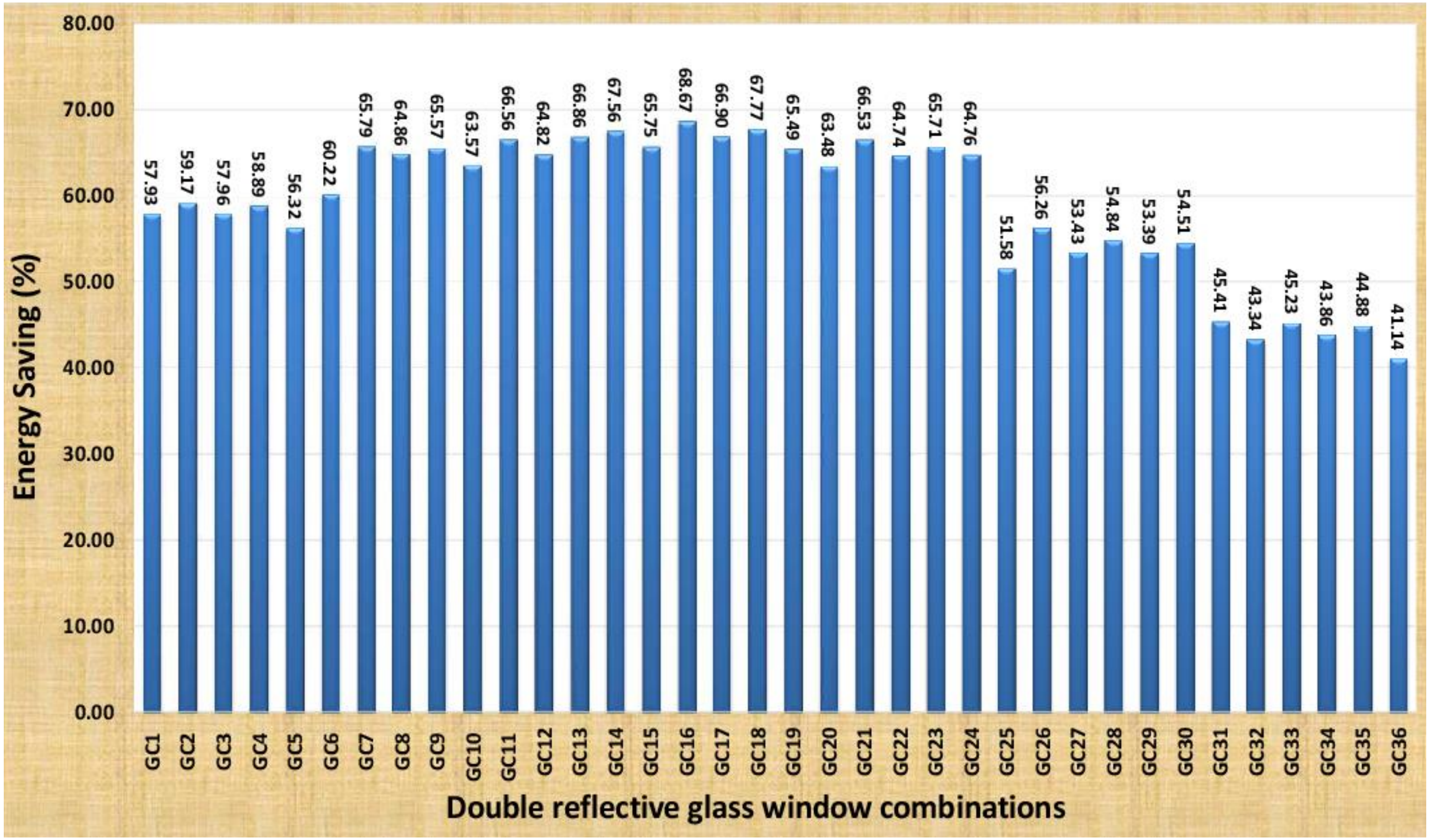


Figure 5.4.39 Annual energy saving of buildings using double reflective glass window combinations compared with double clear glass window in summer season

5.4.20 Annual cost saving of buildings using double reflective glass window combinations for buildings compared with double clear glass window in south orientation

Figure 5.4.40, shows that the net annual cost saving of thirty-six double reflective glass window combinations for buildings compared with double clear glass window in south orientation for Jodhpur climatic region in India. From the results, GC16 glass window combination (Grey reflective glass window + Air gap 10mm + Gold reflective glass window) is saving more cost of 5386.5 Rupees per year compared to double clear glass window.

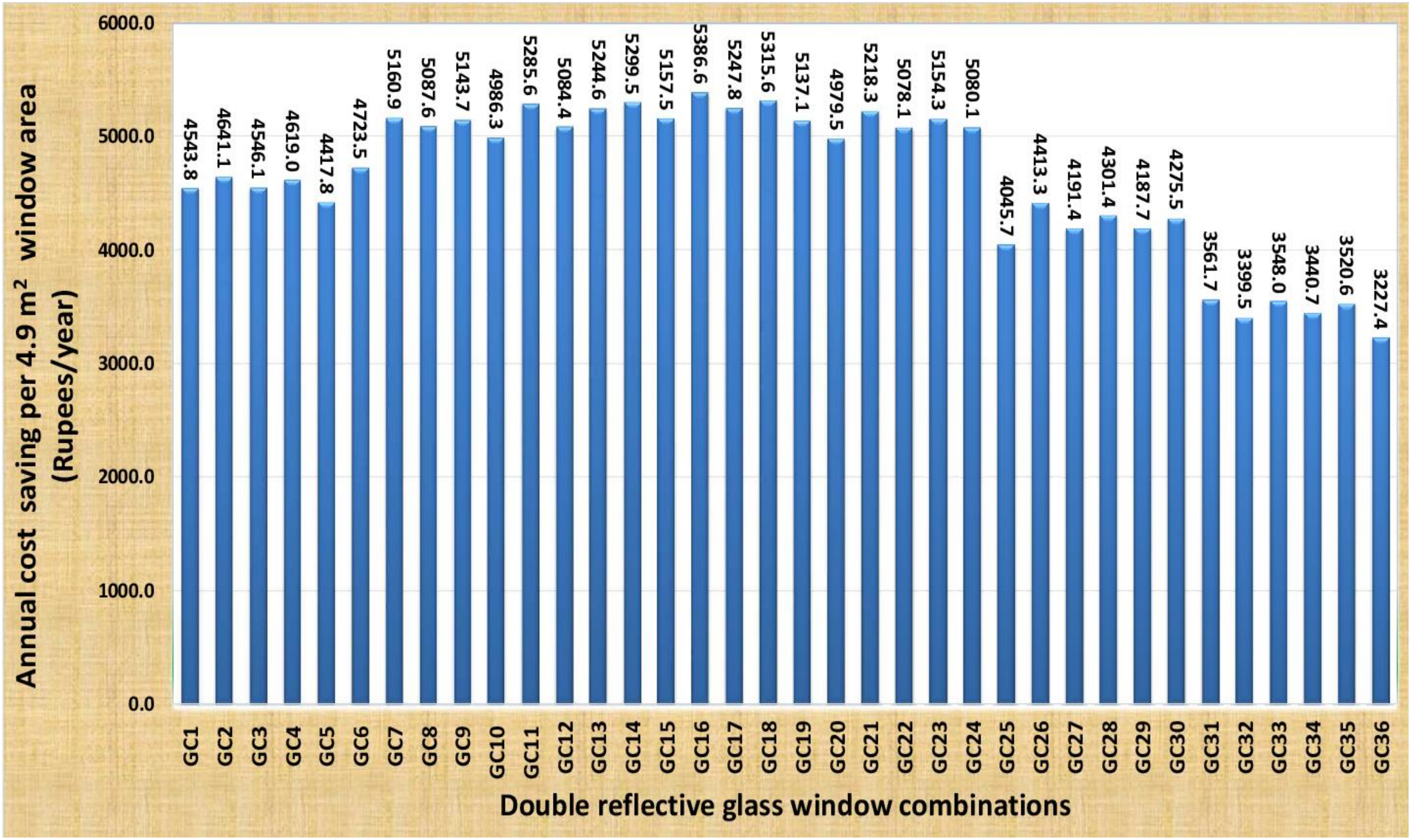


Figure 5.4.40 Annual cost saving of buildings using double reflective glass window combinations compared with double clear glass window in south orientation

CHAPTER-6

SIMULATION STUDIES OF HEAT GAIN IN BUILDINGS THROUGH WINDOW GLASS MATERIALS AT DIFFERENT WINDOW TO WALL RATIOS

6.1 INTRODUCTION

Window to wall area ratio plays a significant role in heat gain inside the buildings. So, it is necessary window to wall area ratio should be maintained for reducing heat gain in buildings. Window to wall ratio is defined as the ratio of the net glass area to the gross exterior wall area. The window to wall ratios maintained for building models are 20%, 40%, 60%, 80% and 100%. In this study, four glass materials namely clear, bronze, green and bronze reflective glasses are selected. Heat gain in buildings was evaluated using Energy plus simulation software for four Indian climatic zones at different window area to wall area ratios. Table 6.1.1 shows the details about the number of glass windows studied in this chapter.

Table 6.1.1 Total glass combinations studied for heat gain in buildings

	Number of glasses studied					
Place	WWR (20%)	WWR (40%)	WWR (60%)	WWR (80%)	WWR (100%)	Orientations
Mangalore	4	4	4	4	4	4
Bangalore	6	6	6	6	6	1 (South)
Jodhpur	6	6	6	6	6	1 (South)
Kolkata	6	6	6	6	6	1 (South)
New Delhi	6	6	6	6	6	1 (South)

6.2 STUDY OF VARIOUS GLASS MATERIALS AT DIFFERENT WINDOW TO WALL RATIOS FOR THE REDUCTION OF HEAT GAIN IN BUILDINGS FOR WARM AND HUMID CLIMATIC REGION

The building model with different window glasses was designed in Design builder software. The building model was designed with laterite building material. The dimensions of the building model were 3.5 m × 3.5 m × 3.5 m with 0.22 m wall thickness. Total sixteen glass combinations (clear, bronze, green, and bronze-reflective glasses) analysed in heat gain point of view using Energy plus simulation software in warm and humid climatic zone. Table 6.2.1, shows the details of four single glass windows which were studied to find heat gain in buildings.

Table 6.2.1 Total glass combinations studied for heat gain in buildings

Number of glasses	Climatic zone	Number of orientations	Window to wall ratios	Total number of combinations arranged
4	Warm & Humid	East, West, North and South	20%, 40%, 60%, 80% and 100%	4×4×1 = 16 in each window to wall ratio

6.2.1 Heat gain in buildings through various types of window glasses from 20% WWR to 100% WWR in four orientations

Figures 6.2.1 to 6.2.4, show heat gain in buildings through four types of window glasses in four orientations. From the graphs, it is observed that heat gain in building increases with the increase in the window to wall ratio. The results also show that, the heat gain is less in south orientation when compared with other orientations. Buildings with clear glass windows gain more amount of heat 4.55 kWh at 40% WWR in south orientation, and with bronze-reflective glass windows gain less amount of heat 2.01 kWh at 40% WWR in south orientation, when compared with other glasses. Buildings with clear glass windows gain more amount of heat 6.83 kWh at 60% WWR in south orientation, and buildings with bronze-reflective glass windows gain less amount of heat 3.01 kWh at 60% WWR in south orientation, when compared with other glasses.

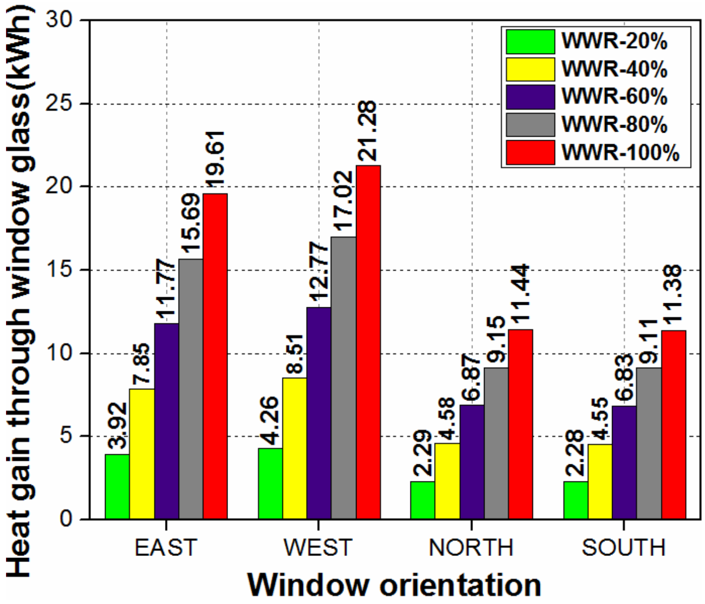


Figure 6.2.1 Heat gain in buildings through clear glass window in four orientations at different window to wall ratios

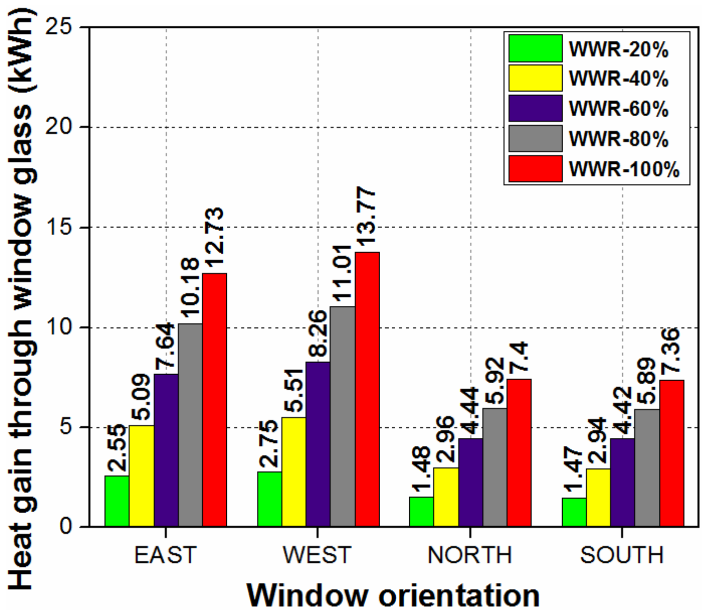


Figure 6.2.2 Heat gain in buildings through bronze glass window in four orientations at different window to wall ratios

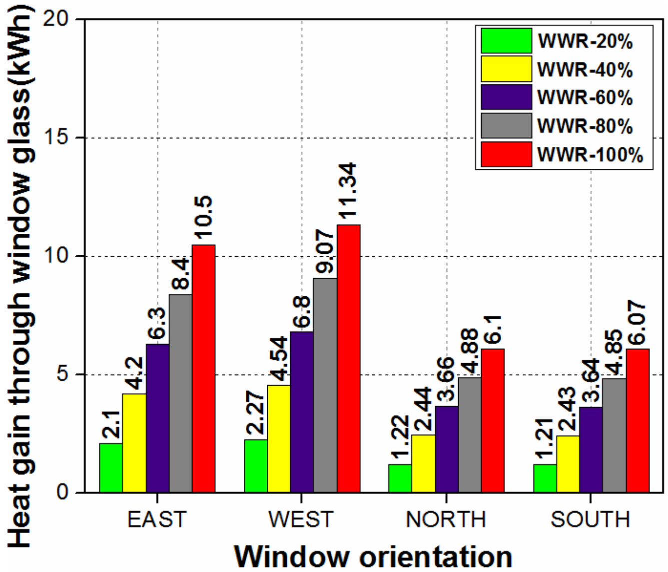


Figure 6.2.3 Heat gain in buildings through green glass window in four orientations at different window to wall ratios

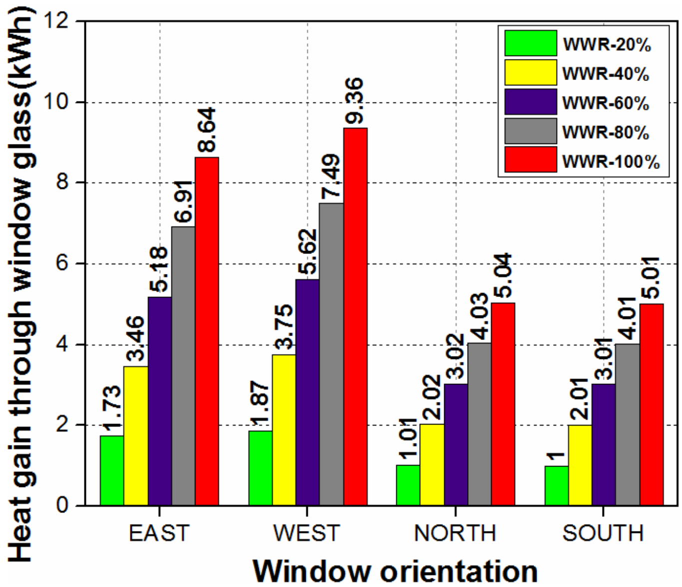


Figure 6.2.4 Heat gain in buildings through bronze reflective glass window in four orientations at different window to wall ratios

6.3 INVESTIGATION OF VARIOUS REFLECTIVE WINDOW GLASS MATERIALS FOR REDUCED COOLING LOADS IN BUILDINGS ACROSS DIFFERENT CLIMATIC REGIONS

The building dimensions considered in this work is same as previous section 6.2, chapter 6 and six type's reflective glass materials such as bronze, green, grey, opal blue, sapphire blue and gold reflective glasses are studied. For Mangalore climatic zone four orientations such as east, west, north and south have been analyzed to find the heat gain in buildings in previous section 6.2. South side glass window at any window to wall area ratios allow less heat in buildings that is due to at summer season Sun rises in north east and sets in the northwest so less heat gain will come in south orientation. Hence in this work only south orientation was analyzed for four climatic zones. Table 6.3.1, shows the details about reflective glass windows studied to find solar heat gain in buildings at various window area to wall area ratios.

Table 6.3.1 Number of glasses studied for heat gain in buildings

Number of glasses	Climatic zones	Window to wall area ratios	Total number of combinations arranged
6	Warm & humid, Hot &dry, Composite, Temperate	20%, 40%, 60%, 80% and 100%	6×5×1 = 30

The heat gain into buildings were found on the peak summer day of each city i.e. 15th April, 21st June,15th May, 21st June for Bangalore, Jodhpur, Kolkata and New Delhi respectively.

6.3.1 Heat gain in buildings through various window glass materials at 20% WWR in four cities of Indian climatic zones

Figure 6.3.1, shows heat gain in buildings through various window glass materials at 20% WWR in four Indian climatic zones. In Bangalore climatic zone, gold reflective glass window gains maximum heat of 1.62 kWh and grey-reflective glass window gain minimum heat of 0.64 kWh. In Jodhpur climatic zone, gold reflective glass window gains maximum heat of 1.58 kWh and grey-reflective glass window gain minimum heat of 0.63 kWh. In Kolkata climatic zone, gold reflective glass window gains maximum heat of 2.35 kWh and grey-reflective glass window gain minimum heat of 0.93 kWh and in New Delhi climatic zone, gold reflective glass window gain maximum heat of 1.9 kWh and grey-reflective glass window gain minimum heat of 0.75 kWh among the six window glass materials studied.

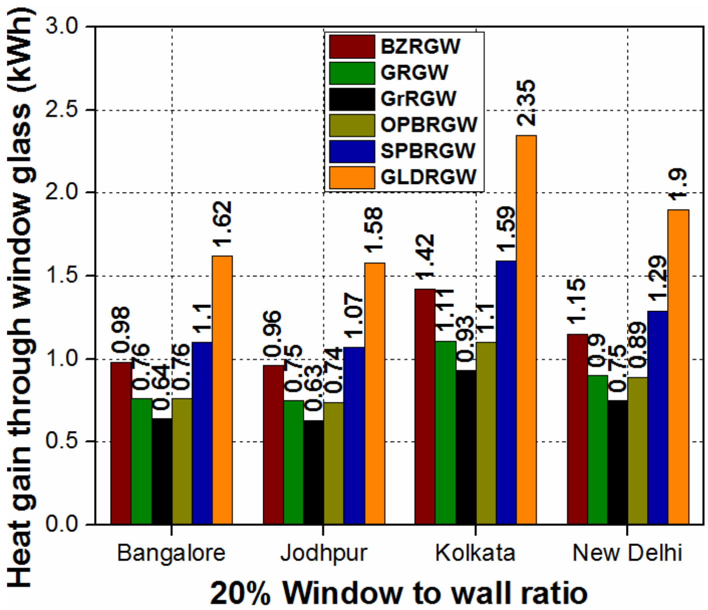


Figure 6.3.1 Heat gain in buildings through different window glass materials in four Indian climatic zones in south orientation at 20% window to wall area ratio

6.3.2 Heat gain in buildings through various window glass materials at 40% WWR in four cities of Indian climatic zones

Figure 6.3.2, shows heat gain in buildings through various window glass materials at 40% WWR in four Indian climatic zones. In Bangalore climatic zone, gold reflective glass window gains maximum heat of 3.24 kWh and grey-reflective glass window gain minimum heat of 1.28 kWh. In Jodhpur climatic zone, gold reflective glass window gains maximum heat of 3.16 kWh and grey-reflective glass window gain minimum heat of 1.25 kWh. In Kolkata climatic zone, gold reflective glass window gains maximum heat of 4.69 kWh and grey-reflective glass window gain minimum heat of 1.85 kWh and in New Delhi climatic zone, gold reflective glass window gain maximum heat of 3.8 kWh and grey-reflective glass window gain minimum heat of 1.5 kWh among the six window glass materials studied.

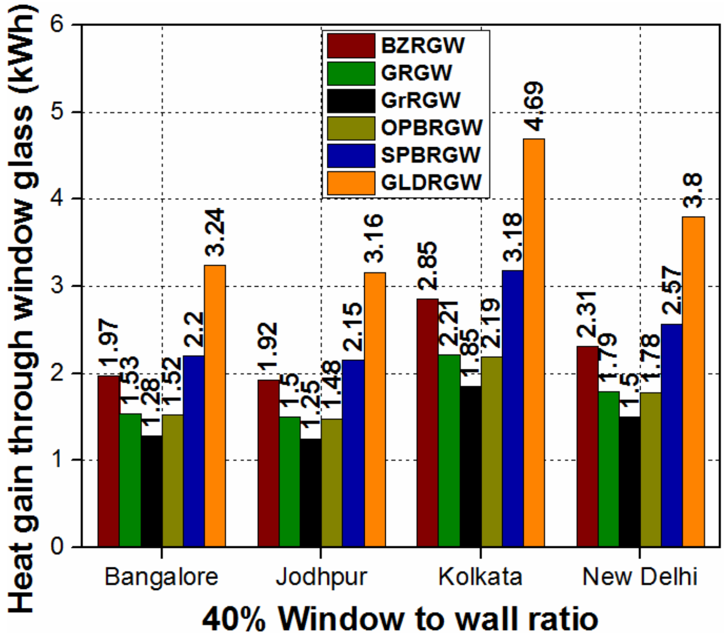


Figure 6.3.2 Heat gain in buildings through different window glass materials in four Indian climatic zones in south orientation at 40% window to wall area ratio

6.3.3 Heat gain in buildings through various types of window glass materials at 60% WWR in four cities of Indian climatic zones

Figure 6.3.3, shows heat gain in buildings through various window glass materials at 60% WWR in four Indian climatic zones. In Bangalore climatic zone, gold reflective glass window gains maximum heat of 4.86 kWh and grey-reflective glass window gain minimum heat of 1.92 kWh. In Jodhpur climatic zone, gold reflective glass window gains maximum heat of 4.74 kWh and grey-reflective glass window gain minimum heat of 1.88 kWh. In Kolkata climatic zone, gold reflective glass window gains maximum heat of 7.04 kWh and grey-reflective glass window gain minimum heat of 2.78 kWh and in New Delhi climatic zone, gold reflective glass window gain maximum heat of 5.71 kWh and grey-reflective glass window gain minimum heat of 2.25 kWh among the six window glass materials studied.

