Performance Evaluation and Energy Mitigation Analysis with Suitable Glazing in Building Sector Using Combination of Insolent Designed Fenestration

Thesis Submitted For the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Civil Engineering

By

Amit Kumar Dhir

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Supervised By

Dr. Pushpendra Kumar Sharma

Transforming Education Transforming India

LOVELY PROFESSIONAL UNIVERSITY

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DECLARATION

“I, Amit Kumar Dhir, hereby state that the proposal of this research is submitted in accomplishment of the requirements for the award of Doctor of Philosophy, in the School of Civil Engineering, Lovely Professional University, Punjab, is entirely my own work excluding the part which is referenced or accredited”.

Amit Kumar Dhir

41800114

2022

CERTIFICATE

I certify that Mr. Amit Kumar Dhir, bearing Registration Number 41800114 has prepared his thesis entitled “Performance Evaluation and Energy Mitigation Analysis with Suitable Glazing in Building Sector Using Combination of Insolent Designed Fenestration” for the honour of Ph.D in Civil Engineering, doctoral degree of Lovely Professional University, under my supervision. He has conceded out the work at the industry in accordance with School of Civil Engineering, Lovely Professional University. This thesis report has never ever been submitted earlier in any institution. So this is the first time work ever”.

Dr. Pushpendra Kumar Sharma

Professor,

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Date: 09th April, 2022

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Organization of Research

The research program carried for the "Performance Evaluation and Energy Mitigation Analysis with Suitable Glazing in Building Sector Using Combination of Insolent Designed Fenestration" was successfully completed and drawn many concrete conclusions for the betterment of society and also deals with challenge of energy generation versus consumption. The main aim of the research was to minimize the energy consumption for the built environment. The key role was played by the building envelope and majorly the windows held largely responsible for the intake of heavy heat which unnecessary heating the space. This heating of the space leads to peak demand of energy. After the careful investigation of the problem, the experimentation carried along with the simulation, outcome of which was promising. The three different types of double glazing unit have been seen performing in mitigating the energy consumption in the residential building which was usually non-engineered and also away from energy analysis especially in the conceptual and design phase.

The thesis contains seven chapters in brief described as under

Chapter-1 deals with the introduction where the issue of energy usage has been populated from state, nation and global view point. Inspite of many research advancements, the situation in developing countries such as India was still the same which needs much more attention in terms of testing of the proposed products and reform policies which can help the government to have energy efficient buildings.

Chapter -2 carries the literature review of the current status and development carries so far. It has been observed that the massive work was carried in the last decade and most of the work was performed using simulation tools which were near to approximations only and required further experimentation in real sites.

Chapter-3 depicts the background of the double glazing unit, its benefit and relate with the innovations occurred till date. The current scenario of the double glazed unit in the present constructed residential building was taken and concerns showed that almost meager amount of the residential building was equipped with DGU.

Chapter -4 covers the research methodology wherein the procedure was well depicted for the experiment program carried in due course of research. The survey was carried in objective 1 and objective 2, covers testing which was performed using two types of prototypes along with their fabrication. The economic assessment also carried to understand the payback period which can be through savings accounted on the part of performing window formation. Objective 3 turns to be validation program wherein the actual fabrication has been tested in the actual site and satisfaction was received from the occupant especially regarding the feel comfort and window configuration. Objective 4 provides the recommendation report being carved out of the research program and can be delivered on various aspects to aware the occupants for the better utilization of the window and its design.

Chapter- 5 deals with the survey, testing and simulation carried in the composite climate, its simulation and the experimentation results were energetic. The economic assessment carries through net incremental cost and operation savings for the double glazed unit.

Chapter-6 outlines the conclusion being drawn out of the experiment framework and depicts the benefits of utilizing performance window configuration.

Chapter- 7 contains the recommendation report that can be helpful to deliver various action based program and can be utilized for the know-how of the product. The utilization of the recommended DGUs can help the occupant to minimize the energy consumption.

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Abbreviation

DGU – Double Glazed Unit

ECM – Energy Conservation Measures

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Abstract

Energy consumption has increased enormously in building sector due to various types of loads. Cooling load and heating loads are consuming more energy especially in residential sector. The envelope of the building plays consumption in the building. Jalandhar, situated in Punjab, India has composite climate wherein approximately nine months which requires air-conditioner and high energy consumption. A precise enormous part of energy used in the country is consumed in residential sector, and thus there is general lack of information, guidelines and implements concerning energy usefulness in buildings.

The purpose of this effort was to add to a framework of knowledge, testing and analysis of the suitable window formation from variety of glazing available in market and tools that can develop the energy efficiency in the buildings, which optimize the use of natural resources, improved indoor comfort in residential buildings and budgeted solution for the end users. The structure consists of several portions, such as survey from the initial phase in the residential units (detached) in the region, careful analysis of the parameters for glazing through the literature review and availability in the market, testing of various window formations of double glass unit (DGU), actual validation of the performance based window in real time scenario in the site as described in the following. The outcomes from the research work was proved to be possessions and resource for professionals especially architect, engineers and also knowledge provider to occupants for awareness and designing of window in the residential buildings, which will advance their potentials of work for better energy efficiency in the residential sector. It has been observed during pandemic (COVID-19) that the house owners due to work from home for maximum duration came to concern about the energy consumption. This sets up trend towards using energy efficiencies in many ways in the building. A reference establishment from Gulmohar Avenue, situated in Jalandhar city in the composite climate was used in the experiment. After the prototype testing of the window formation in laboratory, the performed window formation has been installed in the actual building to understand the impact on lowering the heat from outside. The consumption of electricity in the reference site was inspected through energy bills over the past summer season and found that the cooling load was consuming approximately 24 %. The envelope of the building was retrofitted after deliberation with occupant and the assessment showed that the performance window formation result 39.1 % decrease in solar gains by reducing the outside temperature considerably.

Measurement apparatus for observing outdoor and indoor climate was installed at the site. The IOT based arduino hardware and software were used for collecting the data for the specified time period from the site to exclude human error. Diverse theoretical and investigational practices for analyzing and assessing energy used in the building, was inspected in order to find a suitable glazing system for the climatic environments and building kinds. Design Builder and Energy plus 9.4 simulation tools have been used for assessing the full year simulation coupled with other energy consumption measure strategies, showed the savings of 36.1 % in cooling loads and 74.2 % reduction in solar gains in the building for the performance window formation. The validation of the simulation was carried out for the installed window formation in the actual building and observed the error maximum of 6.89 % which was in permissible limits. The (DG3) performance window configuration was recommended to be utilized in the building envelope having south face to reduce the energy consumption and considerable reduction in cooling loads.

Chapter 1. Introduction

1.1. General

Over more than 2 decades, massive construction happened due to urbanization and needs to meet the economic upliftment from various aspects of human being such as industrial growth, organizational growth, socio-economic growth etc. Energy measures and analysis have taken the backseat while development and records of development is also not well drafted especially in developing countries such as India. Due to such enormous development in terms of infrastructure, no doubt the social economic development has been raised but also the energy demand at the consumer level or manufacturing front becomes a challenge for the country, state and at local level. Building sector especially residential consumes more than one fourth of the share in Energy and will rise to about 8 times as per GBPN report and IEA report, 2020[1]. The statistics showed that there will be situation when power cuts become quite usual and thus the energy demand needs to be slow down to the level. The energy demand in the residential sector takes up maximum share is cooling loads which might be due to various factors such as fast changing lifestyle, urbanization, occupant comfort, global warming scenario that every year the average temperature is increasing by 2 ◦C, inappropriate designing of the buildings etc. [2]. From Energy assessing and conservation scenario, the residential buildings are missing passive strategies that can be easily inducted while designing stage so as to lower the energy consumption of the buildings and comfort of users[3]. The envelope of the buildings plays major role in increasing the energy demand critical being the windows that are not given proper designing aid while initial stages[4]. Many researchers have contributed ample of passive strategies which can be applied to reduce energy demand in the residential sector[3][5-8]. Windows needs proper attention and can be designed with various factors such as orientation, glazing type, windows formations etc. Building requires cost of construction and decision not taken in the initial stages proves to be fatal at the operation phase of the building which then be retrofit and add to the cost of construction[9-12]. To ensure to the near approximations of passive and active strategies, 3D software are of immense help and simulation can be carried out on the models stating multiple benefits before actual construction and saves cost as well[13-16]. When comes to window formations, windows should be properly designed to have goal of reduction in energy consumption. Different novel glazing and configurations has been studied proves promising results which can reduce the energy consumption in the residential buildings by 18- 37% [17-19]. The proposal for one climate and typology cannot be copied to another climate and typologies, one need to investigate properly the various parameters required and results in savings of energy thereby controls and slow down the demand at state and nation level. As far as simulation of the models are concerned, the data input is rigorous and needs to be more précised, there are certain limitations in gathering of the data from the actual sites so as to have the real scenario simulations [17][20-21]. More than 10% variation in the results from simulation has been observed by researchers and software is updating time to time[22]. The promised product when applied to actual sites, the owner does not feel confident due to the difference with the performance as stated in the manual and the actual performance on the site[22]. The reason may be simulation results must be validated and more experimentation should be actually checked at the site so that the end user will get the performance manual which surely works making the owner's confidence on the product[23].

This research work embraces the literature review, survey, experimentation and the validation of the performance product on the site. The window formations out of various types of reflective glasses and gap filled with argon gas and air showed the promising results which have the potential to lower the energy consumption especially cooling loads [24- 26].

Chapter 2. Literature Review

2.1. Introduction

This chapter collects the theory related to the thesis. The section deals with the energy consciousness and sensitization, current research performed in the field of windows through the different configurations utilized at site and simulation related review with the help of software (Design Builder) and empirical analysis.

For the last 2 decades, new building envelope materials have been more and more frequently used as façade. To gel with the current changing lifestyles, problem crops up in the various issues that has been descripted in this section as follows

2.2. Literature review in regards to energy and windows

Researcher [27] emphasis on the global warming scenario and highlighted the immense trace gasses such as methane, chlorofluorocarbons and nitrous oxide which are responsible for 43% of the increase in radiates forcing from 1980 to 1990. Author insists the formation of cost effective emission policies both at national and international levels. Study carried for energy consumption that major consumer of energy is buildings and lead to environmental impacts. Author emphases the usage of double skin glazing and other window elements which should be studied in light of operational energy and embodied energy. They find the gathering of data from industries were incomplete, hybrid approach has been utilized in analysis of embodied energy which highlights the usage of double skin glazing with the results on higher sides in Australia. The fruit fullness of the proposed glazing lowers life cycle use and associated greenhouse gasses with occupant behavior options. Life cycle Cost assessment [28] carried for the window and found considerable savings for windows life span by optimizing the specification. The cost analysis brought that the payback period of some of the alternatives are within limits. Also they stressed that the initial cost of the energy efficient solutions were higher. The indication of savings brought the payback period within limits and near future solution to energy efficient windows. TERI (the energy and resources institute, [29] had carried tests to measure energy consumption for metros in residential buildings and came to conclusion that the components namely refrigerators and air conditioners were consuming more energy approximately 27 % and used extensively in summer season. Different models for energy saving potential related to windows in residential houses using simulation software TRNSYS16 and WINDOW5 has been studied. Three cases have being explored and found that the heating savings was maintained on changing the window [30]. A window energy rating system (WERS) was proposed for the residential buildings wherein the final categories were A, B, C, D and E based on the energy index. The energy index work on the basis of the solar gain criteria. [31] Study carried out for the day lighting analysis on the basis of parameters such as window size, glazing, geometry etc. Ihm concluded that the day lighting controls proves to be best method for savings energy about 60 % in case of lighting. Formulae have been utilized and simulation performed over the office room for the effect of day lighting with combination of stepped and minimizing artificial lighting. In this double pane glass unit is utilized with low e Glass on west façade. It has observed that 500 lux is achieved with the windows tested. The simulation is validated in office of US from 8 am to 6 pm. Measurements verses simulation results showed the difference from 0.5 percent to 3.6 percent. It was evident that 60 percent of the electricity bill can be saved annually with dimming control strategy. Studied the effect of alternatives of windows in cold climates in lowering the heating loads, heating conversions with different combinations and types of double skin windows using Design Builder [32]. Life cycle cost was also analyzed and concluded that the savings can be approximately 40 -60 % in cooling energy. Further, observed that the low e glass good in reducing cooling units was not suitable for cold climate. Occupant behavior was one of the key factor [33] studied for opening of windows for the real life mapping in simulation. Four groups of different ventilation types has been studied and observed that the two parameters that is CO2 concentration and outdoor temperature plays critical role in defining the opening and closing pattern of windows. Using this behavior pattern, the simulation program can be as close to reality and predict the accurate energy consumption. EU directed regulation for building sector to follow the nearly zero energy buildings for cold climate of Estonian were carried with energy efficiency and cost were taken into account. It has been observed that with wall thickness 200 mm, smaller WWR, triple glazed unit filled with argon having clear low emissivity glazing was the optimum solution. Payback period was approximately 20 years for office building facades. The test performed for 2, 3, 4, 5 pane unit having air, argon and krypton gas. Recommendations are provided with key performance factors of investment, Primary Energy, Total energy cost per year and NPV. The work was performed using simulation only [34]. The energy savings behavior of two types of buildings that is green buildings and conventional buildings has been studied [35]. The survey method has been adopted and the strategies such as raising energy awareness, commitment to save over energy etc. will encourage the occupant over saving energy. It was concluded that the occupants living in green buildings has more tendency to save the energy than conventional buildings. Established and studied for the energy consumption using simulation where features such as climate, energy consumption and energy intensity were the accounted on basis of classification. The model proposed calculates and validates the energy consumption in residential buildings. The simulated value based on model deviates from actual by 22.4% and both values are in agreement if heating energy consumption will be taken in to account. The author needs further research to ease the simulation taking into heating energy consumption[8]. The effect of various parameters in terms of window to wall ratio especially with low-e glass and orientation using Designer's simulation Toolkit has been carried [36]. The simulation was performed for the building model in hot climate for the envelope strategies taking into the account the visual comfort using Design Builder software. Lighting energy and cooling energy consumption was evaluated using model. Study concluded no change or meager change in energy savings and no visual comfort. Using automatic interior shading, the visual comfort was felt but no significant change in energy saving [37]. Focused the research which collects the three step procedure as (1) old apartment features were studied leading to increase energy consumption. (2) The identification of features that could lead to reduce energy consumption out of 8 configurations. (3) Ranking the features in light of energy savings. Jang observed maximum of 43.65 KWh/m2/year in heating and 5.70 KWh/m2/year in cooling were resulted out of transformation in the building [38]. The increase of energy consumption in the region of Egypt was 57 % from 2001 to 2012 and showed concern about increasing CO_2 footprint. Various retrofitting measures have been suggested in the paper such as changing glazing types, roofs insulation etc. to reduce energy consumption and Carbon footprints using simulation. Further, concluded that the reduction in savings of 15 % is achieved using retrofitting measures for the hot climate of Egypt [11]. Studied the impact of glazing on energy demand and indoor climate where measurements have been carried from the site and using computational analysis, observed that the heating energy demand was reduced in range of 5.6 % to 25.3 %. The study carried in cold climate where heating energy needs to be mitigated [39]. The low cost smart windows with two methods were discussed wherein the first method contains variation in pressure in window and acting as shading and second is the two phase liquids in the form of transparent and translucent material with differential thermal expansions. Author concluded that the smart window works without energy and also lowers the initial cost in comparison to the expensive smart windows in the market [11]. The simulation for the parametric analysis of the window were taken care in two phases; first phase includes the testing of the window parameters such as orientation, opening type, sizes and the second works on the shading using dynamic simulation. It was concluded that the overhangs does not make high impact over the comfort and optimal window aspect does not infer equal space cooling and heating requirements [40]. Research presented the widespread review of the vacuum glazing windows which can be futuristic windows. Usage of the study and implementation of the research can save carbon footprints of 40 million tonnes a year proves to be beneficial [41]. Cost optimal solutions and nearly zero energy building (nZEB) in residential building was taken into consideration with renovation of the windows. Renovation packages developed which reduces energy consumption and low carbon emissions. The uncertainties in the outcomes while using simulation which was the main reason of nonconformity between operational and virtual performances were discussed in the research. There were certain parameters that can be controlled and close to the actual weather data sets but the schedules at various stages may not be able to have close resemblance with the onsite and simulated inputs. The performance difference was highlighted in city of Milan was showcased [5]. Highlighted that the simulation software does not work on local micro climate which heeds towards miscalculations of energy for heating and cooling loads [13]. A coupling for the simulation which includes convection heat transfer coefficient and micro climate variations for the real life scenario is developed which can be employed to have closely related energy values. Investigated the rate of air leakage in poorly framed double glaze windows in the study [42].