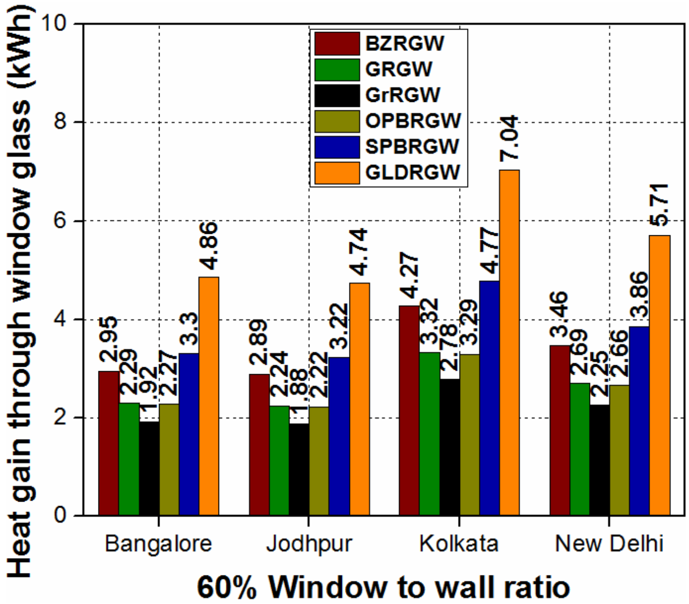


Figure 6.3.3 Heat gain in buildings through different window glass materials in four Indian climatic zones in south orientation at 60% window to wall area ratio

6.3.4 Heat gain in buildings through various types of window glass materials at 80% WWR in four cities of Indian climatic zones

Figure 6.3.4, shows heat gain in buildings through various window glass materials at 80% WWR in four Indian climatic zones. In Bangalore climatic zone, gold reflective glass window gains maximum heat of 6.49 kWh and grey-reflective glass window gain minimum heat of 2.56 kWh. In Jodhpur climatic zone, gold reflective glass window gains maximum heat of 6.32 kWh and grey-reflective glass window gain minimum heat of 2.51 kWh. In Kolkata climatic zone, gold reflective glass window gains maximum heat of 9.39 kWh and grey-reflective glass window gain minimum heat of 3.7 kWh and in New Delhi climatic zone, gold reflective glass window gain maximum heat of 7.61 kWh and grey-reflective glass window gain minimum heat of 3 kWh among the six window glass materials studied.

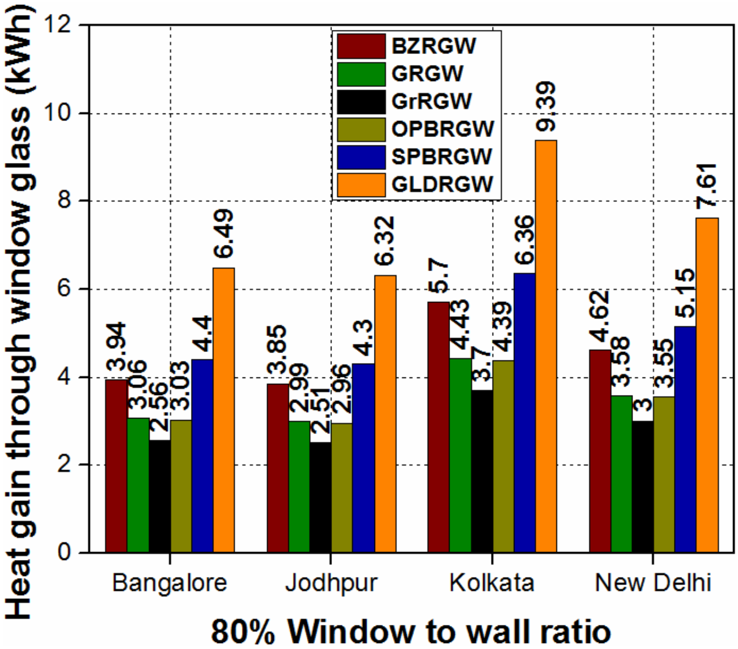


Figure 6.3.4 Heat gain in buildings through different window glass materials in four Indian climatic zones in south orientation at 80% window to wall area ratio

6.3.5 Heat gain in buildings through various types of window glass materials at 100% WWR in four cities of Indian climatic zones

Figure 6.3.5, shows heat gain in buildings through various window glass materials at 100% WWR in four Indian climatic zones. In Bangalore climatic zone, gold reflective glass window gains maximum heat of 8.11 kWh and grey-reflective glass window gain minimum heat of 3.2 kWh. In Jodhpur climatic zone, gold reflective glass window gains maximum heat of 7.9 kWh and grey-reflective glass window gain minimum heat of 3.13 kWh. In Kolkata climatic zone, gold reflective glass window gains maximum heat of 11.73 kWh and grey-reflective glass window gain minimum heat of 4.63 kWh and in New Delhi climatic zone, gold reflective glass window gain maximum heat of 9.51 kWh and grey-reflective glass window gain minimum heat of 3.75 kWh among the six window glass materials studied.

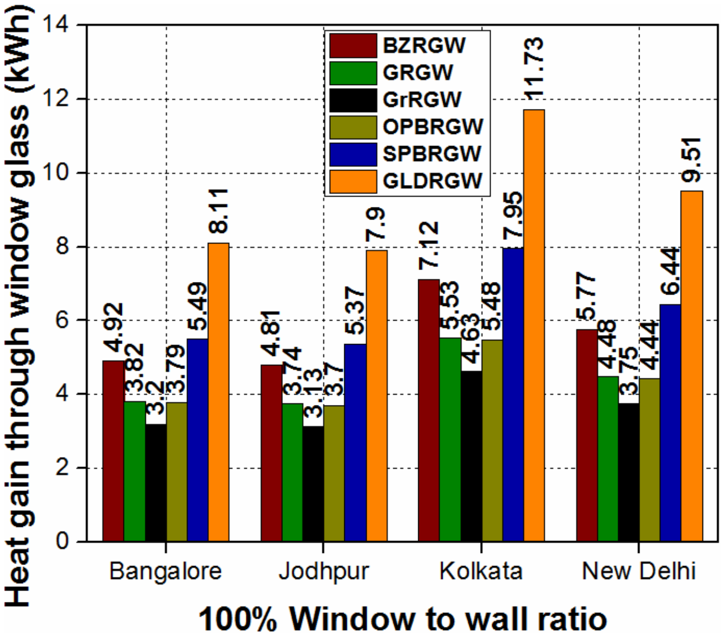


Figure 6.3.5 Heat gain in buildings through different window glass materials in four Indian climatic zones in south orientation at 100% window to wall area ratio

CHAPTER-7

SIMULATION STUDY OF SINGLE, DOUBLE, TRIPLE AND QUADRUPLE WINDOW GLASSES ON HEAT GAIN IN BUILDINGS

7.1 INTRODUCTION

In modern residential and commercial buildings more and more glass is used in the construction. Extensive usage of glass in buildings increases heat gain, which in turn increases the energy requirement to maintain the building at comfortable conditions. In this study four glass materials are used. The same glass material is made combinations as single, double, triple and quadruple. The building selected has the dimensions of 3.5 m × 3.5 m × 3.5 m. Table 7.1.1 shows the details about the glass windows studied, to find heat gain in buildings at 40% window area to wall area ratios in four climatic zones.

Table 7.1.1 Total glass combinations studied for heat gain in buildings

Place	Number of single glasses	Number of Double glasses	Number of Triple glasses	Number of Quadruple glasses	Orientations	Number of combinations
Bangalore	4	4	4	4	4	16×4=64
Jodhpur	4	4	4	4	4	16×4=64
Kolkata	4	4	4	4	4	16×4=64
New Delhi	4	4	4	4	4	16×4=64
Bangalore	-	4	-	-	4	4×4=16
Jodhpur	-	4	-	-	4	4×4=16
Kolkata	-	4	-	-	4	4×4=16
New Delhi	-	4	-	-	4	4×4=16
Total number of combinations studied						320

7.2 EFFECT OF SINGLE, DOUBLE, TRIPLE AND QUADRUPLE WINDOW GLASS ARRANGEMENTS OF VARIOUS GLASS MATERIAL TYPES ON HEAT GAIN IN BUILDINGS

In this study, four glass materials namely clear, bronze, green and grey glasses are arranged as shown in Figure 7.2.1 (a) single glass (b) double glass (c) triple glass and (d) quadruple glass windows to find heat gain using Energy plus software. Air gap of 10 mm was maintained between glasses. The heat gain was found on peak summer day in four different climatic zones. The different climatic zones considered were: temperate (Bangalore), hot and dry (Jodhpur), warm and humid (Kolkata) and composite (New Delhi). Table 7.2.1, shows the details about the glass windows.

Table 7.2.1 Glass materials studied

Number of glasses	Climatic zones	Glass arrangement	Number of orientations	Total number of combinations
4	Bangalore, Jodhpur, Kolkata and New Delhi	Single, double, triple and quadruple	4	4×4×4=64 in each climatic zone

The window was placed in one side wall of the building. And the building model was rotated as per the requirement to face the window to the four orientations such as east, west, north and south, to find the heat gain in buildings. The window area to wall area ratio was considered 40% as per recommendation done in Chapter 6.

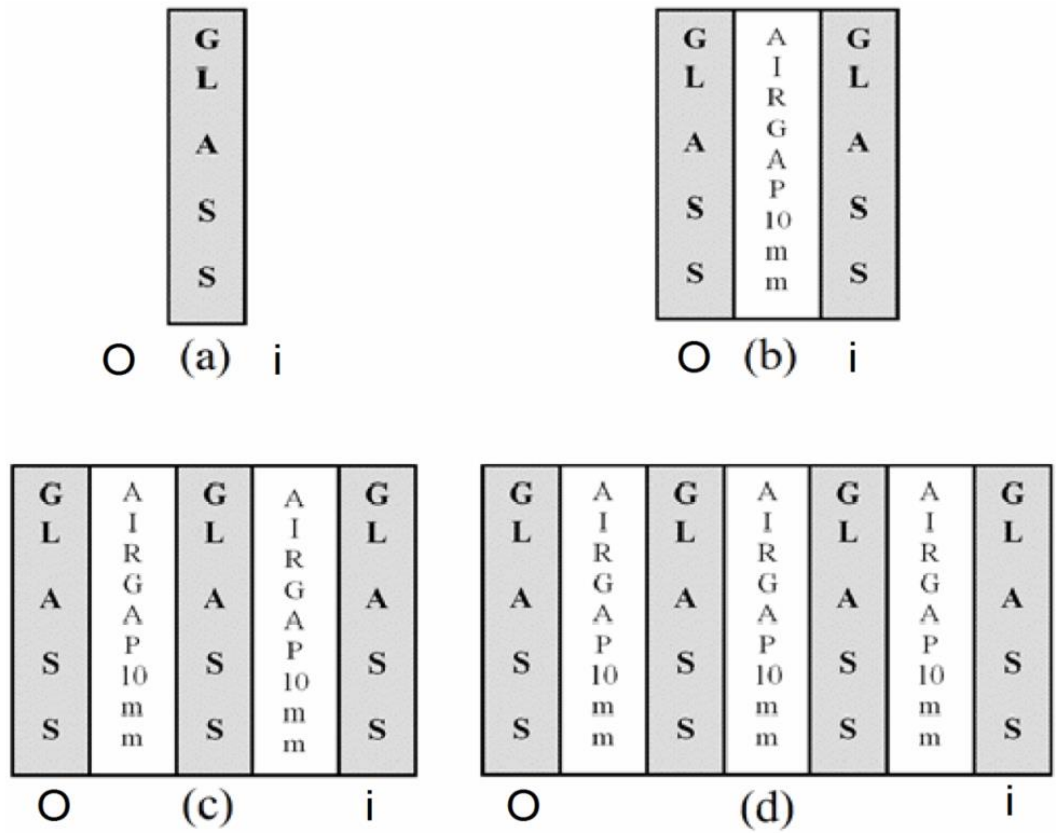


Figure 7.2.1 Glass material arrangements: (a) Single glass (b) Double glass (c) Triple glass and (d) Quadruple glass O-Outdoor, i-Indoor

7.2.1 Heat gain in buildings through glass windows at Bangalore climatic region

Figure 7.2.2 shows the heat gain in buildings through single, double, triple and quadruple arrangements of the same glass types such as clear, bronze, green and grey glasses for Bangalore climatic region in four orientations, one by one at peak summer day. From the results, it is observed that heat gain inside the buildings through all glass windows from south orientation is least when compared with the other orientations. Heat gain in buildings through clear glass window is more and through grey glass windows is less due to their optical properties. Quadruple grey glass window is located in south orientation is the best to reduce more percentage of heat 95.97%, 77.08% and 47.61% compare with quadruple clear, bronze, green window glasses respectively.

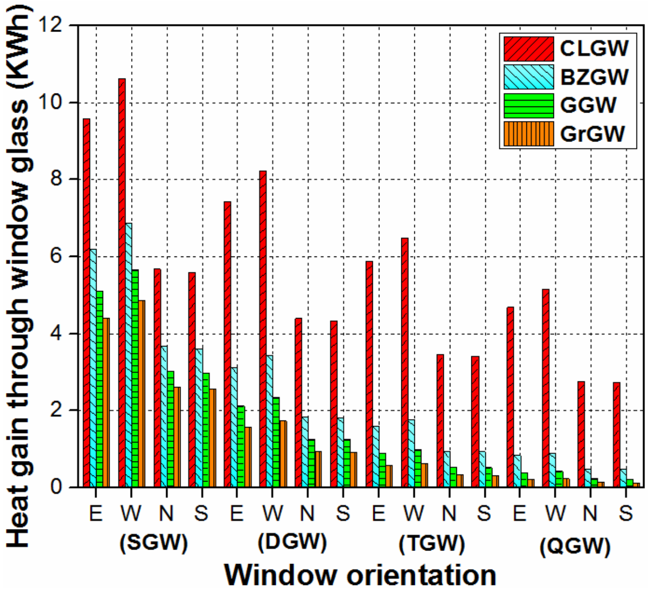


Figure 7.2.2 Heat gain in buildings through glass windows for Bangalore climatic region

7.2.2 Heat gain in buildings through glass windows at Jodhpur climatic region

Figure 7.2.3 shows the heat gain in buildings through single, double, triple and quadruple arrangements of the same glass materials for Jodhpur climatic region. From the results it is observed that heat gain in buildings through all glass windows from south orientation is least when compared with other orientations. Quadruple grey glass window is located in south orientation is the best because it reduces more percentage of heat 95.57%, 75% and 45.45% compare with quadruple clear, bronze, green window glasses respectively.

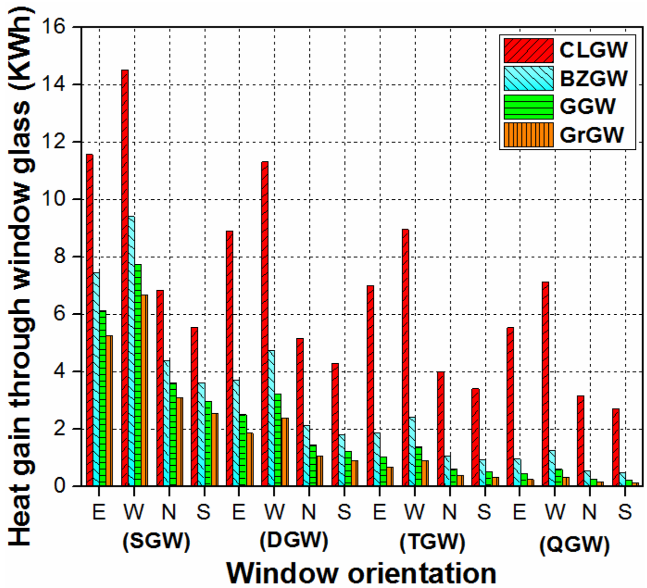


Figure 7.2.3 Heat gain in buildings through glass windows for Jodhpur climatic region

7.2.3 Heat gain in buildings through glass windows at Kolkata climatic region

Figure 7.2.4 shows the heat gain in buildings through single, double, triple and quadruple arrangements of the same glass materials for Kolkata climatic region. From the results it is observed that heat gain in buildings through all glass windows from south orientation is least when compared with other orientations. Quadruple grey glass window is located in south orientation is the best because it reduces more percentage of heat 95.48%, 82.2% and 45.45% compare with quadruple clear, bronze, green window glasses respectively.

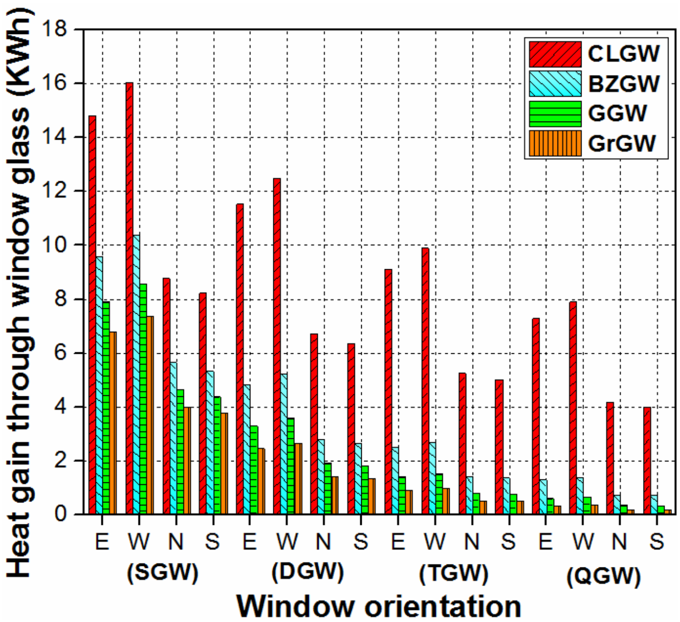


Figure 7.2.4 Heat gain in buildings through glass windows for Kolkata climatic region

7.2.4 Heat gain in buildings through glass windows at New Delhi climatic region

Figure 7.2.5 shows the heat gain in buildings through single, double, triple and quadruple arrangements of the same glass materials for New Delhi climatic region. From the results it is observed that heat gain in buildings through all glass windows from south orientation is least when compared with other orientations. Quadruple grey glass window is located in south orientation is the best because it reduces more percentage of heat 95.35%, 73.68% and 44.44% compare with quadruple clear, bronze, green window glasses respectively.

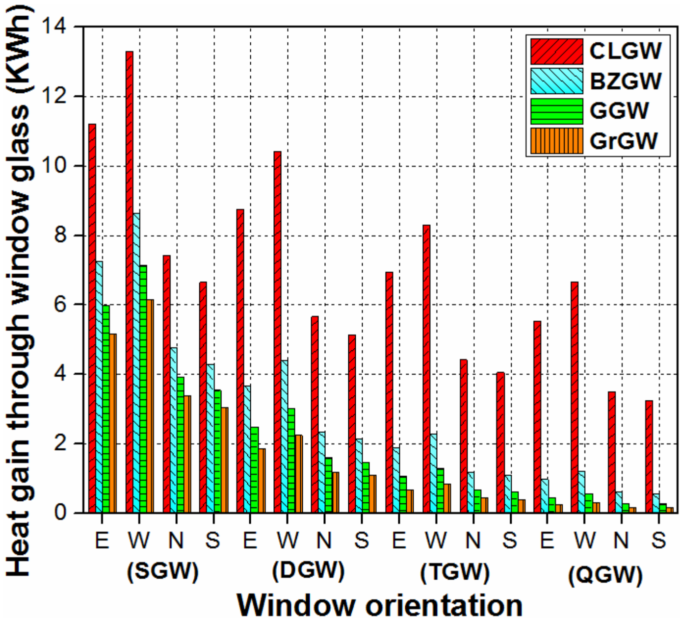


Figure 7.2.5 Heat gain in buildings through glass windows for New Delhi climatic region

7.3 EFFECT OF DIFFERENT DOUBLE GLASS WINDOW COMBINATIONS ON HEAT GAIN IN BUILDINGS

The double glass window combinations were taken such as clear glass–air gap 10mm–clear glass, bronze glass–air gap 10mm–clear glass, green glass–air gap 10mm–clear glass and grey glass–air gap 10mm–clear glass was used in the study as shown in Figure 7.3.1. Table 7.3.1, shows the details about the number of double glass window studied.

Table 7.3.1 Glass materials studied

Number of glasses	Climatic zones	Glass arrangement	Number of orientations	Total number of combinations
4	Bangalore, Jodhpur, Kolkata and New Delhi	Double glass	4	4×4×1=16 in each climatic zone

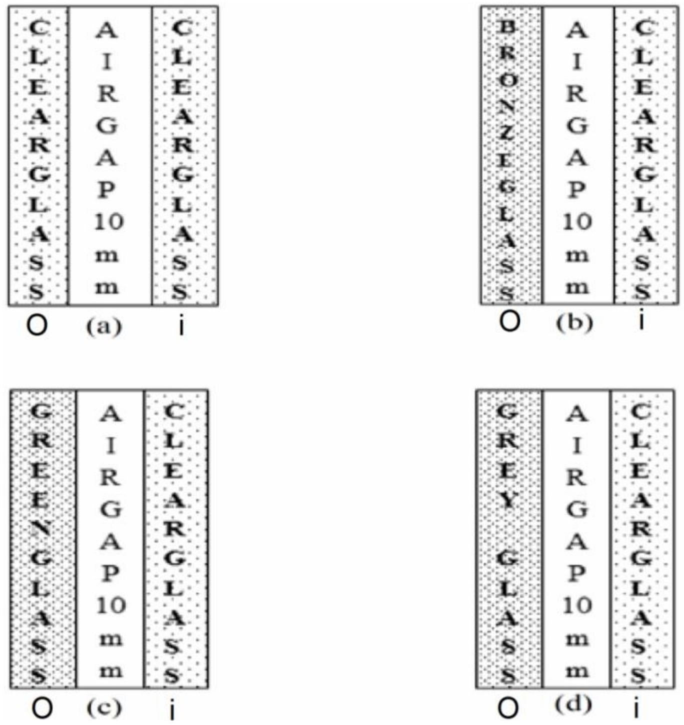
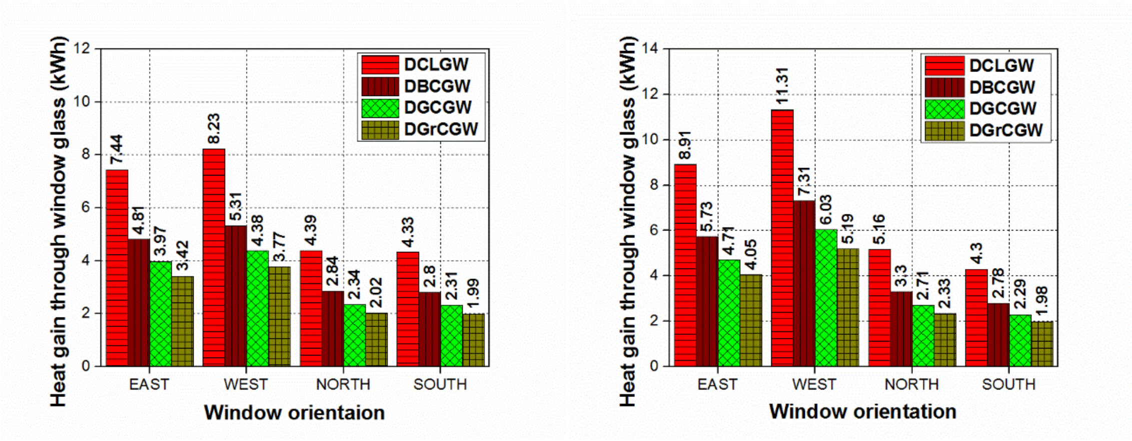


Figure 7.3.1 Double window glass combinations (a) clear glass-air gap 10mm-clear glass (b) bronze glass-air gap 10mm-clear glass (c) green glass-air gap 10mm-clear glass (d) grey glass-air gap 10mm-clear glass O-outdoor, i-indoor

7.3.1 Heat gain in buildings for Bangalore and Jodhpur climatic zones

Figure 7.3.2 (a), shows the heat gain in buildings for Bangalore climatic zone, through four double glass window combinations, in four orientations on a peak summer day (April 15th). From the results, it is clear that, heat gain in buildings through double glass window units is more in west and less in south orientation. Buildings which have double clear glass window unit gain maximum 4.33 kWh of heat; buildings with double grey-clear glass window unit gain minimum 1.99 kWh of heat into the buildings.