The U-value for airtight windows and conventional windows were 1.79 W/m2 K and 2.67 W/m2 K. 33 % of heat loss can be reduced using airtightness in the double glazed windows than conventional windows. [43] Proposed a tool for forecasting the heating energy and concluded that the retrofitting of envelope such as changing the performant windows and the thermal insulation of external wall helps in mitigating the heating energy of the residential buildings. Studied the effect of window to wall ratio and orientation on the built environment in mitigating the heating and cooling loads for the building where simulation was carried out with Energy Plus simulation tool. Author underlined that the cooling demand increases substantially when window were provided on the southern sides of buildings whereas heating loads becomes meager. The annual total energy increases from 6 % to 181 % on adding the windows to the envelope for series of different configurations and concluded that the cooling load increases with increasing in WWR [44]. [45] Tested retrofit measures in Dubai on the villas towards the energy efficacy and strict regulations of German building regulations. It has been observed the peak demand can reduce by 40 % and CO2 footprints by 32 %. Wall insulation was better by U-value of 0.3 W/m2K and upgrading the HVAC system to a COP of 2.78 becomes feasible solution. [46] Studied the impact of SHGC and VT parameter to establish a tradeoff relationship for the energy consumption and concluded that energy consumption decreases in offices building but no significant decrease was observed for residential building. It was underlined that when the energy cost declines then initial investment increases and lead to uncertain situations. Model was prepared and eQUEST simulation tool was used. [47] Investigated the feasible solutions using envelope change from conventional windows to double glazing windows in various climatic conditions of India. The models were created using Design Builder and Energy Plus simulation tool. Grey clear glass window found to be the most suitable glazing in reducing heat gain in the buildings. The results can be helpful for making suitable double glaze units to reduce the cooling loads. Spectral optical properties of four glass materials using spectrophotometer were studied and heat gain was analyzed due to different glazing in all the four orientations. Design Builder software has been utilized for the model preparation and Energy Plus tool has been employed for simulation. Reflective glazing glass was sufficient in dropping the cooling loads in the buildings. Most energy efficient solution was mud brick buildings as they limit the heat gain [21]. [48] Highlighted the present revisions on the opening of windows and emphasized the role of glazing in minimizing the cooling loads must be carefully studied before optimizing. Great work is necessary in semi-arid climate to forecast prospect research. [13] Studied the modeling of building in Iran with the help of Design Builder and Energy Plus simulation tool . The validation was performed by the electricity bills and observed the maximum error of 1.6 % in real time data and simulated data. Three different ECM was employed and find that 13 % to 18 % can be reduced in terms of cooling loads in the buildings. Low e glazing in double glaze unit has been studied for the windows and observed that 14 % savings can be done. [49] Proposes the framework where energy saving impending has been analyzed of high rise office building stock and energy forecast for next 20 years showed that there are substantial prospects that can save approximately 24 % would be possible. Studied the optimal aspect ratio of window so as to balance the various types of loads in the small commercial building having size lesser than 50000 square feet [50]. 7 different climatic zones of US have been studied using Design Builder and Energy plus simulation tool. It has been observed that aspect ratio should be increased for hot climate and reduces for cold climate. [51] Forecasted the energy saving by retrofitting the flat in China for the different load minimizations through models simulated in Energy Plus and modeled in Design Builder. Indoor air temperature was confirmed to authenticate the results for one week of April. Five ECM were taken into account. It was concluded that 40 % to 68 % of the annual space-conditioning system can be saved for great energy handlers depending upon the retrofits in the building and 30 % to 58 % for low energy users. No improvement was seen in summer season but thermal comfort was verified in winter season [52]. [53] Highlighted the crucial component of building envelope that is windows in respect to other components which is majorly responsible for major heat loss/ gain as shown in figure 2.1. Author pin pointed the need of experimental program in the actual field conditions as users complain for the commercially available products that the certificated data is not pleasing when the product is actually installed. DGU was tested (4mm + 20mm argon filled gap + 4 mm glass). Found the deviation of experimental U value (0.89 W/m2 K) from site and simulated (0.80 W/m2 K). 10% deviation was due to assumption of argon gas. The reason may be argon gas is assumed to be stagnant whereas argon gas is dynamic at site.

Figure 2.1 Comparison of elements of buildings for U-value [53]

Day-lighting in Malaysia were studied wherein 03 windows casement with obscure glass window, fixed louver with clear glass window and adjusted louver with tinted glass windows were taken into consideration as these were the commonly used fenestration in the Malaysia where the daylight is sufficient throughout the year. Measurements were simply taken at living area from center of the window. Experience of user was casement with obscure glass has sufficient daylight to have general task in their living room. Key parameters are type of glazing and windows has major impact on natural light [9]. [54] Observed the energy saving potential in the buildings by developing different types of ECMs in envelope pertaining to windows and choice of glazing. Author underlined the importance of initial cost which becomes the hindrance in implementation at ground stage and emphasized the careful design of windows for composite climate in the region of Punjab, India. It was observed that the temperature from outside to inside difference was better in case of DGU with one pane clear and other pane tinted. Author urges the need of experimentation in the various climatic conditions prior to its certification for the end user. Rigorous training is required to the owners towards saving potential parameters and windows from the concerned governmental organizations. [55] Optimized the WWR with or without day lighting in the building. According to orientations, 13 % to 30% savings can be possible in the building in the cooling loads with respect to different EEM. [22] Reviewed 100 studies across globe and trend seen in the increase in research in building envelope rises after 2010. Wall, roof and glazing materials are mostly taken under observation. Buildings with the help of models in different software were analyzed such as simulation studies were 92% whereas experimental studies was 2, experimental and simulation studies were 3% and Mathematical approach studies 3%.

Studies of residence were 23 % only and office study was 53% as shown in figure 2.2. Simulation tools used mostly were Energy Plus, Design Builder and DOE and around 60 % studies were focused at Energy in regard to cost which is only 20 %. Only 23 % studies happened over residential buildings which means ample work is needed in the residential sector as shown in figure 2.3. The studies presented online in the form of research articles, publications etc., outlined that there is increase in research exponentially after 2010 means last decade only as shown by figure 2.4.

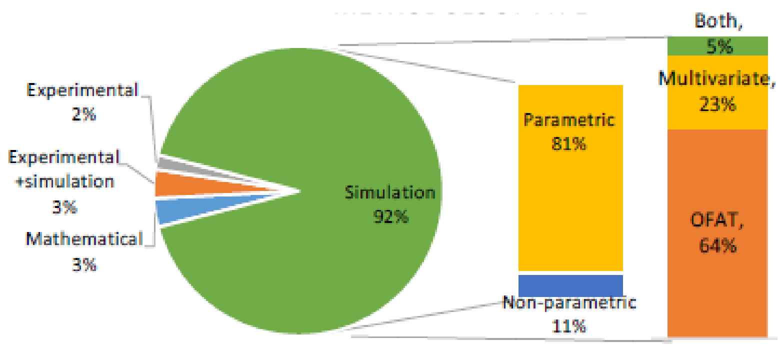


Figure 2.2 Parametric analysis of study [22]

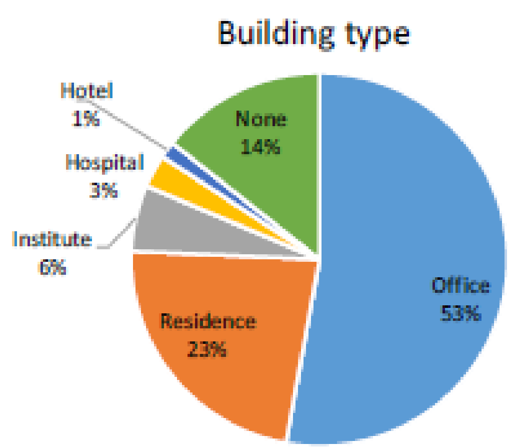


Figure 2.3 Energy utilization in built environment [22]

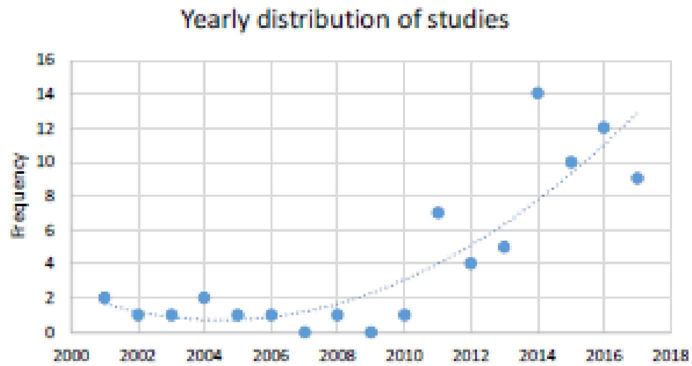


Figure 2.4 year wise publication in the filed [22]

The simulation using Energy plus tool and Design Builder to create the models has been studied for various energy conservation measures. It has been observed by the simulations that low e glass is suitable glass for reducing building thermal energy demand with infusion of argon gas for hot and cold climates. Double glass units over single clear glass can reduce the cooling loads by 2.5%. Results revealed that the increase of 40 % in energy demand in buildings when WWR increase from 0.15 to 0.75 [56]. Investigated the effect of DGU on the building envelope in lab and with simulation tool and observed that using low e glass in DGU can save up to 9 % on daily energy consumption of AC on south-east and north-west sides [24]. [57] Presented simulation of two cases DGU and DCC for annual thermal evaluation for environment of Mexico. Findings were DCA showed better performance by reducing 97 W/m^2 on extreme warm dry climate. DCA was observed as the beast solar passive strategy in terms of savings throughout the year. [58] Analyzed the worker performance with respect to different proportions of WWR using simulation tool. Author observed that 60 % WWR revealed the utmost job performance of the workers. The optimal WWR range from 40.9 % in north side to 50.5 % on south side thus delivers energy efficiency and well-being environment. [59] Studied the building envelope using PLEADES-COMFIE software and result showed the energy reduction up to 50 % in terms of heating load for Algerian city. [60] Presented an extensive review paper highlighting the scenario of residences and workspaces mostly used by people. Author stated the benefit of utilizing the outer to inner landscaping for flourishing of physiological, psychological and cognitive health. Emphasis on WWR was highlighted and recommended to use as much as possible. It was concluded that with the increase in daylight, the physical snags reduces and noteworthy increase in occupant presentation. [25] Worked upon the changes in DGU to have lower heat loss. Through minor and low cost changes to DGU makes it energy efficient and save up to 40 % in total energy consumption of the building. By changing the PCM in the gap improves thermal comfort using 3-D numerical simulation. [18] Performed extensive review on the building parameters in reducing energy consumption with relation to comfort. Author confines to 91 research full text journal articles out of 650 initially and finally 80 articles have been seriously studied. The factors highlighted in study were occupant behavior, building envelope and building energy systems which underwrites to building overall energy enactment. Several factors need to be assessed accurately and as close to real climate for the data gathering procedure. Studied the impact of window elements such as optimum window dimension and location on the energy consumption in the building using optimization model with Energy Plus simulation tool using a 2-storied office building was modeled in Design Builder for the study and 2000 iterations were performed in each climate. It has been observed that the total building energy consumption in cold and hot climate can be reduced by 2 % and 15 % respectively [50]. The residential owners were studied in context with applying four types of EER through survey in Netherland. Results revealed that the owners were possessive for going with PV panels through economic considerations rather than DGU retrofitting. Motivation plays important role in selecting the DGU for the occupants [61]. Model various windows configuration models in Design Builder in hot arid climate to study heating island effect and investigation of DGU with air, argon gas, krypton etc. as insulator has been performed. It has been observed that increasing the thickness leads to rise in cooling load and chiefly reduces heating load. The thickness of DGU relates directly proportional to cooling loads in the building. Significant increase is possible with krypton in comparison to air in gap [62]. [23] Proposed energy enactment assessment basis for residential houses in Saudi Arabia where approximately 50 % energy is consumed by residential sector. Operational energy, GHGs and cost were the main elements of study and applied in three different types of residential buildings that is separated, attached and low rise apartments. The model was prepared in Design Builder and simulation carried on Energy Plus simulation tool with 4 different types of ECM coupled having 12 conformations in the buildings.

Covering 5 regions and total of 180 simulations were performed and observed that energy was consumed less on south and north regions whereas high energy consumption on western and eastern regions of Saudi Arabia. Further, concluded that 3 types of ECM that is double glazed windows, triple glazed windows and LED lighting helps in reducing the energy consumption and recommended for the fruitfulness towards lesser carbon footprints to ensure environmental friendly buildings. LED lighting proves to be the costly ECM in comparison to others in separated residential buildings. Studied the impact of naturally ventilated DGU and air flow characteristics were experimented. Two factors play crucial role that is opening size and size of DGU. It has been observed that models with room only attained 85-93% of the airflow rate contingent on opening dimensions. Author underlines that consider room and windows should be done for an accurate and practical assessment [63]. [64] Investigated the impact of DGU in hot-humid climatic zone. Model was carved in Design Builder and Energy Plus simulation tool has been employed to understand the effect of DGU on the cooling loads in buildings of Dubai city. It has been observed that using DGU can lower the cooling loads by 22 % from the benchmark. In all four different types of DGU has been simulated in the building. The two types that is naturally ventilated and mechanical ventilated system has been taken care and found the benefits over cooling loads. The box type window façade provides the best results and 22% saving in cooling loads. [25] Emphasized the importance of energy crises and underlined the energy loss majorly held by windows which needs careful design. DGUs with minor and inexpensive changes lead the window to be energy efficient in such that Nusselt number decreased to 4 and savings of 20 % can be made in the buildings. The numerical formulas were carried on one hot day in the middle of summer. [65] Studied the impact of WWR on the thermal loads for the opening in the envelope of the buildings and observed that the thermal load increases with increase in WWR. Framework proposed where conclusions highlight that construction works of external walls and openings are liable for around 93.7 to 97.6% of thermal loads in buildings. [66] Reviewed the extensive technical characteristics and energy performance of Double skin façade DSF. Two types of performance have been reviewed that is thermal and ventilation. Author underlines the importance and performance of DSF to have the capability of reducing the noise, thermal loads and ventilation. The concern with the decision holders to employ is initial investment and maintenance. Also the fire risk is there with DSF which can lead the smoke and smog to other parts of the building. DSFs need more refinement to be projected for total energy saving effect which can offer societal and fiscal benefits to civilization. [67] Explored the potential of low-e glazing usage in place of clear glass and observed the increase in ventilation rate by 13.0 %. CFD analysis was performed for the results. The author proved the benefits of changing glazing can bring the increase in ventilation rate. [68] Investigated the effect of various parameters such as wall thickness, glazing and WWR on the energy consumption of the building. Five glasses has been studied, 5 different ratios of WWR and 4 different thickness of wall has been studied with the simulation tool of energy Plus and models were crafted in Design Builder. Laterite stone has been used in the wall. With comparison to conventional glazing, PDLCGW polymer dispersed liquid crystal glass window for wall thickness 0.23 m at 20 % WWR serves the performance glazing system and reduces 18.9 % heat gain in the building which will further reduces the cooling loads. Energy efficient order of glasses was polymer dispersed liquid crystals (PDLCGW), bronze reflective (BRGW), tinted green (TGGW), tinted bronze (TBGW), and clear glass (CGW). In comparison to conventional glass, the reflective glazing proves to be the next promising system in controlling the cooling loads of the building. [69] Determined the predictive tool for the most efficient ECM as per the categories of the end users concerned. The end user categories include energy spender, austerity user and normal user. Modeling was achieved through Design Builder and Energy plus rolled for simulation of the experiments under study. ECMs based on payback and thermal comfort improvements. ECMs increases energy proficiency by 32.0 %, 56.0 %, and 60.0 % with the energy spender, normal, and austerity OEB models, respectively. Energy spender was more concerned about HVAC and lighting so their behavior was more inclined towards such ECM. Normal user was concerned about ECM of wall thickness. The annual energy for the retrofitted building lowers by 29 % in comparison to un-retrofitted building as base case. Author addressed here the fact that occupant education on ECMs rather more important than retrofitting as awareness plays pivotal role in mitigating the energy consumption in the building and can be taken rightly in the initial stages of the design of the buildings. [70] Retrofitting is needed as explored in the research to make the building sustainable and energy efficient. Different retrofitting scenarios have been accounted to minimize the energy consumption such as global warming potential (GWP) emissions, embodied energy and cost for each technology. Energy Plus software has been employed to check the effect of various alternatives and observed that DGU has been the better choice in concern with GWP and embodied energy. Multi criteria decision making has been used for getting most sustainable windows and observed that DGU was the best sustainable retrofitting solution.

Energy efficiency becomes the necessity of the time as this can reduces the cooling loads for the end user on one hand and reduces peak demand for the state/ nation on another hand. Lot of ECMs have been studied using simulation, few of these were tested with empirical formulas and a very few have been experimentally analyzed. Depending upon the climatic conditions, the solution for saving energy deviates and thus let researchers to come up with rigorous experimentation so that the energy at micro level can be saved resulting in considerable savings in the state, country and nation level. Simulation studies tries to update the software time to time so that the actual real life scenarios can be tested without going into the site and cost for the experimentation is to some extent also saved but simulation need great deals of enactment with the actual site conditions, behavior patterns for the opening and closing of the windows especially in countries like India. Schedule, construction, HVAC elements etc. required for the simulation in the model should be carried from the data carefully as variation has been reported by many researchers and claimed as well that the real time situations can be matched closely but not accurately. Studies with software Design Builder has come into existence from last decade only and growing at fast speed which results the refinement of software in terms of schedules, product inbuilt capabilities etc. out of 60 research publications reviewed, 20 out of these were using Design Builder software only for the simulation means more than 33.33 %. Experimentation is almost meager and needs more investigation.

The aim of this study was to come up with more experiment oriented window glazing for composite climatic condition. Economic assessment for each of the formation has been carried so as to understand the initial investment in comparison to conventional window glazing. Conventional window glazing increases the heat gains and high cooling loads that is burden on end user and also on state electricity manufacturers. Double glazed units are common but behind mechanism is complex enough which requires attention and needs urgent attention in careful design. The finally performance window formation has been tested as well at the in-situ to check the performance from prototype level to macro level investigation.

2.3. Identified Gaps:

The gaps identified from the literature review were as follows:

- Due to rapid growth of construction sector and requirement to users, the construction prevails at much higher speed without taking care of energy efficiency.
- Designing of window is not properly addressed and windows were placed as per need without going into energy analysis.
- Initial investment of ECM is more than traditional window which is a deciding factor to shift towards energy efficiency measures. Most the ECM was based on simulation which requires expertise, hence one need to be more careful in inputting the complex parameters.

2.4. Objectives of the research:

After the careful investigation and assessment of the literature review, research questions come in mind and these questions need to be addressed. The objectives of the proposed research work are as follows –

1. To analyze feasibility of key factors in building sector for less utilization of better fenestration than traditional one.
2. To determine and identify the most suitable fenestration for region of Punjab using analytical and experimental approach.
3. To validate the feasibility of the optimum fenestration to be installed in a particular residence.
4. Recommendation in the building sector to policy makers who can blend the incentive approach with the help of subsidy to help society.

Chapter 3. Background and current scenario of glazing system in India

3.1. General

Speedy development around the globe is motivating energy demand and because of this, supplementary greenhouse gas productions are growing. Energy disbursed in the building sector involves residential and commercial users and liable for 20.0 % of the total distributed energy spent worldwide. Energy consumption for a building embraces energy used for various applications such as heating, cooling, lighting, and appliances. As per IEA report of 2020, due to COVID-19, the rate of converting the building sector in energy efficiency level has been decreased and the path is now slow down than as shown and expected by the road map of IEA. This way the payback period are now increased from 10.0 % to 40.0 % as stated in the report of IEA, 2020 after the analysis of building sector energy consumption during COVID-19, which reduces the attractiveness compared with the investments. During lockdowns, the contractors were unable to get in touch to their premises and construction somehow completed without adhering to energy efficiency measures. Economic uncertainty might add delay funds in the buildings sector, with future development forecasts for materials such as energy-efficient glass around 6.0 % weaker than pre-pandemic forecasts. COVID-19 has shifted the power-play of energy from commercial to residential sector as more n more official works even continues to deliver from residential sector due to non-movement towards commercial buildings such as offices, institutions etc. Crisis-induced factors that could affect energy intensity in buildings are presented in table 3.1

Table 3.1Crisis-induced factors that could affect energy intensity in buildings [71]

Type of effect	Factor	Potential impact on energy intensity improvement
Activity and structural	More activity in residential buildings; less in commercial buildings.	
	A greater share of services sector energy use comes from more energy-intensive services sub-sectors.	
	Commercial building ventilation rates are increased for health reasons.	
Technical efficiency	Economic recession and job losses lead to lost income for owners (partly due to lower rental payments) and tenants, and lower rates of building renovation and stock turnover.	
	Continuing low fuel prices prolong the payback period for building energy efficiency upgrades.	
	Continued health risks prevent professional energy efficiency contractors from accessing residential buildings, delaying building upgrades.	
	Energy services companies lose revenues and possibly default, starving the market of providers.	
	Government stimulus spending targets building retrofits and efficient new buildings.	
	Higher residential energy bills due to increased time at home encourage homeowners to invest in efficient building upgrades.	
	Commercial building owners take advantage of the absence of tenants and building users to upgrade buildings without inconveniencing tenants.	
	More time spent at home encourages do-it-yourself renovations as people invest in increasing their comfort.	

Now the energy efficiency of buildings has shifted towards residential sector as more than 2 years due to COVID-19, the work has commenced from home only and thus due to comfort requirement, owners were wishes to have energy efficiency buildings so as to lower their cooling and heating loads results in reduced energy bills. Also if economic recession deepens, households and trades may reduce expenses on building advancements, which will slow technical efficiency enhancements. In India, the construction sector is expanding due to increased demands for housing, expansion of organized retail, and increased demand for commercial office spaces by MNC & IT hubs. In the residential sector, projection scenarios indicate that electricity consumption is predicted to rise by more than 08 times by 2050 under the business-as-usual scenario [71]. Thus, energy efficiency strategies should be designed, practices and recommended to the society to enable the use of energy efficient techniques. The building envelopes plays major role in gaining the heat and increases the peak loads. The window is the crucial element that should need careful design. The traditional built of residential sector includes clear glass largely in the window due to low price. Such traditional windows are responsible in increasing the cooling loads and consuming much more energy in the building sector. Ample of the building energy use is lost due to "poor design, inadequate technology and inappropriate behaviors". The use of double glaze unit (DGU) with combination of suitable glazing as per the various parameters such as orientation, climate and micro climate analysis, location of the building, need and purpose of the opening etc., can save more than 40 – 50 % of the comfort loads [24][26][47][72-75]. The DGU consists of two glasses parallel placed with suitable gap ranging from 12 mm – 24 mm for barrier and phase change material such as argon gas; krypton gas etc. can be filled as shown in figure 3.1 [76]. These types of unit helps mainly two benefits, 1) cuts the heat radiations and cool the space and 2) lower the energy consumption in the building sector. The one successful type of DGU for southern part of the India may not be suitable for the northern part, so careful investigation and design as per various parameters should be worked out so as to enable the envelope of the building energy efficient and reduces the energy consumption. Motivation in the form of incentives should be worked out from policy makers to excel the energy efficient program for the society. The two glasses are to be selected based on various parameters as mentioned earlier such as orientation, climatic zone, type of aggressive temperature, available of glass in market etc.

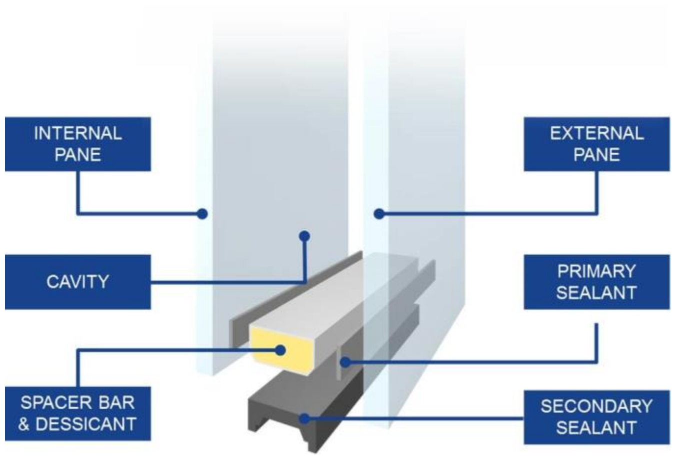


Figure 3.1 Cross section of Double Glaze Unit [76]

It has been clearly identified from literature review about saving potential of DGU in various climatic conditions in the building envelope. The energy consumption can be reduced from as low as 18 % to maximum of 50 % of cooling loads as explained from various researchers on the basis of simulations, numerical analysis and experimentation. Still it has been highlighted in many research articles that physical experimentation at insitu is required and should be rigorous so as to make the owner confident.

3.2. Aim and research questions:

The aim was to find out the possible and feasible DGU for the building envelope, its testing in the climate and their savings so that the initial investments can be offset with savings and result in lower payback periods. This will enable the users to seek for the energy efficient solutions/ retrofits. In the traditional buildings especially residential sector, contractors are still practicing the traditional methods and energy efficient techniques are not employed, the possible reason is unawareness, less testing at the site and also lack of explicit literature. As such there are no codes available and applicable to the residential sector in regard to energy efficiency.

Through this research, the following questions can be addressed.

- What is the unawareness level towards glazing materials to occupant?
- What is the various possible and efficient glazing as per performance in the micro and macro climate?
- How much is the difference between simulated model and actual performance in the fields?
- What are the other possible ECMs to reduce energy consumption in the building sector?

Chapter 4. Research Methodology

4.1. Introduction

The section focuses towards the residential buildings which needs energy efficient measures and can reduce the energy consumption and bills. Research framework has been designed for all the objectives in phases in figure 4.1. To achieve the same, for the first objective, research work is carried through questionnaire from the selected region to understand the issues for why the occupants were not interested in taking the energy efficient solutions? The schematic view of the research work is shown in figure 4.2.