(a) (b)

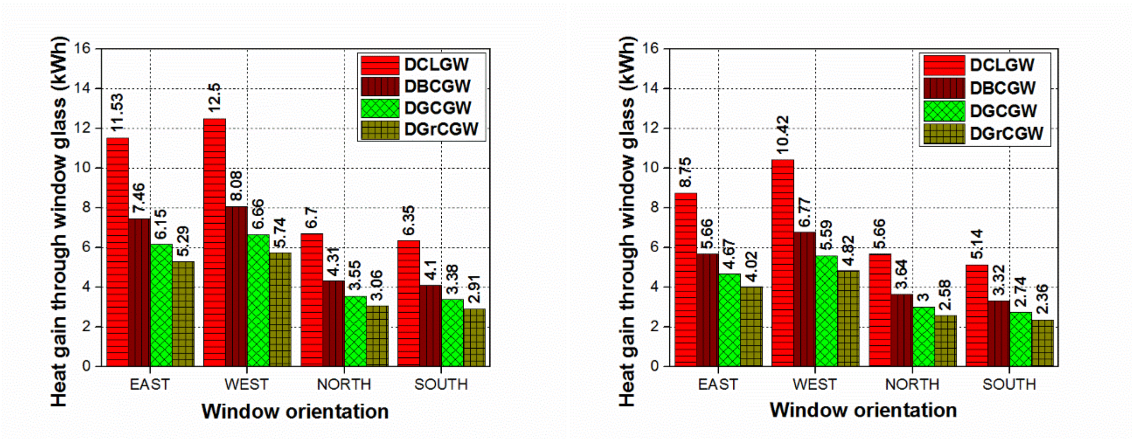
Figure 7.3.2 Heat gain in buildings through double glass windows: (a) Bangalore climatic condition (b) Jodhpur climatic condition

Figure 7.3.2 (b), shows the heat gain in buildings through four double glass window combinations of Jodhpur climatic zone in four orientations on a peak summer day (June 21st). From the results it is clear that, buildings with double clear glass window unit gain maximum 4.3 kWh of heat, buildings with double grey-clear glass window unit gain minimum 1.98 kWh of heat into the buildings from south orientation.

7.3.2 Heat gain in buildings for Kolkata and New Delhi climatic zones

Figure 7.3.3 (a), shows the heat gain in buildings located in Kolkata climatic zone, through four double glass window combinations in four orientations on a peak summer day (May 15th). From the results, it is clear that buildings with double clear glass window unit gain maximum 6.35 kWh of heat; buildings with double grey-clear glass window unit gain minimum 2.91 kWh of heat into the buildings from south orientation.

Figure 7.3.3 (b), shows the heat gain in buildings of New Delhi climatic zone, through four double glass window combinations in four orientations on a peak summer day (June 21st). From the results it is clear that, buildings with double clear glass window unit gain maximum 5.14 kWh of heat, buildings with double grey-clear glass window unit gain minimum 2.36 kWh of heat into the buildings from south orientation.



(a) (b)

Figure 7.3.3 Heat gain in buildings through double glass windows: (a) Kolkata climatic condition (b) New Delhi climatic condition

CHAPTER-8

EFFECT OF DIFFERENT SINGLE AND DOUBLE REFLECTIVE GLASS WINDOWS TO PROVIDE THERMAL AND VISUAL COMFORT IN BUILDINGS

8.1 INTRODUCTION

The use of Sunlight to illuminate buildings in an effective way of designing energy efficient buildings. The window glass is one of the significant enclosures to admit daylight into the building. Daylighting is a natural source of light, which meets all the requirements of good lighting while enhancing user efficiency and productivity. Daylight factor is defined as the ratio of indoor illumination to outdoor illumination available outside the building. Units of daylight factor is in (%) or in (Lux).

$$\mathrm{DF} = \frac{\mathrm{E_i}}{\mathrm{E_o}} \times 100\% \tag{8.1}$$

The daylighting strategies not only reduce lighting energy, but they are also responsible for an increase in cooling/heating loads. Hence, proper attention should be focused on selection of window glass material for buildings. In this work, visible and solar optical properties were given input to Energy plus software simulation tool. Visible optical properties (380 nm to 780 nm) were used to find average daylight factor levels inside the buildings using various glass windows. In this work building was designed and the window was provided to the only one wall of the cubical room. But the cubical building model was rotated as per the requirement to face the window to the four orientations such as east, west, north and south. The average day light factor inside the building model was evaluated at a distance of 0.75 m from floor and 0.5m distance from to the walls and window as per (International Commission on Illumination standards (CIE 2006)) CIE standards using Energy plus 8.1.0.009 simulation software. Total glass combinations studied for heat gain and daylighting is tabulated in Table 8.1.1.

Table 8.1.1 Total glass combinations studied for heat gain and daylighting

Place	Number of single glasses	Number of double glasses	Orientations	Number of combinations
New Delhi (28.58^0N,77.12^0E)	6	6	4	6×4=24(summer) 6×4=24 (winter)

For validating daylight simulation results, clear glass window of area 0.68 m^2 was used for the daylight calculations for Varanasi climatic region, during both summer and winter seasons using Energy plus simulation tool and these results were compared with Madhu Sudan et al. (2015) experimental results. The deviation of simulation results is listed in Table 8.1.2. The Simulation software tool results deviation from experimental results are below $\pm$1%. Hence, the software is used for computation of daylight factor in buildings through various glasses at different latitudes.

Table 8.1.2 Day light factor simulation values compare with experimental results of Madhu Sudan et al. (2015), for Varanasi climatic zone (25.28^0N, 82.95^0E), on June 8^{th} during summer season and January 25^{th} during winter season at clear sky conditions

Time (hr)	**In summer season (June 8^{th}) Varanasi (25.28^0N, 82.95^0E)**			**In winter season (Jan25^{th}) Varanasi (25.28^0N, 82.95^0E)**		
	Experimental results	Simulation results	Ratio	Experimental results	Simulation results	Ratio
8:00	3.3	3.4	0.03	2.6	2.8	0.07
9:00	2.8	2.9	0.03	2.5	2.6	0.04
10:00	2.6	2.4	0.07	2.3	2.5	0.08
11:00	2.4	2.3	0.04	2.1	2.0	0.05
12:00	2.1	1.9	0.09	1.8	1.6	0.11
13:00	1.7	1.6	0.06	1.5	1.3	0.13
14:00	1.4	1.2	0.07	1.3	1.2	0.07
15:00	0.9	1.1	0.22	1.1	1.1	0.00
16:00	0.6	0.7	0.17	0.8	0.9	0.13
17:00	0.4	0.5	0.25	0.6	0.7	0.17

8.2 EFFECT OF VARIOUS SINGLE REFLECTIVE GLASS MATERIALS TO PROVIDE THERMAL AND VISUAL COMFORT IN BUILDINGS

In this work, in order to find the optimum heat gain and optimum daylight factor in building of dimensions 3.5 m × 3.5 m × 3.5 m, having window of 2.45 m × 2 m dimensions, six reflective glass materials such as bronze, green, grey, opal blue, sapphire blue and gold reflective glasses are placed one by one in each orientation for New Delhi region. Table 8.2.1, shows the details of six single glass windows studied.

Table 8.2.1 Glass materials studied

Number of glasses	Climatic zone	Glass arrangement	Number of orientations	Total number of combinations
6	New Delhi	Single glass	4	6×1×4=24

8.2.1 Heat gain into the buildings through various reflective glass windows in New Delhi climatic region on peak summer and winter days

Figures 8.2.1 and 8.2.2, show the heat gain into the buildings through different reflective glass windows were placed in four directions for New Delhi climatic region on a peak summer day i.e. June 21st and on a peak winter day i.e. December 21st as per Indian standards. From the graphs, it is clearly observed that heat gain into the buildings through all reflective glass windows is more in west orientation and less in south orientation during summer season. During winter season, the heat gain in buildings through all reflective glass windows is more in south orientation and less in north orientation. On a peak summer day (June 21st), grey reflective glass window is gaining less heat of 1.9 kWh and on peak winter day (Dec 21st), bronze glass window is gaining more heat of 11.62 kWh inside the building in south orientation as shown in Figure 8.2.1 and 8.2.2, when compared to other orientations.

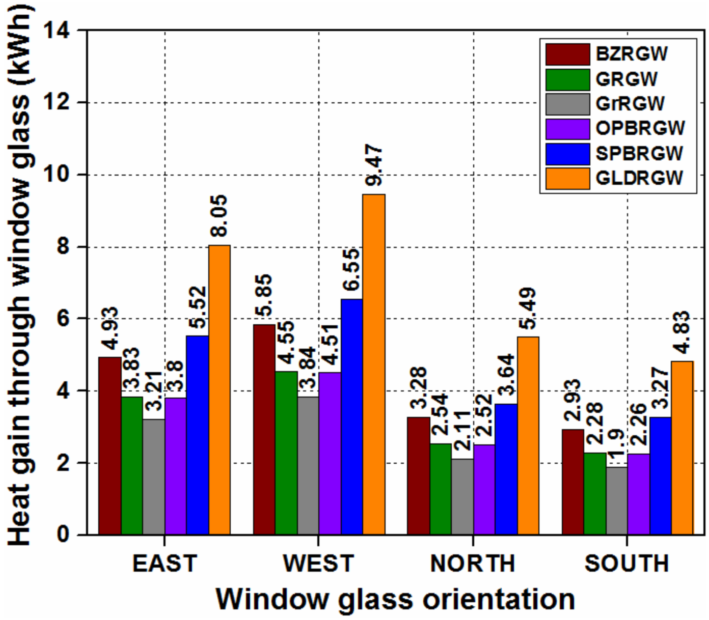


Figure 8.2.1 Heat gain into the buildings through six reflective glass windows for New Delhi climatic region at peak summer day

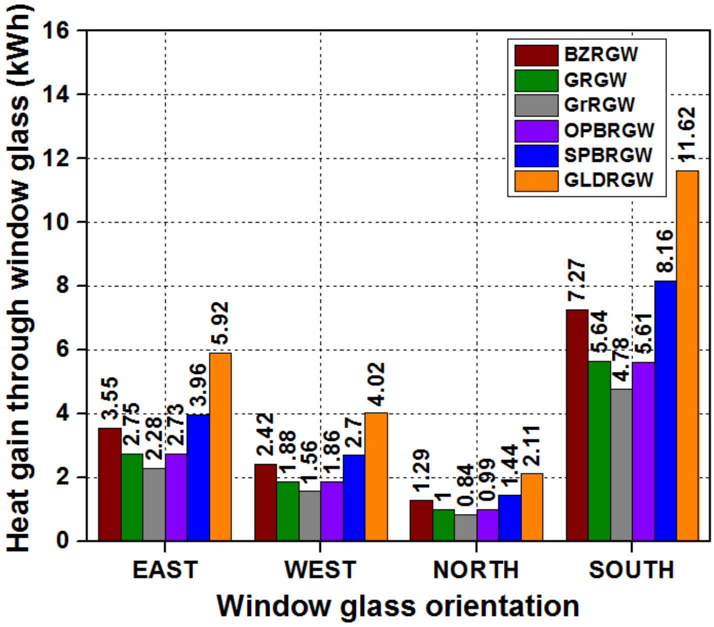


Figure 8.2.2 Heat gain into the buildings through six reflective glass windows for New Delhi climatic region at peak winter day

8.2.2 Average daylight factor inside the buildings through six single reflective glass windows

Figures 8.2.3 to 8.2.8, show the average daylight factor in buildings from six reflective glass windows were placed in four orientations one by one on a peak summer day and on a peak winter day for New Delhi climatic zone. Figures 8.2.3 to 8.2.8, show that average daylight factor in buildings through glass windows in east orientation decreases with decrease in time, during both summer and winter seasons. In west orientation average daylight factor inside the buildings through glass windows increases with increase in time during both summer and winter seasons. In north orientation, average daylight factor inside the building is periodic in nature during summer season, this is due to Sun movement from northeast to northwest orientation and also due to solar insolation outside at that particular day and time. In winter, average daylight factor is presented as shown in 8.2.3 to 8.2.8, this is due to Sun movement from southeast to southwest orientation and also due to solar insolation outside at that particular day and time. In south orientation, average day light factor inside the building is periodic in nature during summer season, this is due to Sun movement from northeast to northwest orientation and also due to solar insolation outside at that particular day and time. In winter, average daylight factor is presented as shown in 8.2.3 to 8.2.8, this is due to Sun movement from southeast to southwest orientation and also due to solar insolation outside at that particular day and time.

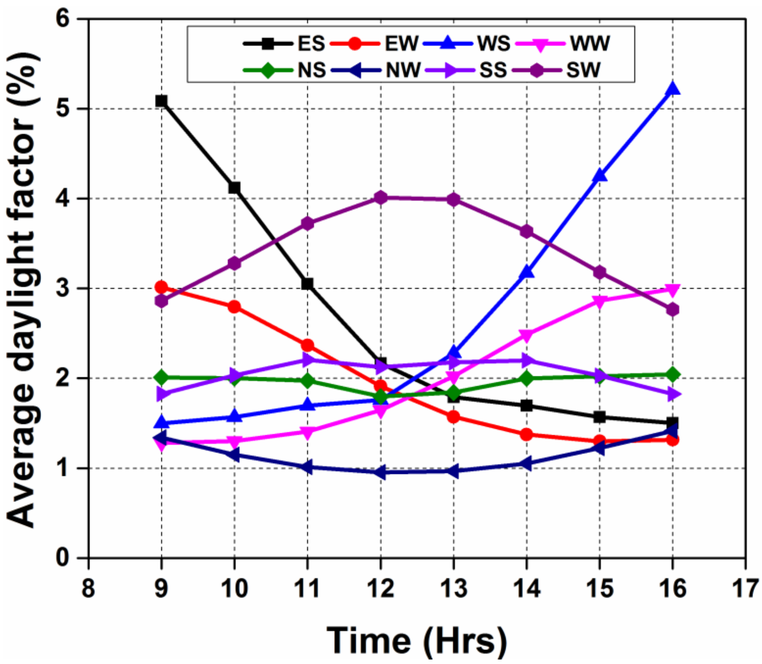


Figure 8.2.3 Average daylight factor in buildings through bronze reflective glass window in four orientations at peak summer and winter days

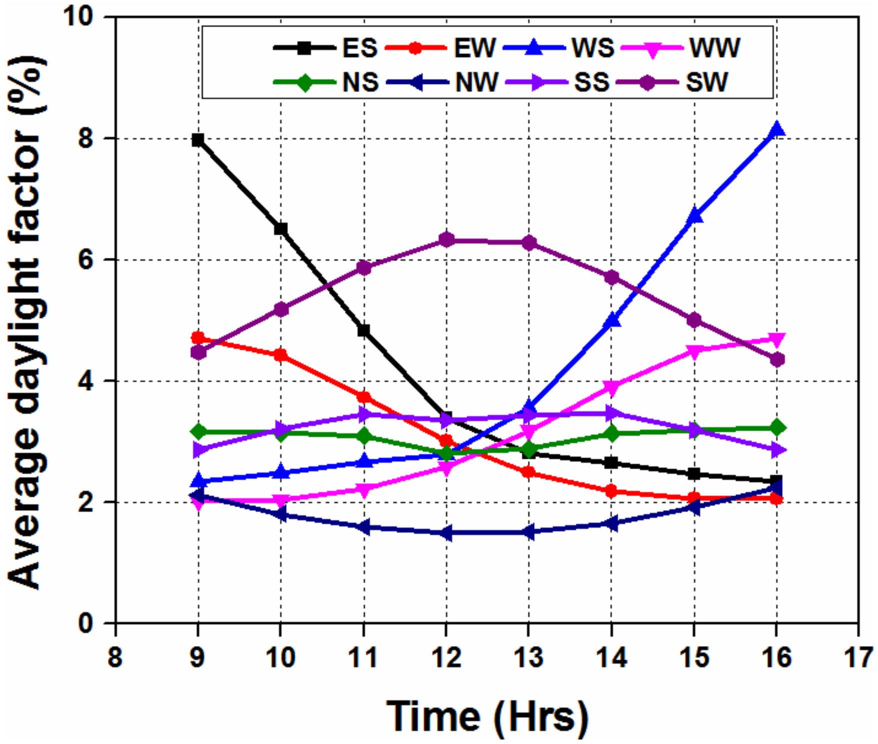


Figure 8.2.4 Average daylight factor in buildings through green reflective glass window in four orientations at peak summer and winter days

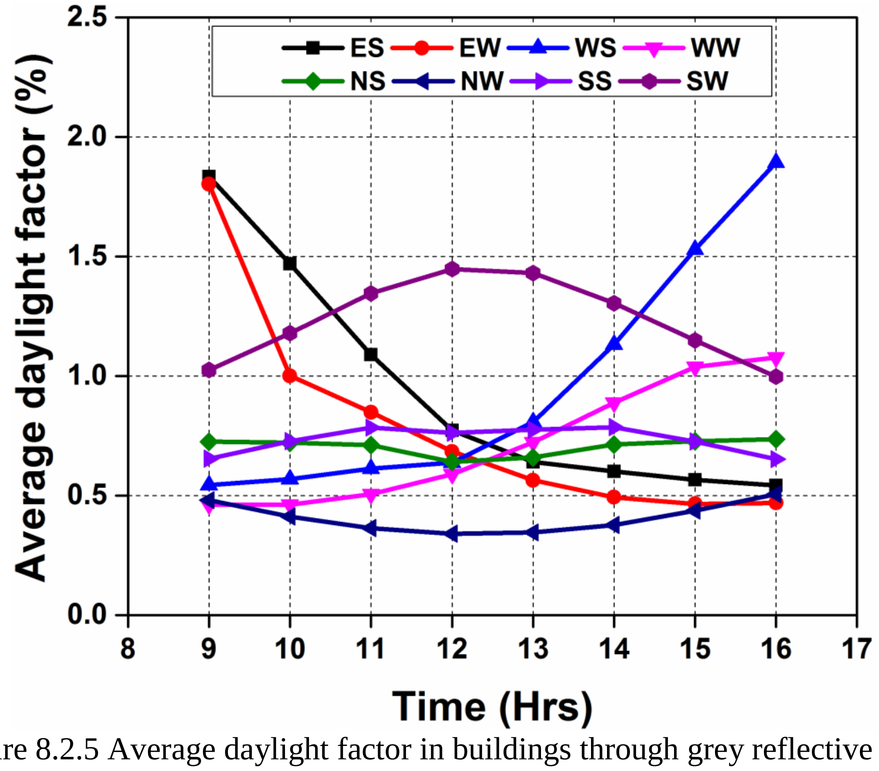


Figure 8.2.5 Average daylight factor in buildings through grey reflective glass window in four orientations at peak summer and winter days

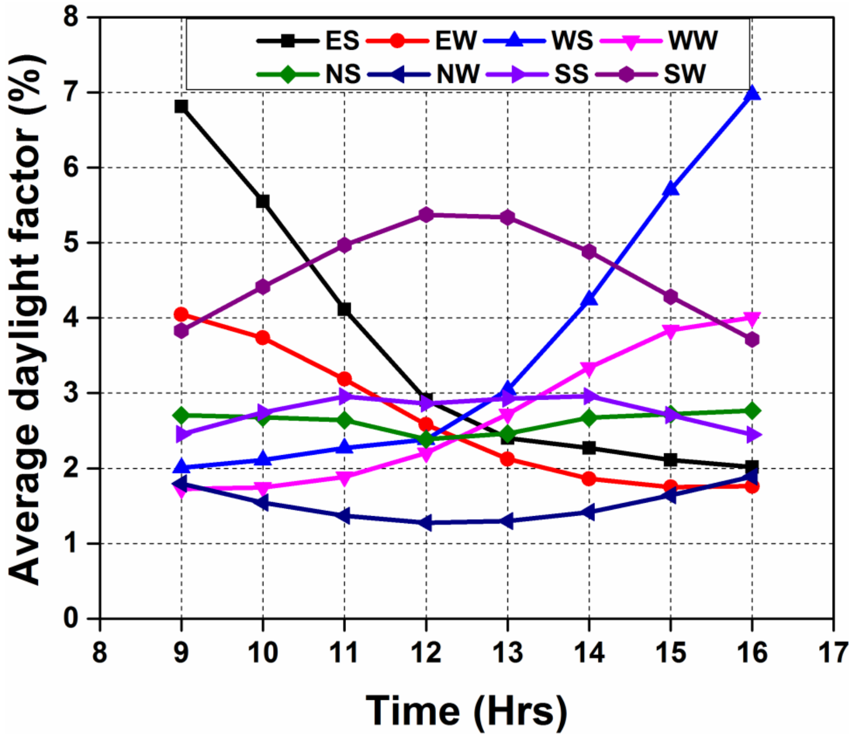


Figure 8.2.6 Average daylight factor in buildings through opal blue reflective glass window in four orientations at peak summer and winter days

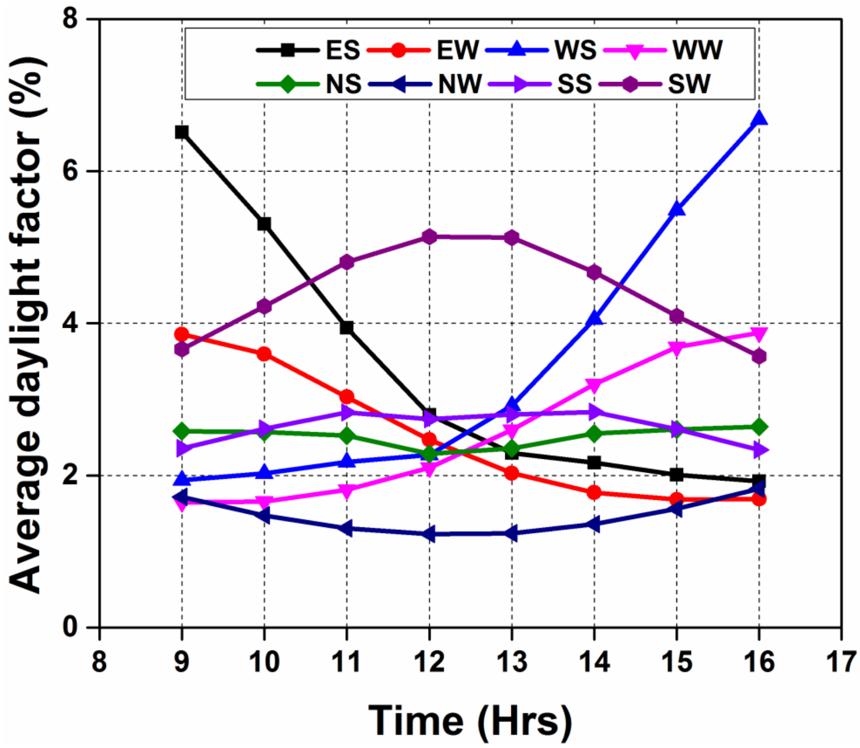


Figure 8.2.7 Average daylight factor in buildings from sapphire blue reflective glass window in four orientations at peak summer and winter days

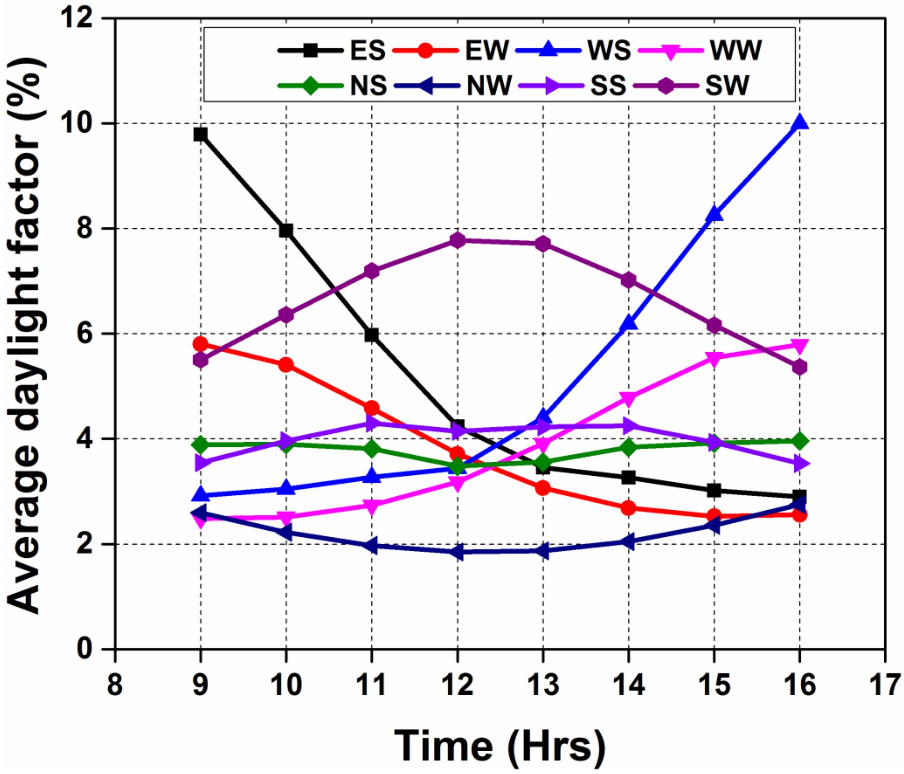


Figure 8.2.8 Average daylight factor in buildings from gold reflective glass window in four orientations at peak summer and winter days

8.3 THERMAL AND VISUAL COMFORT ANALYSIS IN BUILDINGS USING DOUBLE REFLECTIVE WINDOW GLASSES

In this work, the optimum heat gain and optimum daylight factor in buildings was found, using double reflective glass materials. Table 8.3.1, shows the details of six double reflective glass windows.

Table 8.3.1 Glass materials studied

Number of glasses	Climatic zones	Glass arrangement	Number of orientations	Total number of combinations
6	New Delhi	Double glass window	4	6×1×4=24

In this present work, six reflective glasses were placed like double windows with an air gap 10 mm, i.e. glass -air gap (10mm) -glass, one by one were analyzed on peak summer day and on peak winter day in four orientations of the building. Figure 8.3.1(a), shows the building model and Figure 8.3.1(b) shows the double reflective glass windows.

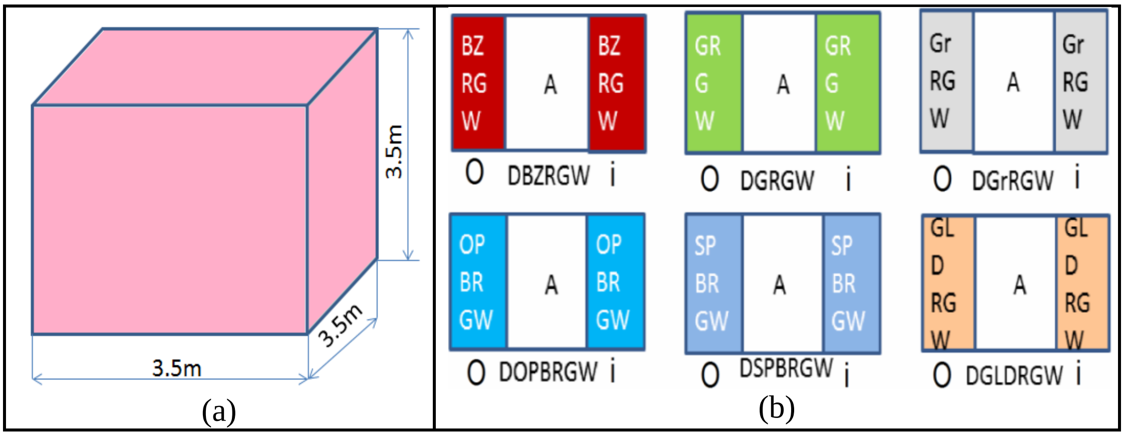


Figure 8.3.1 (a) Building dimensions 3.5m × 3.5 m × 3.5m (b) Double reflective glasses with an air gap of 10mm, O-Outdoor, i-Indoor

8.3.1 Heat gain into the buildings through various double reflective glass windows on peak summer and winter days

Figures 8.3.2 and 8.3.3, show the heat gain into the buildings through six double reflective glass windows, were placed in four directions for New Delhi climatic region on peak summer day and on peak winter day. From the graphs, it is clearly observed that the heat gain in buildings through all double reflective glass windows is more in west, and less in south orientation during summer season, and also clearly observed that the heat gain in buildings through all double reflective glass windows is more in south, and less in north orientation during winter season. At peak summer day, double grey reflective glass window (DGrRGW) is gaining less heat of 0.43 kWh in the south direction and at peak winter day double gold reflective glass window (DGLDRGW) is gaining more heat of 7.08 kWh in south orientation of the building as shown in Figure 8.3.2 and 8.3.3, when compared with other orientations. Figure 8.3.4 (a), shows the Sun path diagram of New Delhi climatic region at peak summer day June 21st at 3 PM and Figure 8.3.4(b) shows the daylight factor inside the building in lux and in percentage at peak summer day June 21st at 3 PM. Figure 8.3.5 (a), shows the Sun path diagram of New Delhi climatic region at peak winter day Dec 21st at 3 PM and Figure 8.3.5 (b) shows the daylight factor inside the building in lux and in percentage at peak winter day Dec 21st at 3 PM.

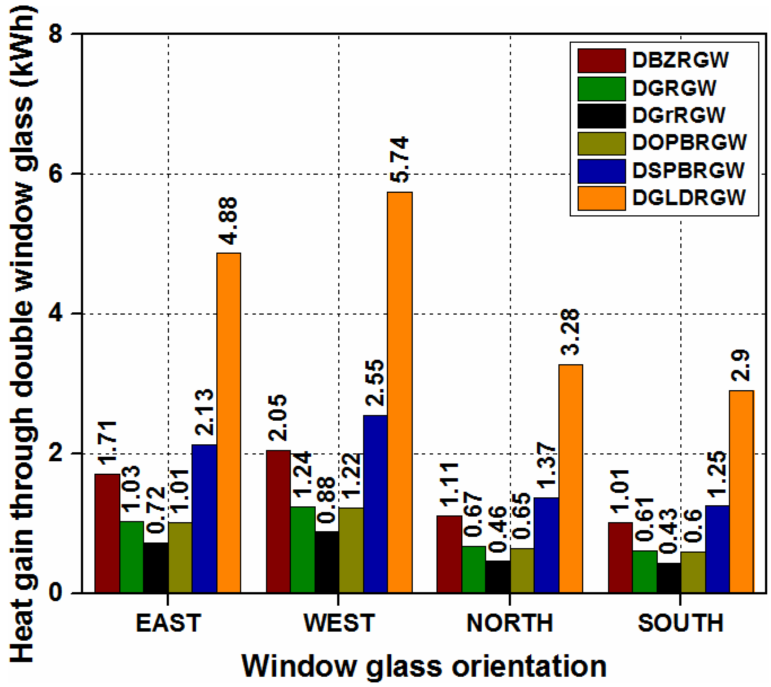


Figure 8.3.2 Heat gain into the buildings through six double reflective glass windows for New Delhi region at peak summer day

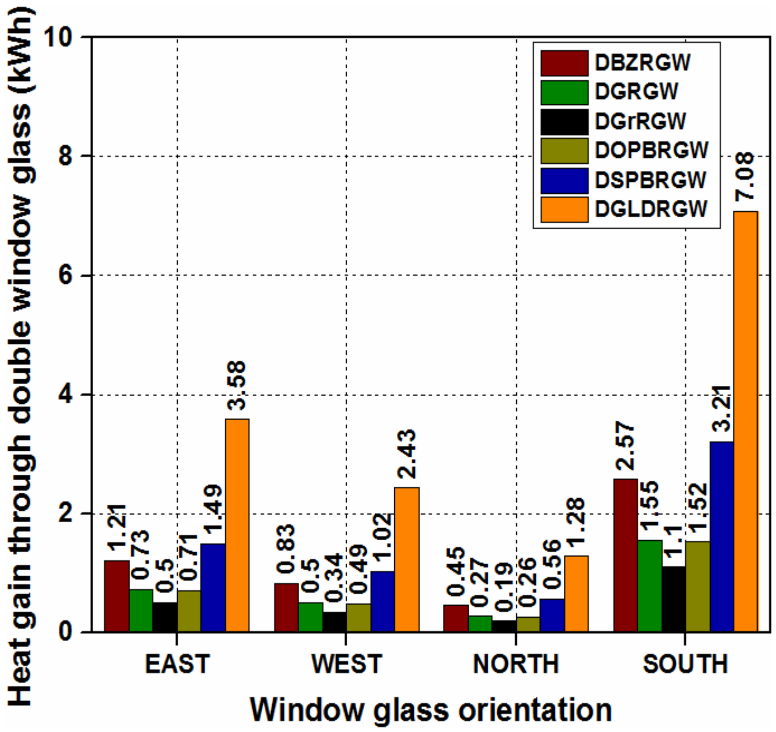


Figure 8.3.3 Heat gain into the buildings through six double reflective glass windows for New Delhi region at peak winter day

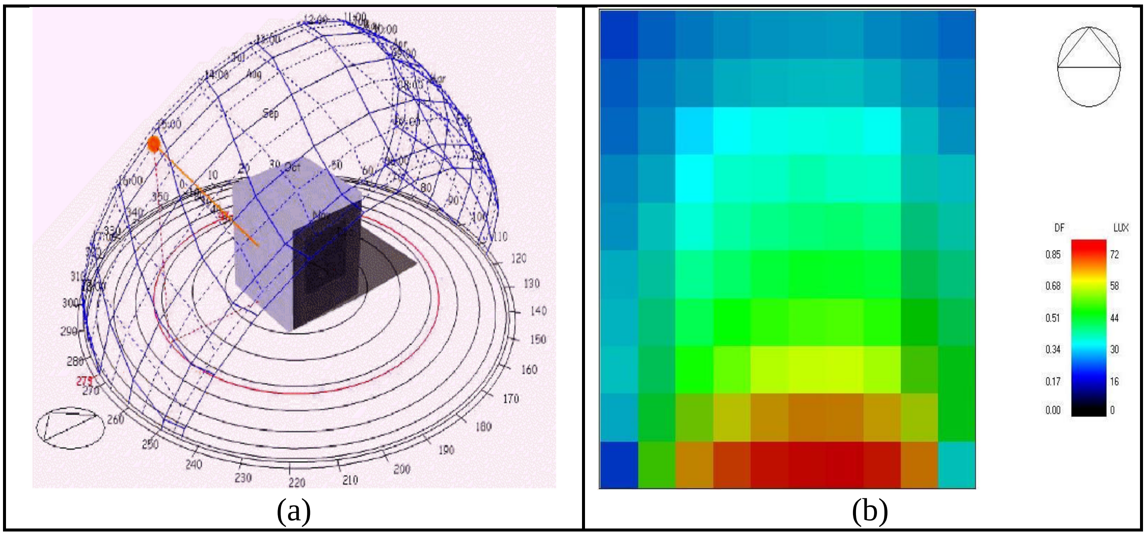


Figure 8.3.4(a) Sun path diagram of New Delhi climatic region at peak summer day June 21st at 3 PM (b) Daylight factor inside the building at 3 PM

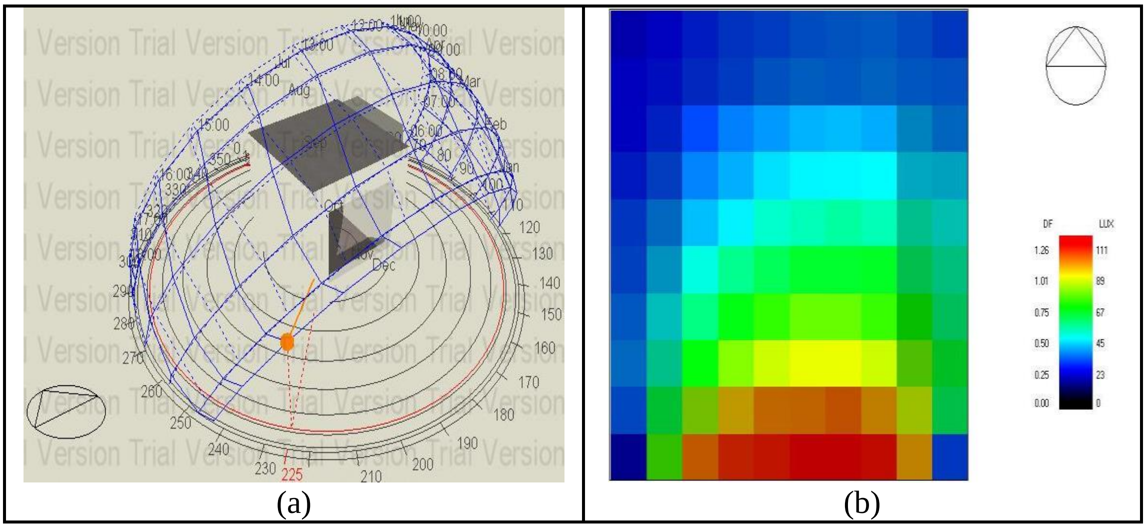


Figure 8.3.5(a) Sun path diagram of New Delhi climatic region at peak winter day Dec 21st at 3 PM (b) Daylight factor inside the building at 3 PM

8.3.2 Effect of double reflective glass windows on average daylight factor in buildings

Figure 8.3.6 to 8.3.11 show the average daylight factor inside buildings through six double reflective glass windows were placed in four orientations. The average daylight factor was calculated on peak summer and on peak winter days of New Delhi climatic zone. Figures 8.3.6 to 8.3.11; show that average daylight factor in buildings through glass windows in east orientation decreases with decrease in time, during both summer and winter seasons. In west orientation average daylight factor inside the buildings through glass windows increases with increase in time during both summer and winter seasons. In north orientation, average daylight factor inside the building is periodic in nature during summer season, this is due to Sun movement from northeast to northwest orientation and also due to solar insolation outside at that particular day and time. In winter, average daylight factor is presented as shown in 8.3.6 to 8.3.11; this is due to Sun movement from southeast to southwest orientation and also due to solar insolation outside at that particular day and time. In south orientation, average daylight factor inside the building is periodic in nature during summer season this is due to Sun movement from northeast to northwest orientation and also due to solar insolation outside at that particular day and time. In winter, average daylight factor is presented as shown in 8.3.6 to 8.3.11; this is due to Sun movement from southeast to southwest orientation and also due to solar insolation outside at that particular day and time.

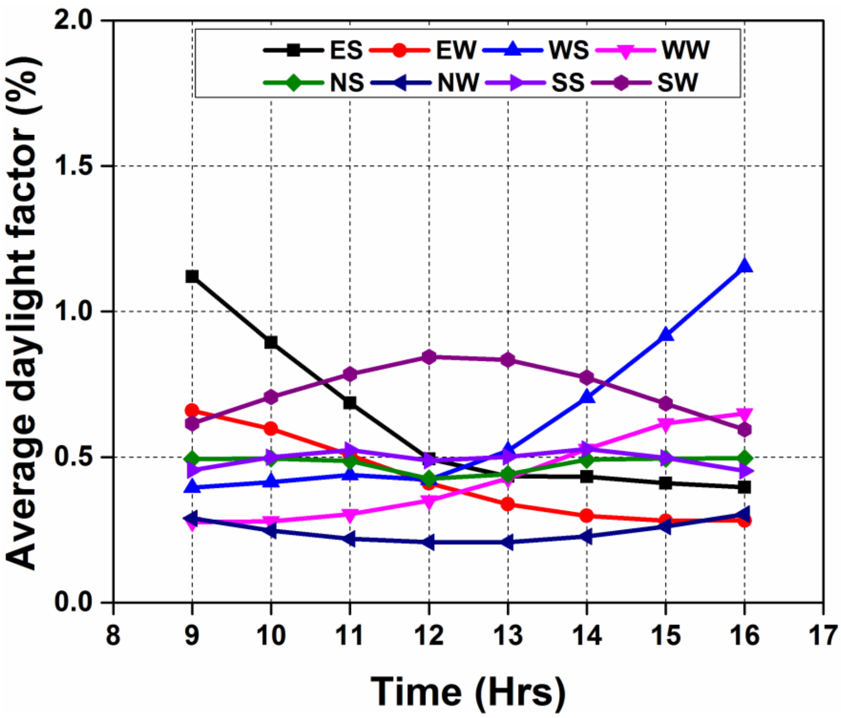


Figure 8.3.6 Average daylight factor in buildings through double bronze reflective glass window at peak summer and winter days

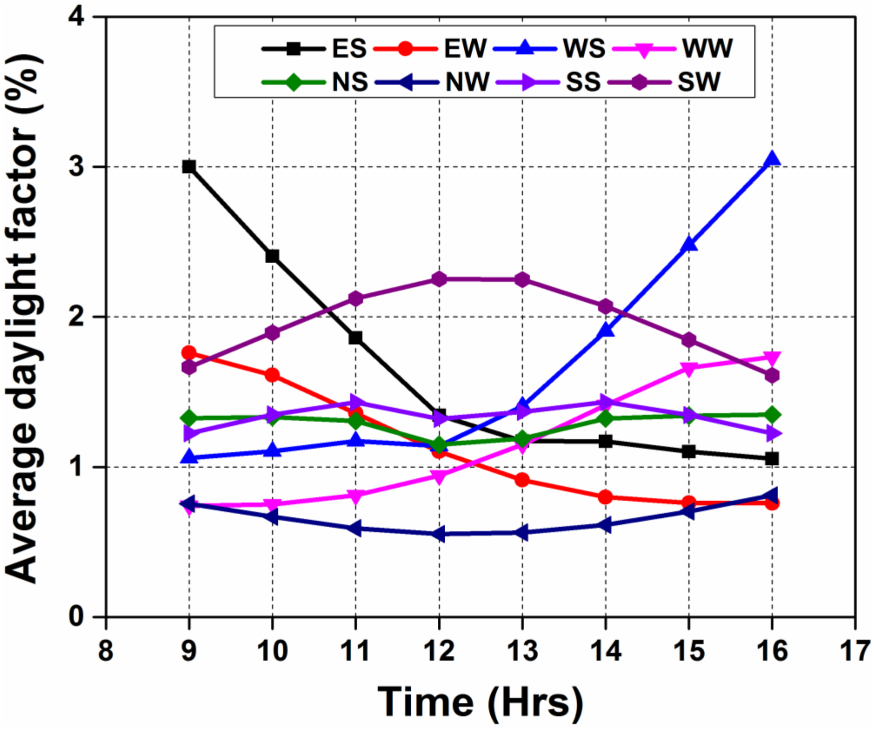


Figure 8.3.7 Average daylight factor in buildings through double green reflective glass window at peak summer and winter days

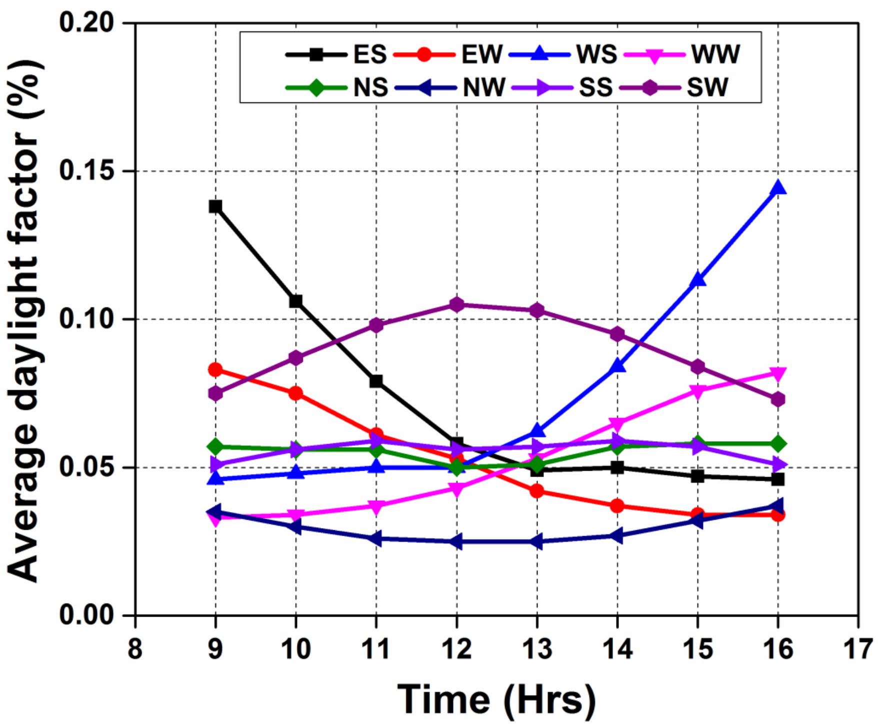


Figure 8.3.8 Average daylight factor in buildings through double grey reflective glass window at peak summer and winter days

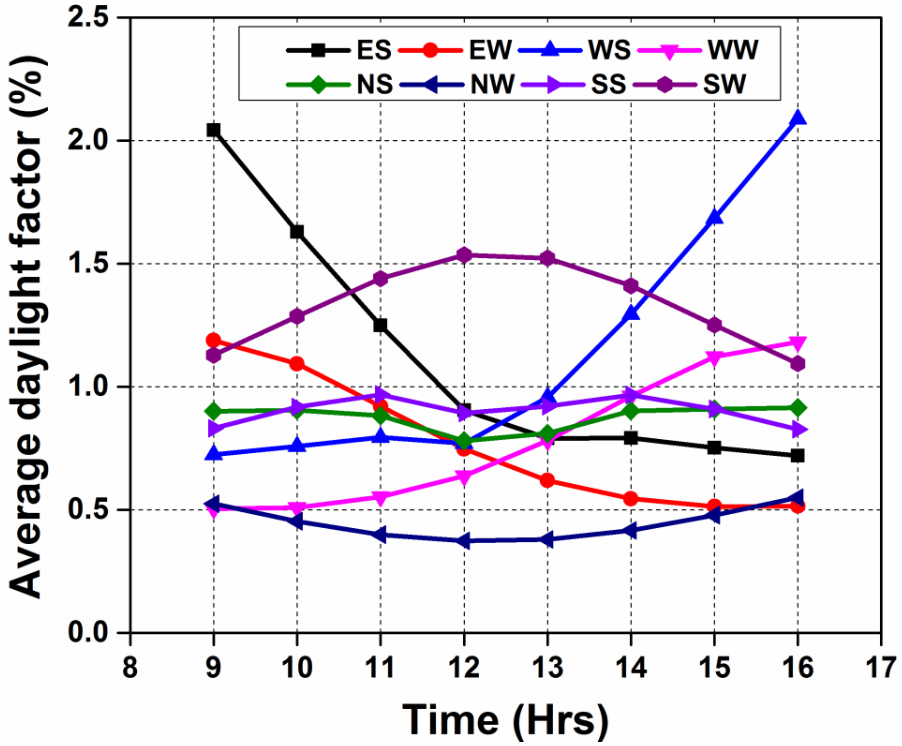


Figure 8.3.9 Average daylight factor in buildings through double opal blue reflective glass window at peak summer and winter days

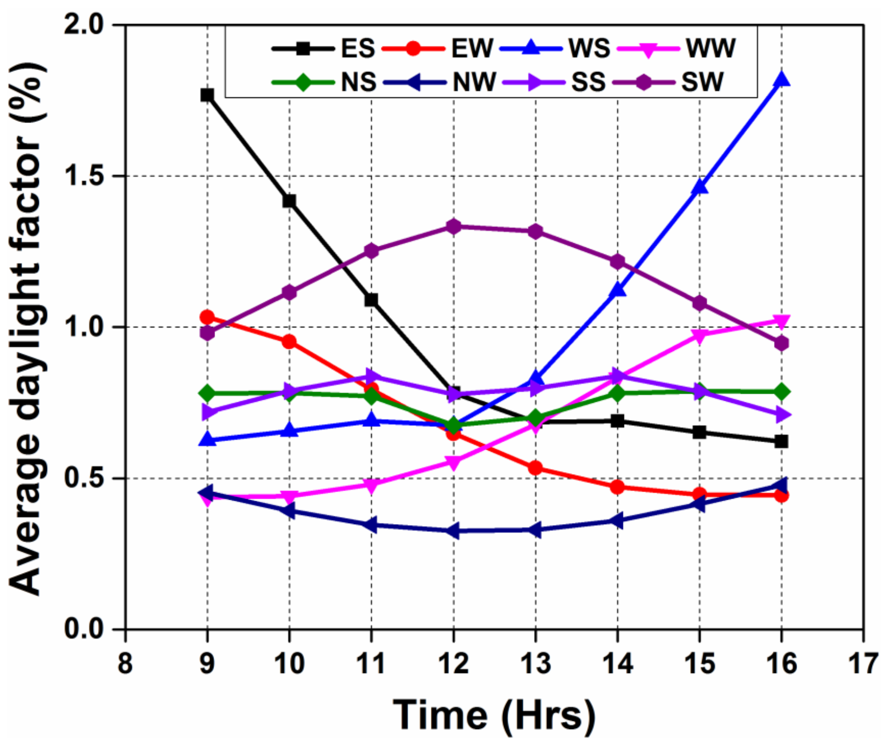


Figure 8.3.10 Average daylight factor in buildings through double sapphire blue reflective glass window at peak summer and winter days

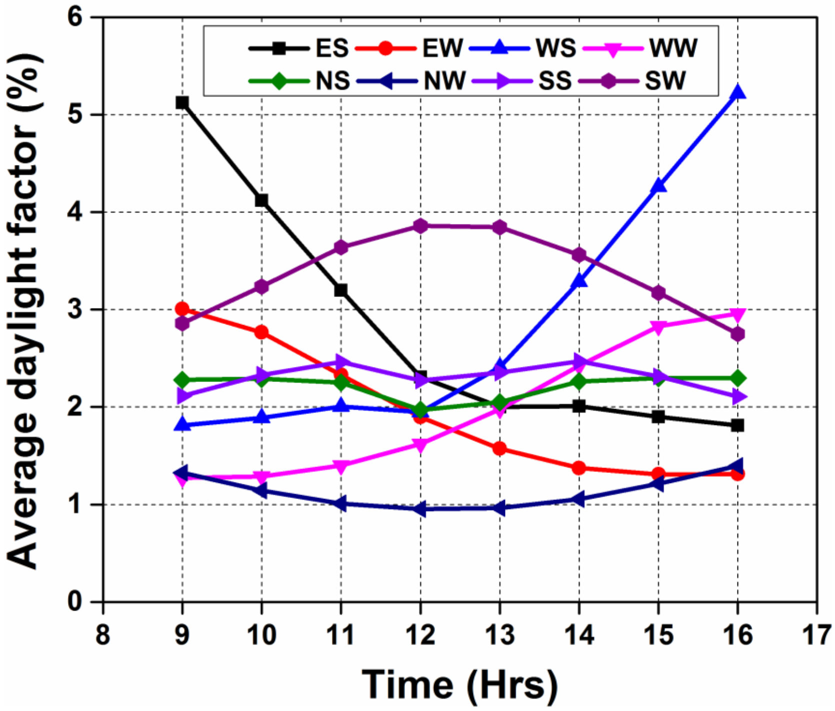


Figure 8.3.11 Average daylight factor in buildings through double gold reflective glass window at peak summer and winter days

CHAPTER-9

EFFECT OF VARIOUS TYPES OF EXTERNAL SHADING DEVICES ON WINDOWS TO PROVIDE OPTIMUM HEAT AND OPTIMUM DAYLIGHT IN BUILDINGS

9.1 INTRODUCTION

The glass used in buildings allows solar heat gain and at the same time it allows daylighting into buildings. To reduce maximum heat gain and allow ample daylighting levels into the buildings through windows, some devices (shading devices) are used without any change of window glass material. These are used on windows to minimize the quantity of direct Sun radiation into the buildings through windows. Shading devices are of different types i.e., overhang, overhang with side fins, venetian blinds, louvers, inside louvers and outside louvers. Table 9.1.1, shows the details of various shading devices on glass windows.