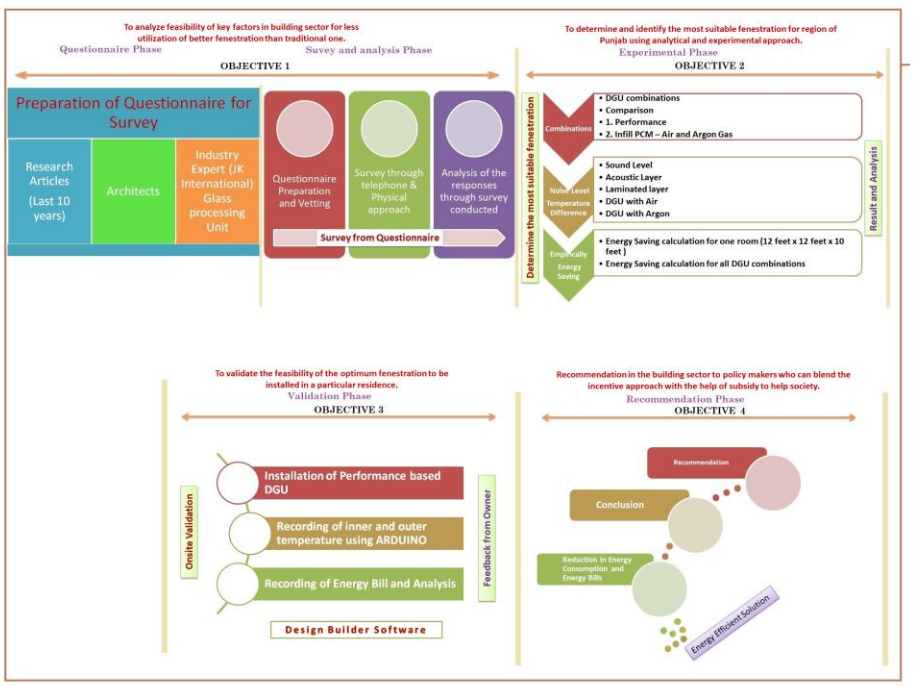


Figure 4.1 Research framework

Figure 4.2 Schematic Representation of procedure followed

The research experimental setup was carried in Jalandhar city, Punjab. The climate of Jalandhar, Punjab was composite and Jalandhar situated at 31.3260° N, 75.5762° E at a distance of 149 kms from state capital Chandigarh as shown in figure 4.3. The weather for full year composed of approximately summer season (from April till November) and winter season (from December till March). The summer season further have four severe months where the days and nights were warmer. Highest temperature in summer season was higher approximately 46° - 48° C and at nights the minimum temperature was approximately 25°C. During transition months, dehumidification was required for comfort to the users. The average minimum and average maximum temperature during entire year in the Jalandhar was shown in figure 4.4. Total of nine months where air-conditioner needs to be operational, out of which approximately 4 to 5 months of severe running of air-conditioner even in day time and 2 months approximately for the purpose of dehumidification. Due to high demands in the region during high summer season, power outages are common problem due to short supply against demand. The peak demand was possibly due to cooling loads.

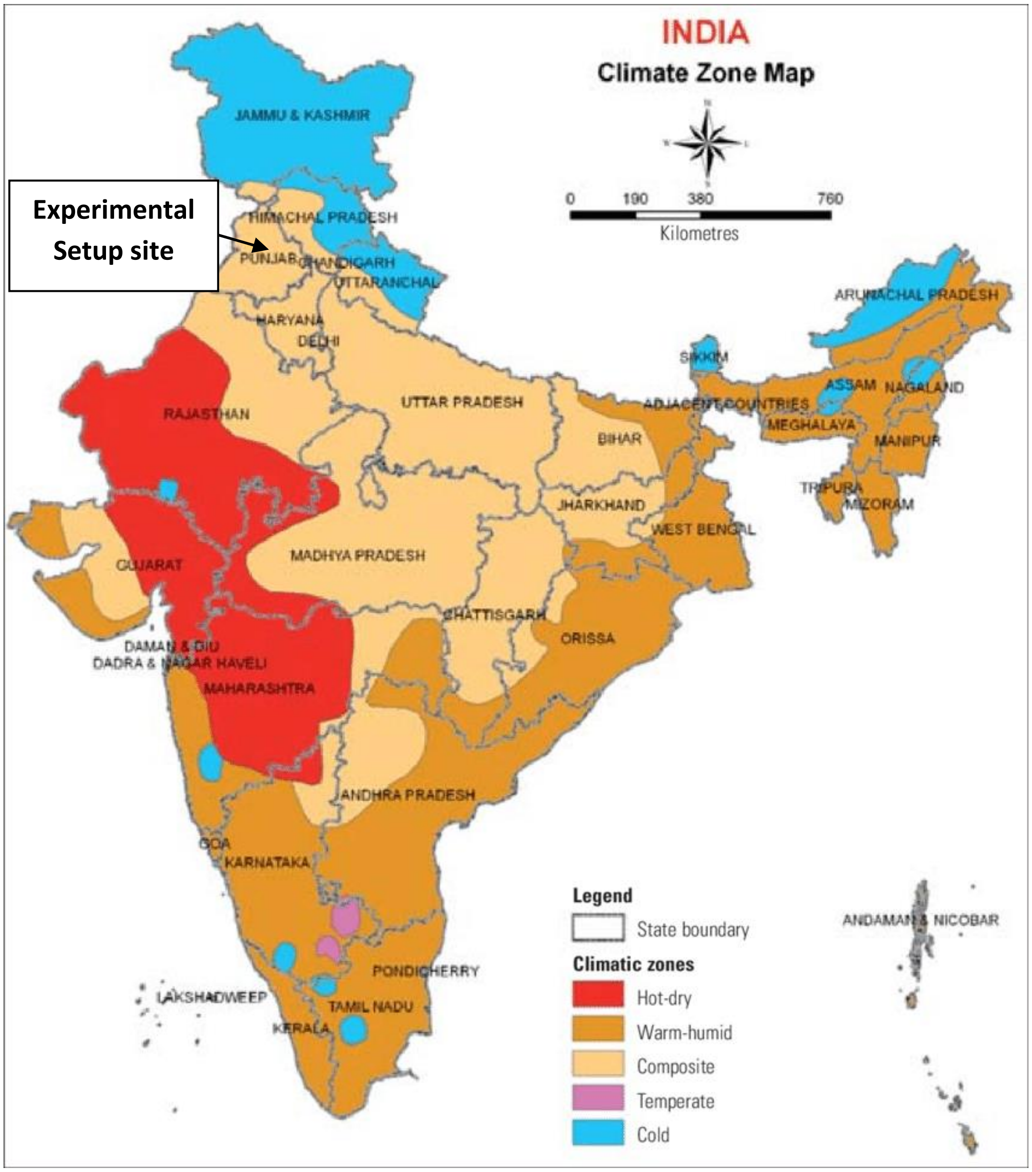


Figure 4.3Climatic zones in India

Climate data for Jalandhar												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average high °C (°F)	19.4 (66.9)	21.6 (70.9)	26.0 (78.8)	34.5 (94.1)	39.4 (102.9)	40.6 (105.1)	34.1 (93.4)	33.1 (91.6)	32.6 (90.7)	31.5 (88.7)	27.2 (81.0)	22.3 (72.1)
Average low °C (°F)	6.2 (43.2)	8.6 (47.5)	13.2 (55.8)	19.0 (66.2)	23.8 (74.8)	25.6 (78.1)	24.7 (76.5)	25.8 (78.4)	21.8 (71.2)	18.3 (64.9)	12.1 (53.8)	7.2 (45.0)
Average precipitation mm (inches)	10.7 (0.42)	16.7 (0.66)	32.8 (1.29)	15.2 (0.60)	20.4 (0.80)	69.7 (2.74)	155.2 (6.11)	183.6 (7.23)	60.0 (2.36)	1.5 (0.06)	6 (0.2)	15 (0.6)

Figure 4.4Average low and high temperatures for Jalandhar

The first phase of the research program focus on the literature review which has been taken care by many researchers on the built environment, and then preparation of the questionnaire and questionnaire vetting from the industry experts and architect having ample experience in the construction field. The well framed and vetted questionnaire was used for collection of data from the actual sites through survey.

4.2. About Questionnaire:

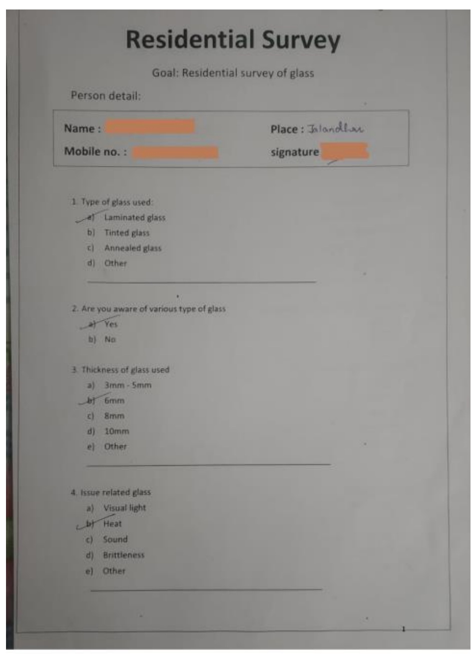
After the extensive review of literature and extended talks with the experts in the buildings (designing, execution) and glass processing (Industry personnel, Architect and Vendors), the key parameters have been studied and total of 11 parameters has been considered. The same has been discussed with experts and curtailed to 9 and then finally questionnaire has been framed and recommended by the experts in form of 4 questions only which covers all the parameters required for analysis. The framed questionnaire collected the data such as glass type, awareness about glass, thickness etc. presented in table 4.1.

Table 4.1Parameters for questionnaire

S.No	Parameter	S.No	Parameter
1	Type of Glass	6	Profession of owner
2	Awareness about glass	7	Year of construction
3	Thickness of glass	8	Issue 1
4	Direction facing of building	9	Issue 2
5	Nearby road		

4.3. Discussion on key elements in questionnaire:

The aim of the survey was to collect the data which lets us understand why there is less utilization of performance fenestration than traditional ones. The question 1 will fetch about the type of glass that has been utilized in buildings and the percentage of its utilization. The question 2 will tell about the fact that the person utilizing the glass is actually aware about the benefits of the glass type or he has gone for the decisions on some other thoughts may be economical/ less finances or may be under the best impression of architect/ consultation. The question 3 will gather data regarding the thickness of the glass being used in the building. The thickness is responsible to extent that varying the thickness, comfort changes. Researchers study revealed more benefits as far as energy utilization is concerned with more thick glass. The question 4 will relate to the issues which an owner is feeling, witnessing and addressing. Question 5 collecting data about year of construction and profession of owner to understand the impact of time and learning attitude of the owner. The survey is conducted in the month of February and March, 2020. The copy of first page of survey is shown in figure 4.5.



Residential Survey

Goal: Residential survey of glass

Person detail:

Name : | **Place :** Jalandhar
Mobile no. : | **signature**

1. Type of glass used:
   a) Laminated glass
   b) Tinted glass
   c) Annealed glass
   d) Other

2. Are you aware of various type of glass
   a) Yes
   b) No

3. Thickness of glass used
   a) 3mm - 5mm
   b) 6mm
   c) 8mm
   d) 10mm
   e) Other

4. Issue related glass
   a) Visual light
   b) Heat
   c) Sound
   d) Brittleness
   e) Other

1

Figure 4.5 Sample of questionnaire

4.4. Survey:

The survey has been carried with the developed questionnaire, very concise and informative to collect the data for analysis. The key target was the buildings energy consumption that can be lowered (as revealed by the literature review) which has been designed in consultation with architect and the expert from glass industry. The data was collected from 240 building through in person and telephonically (during COVID-19). Also 711 data has been gathered through goggle form to understand the aspect globally.

4.5. Data Analysis:

The data collected from the owners has been entered in spreadsheets for analysis and presented in next section.

4.6. Prototype for the research work:

For the assessment from the real climatic situation, the prototype was design and fabricated to assess two parameters,

- Sound/ Noise level
- Temperature

4.6.1 Experiment Prototype for sound level

Seeing the benefits through literature review for the reduction in sound level, double glass pane has more added performance than traditional windows? Various glass for glazing have been studied from market along with their optical properties and then three DGU was formulated using acoustic layer, PVB layer and air as infill material. The effect of the sound has been investigated through experiment and the sound level has been recoded using sound level meter. The prototype has been discussed as under-

SOUND LEVEL:-

The prototype has been fabricated for measuring the effect of glass towards minimizing noise as shown in figure 4.5. The dimension of the prototype is as under

Dimension of Box	912 mm x 765 mm x 1070 mm
Dimension of Glass	535 mm x 410 mm

The glasses were changed one after another type and sound level in Db. has been recorded. Three different DGUs are prepared for checking the impact of sound reduction. Two materials available in the market are acoustic layer and PVB layer. In two combinations DGU1 and DGU2, the PVB layer and acoustic layer has been used and DGU3 composed of 5 mm clear toughened glass sandwiched with 12 mm air gap as shown in figure 4.6 and figure 4.7.

1. - Speaker system
2. - Double Glass Unit

Figure 4.6 Prototype for measuring Sound Level

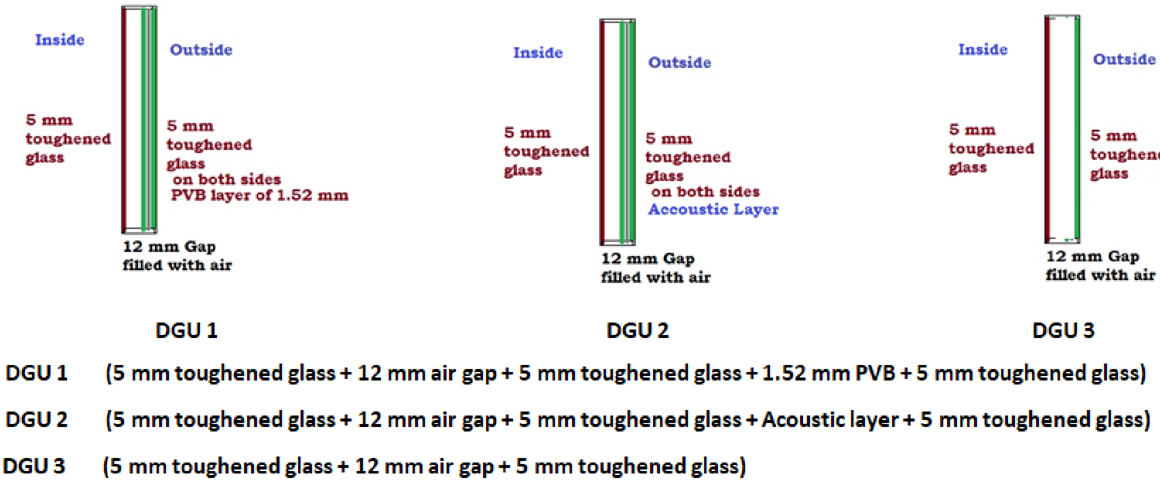


Figure 4.7Combination of DGU for Noise cancellation

4.6.2 Prototype for measuring temperature and performance

The Prototype was fabricated to check the effect of various DGUs with respect to traditional glass (Clear toughened Glass) figure 4.8. The dimension of the glass and experiment box as under:

GLASS (mm x mm)	180 mm x 130 mm
GROSS AREA (mm x mm)	240 mm x 160 mm

The aim of the research has two parts –

- Understand the effect of air versus argon gas in performance of the glass.

- Ability of the different DGUs to reduce the temperature from one side to the other side of the DGU.