Table 9.1.1 Total glass combinations studied for heat gain and daylighting

Climatic zone	Number of single glasses	Louvers on window (10^0 to 60^0 deg)	Orientations	Number of combinations in summer	Number of combinations in winter
New Delhi	1	6	4	1×6×4=24	1×6×4=24
Climatic zone	Number of single glasses	Shading devices on window	Orientations	Number of combinations in summer	Number of combinations in winter
New Delhi	4	4 (Overhang, Louver, Egg crate and Egg crate+ louver)	1 (South)	4×4=16	4×4=16

9.2 INFLUENCE OF LOUVER TILT SHADING DEVICE ON A GLASS WINDOW ON OPTIMUM HEAT GAIN AND OPTIMUM DAYLIGHTING IN BUILDINGS

In this work, dimensions of the building were taken as 3.5 m × 3.5 m × 3.5 m. The building was having window area of 2.45 m × 2 m dimensions. Louver shading devices at various tilts were studied on clear glass window to reduce more quantity of heat gain as well as to provide sufficient day lighting on both peak summer and winter days of composite climatic region (New Delhi) in India in all four orientations. Slant louver shading devices made up of timber wood material and thickness of 0.020 m at tilt positions of 10^0, 20^0, 30^0, 40^0, 50^0, and 60^0 on window were arranged one by one, such that total six louver shading windows were analyzed in each orientation. Table 9.2.1 shows the details of louver shading devices on clear glass window in four orientations. Figure 9.2.1(a) shows the building model having slant louver shading devices on window and Figure 9.2.1(b) shows the slant louver shading devices arranged on glass.

Table 9.2.1 Glass materials studied

Number of glasses	Climatic zones	Glass	Number of orientations	Louvers at various tilts	Total number of combinations
1	New Delhi	clear glass	4	6 (10^0, 20^0, 30^0, 40^0, 50^0 and 60^0)	1×4×6=24

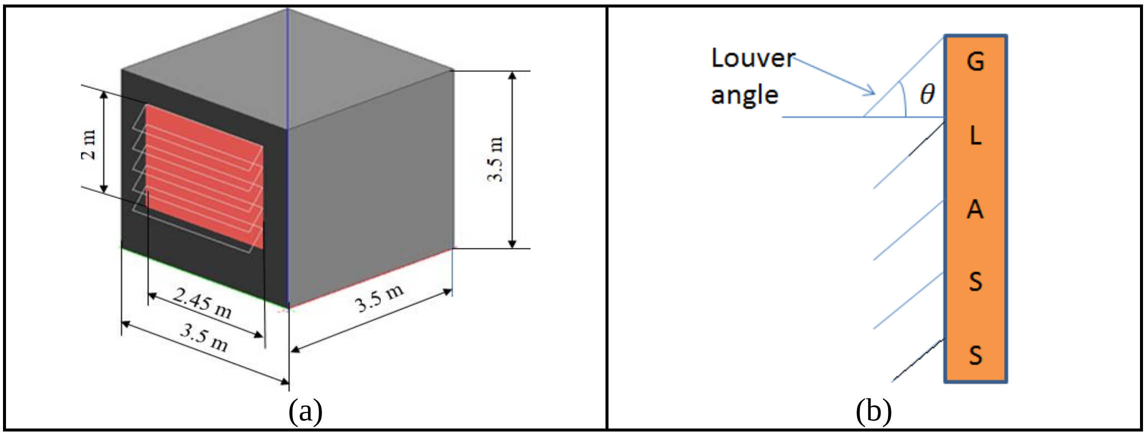


Figure 9.2.1(a) Building model having louver shadings on window (b) Glass window having louver shading device at inclination

9.2.1 Heat gain into the buildings through louver shadings at six tilt positions on window in New Delhi climatic region on peak summer and winter days

Figures 9.2.2 and 9.2.3, show the heat gain into the buildings through clear glass window having louver shading devices at six tilt positions like 10^0, 20^0, 30^0, 40^0, 50^0 and 60^0 in four directions on peak summer and winter days for New Delhi region. From the graphs it is clearly observed that, the heat gain into the buildings through windows is more in west orientation and less in south orientation, during peak summer day. It is also clearly observed that, the heat gain into the buildings through windows is more in south orientation and less in north orientation, during peak winter day. At peak summer day in the south orientation, louver shading device with 60^0 tilt is gaining less heat of 2.45 kWh as shown in Figure 9.2.2. On peak winter day, in the south orientation louver shading device with 10^0 tilt is gaining more heat of 3.13 kWh as shown in Figure 9.2.3, when compared with other orientations.

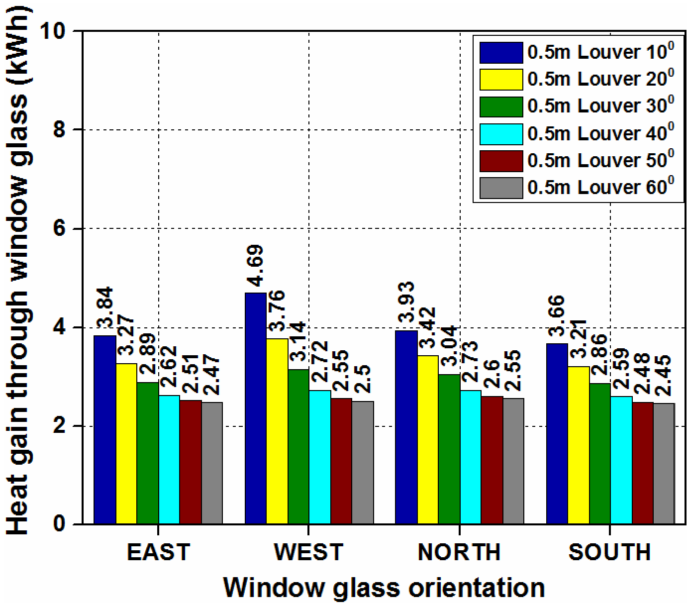


Figure 9.2.2 Heat gain into the buildings through glass window having louvers at various tilts for New Delhi region at peak summer day

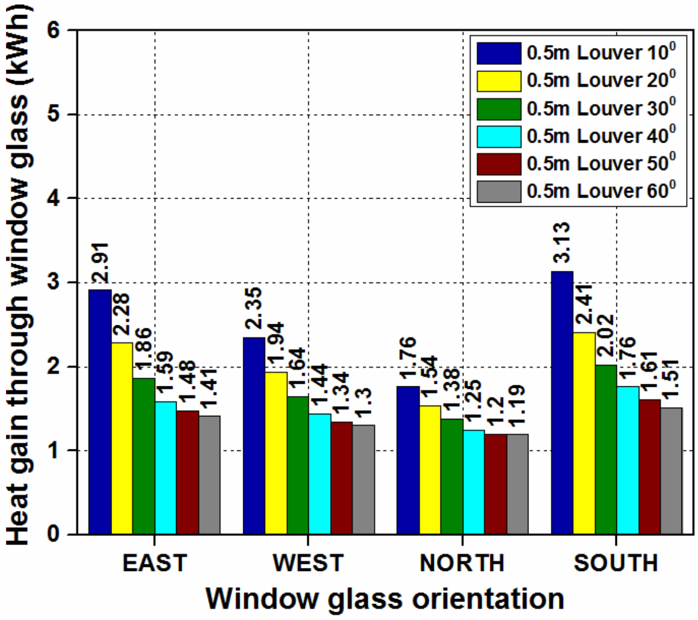


Figure 9.2.3 Heat gain into the buildings through glass window having louvers at various tilts for New Delhi region at peak winter day

9.2.2 Average daylight factor inside the buildings through clear glass window having louver shading devices at different tilt positions

Figures 9.2.4 to 9.2.9, show the average daylight factor in buildings having slant louver shading devices at different tilt positions like 10^0, 20^0, 30^0, 40^0, 50^0 and 60^0 on clear glass window placed in four orientations, one by one on peak summer and peak winter day, for New Delhi zone. Figures 9.2.4 to 9.2.9 show that average daylight factor in buildings from east orientation is periodic in nature during summer season from all six louver shading devices and it is also noticed that, the daylight factor in the buildings from east orientation decreases with increase in time during winter season. In west orientation, average daylight factor inside the building is periodic in nature during summer season, and in winter, average daylight factor increases with increase in time. In north orientation, average daylight factor inside the building is periodic during summer this is due to Sun movement from northeast to northwest orientation and also due to solar insolation outside at that particular day and time. In winter season, average daylight factor is presented as shown in 9.2.4 to 9.2.9; this is due to inclination of the shading device and Sun movement from southeast to southwest orientation and also due to solar insolation. In south orientation, average daylight factor inside the building is periodic during summer season and this is due to Sun movement from northeast to northwest orientation and also due to solar insolation outside at that particular day and time. In winter season, average daylight factor is presented as shown in 9.2.4 to 9.2.9; this is due to inclination of the shading device and Sun movement from southeast to southwest orientation and also due to solar insolation.

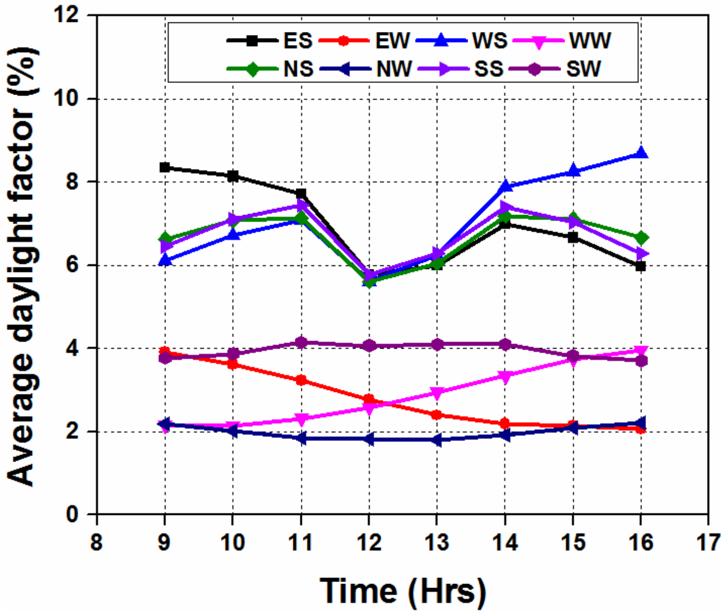


Figure 9.2.4 Average daylight factor in buildings through clear glass window having 10^0 louver shading devices in four orientations at peak summer and winter days

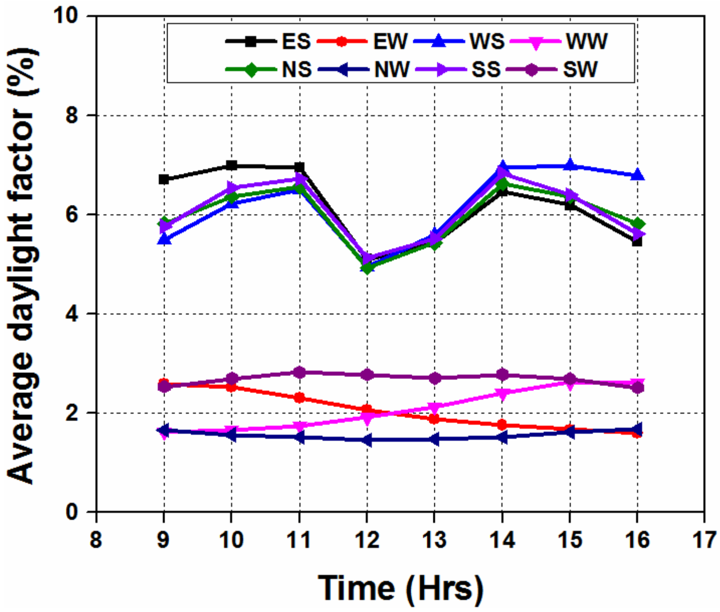


Figure 9.2.5 Average daylight factor in buildings through clear glass window having 20^0 louver shading devices in four orientations at peak summer and winter days

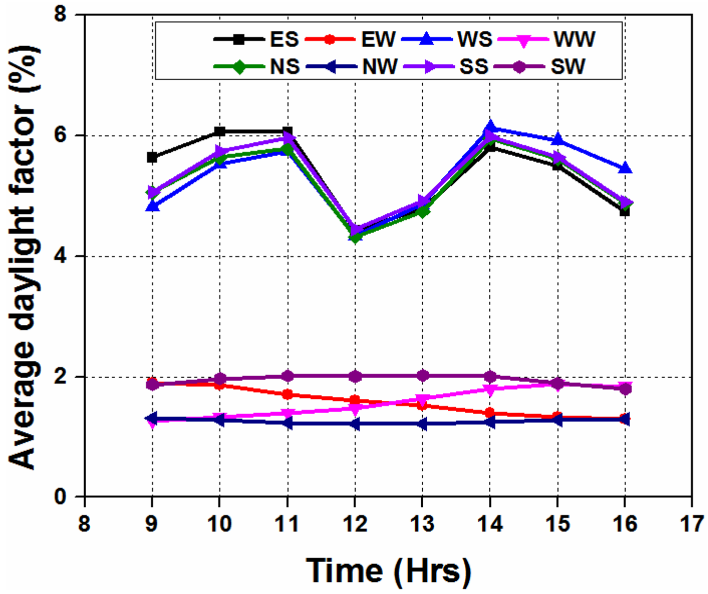


Figure 9.2.6 Average daylight factor in buildings through clear glass window having 30^0 louver shading devices in four orientations at peak summer and winter days

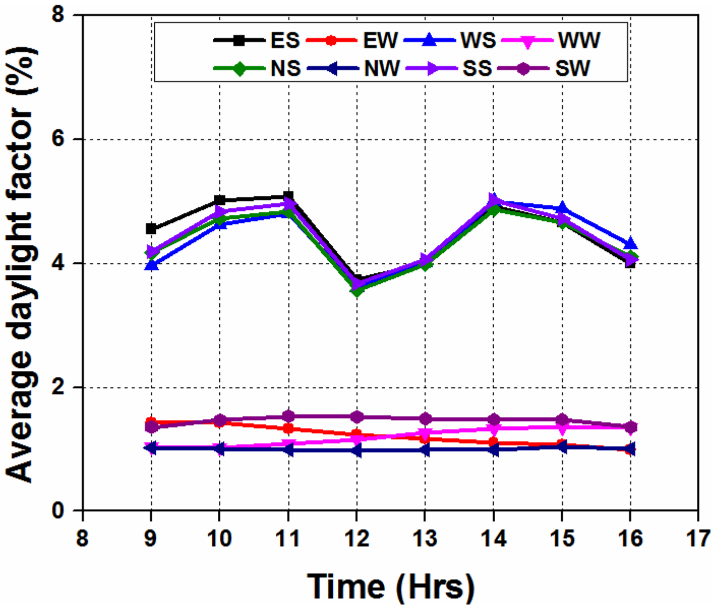


Figure 9.2.7 Average daylight factor in buildings through clear glass window having 40^0 louver shading devices in four orientations at peak summer and winter days

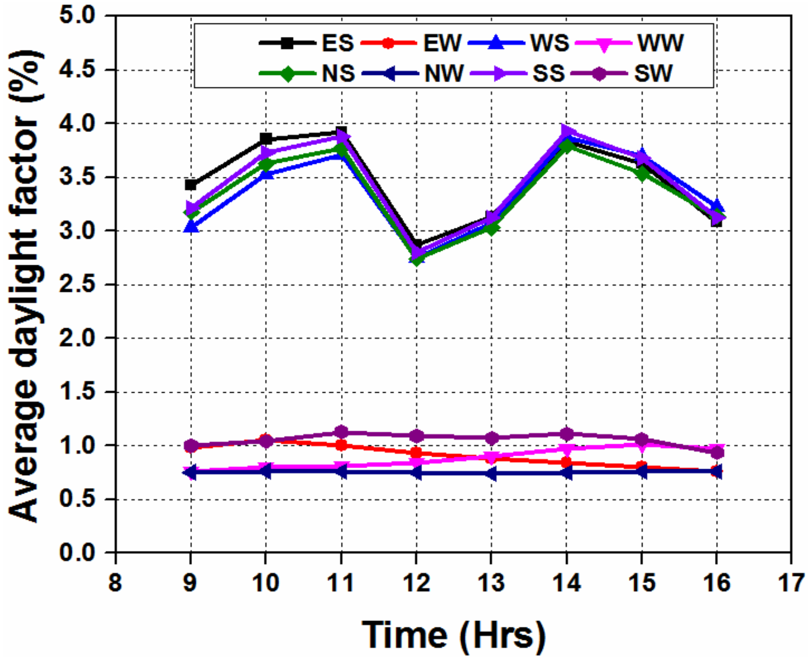


Figure 9.2.8 Average daylight factor in buildings through clear glass window having 50^0 louver shading devices in four orientations at peak summer and winter days

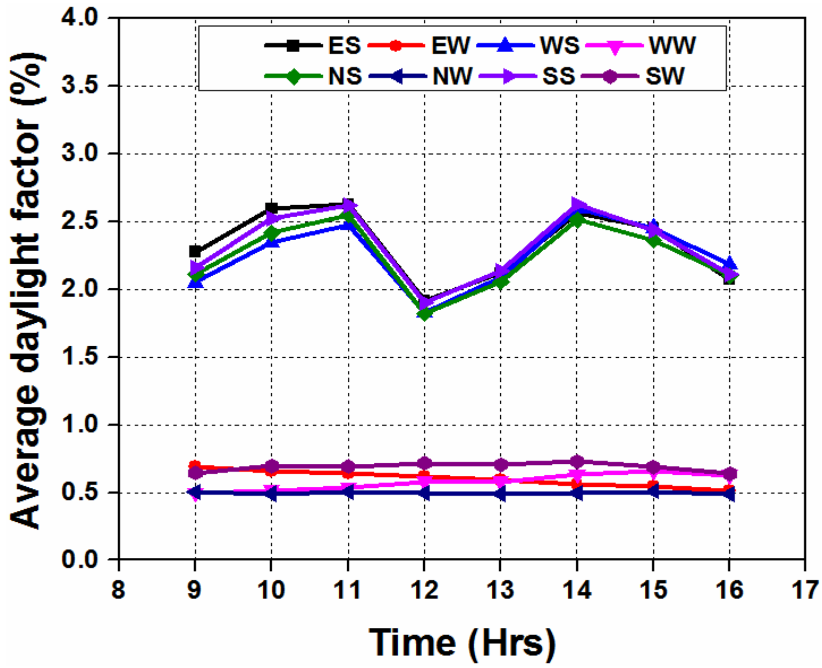


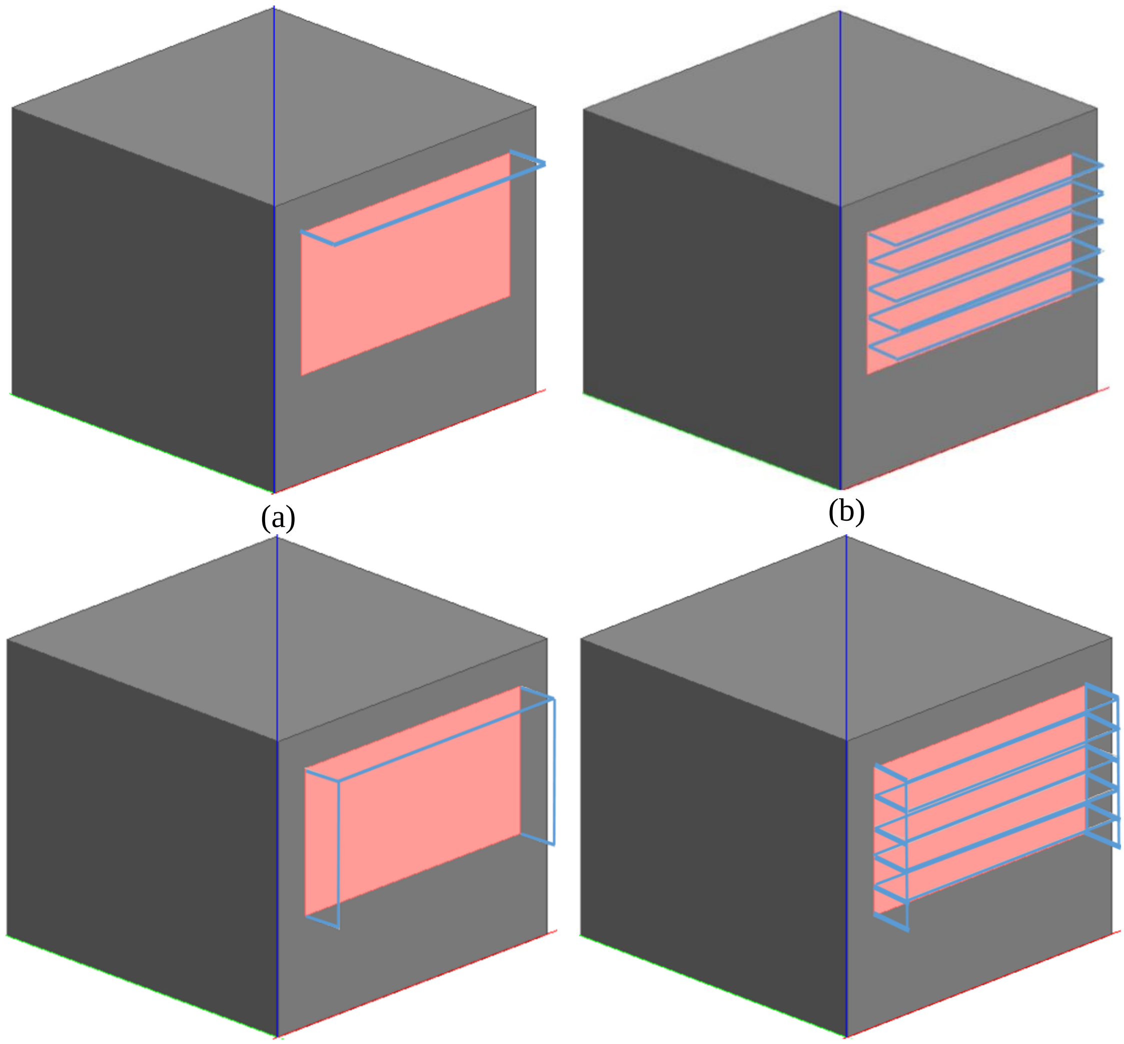
Figure 9.2.9 Average daylight factor in buildings through clear glass window having 60^0 louver shading devices in four orientations at peak summer and winter days

9.3 IMPACT OF DIFFERENT EXTERNAL SHADING DEVICES ON GLASS WINDOWS ON OPTIMUM HEAT GAIN AND OPTIMUM DAYLIGHTING IN BUILDINGS

This section discusses about various external shading devices such as overhang, louver, egg-crate and (egg-crate + louver) shading devices, tried on four glass windows in south orientation, due to less solar heat gain in summer due to Sun rises in north east and sets in the northwest so less heat will fall in south orientation at summer solstice (June 21^{st}) and more solar heat gain in winter due to Sun rises in south east and sets in the southwest so more heat will fall in south orientation at winter solstice (Dec 21^{st}) in buildings. Table 9.3.1 shows the details about the different shading devices on four glass windows studied. Figures 9.3.1(a to d), show a building model having external shading devices such as 0.5 m overhang shading device, 0.5 m louver shading device, 0.5m Egg-crate shading device and (0.5m Egg-crate + 0.5m Louver) shading device.

Table 9.3.1 Number of shading devices and glass materials studied

Number of glasses	Climatic zones	Glass arrangement	Shading devices	Total number of combinations
4	New Delhi	Single glass (Clear, Bronze, Green and Grey)	4 (Over hang, Louver, Egg Create, (Egg create + Louver))	1×4×4=16



(a) (b) (c) (d)

Figure 9.3.1 Building dimensions 3.5 m × 3.5 m × 3.5m having external shading devices on window: (a) 0.5m Overhang (b) 0.5m Louver (c) 0.5m Egg-crate and (d) (0.5m Egg-crate + 0.5m Louver)

9.3.1 Heat gain into the buildings through glass windows having four types of external shading devices in the climatic region of New Delhi

Figures 9.3.2 and 9.3.3, show the heat gain into the buildings through various glass windows having four types of shading devices in south orientation, in the climatic region of New Delhi, on peak summer and on peak winter day. From the graph 9.3.2, it is clearly observed that the heat gain inside the building is more through clear glass window and less through grey glass window, during both summer and winter seasons. On peak summer day heat gain in buildings through grey glass window having (0.5m

Egg-crate+0.5m Louver) external shading device is the least with a heat gain of 1.74 kWh and on peak winter day, solar heat gain in buildings having 0.5m overhang shading device is more through clear glass window, with a heat gain of 14.16 kWh, when compared to all other shading devices.

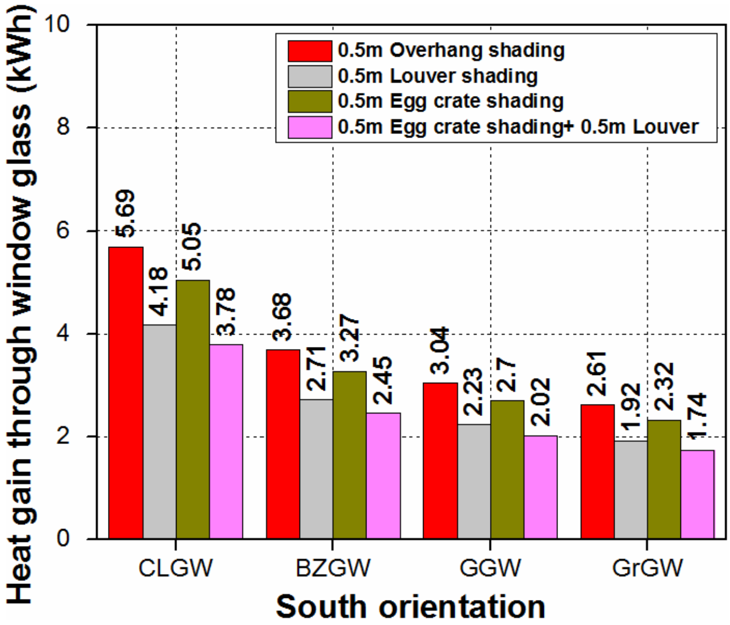


Figure 9.3.2 Heat gain in buildings through glass windows having external shading devices in the climatic region of New Delhi at peak summer day

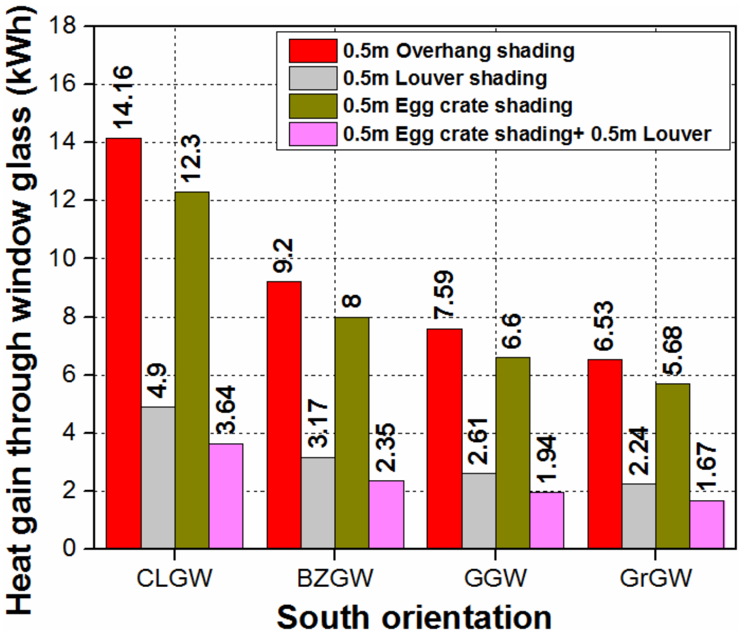


Figure 9.3.3 Heat gain in buildings through glass windows having external shading devices in the climatic region of New Delhi at peak winter day

9.3.2 Average daylight factor inside the building through glass windows having overhang shading device

Figures 9.3.4 and 9.3.5, show the average daylight factor inside the buildings through four types of glass windows having overhang shading device, placed externally in south orientation, one by one, on a peak summer day and on a peak winter day, in the climatic region of New Delhi, from morning (9:00 hr) to evening (16:00 hr).

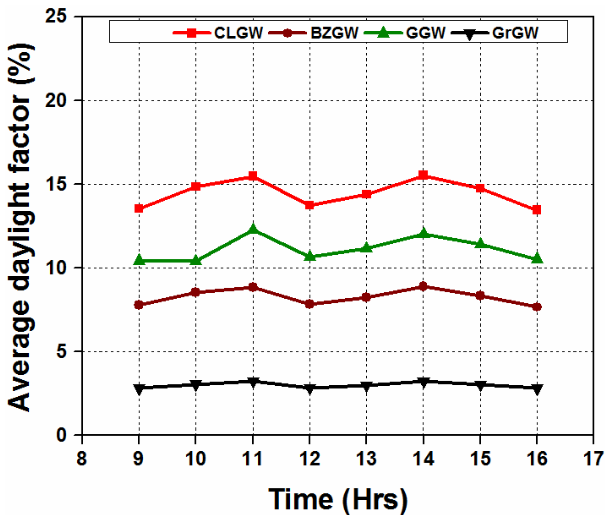


Figure 9.3.4 Average daylight factor in buildings through glass windows having overhang shading device in south orientation at peak summer day

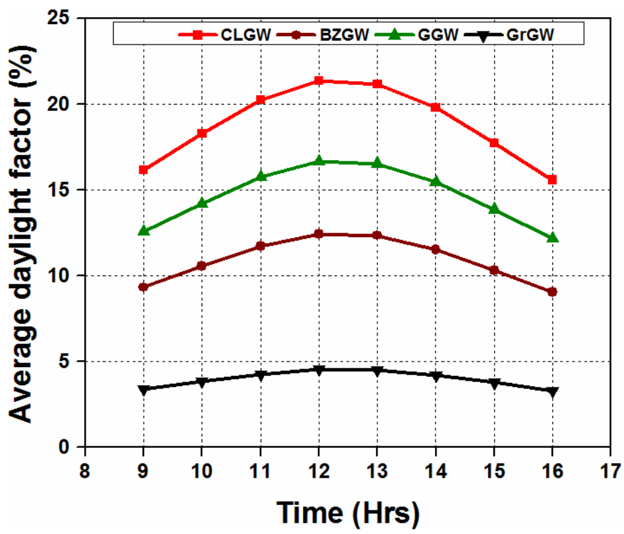


Figure 9.3.5 Average daylight factor in buildings through glass windows having overhang shading device in south orientation at peak winter day

Figure 9.3.4, shows that average daylight factor is periodic during summer, which is due to Sun movement from northeast to northwest orientation and it also depends on solar insolation outside at that particular day and time. In winter, average daylight is presented as shown in Figure 9.3.5, that is due to Sun movement from southeast to southwest orientation and it also depends on solar insolation outside at that particular day and time.

9.3.3 Average daylight factor inside the building through glass windows having Louver shading device

Figure 9.3.6 and 9.3.7, show the average daylight factor inside the buildings through four types of glass windows having Louver shading device placed externally in south orientation.

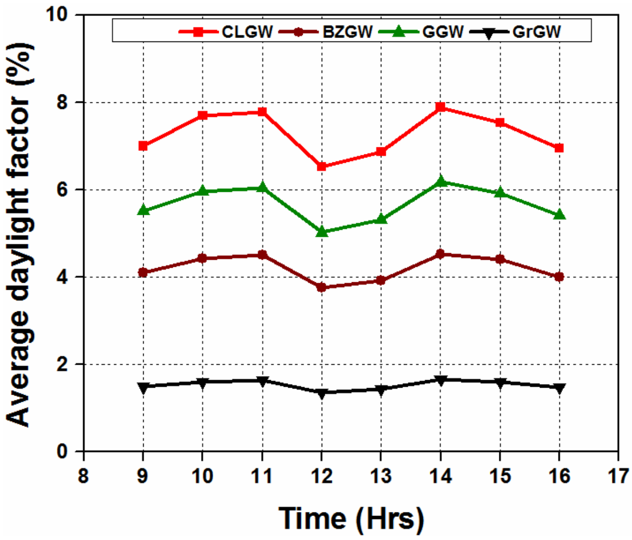


Figure 9.3.6 Average daylight factor in buildings through glass windows having louver shading device in south orientation at peak summer day

Figure 9.3.6 shows that the average daylight factor is periodic during summer, which is due to Sun movement from northeast to northwest orientation and it also depends on solar insolation outside at that particular day and time. In winter, average daylight factor is presented as shown in Figure 9.3.7, that is due to Sun movement from southeast to southwest orientation and it also depends on solar insolation outside at that particular day and time.

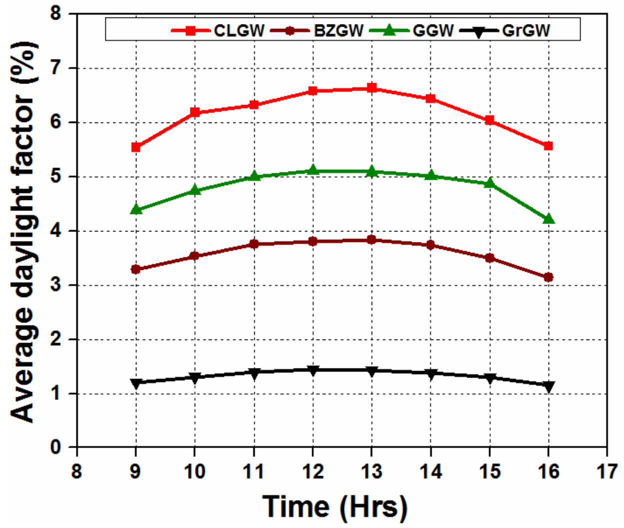


Figure 9.3.7 Average daylight factor in buildings through glass windows having louver shading device in south orientation at peak winter day

9.3.4 Average daylight factor inside the building through glass windows having Egg-crate shading device

Figures 9.3.8 and 9.3.9, show the average daylight factor inside the buildings through four types of glass windows having Egg-crate shading device placed externally in south orientation.

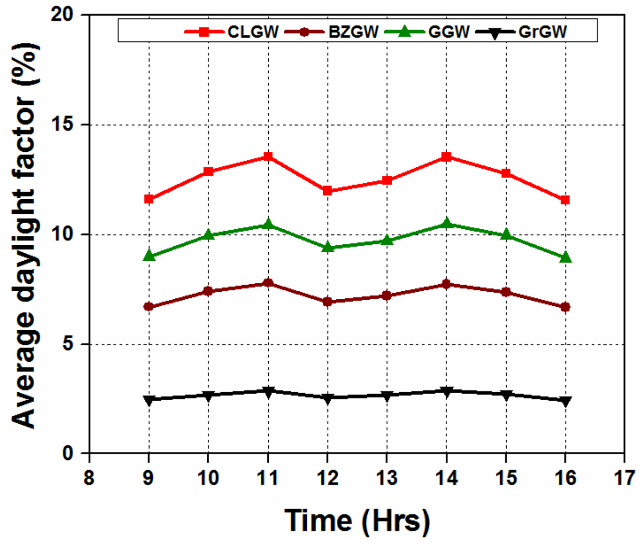


Figure 9.3.8 Average daylight factor in buildings through glass windows having Egg-crate shading device in south orientation at peak summer day

Figure 9.3.8 shows that the average daylight factor is periodic during summer, which is due to Sun movement from northeast to northwest orientation and also, it depends on solar insolation outside at that particular day and time. In winter, average daylight factor is presented as shown in Figure 9.3.9, that is due to Sun movement from southeast to southwest orientation and it also depends on solar insolation outside at that particular day and time.

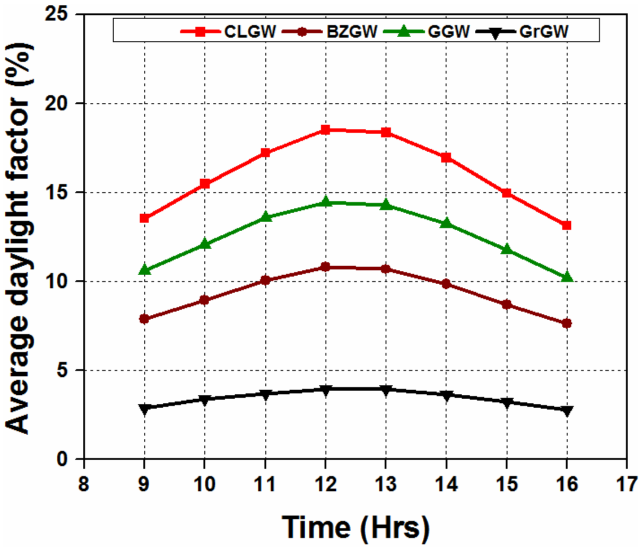


Figure 9.3.9 Average daylight factor in buildings through glass windows having Egg-crate shading device in south orientation at peak winter day

9.3.5 Average daylight factor inside the building through glass windows having (Egg-crate + Louver) shading device

Figures 9.3.10 and 9.3.11, show the average daylight factor inside the buildings through four types of glass windows having (Egg-crate + Louver) shading device placed externally in south orientation. Figure 9.3.10, shows that the average daylight factor is periodic during summer, which is due to Sun movement from northeast to northwest orientation and it also depends on solar insolation outside at that particular day and time. In winter, average daylight factor is presented as shown in Figure 9.3.11, that is due to Sun movement from southeast to southwest orientation and it also depends on solar insolation outside at that particular day and time.

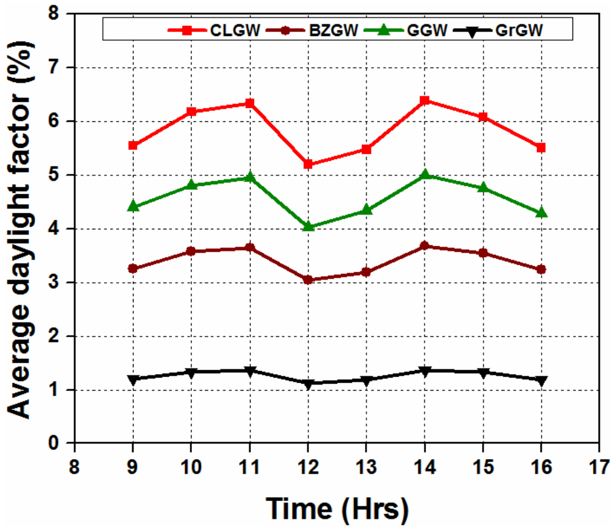


Figure 9.3.10 Average daylight factor in buildings through glass windows having Egg-crate + Louver shading device in south orientation at peak summer day

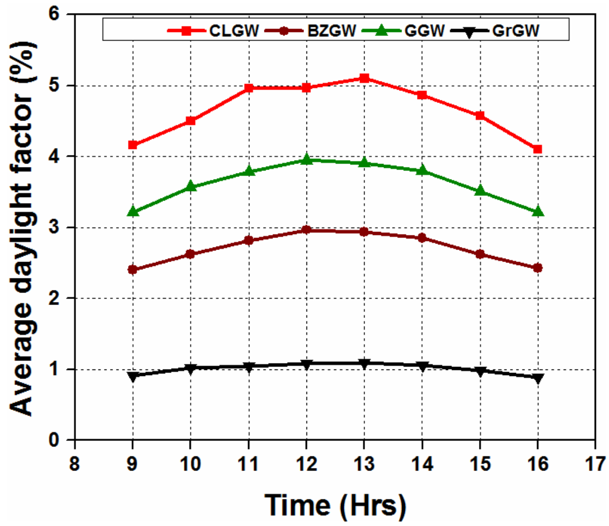


Figure 9.3.11 Average daylight factor in buildings through glass windows having Egg-crate + Louver shading device in south orientation at peak winter day.

CHAPTER-10

CONCLUSIONS

From this study it is concluded that window orientation in south direction is good for all climatic conditions in India, hence it is recommended to provide the maximum glass area in south direction of the buildings.

- For single glass vertical position, it is recommended to use Grey reflective glass for window to save energy which is clear from Table 10.1.
- For single glass an inclination of 6^0 facing towards earth is recommended for all climatic zones studied. The results are listed in Table 10.2.
- Double glass window combination, GC 16 combination is suggested to save the energy summer. The results are listed in Table 10.3.
- 40% to 60% and 60% to 80% window to wall ratios are recommended for domestic buildings and commercial buildings respectively.
- The simulation studies show that double grey clear glass window combination is best to reduce cooling loads when compare with single glass windows like clear, bronze, green, grey and double clear, triple clear and quadruple clear glasses because this is due to double grey clear glass window is having less transmission property. Hence it is concluded to optional for double grey clear glass.
- Green reflective glass is meeting the required daylight factor values in different buildings, so it is recommended to use as window for these buildings. On the other hand, green reflective glass window allows more daylight factor in winter season. In order to maintain adequate day lighting in winter, external shading devices can be used on green reflective glass window, so that required day lighting can be maintained in winter season. Double gold reflective glass window is recommended to allow optimum heat and to maintain day light

factor values and these are suitable for various builsings in both peak summer and winter days, and the results are listed in Table 10.4.

- Louver shading device on clear glass at 50^0 tilt position in summer and 10^0 tilt positions in winter, is suggested to allow optimum heat gain and daylighting. So, louver at 50^0 tilt position in summer and 10^0 tilt position in winter are recommended to maintain both heat as well as daylight levels in various buildings. Egg crate shading device on grey glass window and (Egg crate + louver) shading device on bronze glass window both are recommended in both peak summer and winter days in both heat gain and day lighting perspective. As these shading devices are required to maintain daylight factor values in various buildings and the results are listed in Table 10.5.

Table 10.1 Various Recommended Glasses for Reduced Cooling and Increased Heating Loads in summer and Winter Seasons

Place	**Jodhpur**	**Kolkata**	**New Delhi**
Decrease in cooling load in summer (kWh)	635.92	630.19	634.72
Energy saving in summer (%)	Grey reflective glass 51.3	Grey reflective glass 50.87	Grey reflective glass 51.3
Cost saving per annum (Rs) (Saving in summer-Increase in winter)	4565.5	4378.7	4636.8

Table 10.2 Various Recommended Glasses at 6 Deg glass tilt position in window for Reduced Cooling and Increased Heating Loads in summer and Winter Seasons

Place	**Jodhpur at 6 Deg tilt**	**Kolkata 6 Deg tilt**	**New Delhi 6 Deg tilt**
Decrease in cooling load in summer (kWh)	680.88	693.98	678.07
Energy saving in summer (%)	Grey reflective glass 47.89	Grey reflective glass 45.98	Grey reflective glass 47.92
Cost saving per annum (Rs) (Saving in summer-Increase in winter)	4599.8	4490.9	4662.2

Table 10.3 Various Recommended Double Window Glass Combinations for Reduced Cooling and Increased Heating Loads in summer and Winter Seasons

Place	**Jodhpur**
Decrease in cooling load in summer (kWh)	791.36
Energy saving in summer (%)	GC16 (68.67)
Cost saving per annum (Rs) (Saving in summer-Increase in winter)	5386.5

Table 10.4 Various Recommended Glasses for Heat gain and Daylighting at both Peak Summer and Winter Days

Place	**Best single glass**	**Best double glass**	**Heat gain**	**Day light**
New Delhi	Grey reflective	-	Grey reflective in summer	Green reflective in summer
	Bronze reflective	-	Bronze reflective in winter	Bronze reflective in winter
New Delhi	-	Grey reflective	Double grey reflective in summer	Double gold reflective both in summer
		Gold reflective	Double gold reflective in summer	Double gold reflective both in winter

Table 10.5 Various Recommended Shading Devices on Windows for Heat gain and Daylighting at both Peak Summer and Winter Days

Place	**Louvers shading on glass (10^0 to 60^0)**	**Best louver position on glass in summer**	**Best louver position on glass in winter**	**Day light**
New Delhi	Clear glass	50^0 louvers	10^0 louvers	50^0 louvers in summer 10^0 louvers in winter
Place	**Four glasses**	**Best shading device in summer**	**Best shading device in winter**	**Day light, glass and Shading at summer and winter seasons**
New Delhi	Clear, bronze, Green and Grey glass	(Egg crate +Louver)	Overhang	Egg crate on Grey glass and (Egg crate + Louver) on Bronze glass in both summer and winter

SCOPE FOR FUTURE WORK

The different types of metal coatings, metal oxide layer coatings, and various polymer coatings on window glasses, affect the increase or decrease in cooling and heating loads inside the buildings. The different ideas that have been put forth in this work will improve and enhance the research in this field.