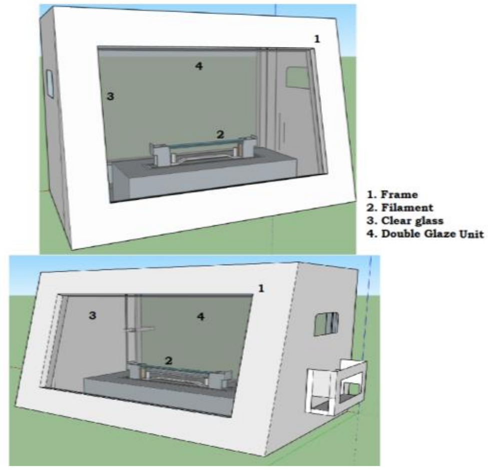
Total of 15 window combinations have been prepared out of which 13 combinations contain air in gap between two panes and 2 combinations has argon gas in gap of 12 mm. The table 4.2 presents the various combinations. The aim of the experiment was to check (1) the effect of argon gas over air medium to act as insulation and (2) the difference in temperature with respect to clear glass. Experiment prototype, Lux meter, sound level noise dosimeter, temperature gauge etc. have been utilized in the experiment stage. The filament placed in the center of prototype has 500 Watt and capable of producing 48 ˚C. At the same time interval, the temperature on the clear glass side and on DGU side are measured and recorded for various types of different DGU as per table 4.2.

About argon gas:

The space between window panes was filled with argon gas for double glass unit to improve thermal effectiveness. The argon gas is inert gas, denser than air and non-reactive gas. From literature review it was evident that argon gas has impact in lowering the U-value of the component and thus makes it energy efficient product. Heat transfer and losses can be reduced using argon gas in comparison to air. The issue with argon gas is that it leaks through the pores at the rate of 1 % per year which takes about two decades and will not affect the efficiency of the product as such over the time. Due to its cost effectiveness and benefits over saving, was used in the present study to check the impact of reducing heat gain from outside by cutting the outside temperature.

Table 4.2Window Combinations of DGU

DGU Code	Surface 1 (Outside)	mm	Type	Surface 2 (Inside)
DG1	6 mm clear glass	12	Air	6 mm clear glass
DG2	6 mm clear glass	12	Argon gas	6 mm clear glass
DG3	6 mm clear glass	12	Argon gas	6 mm Solar Silver Low e glass
DG4	6 mm clear glass	12	Air	6 mm Golden Brownish Low e glass
DG5	6 mm clear glass	12	Air	6 mm Silver glass Low e
DG6	6 mm clear glass	12	Air	6 mm Neutral Grey Low e glass
DG7	6 mm clear glass	12	Air	6 mm Dark Blue Low e glass
DG8	6 mm clear glass	12	Air	6 mm Neutral Low e glass
DG9	6 mm clear glass	12	Air	6 mm clear Neutral Low e glass
DG10	6 mm Golden Brownish Low e glass	12	Air	6 mm clear glass
DG11	6 mm Silver glass Low e	12	Air	6 mm clear glass
DG12	6 mm Neutral Grey Low e glass	12	Air	6 mm clear glass
DG13	6 mm Dark Blue Low e glass	12	Air	6 mm clear glass
DG14	6 mm Neutral Low e glass	12	Air	6 mm clear glass
DG15	6 mm clear Neutral Low e glass	12	Air	6 mm clear glass



(a) (b)

Figure 4.8Prototype for measuring temperature (a) Physical fabricated model (b) 3d model designed

4.7. Validation of the Experiment:

Validation was essential as the product after installation should not deviate from its manual facts more than acceptable limits, this will nullify the ECM and bring issues from the end user perspective. For this, two types of experimental program were carried.

4.7.1 Experiment Method

To validate the feasibility of the performance window fenestration to be installed in a particular residence, the performance of DG3 from table 4.2 was better and to check the same at insitu stage, the same prototype of DGU needs to be installed in the residential building (South facing). For this, a residential house owner has integrated and discussed regarding the benefits, savings, initial cost and product specification. After the owner consent, the DG3 was installed in the house. The experiment of studying the temperature on inside and outside of the designated room was carried from 11th June, 2021 to 30th June, 2021 in the composite climate. Figure 4.9 was showing the room, its details and the windows with various views. The area of the room (12ft x 14ft) was 168 sqft and the window area (9ft x 6ft) was 54 sqft, the wall area was 120 sqft. The WWR achieved was 45%.

Figure 4.9The view of room for the installed DG3 fenestration

Technology has been utilized in the experiment to avoid human error. For the temperature recording, the arduino hardware has been used; the temperature sensor LM35 was used to capture the temperature reading at interval of 15 minutes for these 20 days from 11 AM to 4 PM. Figure 4.10 showed the hardware used for the study. This helps in automatic capturing of the temperature both on inside and outside of the room. The inside temperature was taken at 3 feet from the window at the height of 2.5 feet from the ground as shown in figure 4.11 to understand that the end user comfort near by the glass unit. Location through satellite was showed in figure 4.12 for the residential building under study.

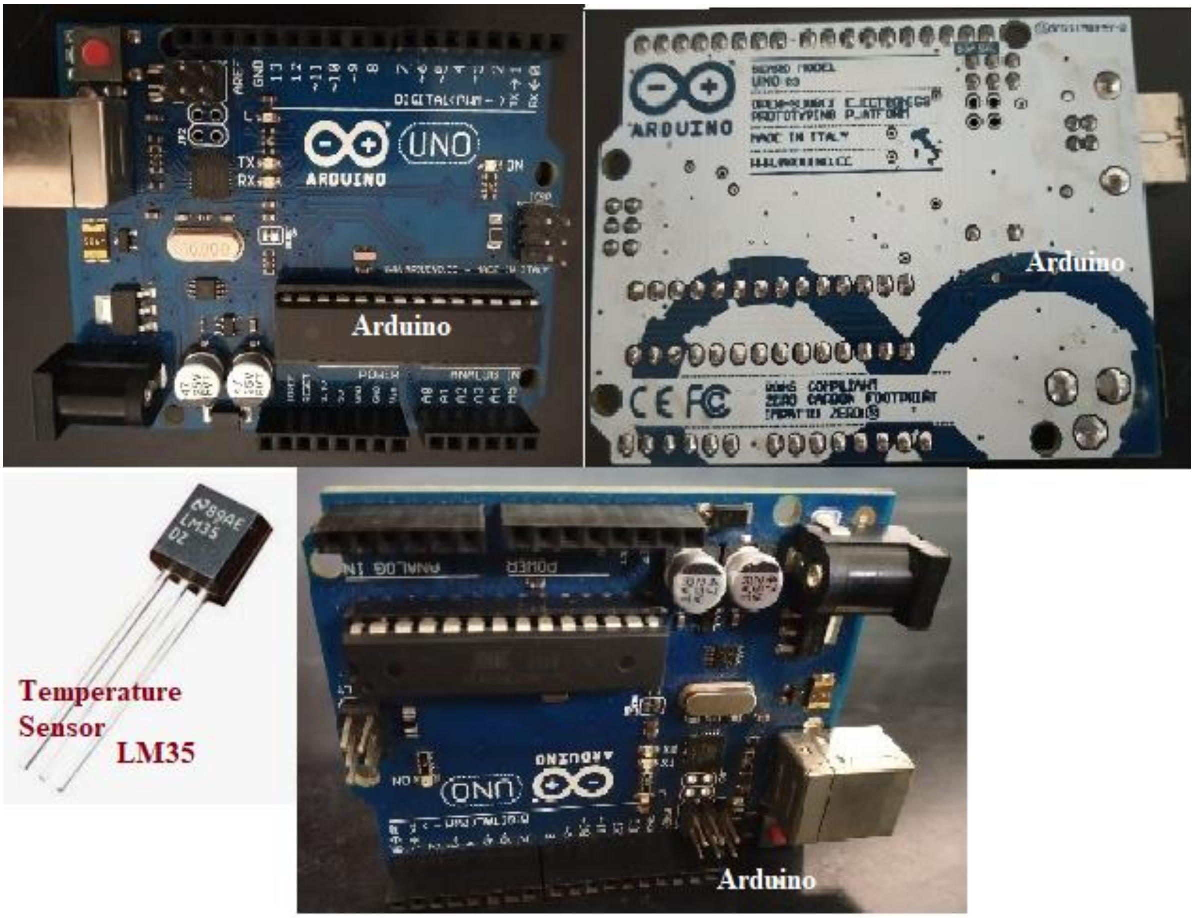


Figure 4.10Arduino hardware for capturing temperature

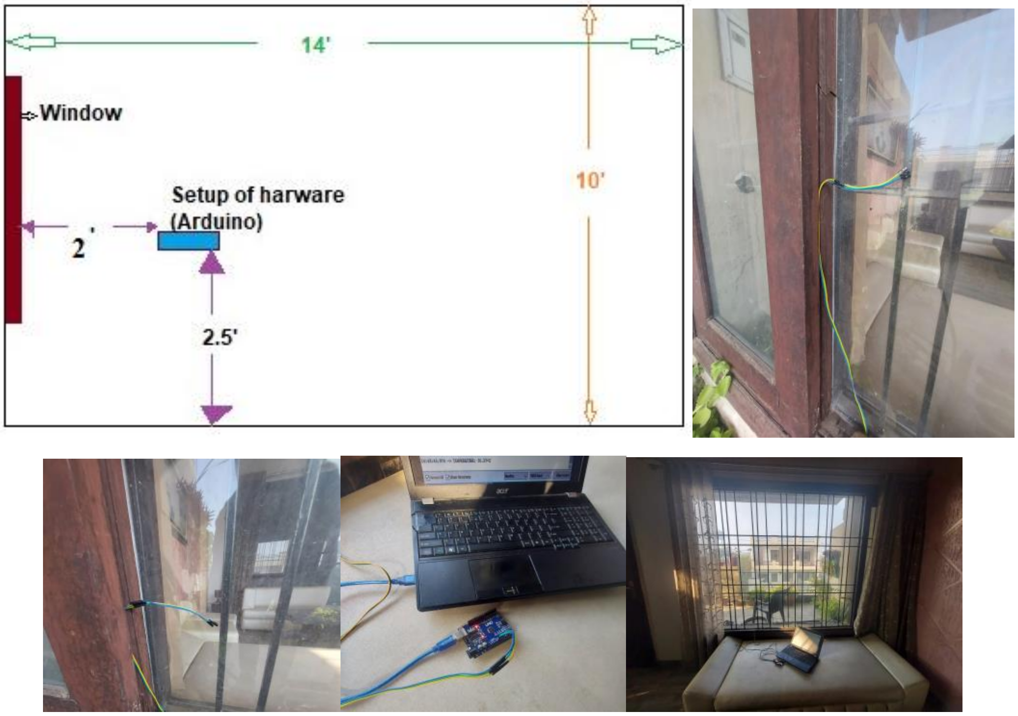
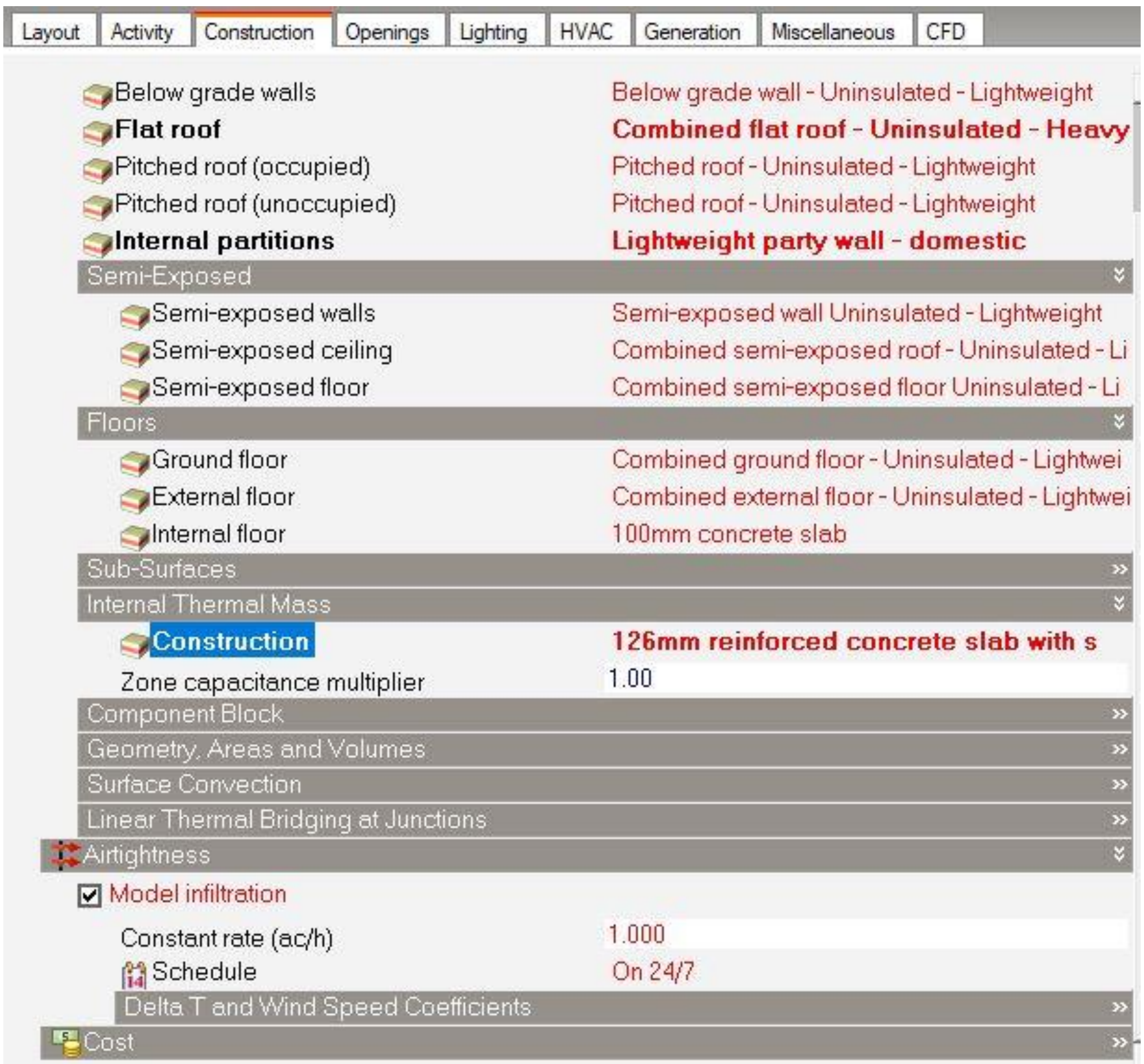