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APPENDIX-I

Spectral characteristics of bronze glass in visible wavelength region

Wavelength(nm)	Transmission (%)	Reflection (%)	Absorption (%)
380	40.85	5.56	53.59
382	41.76	5.60	52.65
384	43.46	5.69	50.86
386	45.67	5.80	48.53
388	47.92	5.88	46.19
390	49.92	5.99	44.09
392	51.64	6.08	42.28
394	53.14	6.18	40.68
396	54.13	6.23	39.64
398	54.94	6.26	38.80
400	55.41	6.29	38.29
402	55.72	6.31	37.97
404	55.92	6.31	37.77
406	55.86	6.30	37.84
408	55.68	6.29	38.02
410	55.37	6.26	38.37
412	55.10	6.24	38.66
414	54.82	6.21	38.97
416	54.58	6.20	39.23
418	54.33	6.18	39.48
420	54.18	6.15	39.67
422	54.04	6.14	39.82
424	53.80	6.13	40.08
426	53.65	6.12	40.24
428	53.48	6.10	40.42
430	53.18	6.07	40.75
432	52.94	6.05	41.01
434	52.62	6.03	41.35
436	52.33	6.00	41.67
438	52.07	5.99	41.94
440	51.85	5.97	42.18
442	51.64	5.94	42.42
444	51.55	5.94	42.50
446	51.43	5.94	42.64
448	51.38	5.93	42.68
450	51.43	5.94	42.63
452	51.42	5.93	42.65
454	51.48	5.93	42.60
456	51.48	5.93	42.59
458	51.45	5.92	42.63
460	51.36	5.92	42.72
462	51.20	5.90	42.90
464	51.09	5.89	43.02
466	50.94	5.88	43.18
468	50.77	5.86	43.37

470	50.57	5.84	43.59
472	50.36	5.82	43.82
474	50.20	5.80	44.01
476	50.01	5.79	44.20
478	49.81	5.79	44.40
480	49.62	5.77	44.61
482	49.45	5.75	44.79
484	49.30	5.73	44.97
486	49.18	5.72	45.10
488	49.04	5.72	45.24
490	48.93	5.72	45.34
492	48.88	5.73	45.39
494	48.85	5.72	45.43
496	48.84	5.72	45.44
498	48.88	5.73	45.39
500	48.91	5.72	45.36
502	48.94	5.73	45.32
504	49.00	5.72	45.28
506	49.04	5.72	45.24
508	49.09	5.73	45.18
510	49.13	5.72	45.15
512	49.23	5.72	45.05
514	49.43	5.72	44.85
516	49.60	5.72	44.69
518	49.75	5.72	44.54
520	49.93	5.73	44.34
522	50.13	5.74	44.13
524	50.37	5.75	43.88
526	50.63	5.75	43.62
528	50.86	5.77	43.37
530	51.22	5.78	43.00
532	51.63	5.79	42.57
534	52.06	5.82	42.13
536	52.60	5.84	41.57
538	53.18	5.87	40.95
540	53.79	5.90	40.31
542	54.47	5.94	39.60
544	55.14	5.97	38.88
546	55.84	6.01	38.14
548	56.55	6.05	37.40
550	57.26	6.09	36.65
552	57.88	6.13	35.99
554	58.40	6.16	35.44
556	58.85	6.19	34.96
558	59.24	6.21	34.55
560	59.49	6.22	34.29
562	59.62	6.22	34.16
564	59.68	6.22	34.10
566	59.61	6.21	34.18
568	59.45	6.20	34.35

570	59.22	6.18	34.60
572	58.90	6.15	34.95
574	58.46	6.12	35.42
576	58.04	6.10	35.87
578	57.55	6.06	36.39
580	57.00	6.03	36.97
582	56.47	6.00	37.53
584	55.96	5.96	38.09
586	55.51	5.92	38.57
588	55.19	5.91	38.90
590	54.98	5.90	39.12
592	54.87	5.89	39.24
594	54.91	5.89	39.20
596	55.04	5.90	39.06
598	55.25	5.91	38.84
600	55.47	5.92	38.61
602	55.69	5.93	38.38
604	55.90	5.94	38.16
606	56.09	5.95	37.96
608	56.27	5.96	37.77
610	56.42	5.96	37.62
612	56.57	5.97	37.46
614	56.66	5.97	37.37
616	56.73	5.97	37.30
618	56.78	5.98	37.25
620	56.79	5.97	37.23
622	56.79	5.98	37.24
624	56.77	5.98	37.26
626	56.73	5.97	37.31
628	56.64	5.97	37.39
630	56.52	5.95	37.54
632	56.37	5.94	37.70
634	56.19	5.93	37.89
636	56.08	5.92	38.00
638	55.98	5.90	38.12
640	55.84	5.90	38.26
642	55.68	5.89	38.43
644	55.58	5.88	38.54
646	55.54	5.88	38.58
648	55.54	5.88	38.58
650	55.61	5.88	38.51
652	55.73	5.89	38.38
654	55.81	5.89	38.30
656	55.97	5.89	38.13
658	56.20	5.92	37.89
660	56.44	5.94	37.62
662	56.73	5.95	37.32
664	57.15	5.97	36.88
666	57.53	5.99	36.48
668	57.97	6.02	36.01

670	58.46	6.04	35.50
672	58.98	6.06	34.96
674	59.51	6.09	34.40
676	60.09	6.14	33.77
678	60.69	6.17	33.14
680	61.38	6.21	32.41
682	61.94	6.26	31.79
684	62.48	6.29	31.23
686	63.10	6.32	30.58
688	63.66	6.37	29.96
690	64.07	6.40	29.52
692	64.57	6.43	29.00
694	65.00	6.46	28.54
696	65.35	6.47	28.17
698	65.64	6.50	27.85
700	65.91	6.53	27.56
702	66.06	6.55	27.39
704	66.17	6.55	27.28
706	66.38	6.56	27.05
708	66.54	6.56	26.89
710	66.47	6.57	26.96
712	66.48	6.55	26.97
714	66.50	6.56	26.94
716	66.44	6.56	27.00
718	66.31	6.55	27.13
720	66.29	6.56	27.15
722	66.24	6.55	27.21
724	66.08	6.53	27.39
726	66.02	6.53	27.45
728	65.83	6.52	27.65
730	65.73	6.49	27.77
732	65.59	6.51	27.90
734	65.41	6.52	28.07
736	65.23	6.49	28.28
738	65.16	6.48	28.36
740	64.85	6.47	28.68
742	64.73	6.48	28.79
744	64.55	6.46	28.99
746	64.34	6.45	29.21
748	64.27	6.43	29.30
750	63.97	6.43	29.59
752	63.87	6.41	29.72
754	63.57	6.40	30.02
756	63.48	6.36	30.15
758	63.33	6.40	30.27
760	63.24	6.37	30.40
762	63.07	6.34	30.59
764	62.88	6.36	30.76
766	62.67	6.34	30.99
768	62.50	6.33	31.17

770	62.23	6.34	31.42
772	62.25	6.31	31.44
774	62.02	6.28	31.69
776	61.70	6.28	32.01
778	61.61	6.27	32.11
780	61.64	6.27	32.10

APPENDIX-II

Spectral characteristics of bronze glass in solar spectrum wavelength region

Wavelength(nm)	Transmission (%)	Reflection (%)	Absorption (%)
300	0.02	4.96	95.02
302	0.02	4.93	95.06
304	0.04	4.94	95.02
306	0.02	4.88	95.10
308	0.02	4.82	95.16
310	0.01	4.87	95.12
312	-0.03	4.90	95.13
314	0.00	4.77	95.24
316	0.00	4.73	95.27
318	0.00	4.84	95.16
320	0.02	4.91	95.08
322	0.03	4.79	95.19
324	0.02	4.82	95.16
326	0.00	4.80	95.20
328	0.04	4.81	95.15
330	0.08	4.83	95.10
332	0.19	4.77	95.04
334	0.45	4.76	94.79
336	0.88	4.72	94.40
338	1.61	4.70	93.69
340	2.74	4.71	92.55
342	4.30	4.72	90.98
344	6.27	4.73	89.00
346	8.75	4.71	86.54
348	11.55	4.76	83.68
350	14.82	4.86	80.32
352	18.15	4.85	77.01
354	21.44	4.96	73.60
356	25.04	5.03	69.93
358	28.25	5.13	66.63
360	31.30	5.23	63.47
362	34.12	5.35	60.53
364	36.61	5.45	57.93
366	38.81	5.53	55.66
368	40.63	5.57	53.80
370	41.73	5.63	52.64
372	42.22	5.65	52.13
374	42.14	5.67	52.19
376	41.54	5.68	52.77
378	40.85	5.59	53.56
380	40.85	5.56	53.59
382	41.76	5.60	52.65
384	43.46	5.69	50.86
386	45.67	5.80	48.53
388	47.92	5.88	46.19

390	49.92	5.99	44.09
392	51.64	6.08	42.28
394	53.14	6.18	40.68
396	54.13	6.23	39.64
398	54.94	6.26	38.80
400	55.41	6.29	38.29
402	55.72	6.31	37.97
404	55.92	6.31	37.77
406	55.86	6.30	37.84
408	55.68	6.29	38.02
410	55.37	6.26	38.37
412	55.10	6.24	38.66
414	54.82	6.21	38.97
416	54.58	6.20	39.23
418	54.33	6.18	39.48
420	54.18	6.15	39.67
422	54.04	6.14	39.82
424	53.80	6.13	40.08
426	53.65	6.12	40.24
428	53.48	6.10	40.42
430	53.18	6.07	40.75
432	52.94	6.05	41.01
434	52.62	6.03	41.35
436	52.33	6.00	41.67
438	52.07	5.99	41.94
440	51.85	5.97	42.18
442	51.64	5.94	42.42
444	51.55	5.94	42.50
446	51.43	5.94	42.64
448	51.38	5.93	42.68
450	51.43	5.94	42.63
452	51.42	5.93	42.65
454	51.48	5.93	42.60
456	51.48	5.93	42.59
458	51.45	5.92	42.63
460	51.36	5.92	42.72
462	51.20	5.90	42.90
464	51.09	5.89	43.02
466	50.94	5.88	43.18
468	50.77	5.86	43.37
470	50.57	5.84	43.59
472	50.36	5.82	43.82
474	50.20	5.80	44.01
476	50.01	5.79	44.20
478	49.81	5.79	44.40
480	49.62	5.77	44.61
482	49.45	5.75	44.79
484	49.30	5.73	44.97
486	49.18	5.72	45.10
488	49.04	5.72	45.24

490	48.93	5.72	45.34
492	48.88	5.73	45.39
494	48.85	5.72	45.43
496	48.84	5.72	45.44
498	48.88	5.73	45.39
500	48.91	5.72	45.36
502	48.94	5.73	45.32
504	49.00	5.72	45.28
506	49.04	5.72	45.24
508	49.09	5.73	45.18
510	49.13	5.72	45.15
512	49.23	5.72	45.05
514	49.43	5.72	44.85
516	49.60	5.72	44.69
518	49.75	5.72	44.54
520	49.93	5.73	44.34
522	50.13	5.74	44.13
524	50.37	5.75	43.88
526	50.63	5.75	43.62
528	50.86	5.77	43.37
530	51.22	5.78	43.00
532	51.63	5.79	42.57
534	52.06	5.82	42.13
536	52.60	5.84	41.57
538	53.18	5.87	40.95
540	53.79	5.90	40.31
542	54.47	5.94	39.60
544	55.14	5.97	38.88
546	55.84	6.01	38.14
548	56.55	6.05	37.40
550	57.26	6.09	36.65
552	57.88	6.13	35.99
554	58.40	6.16	35.44
556	58.85	6.19	34.96
558	59.24	6.21	34.55
560	59.49	6.22	34.29
562	59.62	6.22	34.16
564	59.68	6.22	34.10
566	59.61	6.21	34.18
568	59.45	6.20	34.35
570	59.22	6.18	34.60
572	58.90	6.15	34.95
574	58.46	6.12	35.42
576	58.04	6.10	35.87
578	57.55	6.06	36.39
580	57.00	6.03	36.97
582	56.47	6.00	37.53
584	55.96	5.96	38.09
586	55.51	5.92	38.57
588	55.19	5.91	38.90

590	54.98	5.90	39.12
592	54.87	5.89	39.24
594	54.91	5.89	39.20
596	55.04	5.90	39.06
598	55.25	5.91	38.84
600	55.47	5.92	38.61
602	55.69	5.93	38.38
604	55.90	5.94	38.16
606	56.09	5.95	37.96
608	56.27	5.96	37.77
610	56.42	5.96	37.62
612	56.57	5.97	37.46
614	56.66	5.97	37.37
616	56.73	5.97	37.30
618	56.78	5.98	37.25
620	56.79	5.97	37.23
622	56.79	5.98	37.24
624	56.77	5.98	37.26
626	56.73	5.97	37.31
628	56.64	5.97	37.39
630	56.52	5.95	37.54
632	56.37	5.94	37.70
634	56.19	5.93	37.89
636	56.08	5.92	38.00
638	55.98	5.90	38.12
640	55.84	5.90	38.26
642	55.68	5.89	38.43
644	55.58	5.88	38.54
646	55.54	5.88	38.58
648	55.54	5.88	38.58
650	55.61	5.88	38.51
652	55.73	5.89	38.38
654	55.81	5.89	38.30
656	55.97	5.89	38.13
658	56.20	5.92	37.89
660	56.44	5.94	37.62
662	56.73	5.95	37.32
664	57.15	5.97	36.88
666	57.53	5.99	36.48
668	57.97	6.02	36.01
670	58.46	6.04	35.50
672	58.98	6.06	34.96
674	59.51	6.09	34.40
676	60.09	6.14	33.77
678	60.69	6.17	33.14
680	61.38	6.21	32.41
682	61.94	6.26	31.79
684	62.48	6.29	31.23
686	63.10	6.32	30.58
688	63.66	6.37	29.96

690	64.07	6.40	29.52
692	64.57	6.43	29.00
694	65.00	6.46	28.54
696	65.35	6.47	28.17
698	65.64	6.50	27.85
700	65.91	6.53	27.56
702	66.06	6.55	27.39
704	66.17	6.55	27.28
706	66.38	6.56	27.05
708	66.54	6.56	26.89
710	66.47	6.57	26.96
712	66.48	6.55	26.97
714	66.50	6.56	26.94
716	66.44	6.56	27.00
718	66.31	6.55	27.13
720	66.29	6.56	27.15
722	66.24	6.55	27.21
724	66.08	6.53	27.39
726	66.02	6.53	27.45
728	65.83	6.52	27.65
730	65.73	6.49	27.77
732	65.59	6.51	27.90
734	65.41	6.52	28.07
736	65.23	6.49	28.28
738	65.16	6.48	28.36
740	64.85	6.47	28.68
742	64.73	6.48	28.79
744	64.55	6.46	28.99
746	64.34	6.45	29.21
748	64.27	6.43	29.30
750	63.97	6.43	29.59
752	63.87	6.41	29.72
754	63.57	6.40	30.02
756	63.48	6.36	30.15
758	63.33	6.40	30.27
760	63.24	6.37	30.40
762	63.07	6.34	30.59
764	62.88	6.36	30.76
766	62.67	6.34	30.99
768	62.50	6.33	31.17
770	62.23	6.34	31.42
772	62.25	6.31	31.44
774	62.02	6.28	31.69
776	61.70	6.28	32.01
778	61.61	6.27	32.11
780	61.64	6.27	32.10
782	61.17	6.24	32.59
784	61.30	6.20	32.50
786	61.04	6.23	32.73
788	60.83	6.18	32.99

790	60.68	6.18	33.14
792	60.41	6.20	33.39
794	60.55	6.19	33.27
796	60.43	6.15	33.42
798	60.11	6.16	33.73
800	60.01	6.12	33.88
802	59.89	6.15	33.96
804	59.70	6.13	34.17
806	59.57	6.09	34.34
808	59.50	6.13	34.37
810	59.37	6.08	34.55
812	59.20	6.09	34.71
814	58.97	6.09	34.94
816	59.00	6.06	34.94
818	58.77	6.07	35.16
820	58.58	6.09	35.33
822	58.68	6.05	35.27
824	58.40	6.02	35.58
826	58.39	6.00	35.61
828	58.35	6.03	35.62
830	58.29	6.02	35.70
832	58.02	6.01	35.97
834	57.72	6.03	36.25
836	57.70	6.02	36.28
838	57.81	6.02	36.18
840	57.42	6.04	36.54
842	57.62	5.96	36.42
844	57.15	5.97	36.87
846	56.93	5.97	37.10
848	56.89	5.95	37.16
850	57.06	5.96	36.98
852	57.02	5.94	37.04
854	57.08	5.84	37.08
856	56.75	5.86	37.38
858	56.28	5.96	37.76
860	56.42	6.28	37.31
862	56.28	6.60	37.12
864	55.76	6.10	38.15
866	55.79	6.16	38.05
868	55.84	6.23	37.93
870	55.76	6.32	37.93
872	55.43	6.18	38.39
874	55.74	6.15	38.11
876	55.36	6.23	38.41
878	55.30	6.12	38.58
880	55.33	6.12	38.55
882	55.27	6.28	38.45
884	55.17	6.28	38.54
886	55.23	6.38	38.39
888	54.85	6.19	38.97

890	54.84	6.09	39.07
892	54.75	6.21	39.04
894	54.76	6.10	39.14
896	54.75	6.11	39.14
898	54.74	6.24	39.03
900	54.51	6.07	39.42
902	54.48	6.10	39.42
904	54.41	6.15	39.43
906	54.38	6.13	39.49
908	54.37	6.11	39.52
910	54.28	6.22	39.50
912	54.12	6.06	39.81
914	54.02	6.13	39.85
916	53.96	6.12	39.92
918	53.95	6.10	39.95
920	53.91	6.15	39.94
922	53.88	6.13	39.98
924	53.73	6.05	40.23
926	53.69	6.06	40.25
928	53.65	6.06	40.29
930	53.60	6.06	40.34
932	53.55	6.08	40.37
934	53.56	6.09	40.35
936	53.44	6.03	40.53
938	53.37	6.02	40.61
940	53.33	6.01	40.66
942	53.32	6.00	40.68
944	53.28	6.03	40.69
946	53.28	6.04	40.67
948	53.16	6.01	40.83
950	53.09	6.00	40.90
952	53.06	5.99	40.96
954	53.02	6.00	40.99
956	52.98	6.01	41.02
958	52.97	6.01	41.03
960	52.91	5.98	41.12
962	52.84	5.98	41.18
964	52.79	5.99	41.22
966	52.78	5.98	41.24
968	52.75	5.98	41.27
970	52.71	6.00	41.29
972	52.67	5.98	41.34
974	52.64	5.96	41.40
976	52.59	5.96	41.45
978	52.57	5.97	41.46
980	52.54	5.97	41.49
982	52.50	5.96	41.54
984	52.42	5.94	41.64
986	52.40	5.94	41.66
988	52.39	5.94	41.67

990	52.36	5.94	41.71
992	52.32	5.95	41.73
994	52.29	5.95	41.76
996	52.26	5.93	41.81
998	52.22	5.93	41.85
1000	52.19	5.93	41.87
1002	52.17	5.93	41.90
1004	52.15	5.93	41.92
1006	52.15	5.93	41.93
1008	52.10	5.90	41.99
1010	52.07	5.91	42.02
1012	52.05	5.92	42.04
1014	52.02	5.92	42.07
1016	52.00	5.92	42.08
1018	51.98	5.91	42.11
1020	51.94	5.90	42.16
1022	51.93	5.90	42.18
1024	51.91	5.90	42.19
1026	51.88	5.91	42.21
1028	51.86	5.91	42.23
1030	51.85	5.91	42.24
1032	51.82	5.89	42.29
1034	51.79	5.89	42.32
1036	51.78	5.89	42.33
1038	51.75	5.89	42.36
1040	51.74	5.89	42.36
1042	51.72	5.89	42.39
1044	51.69	5.89	42.43
1046	51.68	5.88	42.44
1048	51.66	5.89	42.45
1050	51.64	5.88	42.47
1052	51.63	5.88	42.49
1054	51.61	5.88	42.51
1056	51.57	5.87	42.56
1058	51.54	5.87	42.59
1060	51.54	5.87	42.59
1062	51.53	5.87	42.60
1064	51.52	5.87	42.61
1066	51.51	5.87	42.62
1068	51.48	5.86	42.66
1070	51.47	5.86	42.67
1072	51.46	5.86	42.68
1074	51.45	5.86	42.70
1076	51.42	5.86	42.72
1078	51.42	5.85	42.73
1080	51.40	5.85	42.75
1082	51.38	5.85	42.77
1084	51.38	5.85	42.78
1086	51.37	5.85	42.78
1088	51.35	5.85	42.80

1090	51.35	5.84	42.81
1092	51.33	5.84	42.83
1094	51.31	5.84	42.86
1096	51.30	5.84	42.86
1098	51.29	5.84	42.87
1100	51.28	5.84	42.88
1102	51.27	5.84	42.90
1104	51.25	5.83	42.92
1106	51.24	5.83	42.93
1108	51.23	5.83	42.94
1110	51.22	5.83	42.95
1112	51.22	5.83	42.96
1114	51.21	5.82	42.97
1116	51.20	5.82	42.98
1118	51.19	5.82	42.99
1120	51.19	5.83	42.98
1122	51.17	5.83	43.00
1124	51.17	5.82	43.01
1126	51.17	5.82	43.02
1128	51.15	5.81	43.03
1130	51.15	5.81	43.03
1132	51.15	5.82	43.03
1134	51.14	5.82	43.04
1136	51.13	5.82	43.05
1138	51.13	5.82	43.06
1140	51.12	5.82	43.06
1142	51.12	5.81	43.07
1144	51.11	5.82	43.07
1146	51.11	5.81	43.08
1148	51.11	5.82	43.08
1150	51.10	5.82	43.08
1152	51.10	5.81	43.08
1154	51.10	5.81	43.09
1156	51.09	5.81	43.09
1158	51.10	5.82	43.09
1160	51.11	5.82	43.07
1162	51.11	5.81	43.08
1164	51.10	5.81	43.08
1166	51.11	5.81	43.08
1168	51.11	5.81	43.07
1170	51.12	5.81	43.07
1172	51.13	5.82	43.06
1174	51.13	5.81	43.06
1176	51.13	5.81	43.06
1178	51.14	5.81	43.05
1180	51.15	5.81	43.04
1182	51.16	5.81	43.03
1184	51.18	5.81	43.01
1186	51.20	5.81	42.99
1188	51.22	5.81	42.97

1190	51.23	5.80	42.96
1192	51.25	5.80	42.94
1194	51.28	5.80	42.91
1196	51.30	5.81	42.89
1198	51.32	5.81	42.87
1200	51.33	5.81	42.86
1202	51.34	5.81	42.85
1204	51.36	5.81	42.83
1206	51.38	5.81	42.81
1208	51.42	5.81	42.78
1210	51.44	5.81	42.75
1212	51.47	5.81	42.72
1214	51.49	5.81	42.71
1216	51.51	5.81	42.68
1218	51.55	5.81	42.64
1220	51.58	5.81	42.61
1222	51.61	5.82	42.57
1224	51.63	5.82	42.55
1226	51.66	5.82	42.52
1228	51.71	5.82	42.47
1230	51.74	5.83	42.43
1232	51.77	5.83	42.40
1234	51.82	5.84	42.35
1236	51.85	5.84	42.31
1238	51.89	5.84	42.28
1240	51.93	5.84	42.23
1242	51.98	5.84	42.18
1244	52.02	5.84	42.14
1246	52.06	5.85	42.09
1248	52.11	5.84	42.05
1250	52.16	5.84	42.00
1252	52.21	5.84	41.95
1254	52.25	5.85	41.90
1256	52.30	5.85	41.85
1258	52.36	5.85	41.79
1260	52.42	5.85	41.73
1262	52.47	5.85	41.68
1264	52.53	5.86	41.61
1266	52.59	5.86	41.55
1268	52.65	5.86	41.48
1270	52.72	5.87	41.41
1272	52.78	5.87	41.34
1274	52.84	5.87	41.28
1276	52.91	5.88	41.22
1278	52.99	5.88	41.14
1280	53.05	5.88	41.07
1282	53.12	5.88	41.00
1284	53.19	5.88	40.93
1286	53.25	5.89	40.87
1288	53.31	5.89	40.79

1290	53.39	5.90	40.72
1292	53.46	5.90	40.64
1294	53.55	5.90	40.54
1296	53.62	5.91	40.47
1298	53.70	5.91	40.39
1300	53.77	5.91	40.31
1302	53.85	5.92	40.23
1304	53.94	5.93	40.13
1306	54.03	5.93	40.04
1308	54.10	5.93	39.97
1310	54.17	5.94	39.89
1312	54.26	5.95	39.80
1314	54.36	5.95	39.69
1316	54.44	5.96	39.61
1318	54.54	5.97	39.49
1320	54.60	5.97	39.43
1322	54.69	5.97	39.34
1324	54.78	5.98	39.24
1326	54.87	5.99	39.14
1328	54.94	5.99	39.07
1330	55.03	6.00	38.98
1332	55.11	6.00	38.89
1334	55.19	6.01	38.80
1336	55.27	6.01	38.73
1338	55.34	6.01	38.65
1340	55.43	6.02	38.55
1342	55.50	6.02	38.48
1344	55.58	6.01	38.40
1346	55.67	6.01	38.32
1348	55.75	6.01	38.24
1350	55.84	6.01	38.15
1352	55.91	6.01	38.08
1354	56.00	6.02	37.98
1356	56.08	6.03	37.89
1358	56.18	6.03	37.79
1360	56.28	6.04	37.67
1362	56.38	6.06	37.56
1364	56.48	6.07	37.46
1366	56.58	6.08	37.35
1368	56.66	6.08	37.26
1370	56.74	6.08	37.19
1372	56.82	6.09	37.09
1374	56.90	6.09	37.01
1376	56.96	6.09	36.94
1378	57.06	6.10	36.84
1380	57.13	6.10	36.77
1382	57.21	6.11	36.68
1384	57.28	6.11	36.61
1386	57.36	6.11	36.53
1388	57.42	6.12	36.46

1390	57.50	6.12	36.38
1392	57.56	6.12	36.32
1394	57.64	6.12	36.24
1396	57.70	6.13	36.17
1398	57.78	6.13	36.09
1400	57.83	6.14	36.04
1402	57.90	6.14	35.95
1404	57.99	6.15	35.86
1406	58.07	6.15	35.78
1408	58.15	6.16	35.69
1410	58.21	6.17	35.63
1412	58.32	6.17	35.51
1414	58.39	6.18	35.43
1416	58.47	6.18	35.35
1418	58.57	6.18	35.25
1420	58.64	6.19	35.17
1422	58.73	6.20	35.07
1424	58.82	6.20	34.98
1426	58.91	6.21	34.88
1428	59.02	6.22	34.76
1430	59.10	6.22	34.68
1432	59.20	6.23	34.57
1434	59.30	6.23	34.47
1436	59.41	6.24	34.35
1438	59.49	6.25	34.26
1440	59.61	6.25	34.14
1442	59.70	6.26	34.04
1444	59.79	6.27	33.94
1446	59.88	6.27	33.85
1448	59.98	6.28	33.74
1450	60.08	6.29	33.64
1452	60.17	6.29	33.54
1454	60.26	6.29	33.45
1456	60.36	6.30	33.34
1458	60.44	6.31	33.25
1460	60.55	6.32	33.13
1462	60.64	6.32	33.03
1464	60.72	6.33	32.95
1466	60.82	6.33	32.85
1468	60.92	6.34	32.74
1470	61.01	6.34	32.65
1472	61.10	6.35	32.54
1474	61.20	6.36	32.44
1476	61.30	6.37	32.33
1478	61.40	6.37	32.22
1480	61.50	6.38	32.12
1482	61.59	6.39	32.02
1484	61.69	6.39	31.92
1486	61.78	6.40	31.82
1488	61.88	6.41	31.72

1490	61.97	6.41	31.62
1492	62.06	6.42	31.52
1494	62.14	6.42	31.43
1496	62.24	6.43	31.33
1498	62.33	6.43	31.23
1500	62.43	6.44	31.13
1502	62.53	6.45	31.02
1504	62.61	6.45	30.94
1506	62.70	6.45	30.84
1508	62.81	6.46	30.73
1510	62.90	6.47	30.63
1512	63.00	6.47	30.53
1514	63.09	6.48	30.43
1516	63.17	6.49	30.34
1518	63.26	6.49	30.24
1520	63.36	6.50	30.14
1522	63.46	6.51	30.03
1524	63.54	6.51	29.94
1526	63.65	6.52	29.84
1528	63.73	6.53	29.75
1530	63.82	6.53	29.65
1532	63.91	6.54	29.55
1534	63.98	6.54	29.47
1536	64.08	6.55	29.37
1538	64.18	6.56	29.27
1540	64.25	6.56	29.18
1542	64.35	6.57	29.08
1544	64.44	6.58	28.98
1546	64.52	6.59	28.89
1548	64.60	6.59	28.81
1550	64.69	6.60	28.72
1552	64.76	6.60	28.63
1554	64.85	6.61	28.54
1556	64.94	6.61	28.45
1558	65.02	6.62	28.36
1560	65.09	6.63	28.28
1562	65.18	6.63	28.19
1564	65.25	6.64	28.11
1566	65.33	6.64	28.03
1568	65.40	6.65	27.95
1570	65.48	6.66	27.86
1572	65.55	6.66	27.79
1574	65.62	6.67	27.71
1576	65.70	6.67	27.63
1578	65.76	6.68	27.56
1580	65.84	6.68	27.48
1582	65.92	6.69	27.39
1584	65.97	6.69	27.34
1586	66.03	6.70	27.27
1588	66.11	6.71	27.19

1590	66.18	6.71	27.11
1592	66.24	6.72	27.04
1594	66.31	6.72	26.97
1596	66.36	6.72	26.91
1598	66.42	6.73	26.85
1600	66.47	6.74	26.79
1602	66.54	6.74	26.72
1604	66.60	6.75	26.65
1606	66.65	6.75	26.60
1608	66.69	6.75	26.55
1610	66.75	6.76	26.49
1612	66.81	6.76	26.43
1614	66.86	6.77	26.37
1616	66.91	6.77	26.32
1618	66.95	6.78	26.27
1620	66.99	6.78	26.23
1622	67.04	6.78	26.19
1624	67.09	6.78	26.12
1626	67.14	6.79	26.07
1628	67.18	6.79	26.03
1630	67.22	6.79	25.99
1632	67.25	6.79	25.96
1634	67.30	6.79	25.91
1636	67.35	6.79	25.86
1638	67.38	6.80	25.82
1640	67.41	6.80	25.79
1642	67.44	6.80	25.75
1644	67.47	6.80	25.73
1646	67.50	6.80	25.70
1648	67.53	6.81	25.66
1650	67.56	6.81	25.63
1652	67.60	6.81	25.60
1654	67.63	6.81	25.56
1656	67.65	6.80	25.54
1658	67.67	6.81	25.52
1660	67.70	6.81	25.49
1662	67.72	6.81	25.47
1664	67.74	6.81	25.45
1666	67.77	6.82	25.42
1668	67.79	6.82	25.40
1670	67.81	6.82	25.37
1672	67.81	6.83	25.36
1674	67.82	6.83	25.36
1676	67.84	6.83	25.34
1678	67.85	6.83	25.32
1680	67.87	6.83	25.31
1682	67.89	6.83	25.28
1684	67.90	6.83	25.26
1686	67.91	6.83	25.26
1688	67.91	6.83	25.26

1690	67.94	6.83	25.23
1692	67.95	6.83	25.23
1694	67.95	6.83	25.22
1696	67.96	6.83	25.21
1698	67.96	6.83	25.20
1700	67.97	6.83	25.20
1702	67.98	6.83	25.19
1704	68.00	6.83	25.17
1706	68.00	6.83	25.17
1708	68.00	6.84	25.16
1710	68.01	6.83	25.16
1712	68.01	6.83	25.15
1714	68.02	6.84	25.14
1716	68.02	6.83	25.15
1718	68.02	6.84	25.14
1720	68.04	6.84	25.12
1722	68.03	6.83	25.13
1724	68.04	6.84	25.13
1726	68.04	6.84	25.12
1728	68.04	6.83	25.12
1730	68.05	6.84	25.11
1732	68.05	6.83	25.12
1734	68.04	6.83	25.13
1736	68.04	6.83	25.13
1738	68.04	6.83	25.13
1740	68.04	6.83	25.13
1742	68.05	6.83	25.12
1744	68.05	6.83	25.12
1746	68.05	6.83	25.12
1748	68.03	6.83	25.14
1750	68.04	6.83	25.14
1752	68.04	6.82	25.14
1754	68.04	6.83	25.14
1756	68.04	6.83	25.14
1758	68.04	6.82	25.14
1760	68.03	6.82	25.15
1762	68.04	6.82	25.14
1764	68.03	6.82	25.15
1766	68.03	6.82	25.14
1768	68.04	6.82	25.14
1770	68.03	6.81	25.16
1772	68.02	6.81	25.17
1774	68.02	6.81	25.16
1776	68.02	6.81	25.17
1778	68.03	6.82	25.16
1780	68.03	6.81	25.16
1782	68.03	6.81	25.17
1784	68.02	6.81	25.17
1786	68.03	6.81	25.16
1788	68.02	6.81	25.17

1790	68.04	6.81	25.15
1792	68.03	6.80	25.17
1794	68.03	6.80	25.18
1796	68.02	6.80	25.18
1798	68.03	6.79	25.18
1800	68.04	6.79	25.18
1802	68.04	6.79	25.17
1804	68.03	6.78	25.18
1806	68.03	6.77	25.19
1808	68.03	6.77	25.19
1810	68.05	6.77	25.18
1812	68.04	6.77	25.19
1814	68.04	6.77	25.19
1816	68.04	6.77	25.19
1818	68.05	6.77	25.19
1820	68.06	6.77	25.17
1822	68.06	6.76	25.18
1824	68.08	6.75	25.16
1826	68.09	6.76	25.15
1828	68.08	6.75	25.17
1830	68.08	6.74	25.18
1832	68.10	6.74	25.17
1834	68.10	6.75	25.15
1836	68.11	6.75	25.14
1838	68.12	6.76	25.12
1840	68.13	6.76	25.11
1842	68.12	6.76	25.13
1844	68.15	6.76	25.10
1846	68.16	6.77	25.07
1848	68.16	6.76	25.08
1850	68.18	6.77	25.05
1852	68.20	6.77	25.03
1854	68.20	6.76	25.04
1856	68.20	6.76	25.04
1858	68.20	6.75	25.05
1860	68.21	6.74	25.05
1862	68.24	6.75	25.01
1864	68.26	6.74	25.00
1866	68.26	6.74	25.01
1868	68.28	6.74	24.97
1870	68.28	6.77	24.95
1872	68.29	6.77	24.93
1874	68.33	6.78	24.89
1876	68.33	6.78	24.88
1878	68.35	6.78	24.87
1880	68.36	6.79	24.85
1882	68.38	6.79	24.83
1884	68.39	6.77	24.84
1886	68.40	6.78	24.82
1888	68.40	6.76	24.84

1890	68.41	6.75	24.84
1892	68.43	6.75	24.82
1894	68.43	6.75	24.82
1896	68.45	6.74	24.81
1898	68.45	6.75	24.79
1900	68.46	6.74	24.79
1902	68.47	6.75	24.78
1904	68.48	6.75	24.77
1906	68.48	6.76	24.76
1908	68.51	6.76	24.73
1910	68.54	6.77	24.69
1912	68.53	6.76	24.71
1914	68.56	6.76	24.67
1916	68.56	6.77	24.67
1918	68.58	6.77	24.65
1920	68.60	6.77	24.63
1922	68.63	6.79	24.58
1924	68.62	6.77	24.61
1926	68.62	6.79	24.60
1928	68.65	6.77	24.58
1930	68.66	6.79	24.55
1932	68.67	6.79	24.54
1934	68.73	6.81	24.46
1936	68.69	6.79	24.51
1938	68.73	6.80	24.47
1940	68.77	6.81	24.42
1942	68.75	6.80	24.45
1944	68.79	6.80	24.40
1946	68.82	6.83	24.35
1948	68.79	6.80	24.41
1950	68.81	6.80	24.39
1952	68.82	6.81	24.37
1954	68.86	6.81	24.33
1956	68.85	6.80	24.35
1958	68.90	6.82	24.28
1960	68.88	6.81	24.31
1962	68.90	6.81	24.28
1964	68.94	6.81	24.26
1966	68.94	6.82	24.24
1968	68.94	6.81	24.25
1970	69.00	6.83	24.18
1972	68.98	6.81	24.22
1974	69.01	6.81	24.18
1976	69.03	6.82	24.16
1978	69.05	6.82	24.13
1980	69.07	6.82	24.12
1982	69.09	6.82	24.08
1984	69.10	6.82	24.08
1986	69.11	6.82	24.07
1988	69.14	6.83	24.03

1990	69.16	6.83	24.02
1992	69.16	6.83	24.00
1994	69.19	6.84	23.97
1996	69.20	6.81	23.98
1998	69.21	6.82	23.96
2000	69.23	6.83	23.95
2002	69.28	6.84	23.88
2004	69.30	6.84	23.86
2006	69.35	6.85	23.80
2008	69.36	6.83	23.81
2010	69.37	6.83	23.80
2012	69.41	6.84	23.75
2014	69.42	6.84	23.74
2016	69.45	6.85	23.70
2018	69.49	6.85	23.66
2020	69.48	6.84	23.67
2022	69.51	6.84	23.65
2024	69.54	6.85	23.62
2026	69.54	6.85	23.60
2028	69.57	6.86	23.58
2030	69.62	6.87	23.52
2032	69.62	6.85	23.53
2034	69.65	6.86	23.49
2036	69.67	6.85	23.48
2038	69.70	6.87	23.43
2040	69.72	6.87	23.41
2042	69.75	6.88	23.37
2044	69.78	6.86	23.36
2046	69.81	6.87	23.32
2048	69.83	6.87	23.30
2050	69.85	6.87	23.28
2052	69.88	6.89	23.23
2054	69.91	6.89	23.20
2056	69.92	6.87	23.21
2058	69.96	6.86	23.18
2060	69.98	6.89	23.13
2062	70.00	6.89	23.11
2064	70.01	6.89	23.10
2066	70.05	6.90	23.05
2068	70.06	6.89	23.06
2070	70.10	6.89	23.01
2072	70.13	6.90	22.96
2074	70.14	6.90	22.96
2076	70.15	6.90	22.94
2078	70.20	6.92	22.87
2080	70.20	6.90	22.90
2082	70.20	6.89	22.91
2084	70.25	6.90	22.85
2086	70.28	6.91	22.82
2088	70.29	6.92	22.79

2090	70.31	6.91	22.78
2092	70.32	6.89	22.79
2094	70.34	6.90	22.75
2096	70.35	6.91	22.75
2098	70.39	6.92	22.69
2100	70.42	6.93	22.66
2102	70.45	6.91	22.63
2104	70.44	6.91	22.65
2106	70.45	6.91	22.64
2108	70.47	6.91	22.62
2110	70.49	6.92	22.60
2112	70.53	6.93	22.54
2114	70.55	6.93	22.52
2116	70.54	6.90	22.56
2118	70.53	6.90	22.57
2120	70.59	6.93	22.49
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2124	70.65	6.91	22.43
2126	70.66	6.94	22.40
2128	70.64	6.91	22.44
2130	70.67	6.92	22.41
2132	70.68	6.93	22.40
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2136	70.72	6.93	22.35
2138	70.74	6.94	22.32
2140	70.71	6.92	22.36
2142	70.70	6.91	22.39
2144	70.69	6.92	22.39
2146	70.69	6.94	22.37
2148	70.71	6.94	22.35
2150	70.71	6.93	22.36
2152	70.69	6.92	22.38
2154	70.68	6.92	22.41
2156	70.67	6.91	22.42
2158	70.63	6.94	22.43
2160	70.63	6.93	22.44
2162	70.63	6.93	22.43
2164	70.57	6.91	22.52
2166	70.51	6.90	22.58
2168	70.47	6.90	22.63
2170	70.45	6.91	22.65
2172	70.41	6.90	22.69
2174	70.34	6.90	22.75
2176	70.26	6.87	22.87
2178	70.19	6.84	22.96
2180	70.12	6.85	23.04
2182	70.02	6.84	23.13
2184	69.95	6.85	23.20
2186	69.88	6.84	23.27
2188	69.76	6.81	23.44

2190	69.66	6.80	23.54
2192	69.58	6.80	23.62
2194	69.51	6.79	23.70
2196	69.45	6.80	23.75
2198	69.38	6.81	23.81
2200	69.31	6.77	23.92
2202	69.24	6.76	24.00
2204	69.18	6.76	24.06
2206	69.14	6.75	24.10
2208	69.12	6.77	24.11
2210	69.09	6.75	24.15
2212	69.04	6.74	24.21
2214	69.04	6.76	24.20
2216	69.02	6.74	24.23
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2222	69.06	6.77	24.17
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2248	69.59	6.78	23.64
2250	69.65	6.77	23.59
2252	69.70	6.80	23.50
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2258	69.89	6.81	23.30
2260	69.92	6.79	23.29
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2264	70.02	6.82	23.16
2266	70.08	6.81	23.11
2268	70.18	6.85	22.97
2270	70.18	6.86	22.95
2272	70.22	6.82	22.96
2274	70.28	6.83	22.88
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2282	70.46	6.87	22.67
2284	70.48	6.86	22.66
2286	70.56	6.86	22.58
2288	70.63	6.86	22.51

2290	70.68	6.87	22.45
2292	70.76	6.89	22.34
2294	70.76	6.89	22.35
2296	70.79	6.87	22.34
2298	70.82	6.87	22.31
2300	70.88	6.88	22.25
2302	70.92	6.89	22.20
2304	71.00	6.90	22.10
2306	71.01	6.90	22.09
2308	70.99	6.86	22.14
2310	71.02	6.88	22.10
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2314	71.09	6.90	22.00
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2320	71.19	6.88	21.93
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2352	71.62	6.99	21.39
2354	71.58	6.96	21.46
2356	71.49	6.89	21.62
2358	71.51	6.92	21.57
2360	71.64	6.94	21.42
2362	71.69	6.91	21.41
2364	71.65	6.92	21.43
2366	71.58	6.93	21.49
2368	71.61	6.88	21.51
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2376	71.74	7.00	21.27
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2382	71.61	6.96	21.44
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2386	71.66	6.89	21.45
2388	71.78	6.93	21.30

2390	71.69	6.89	21.42
2392	71.65	6.82	21.53
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2396	71.64	6.88	21.47
2398	71.62	6.89	21.49
2400	71.67	6.95	21.38
2402	71.56	6.84	21.59
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2408	71.48	6.95	21.57
2410	71.45	6.88	21.67
2412	71.55	6.93	21.52
2414	71.45	6.80	21.76
2416	71.30	6.83	21.87
2418	71.33	6.85	21.82
2420	71.32	6.84	21.83
2422	71.46	6.87	21.67
2424	71.33	6.93	21.74
2426	71.09	6.88	22.03
2428	71.11	6.77	22.11
2430	71.01	6.75	22.24
2432	70.99	6.83	22.18
2434	71.05	6.72	22.23
2436	71.11	6.94	21.95
2438	70.86	6.82	22.32
2440	70.82	6.73	22.45
2442	70.73	6.80	22.47
2444	70.77	6.84	22.39
2446	70.65	6.78	22.57
2448	70.77	6.90	22.34
2450	70.58	6.81	22.61
2452	70.47	6.83	22.70
2454	70.40	6.68	22.92
2456	70.26	6.72	23.01
2458	70.50	6.72	22.78
2460	70.63	6.91	22.46
2462	70.26	6.84	22.90
2464	70.02	6.81	23.18
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2468	70.07	6.80	23.12
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2472	70.48	6.96	22.56
2474	69.88	6.64	23.48
2476	69.65	6.58	23.78
2478	70.07	6.83	23.09
2480	70.06	6.86	23.08
2482	70.27	7.01	22.72
2484	70.23	7.02	22.75
2486	69.75	6.35	23.90
2488	69.50	6.61	23.89

2490	69.74	6.97	23.29
2492	69.47	6.25	24.28
2494	69.98	7.15	22.87
2496	68.89	5.88	25.24
2498	69.60	7.14	23.26
2500	68.96	6.73	24.31

G KIRANKUMAR

■ Personal Data

Date of Birth: 02.06.1986

Address: H.No: 18-82, Rajaji street,

Anantapur- 515001, Andhra Pradesh, India.

Mobile: +91 9740251522, 9035151468

Email: gorantla.kirankumar@gmail.com

Nationality: Indian

Marital status: Married

COURSE	INSTITUTION	YEAR OF PASSING	% OF MARKS
M-Tech (R&AC)	J.N.T.U University, Anantapur, Anantapur, Andhra Pradesh, India.	Jun 2011	79.60%
B-Tech (Mechanical Engineering)	J.N.T.U University, Hyderabad, Telangana, India.	Aug 2007	59.05%
Intermediate	Balaji Junior College, Anantapur, Andhra Pradesh, India.	Apr 2003	73.2%
SSC	Lakshmi Telugu Medium High School, Anantapur, Andhra Pradesh, India.	Mar 2001	77.26%

■ Skills

Green Energy Building Simulation Software's: Design Builder and Energy plus

1. PEER REVIEWED INTERNATIONAL JOURNALS

1. **KiranKumar, G.** Saboor, S. Ashok Babu, T.P. Vanish, K. Ki-Hyun, K. (2018). "Experimental and Theoretical Studies of Various Solar Control Window Glasses for the Reduction of Cooling and Heating loads in Buildings across Different Climatic Regions". *Energy and Buildings* (Publisher: Elsevier; Index: SCI & SCOPUS, Impact factor:**4.457**) 173 326-336. https://doi.org/10.1016/j.enbuild.2018.05.054
2. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2018). "Effect of solar optical properties and window to wall ratio on heat gain in buildings". (Status: Communicated, Publisher: Science Publication; Index: SCOPUS) *International Journal of Engineering and Technology*.
3. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2018). "Thermal and Cost Analysis of Float and Various Tinted Double Window Glass Combinations on Heat Gain into Buildings of Hot & Dry Climatic Zone in India ". *International Journal of heat and Technology* (Publisher: IIETA; Index: ESCI & SCOPUS) 36(1) 252-260. https://doi.org/10.18280/ijht.360134
4. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2018). "Day Lighting and Thermal Analysis Using Various Double Reflective Window Glasses for Green Energy buildings". *International Journal of heat and Technology* (Publisher: IIETA; Index: ESCI & SCOPUS) 36(3) 1121-1129. https://doi.org/10.18280/ijht.360345
5. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2018). "Thermal and Energy Saving Analysis by Using Tinted Double Window Glass Combinations for Heat Gain in Buildings". *International Energy Journal* (Publisher: RERIC; Index: ESCI & SCOPUS) 18(2) 215-230.
6. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2016). " Investigation of Different Window and Wall Materials for Solar Passive Building Design". *Key Engineering materials* 692, 9-16. (Publisher: Transtech; Index: SCOPUS) https://doi:10.4028/www.scientific.net/KEM.692.9

2. PEER REVIEWED INTERNATIONAL CONFERENCES

1. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2017). "Influence of louver tilt on heat gain and daylight through window glazing in composite climatic region of India". 24th National and 2nd International ISHMT-ASTFE Heat and Mass Transfer Conference IHMTC-2017, Dec 27-30th, 2017, BITS Pilani Hyderabad, Telangana, India.
2. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2017). "Effect of Various External Shading Devices on Windows for Minimum Heat Gain and Adequate Day lighting into Buildings of Hot and Dry Climatic Zone in India". MATEC web of conferences 144, 1-12. (Index: Scopus) https://doi.org/10.1051/matecconf/201814404008
3. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2017). "Study of Various Glass Window and Building Wall Materials in Different Climatic Zones of India for Energy Efficient Building Construction". *Energy Procedia* 138, 580-585. (Publisher: Elsevier; Index: Scopus) https://doi.org/10.1016/j.egypro.2017.10.163
4. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2016). "Thermal Analysis of Wall and Window Glass Materials for Cooling Load Reduction in Green Energy Building Design". Materials today proceedings 4, 9514-9518. (Publisher: Elsevier; Index: Scopus) https://doi.org/10.1016/j.matpr.2017.06.215
5. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2017). "Effect of Different Double Glazing Window Combinations on Heat gain in Buildings for Passive Cooling in Various Climatic Regions of India". *Materials today proceedings* 4, 1910-1916. (Publisher: Elsevier; Index: Scopus) https://doi.org/10.1016/j.matpr.2017.02.036
6. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2017). "Experimental and Theoretical Studies of Window Glazing Materials of Green Energy Building in Indian Climatic Zones". *Energy Procedia* 109, 306-313. (Publisher: Elsevier; Index: Scopus) http://doi.org 10.1016/j.egypro.2017.03.072

7. **KiranKumar, G.** Ashok Babu, T.P. (2017). "Study of Various Glass Materials to Provide Adequate Day Lighting in Office Buildings of Warm and Humid Climatic Zone in India" *Energy Procedia* 109, 181-189. (Publisher: Elsevier; Index: Scopus). http://doi.org 10.1016/j.egypro.2017.03.090
8. Saboor, S. **KiranKumar, G.** and Ashok Babu, T.P. (2016). "Effect of Window Overhang shade on Heat gain of Various Single Glazing Window glasses for Passive Cooling" *Procedia Technology* 23, 439-446. http://doi.org/10.1016/j.protcy.2016.03.048
9. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2016). "Investigation of Different Window and Wall Materials for Solar Passive Building Design". *Procedia Technology* 24, 523–530. http://doi.org/10.1016/j.protcy.2016.05.090
10. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2016). "Investigation of Various Low Emissivity Glass Materials for Green Energy Building Construction in Indian Climatic Zones". Accepted Elsevier: Materials today proceedings ISBN:978935254230 (Publisher: Elsevier; Index: Scopus) https://doi.org/10.1016/j.matpr.2017.07.144
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12. **KiranKumar G.** Ashok Babu, T.P. (2015). "Study of Optimum Inward Glass Tilt Position for Window Glass in Different Indian Latitudes to Gain Minimum Heat into Buildings". *Energy Procedia* **79 1039-1045.** (Publisher: Elsevier; Index: Scopus) http://doi.org/10.1016/j.egypro.2015.11.606

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1. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2015). "Effects of thermal and optical properties of building wall and window glass materials on heat gain into the buildings for passive building design". Proceedings of 4th National Conference on Refrigeration and Air Conditioning NCRAC 2015 28-

30th October 2015 organized by Rajalakshmi Engineering College and IIT Madras, Chennai, India.

2. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2018). "Thermal and cost analysis of various tinted double window glass combinations for heat gain into buildings of warm and humid climate zone in India". Proceedings of the 5th National Conference on Refrigeration and Air Conditioning, May 24-26, 2018, National Institute of Technology Karnataka Surathkal, Mangalore, Karnataka, India. (Paper No: 16).

4. THE BEST RESEARCH PAPER AWARDS RECEIVED

1. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2016). "Investigation of Various Low Emissivity Glass Materials for Green Energy Building Construction in Indian Climatic Zones". Proceedings of the International Conference on Advancements in Aeromechanical Materials for Manufacturing, July 7-9, 2016, MLR Institute of Engineering College, Hyderabad, Telangana, India. (Paper No: 127) ISBN: 978935254230.
2. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2018). "Thermal and cost analysis of various tinted double window glass combinations for heat gain into buildings of warm and humid climate zone in India". Proceedings of the 5th National Conference on Refrigeration and Air Conditioning, May 24-26, 2018, National Institute of Technology Karnataka Surathkal, Mangalore, Karnataka, India. (Paper No: 16).

5. SPRINGER BOOK CHAPTER

1. **KiranKumar, G.** Saboor, S. and Ashok Babu, T.P. (2015). "Effects of Single, Double, Triple and Quadruple Window Glazing of Various Glass Materials on Heat Gain in Green Energy Buildings". Proceedings of the International Conference on Advances in Chemical Engineering, Dec 20-22, 2015, National Institute of Technology Karnataka, Surathkal, India.
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