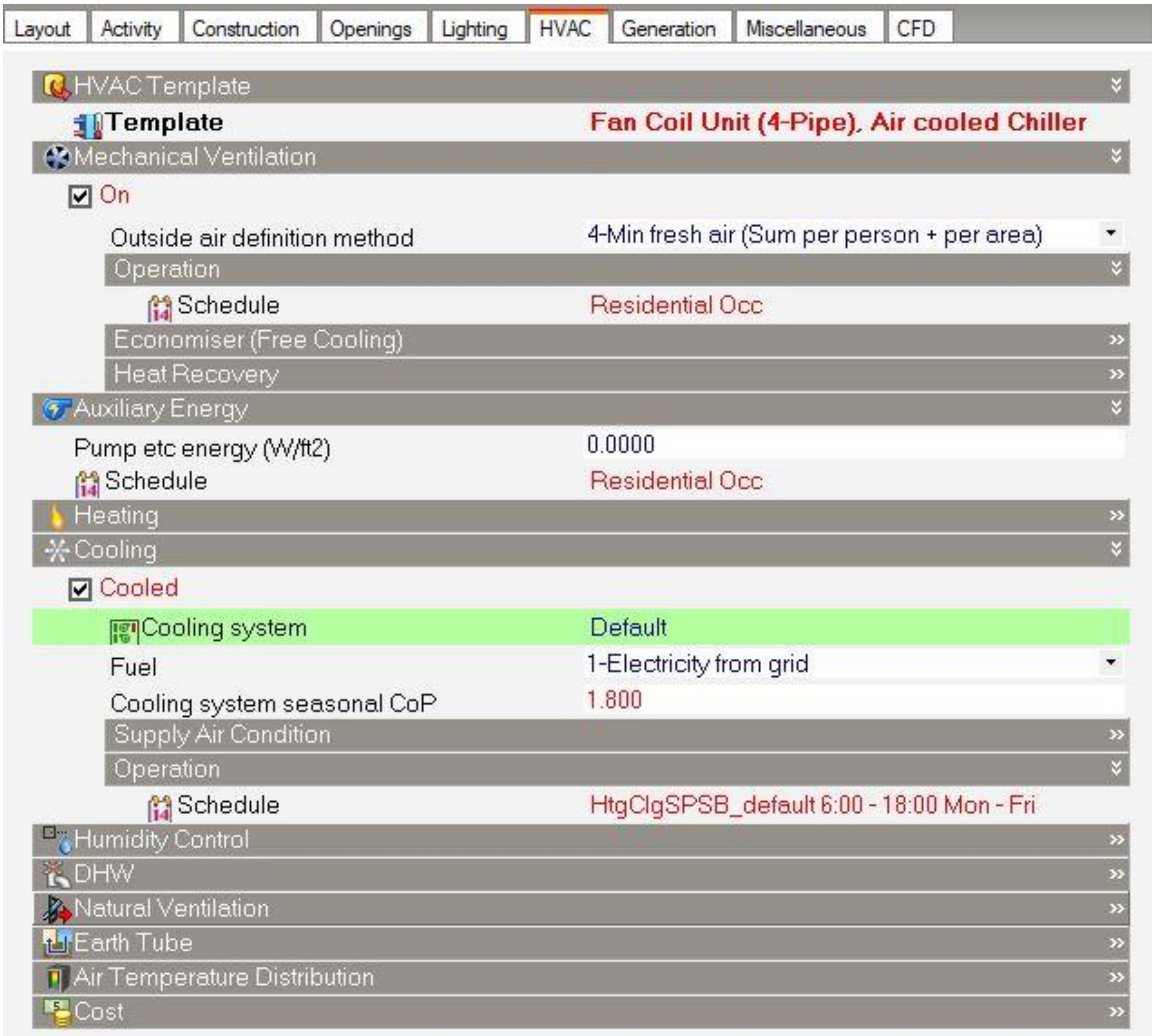
Figure 4.11Position of the hardware in the room

Figure 4.12 Location from Google map of the site

4.7.2 Simulation Method

The simulation was carried through Design Builder software 7.0.0.106 and Energy Plus 9.4 simulation tool to understand the performance of the DG3. To go with this the various inputs provided in the software has been showed in figure 4.13 along with the output. The simulation was carried using Energy Plus software and comparison drawn with respect to traditional window (clear toughened glass).





Layout
Activity
Construction
Openings
Lighting
HVAC
Generation
Miscellaneous
CFD
HVAC Template
Template
Fan Coil Unit (4-Pipe), Air cooled Chiller
Mechanical Ventilation
On
Outside air definition method
4-Min fresh air (Sum per person + per area)
Operation
Schedule
Residential Occ
Economiser (Free Cooling)
Heat Recovery
Auxiliary Energy
Pump etc energy (W/ft2)
0.0000
Schedule
Residential Occ
Heating
Cooling
Cooled
Cooling system
Default
Fuel
1-Electricity from grid
Cooling system seasonal CoP
1.800
Supply Air Condition
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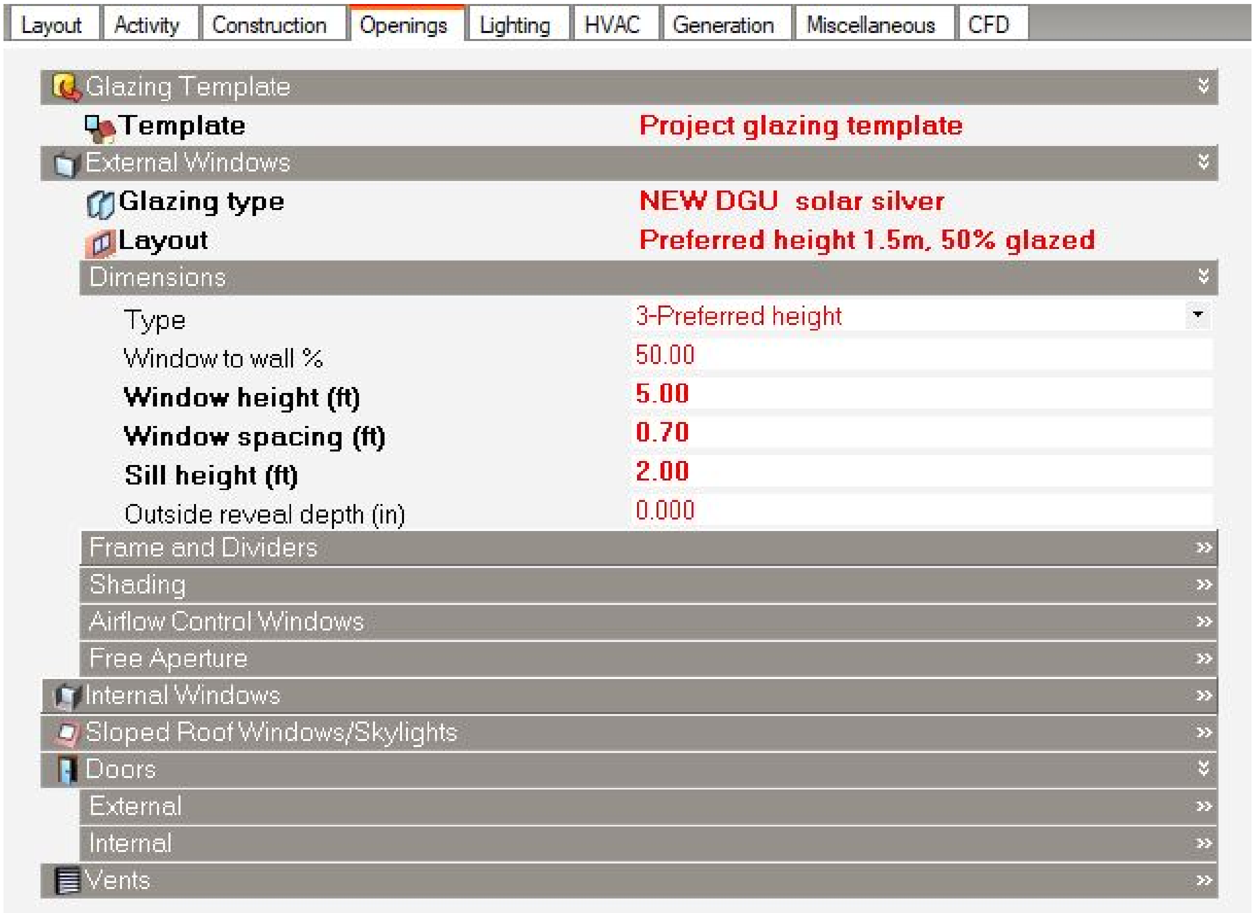
Natural Ventilation
Earth Tube
Air Temperature Distribution
Cost


Layout
Activity
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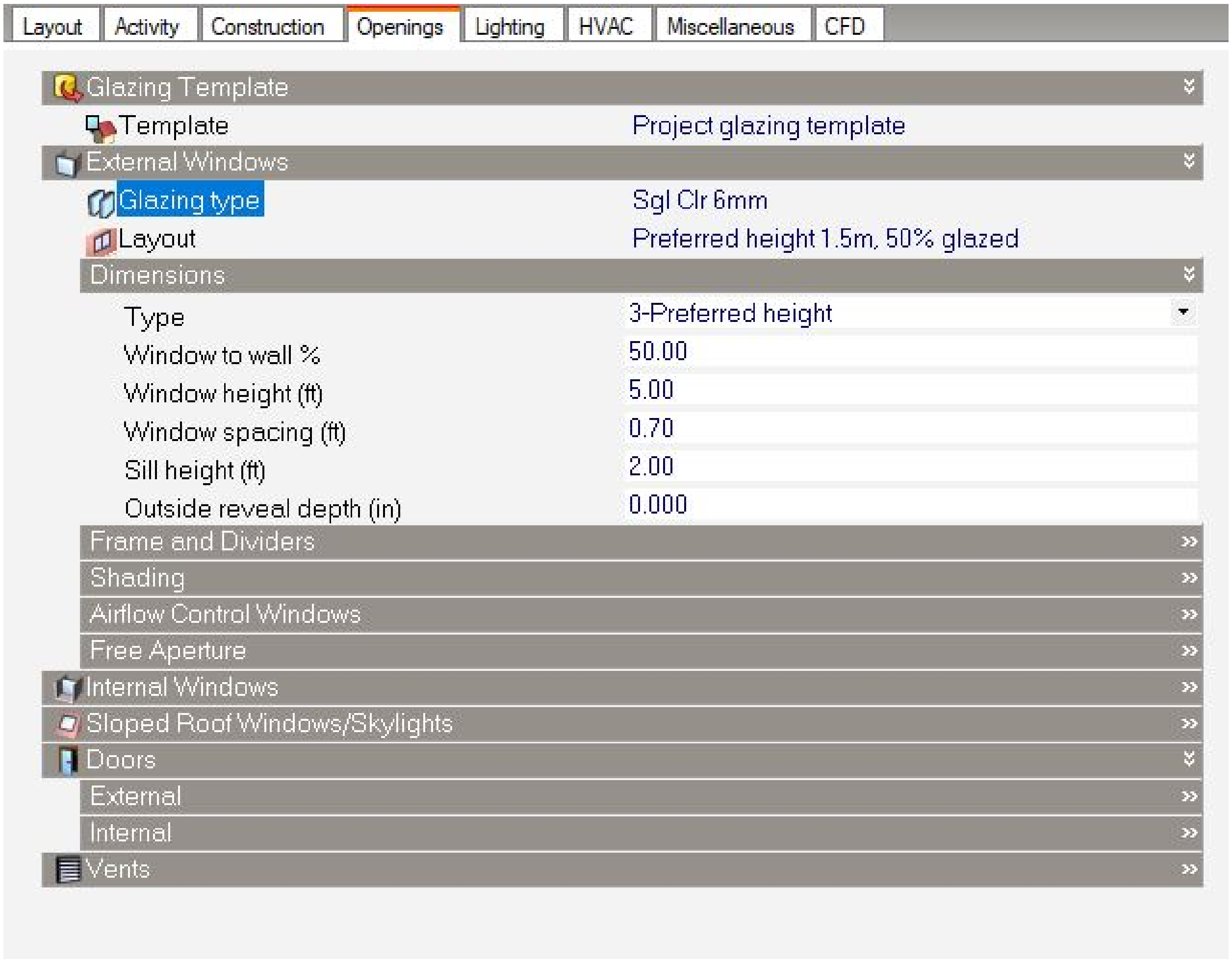
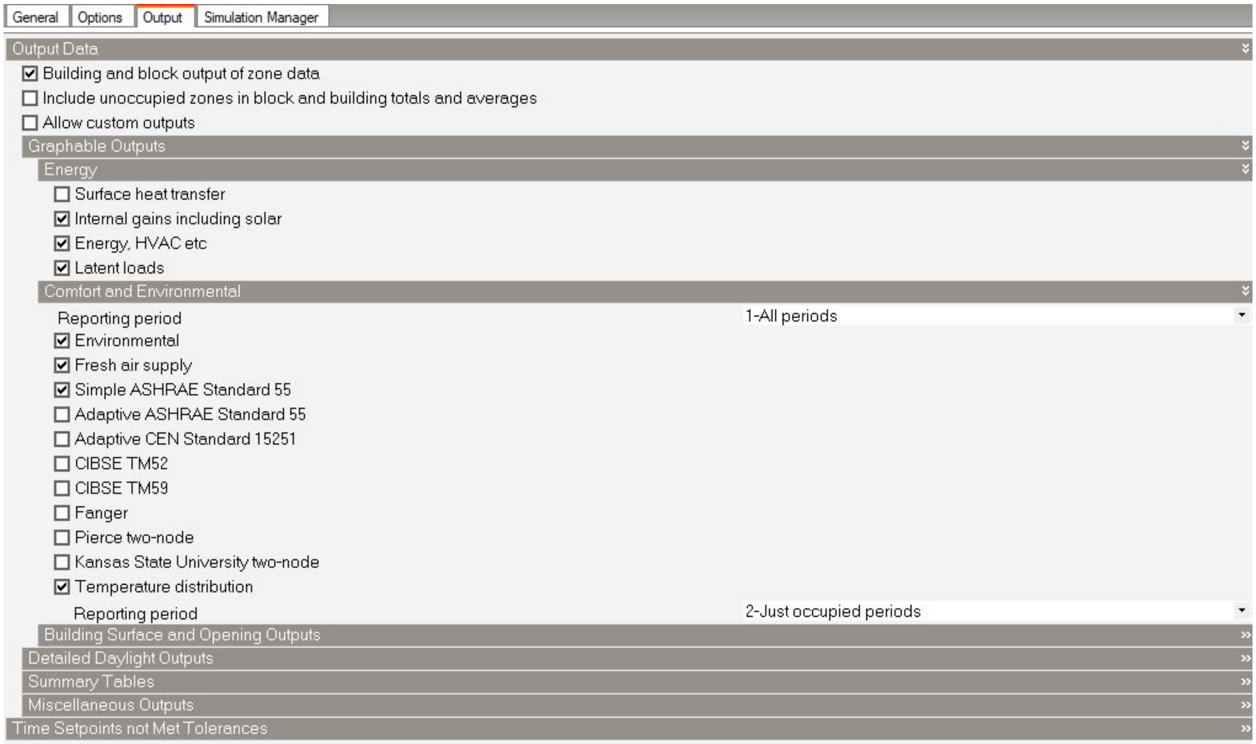
Generation
Miscellaneous
CFD
Glazing Template
Template
Project glazing template
External Windows
Glazing type
NEW DGU solar silver
Layout
Preferred height 1.5m, 50% glazed
Dimensions
Type
3-Preferred height
Window to wall %
50.00
Window height (ft)
5.00
Window spacing (ft)
0.70
Sill height (ft)
2.00
Outside reveal depth (in)
0.000
Frame and Dividers
Shading
Airflow Control Windows
Free Aperture
Internal Windows
Sloped Roof Windows/Skylights
Doors
External
Internal
Vents


Layout
Activity
Construction
Openings
Lighting
HVAC
Miscellaneous
CFD
Glazing Template
Template
Project glazing template
External Windows
Glazing type
Sgl Clr 6mm
Layout
Preferred height 1.5m, 50% glazed
Dimensions
Type
3-Preferred height
Window to wall %
50.00
Window height (ft)
5.00
Window spacing (ft)
0.70
Sill height (ft)
2.00
Outside reveal depth (in)
0.000
Frame and Dividers
Shading
Airflow Control Windows
Free Aperture
Internal Windows
Sloped Roof Windows/Skylights
Doors
External
Internal
Vents



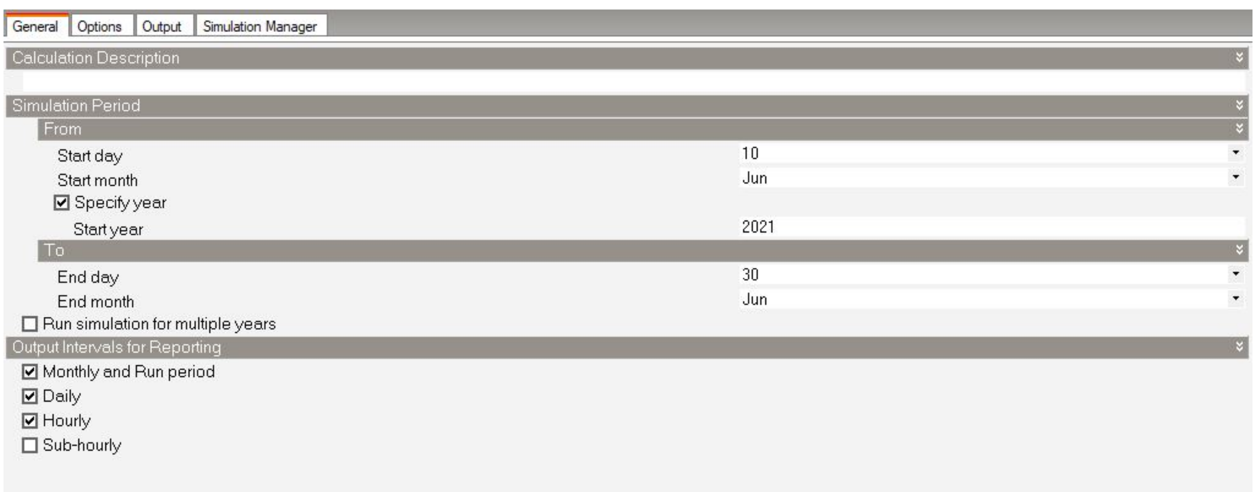
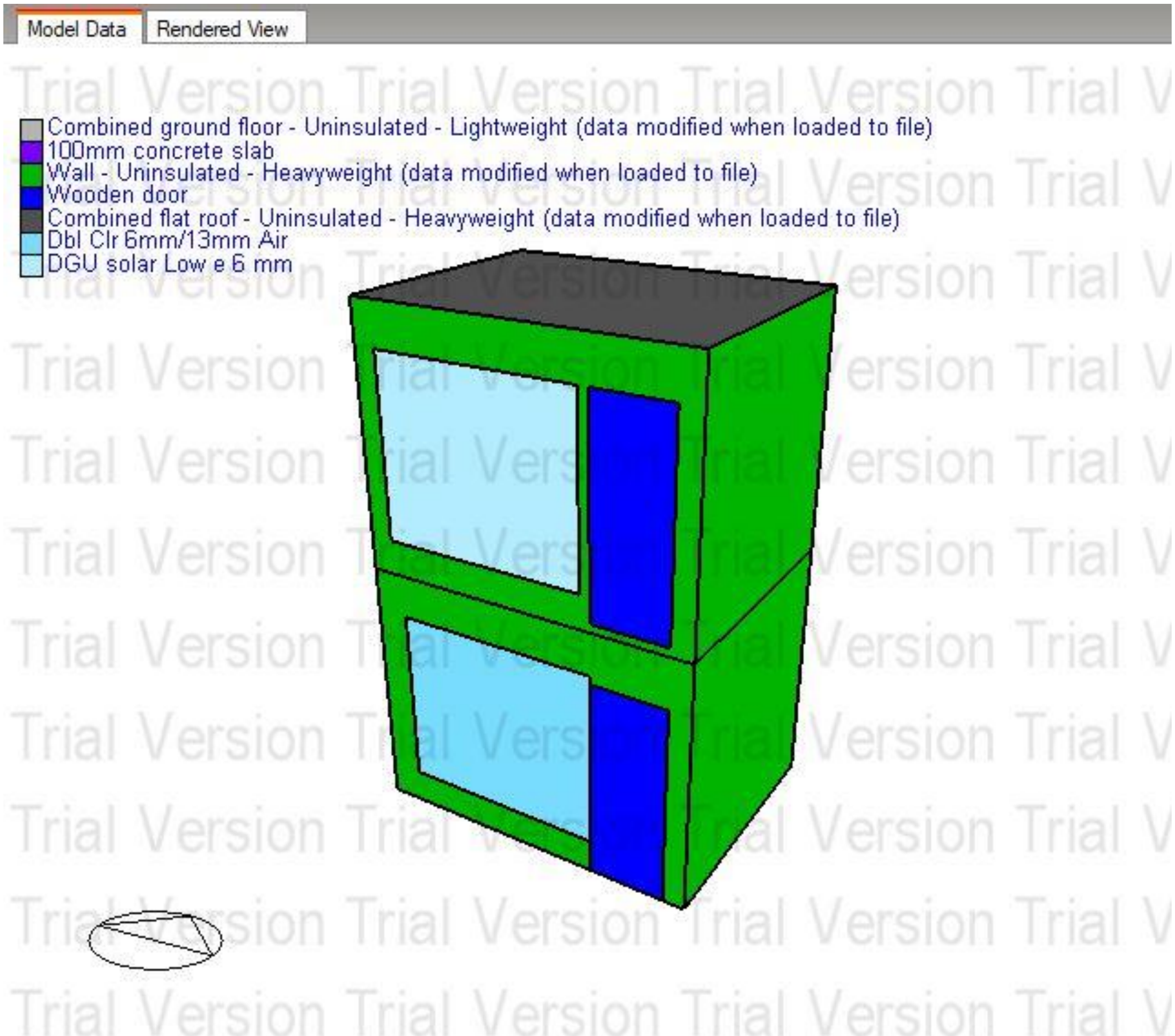


Figure 4.13Inputs for simulation of the model


Model Data
Rendered View
Combined ground floor - Uninsulated - Lightweight (data modified when loaded to file)
100mm concrete slab
Wall - Uninsulated - Heavyweight (data modified when loaded to file)
Wooden door
Combined flat roof - Uninsulated - Heavyweight (data modified when loaded to file)
Dbl Clr 6mm/13mm Air
DGU solar Low e 6 mm
Trial Version

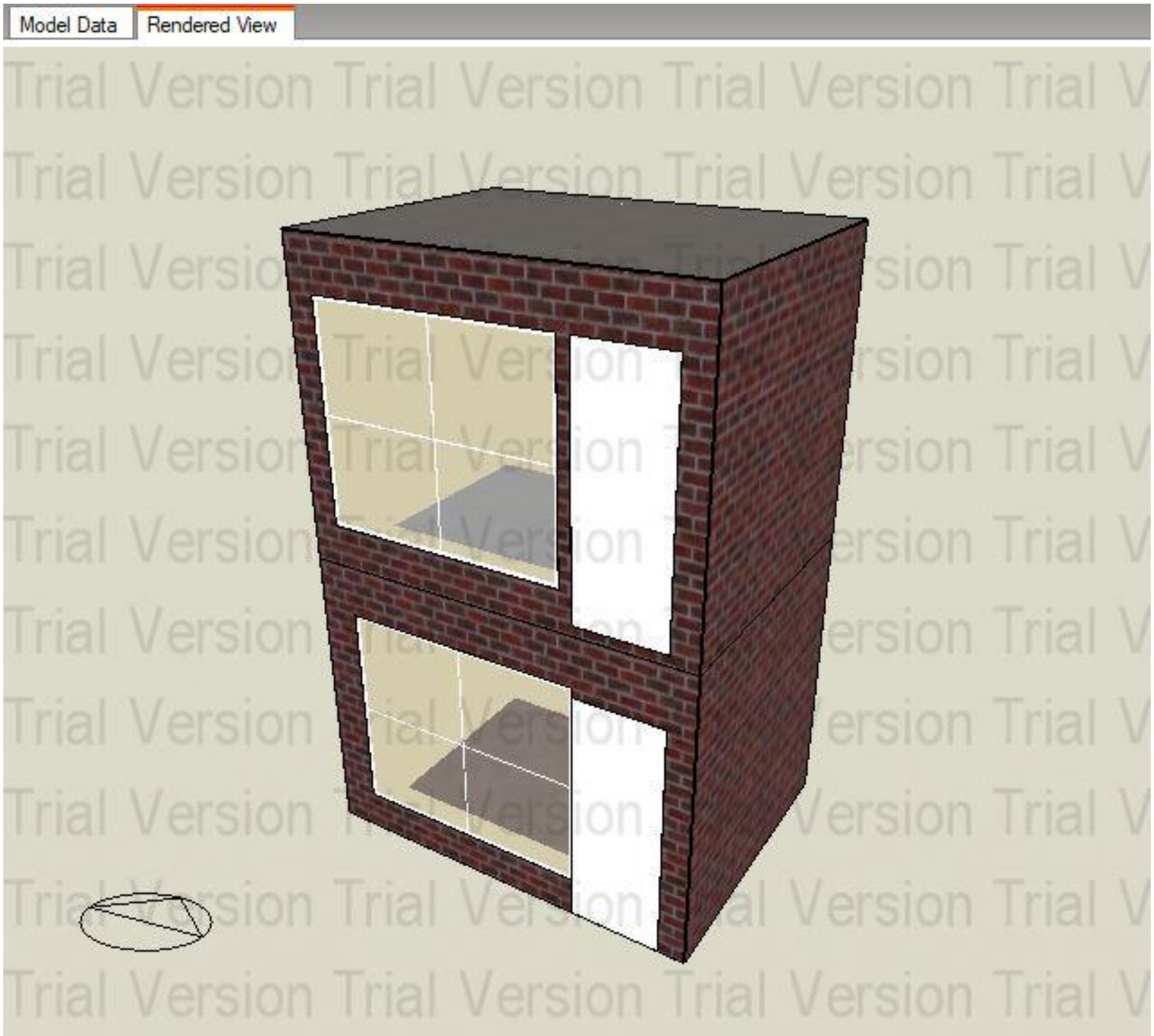


Figure 4.14Model and its rendered View

4.8. Economic assessment and Recommendation

For the various types of DGUs, the saving potential has been studied and initial cost calculated from the manufacturer for various types of DGU utilized in the research as shown in table 4.3. The economic assessment has been carried out with numerical methods wherein the operation savings cost and savings from the performance window has been evaluated and payback period was calculated.

Table 4.3Cost of DGU per square feet

DGU Code	Surface 1 (Outside)	mm	Type	Surface 2 (Inside)	Cost (per Sqft)
DG 1	6 mm clear glass	12	Air	6 mm clear glass	175
DG 2	6 mm clear glass	12	Argon gas	6 mm clear glass	200
DG 3	6 mm Solar Silver Low e glass	12	Argon gas	6 mm clear glass	220
DG 4	6 mm clear glass	12	Air	6 mm Golden Brownish Low e glass	185
DG 5	6 mm clear glass	12	Air	6 mm Silver glass Low e	190
DG 6	6 mm clear glass	12	Air	6 mm Neutral Grey Low e glass	185
DG 7	6 mm clear glass	12	Air	6 mm Dark Blue Low e glass	188
DG 8	6 mm clear glass	12	Air	6 mm Neutral Low e glass	188
DG 9	6 mm clear glass	12	Air	6 mm clear Neutral Low e glass	190
DG 10	6 mm Golden Brownish	12	Air	6 mm clear glass	185

	Low e glass				
DG 11	6 mm Silver glass Low e	12	Air	6 mm clear glass	190
DG 12	6 mm Neutral Grey Low e glass	12	Air	6 mm clear glass	185
DG 13	6 mm Dark Blue Low e glass	12	Air	6 mm clear glass	188
DG 14	6 mm Neutral Low e glass	12	Air	6 mm clear glass	188
DG 15	6 mm clear Neutral Low e glass	12	Air	6 mm clear glass	190

To make the user comfortable, recommendation has been provided which can be taken in the initial stage of window design for the composite climate. The solution can be replicated to the location having same featured climate and orientation.

Chapter 5. Results and Discussions

5.1. General

This section briefs about the experiment work performed, recording, results and discussion regarding various aspects involved in the research.

5.2. Objective 1 result analysis

To achieve the objective -1, survey method was used to gather the data from the owners in person and telephonically. The analysis of the data in spreadsheets answers most of the questions effectively. The analysis is further presented and discussed as under:-

5.2.1 Awareness to Occupants

From the data collected from in-person survey and goggle form, through question no.2, this has been presented in figure 5.1, from the same it was observed that 72.92 % occupants does not know about the types of glass and its benefits and only 27.08 % was aware about the types of glass. From 711 owners, 513 showed no awareness about the glass and benefits. This becomes the first basis wherein the awareness becomes necessity for the authorities as the proper designing and right choice of the glass pertaining to many parameters, can reduce the electricity consumption in the houses and also can save energy consumption at state level. From the data, it was cleared that once the awareness will be with the owners about glass benefits, energy can be saved by utilizing the accurate glazing. This will benefit for the maximize use of the accurate choice of glass as per various other parameters known to designers and the building can save the electricity consumption and the result was in accordance with researches [76] where author especially felt the need of awareness to the occupants so that energy efficient concepts and works should be aware at various training program.

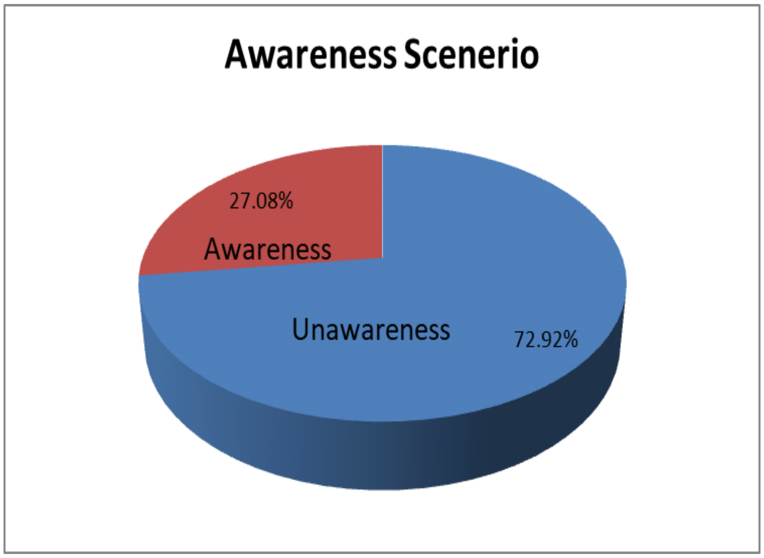


Figure 5.1Awareness scenario about the type of glass and its benefits

5.2.2 Thickness of glass

As far as research articles, the glass thickness plays a pivotal role, on one side, the suitable thickness provided safety against breakage of the glass and on the other hand about the noise level that is the noise level gets reduced from the outside of the building to maximum. From the data collected in question 3, the result presented in figure 5.2 which shows that the usual glass of size less than 5 mm is widely used (82.08 %) followed by 6mm (11.67 %), 8mm (2.08 %) and 10 mm rarely used (4.17 %). As far as 3 – 5 mm glass usage, this is in accordance with the awareness scenario. Very few people in comparison are aware of the type of the glass and its benefits thus they use the basic glass. The other point underline here is that the owner might be worried about breakage part as far as glass is concerned. If this large population got insight about the functionalities and breakage of the other type of glass, then the situation might be on better side. The other reason might be the initial cost, to this if the glass is properly designed as per various parameters by the suitable fenestration specialist then the saving and other benefits can offset the initial cost in longer run. The same has been addressed in research articles as well [21]. Out of 711, 568 owners were using 3-5 mm glass that is traditional glazing which causes overheating and consumes more energy.

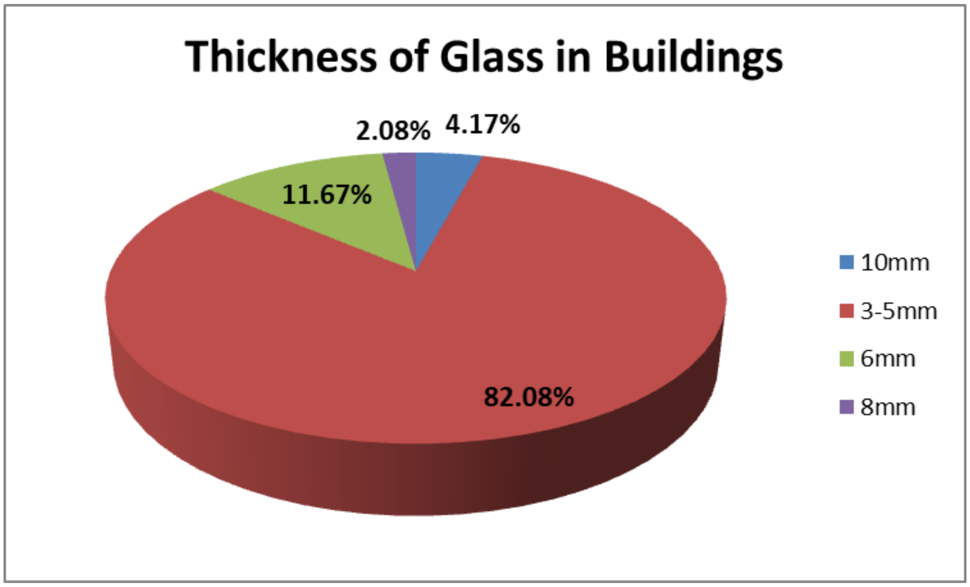


Figure 5.2Thickness of glass utilized in residential buildings

5.2.3 Type of Glass

From question 1, the data reflected the result of type of glass used is presented in figure 5.3. It has been observed that the two type of glass are known only that is Annealed clear glass and tinted glass which has been used in surveyed areas as 52.08 % and 41.25 % respectively. Awareness regarding type of glass utilized plays a deciding role means the persons or decision maker for usage of glass in windows were not aware of other types of glass precisely and thus most probability of using the basic glass that is much than the glass used in better fenestration. Due to the usage of basic glass two problems arises, one deals with the breakage, once this type of glass breaks it breaks in fragments and shards which can injure anybody in contact and second is this type of glass lets the dun light into the building which raises the temperature and leads to more consumption of electricity. DGU is almost not present in any of the buildings, when spoken to experts; they agree that contractors and architect as well need to be aware about the products in combination of insulated glazing unit such as DGU. There is great potential in the residential sector for the utilization of DGU. From 711 owners as received globally, 570 building were having annealed glass which needs to be changed to enhance energy efficacy of the windows.

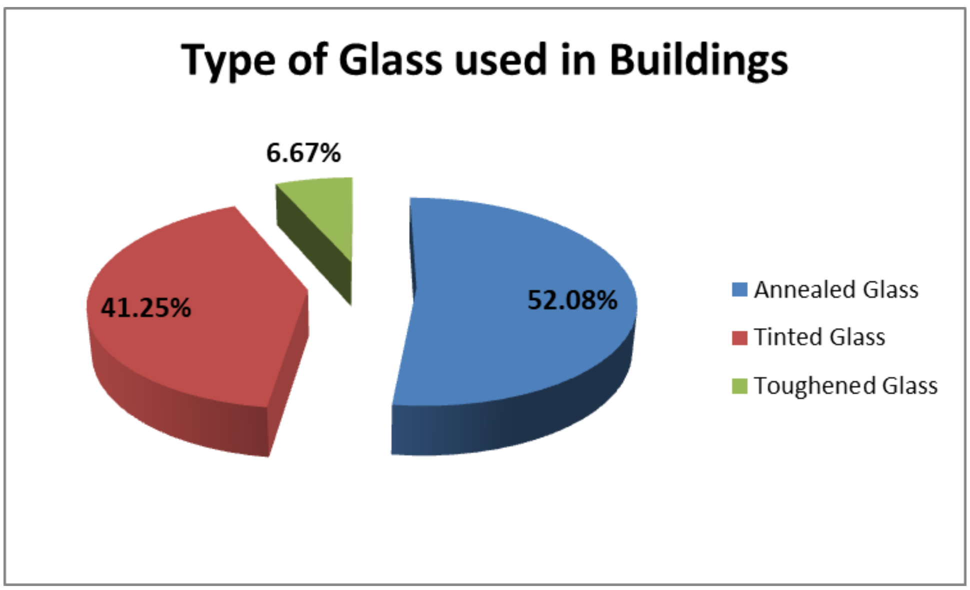


Figure 5.3Type of glass utilized in residential buildings

5.2.4 Issues faced by occupants

When the fenestration is not carefully designed with various essential parameters, then the occupants usually have issues with respect to the installed fenestration. From question 4, the data was collected from various sites and it has been observed that the major issues were heat, glare and noise. Single owner has multiple issues as reported by occupants. Apart from these issues such as privacy due to transparent glass and brittleness means worry about breakage of the glass. Issue heat has been reported by 55.0 %, problems of glare (15.0 %) and noise from outside (15.0 %) from figure 5.4. Heat was the major issue and due to which the electricity consumption was increased in the form of cooling loads. The reason is the ingress of radiation from the clear glass is much more and which increases the temperature finally lead to more energy consumption. 13.8 % occupants does has not shown sincere issues, the reason might be the orientation that is the windows might be lying in north side where the cool waves travel and sparkling heat ingress was very low. When seen globally our of 711 owners, multiple issues reported by single owner and the result showed issue "heat" 547 times, issue "glare" 439 times and issue "nuisance" 289 times. Globally heat and glare were the major problems especially due to usage of traditional window panes.

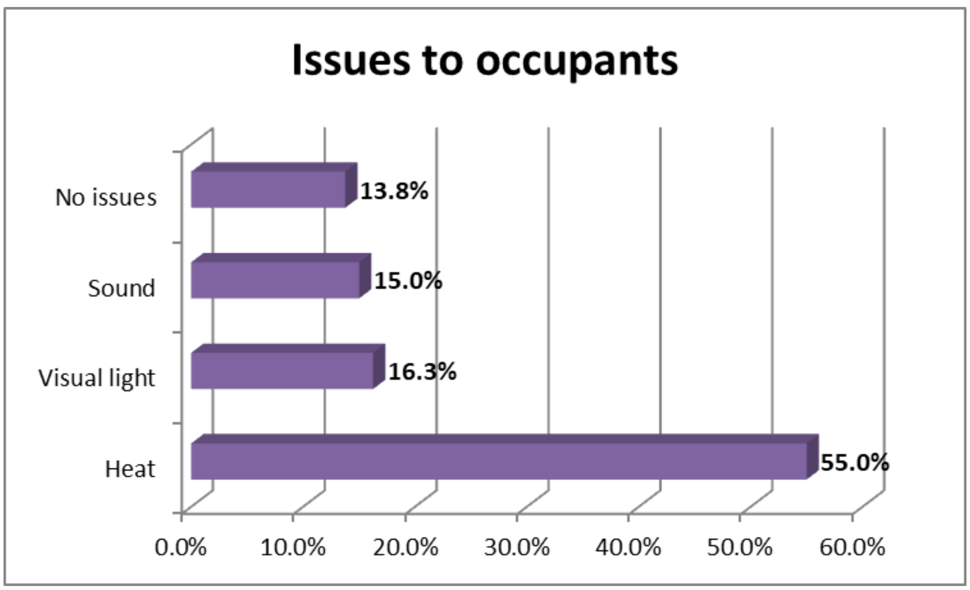


Figure 5.4Issues related to occupants

The results were presented from the survey regarding crucial issues which becomes key factors for the less usage of fenestration. The major issues were the awareness and not only about the glass types but also the kind of savings which can lead to less consumption of the electricity.

The fenestration should be carefully designed seeing the issues reported and lead to less ingress of the heat, reduction in sound and suitable window to wall ratio. With the help of double glaze unit, the occupants can get ease on mentioned issues and also the electricity bills especially in summer and transition phase should be substantially lowered when compared to traditional window.

5.3. Prototype result analysis

The experiment has been carried out with the help of prototype in the lab to assess the noise level and also the performance of the various combinations from the performance point of view.

5.3.1 Noise Level result analysis

In order to check the performance of suitable glazing that can reduce the sound level/ noise level, three DGU (Figure 5.5) have been tested with prototype and readings recorded. The results are presented in Figure 5.6.

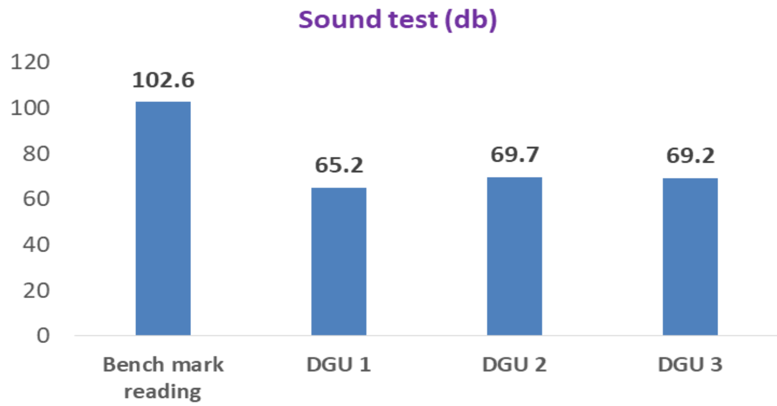


Figure 5.5Sound level performances

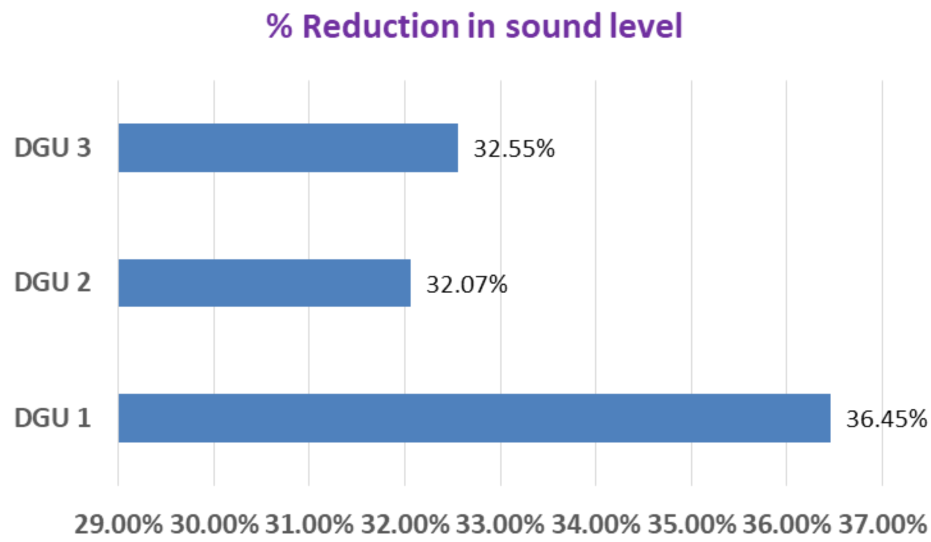


Figure 5.6 Performances of DGUs for reduction in sound level.

It has been observed that

- The PVB layer is better than acoustic layer in reducing the sound level from outside to inside.
- The DGU3 has better performance than acoustic layer DGU2 and also DGU3 is less expensive than DGU2.

Comparing DGU3 and DGU2, there is only reduction of 5.7 % which is not considerable difference when it comes to cost comparison and value for money.

5.3.2 Experiment result analysis

Out of 15 different DGUs have been tested in the prototype and results recorded. It has been observed that performance of DG3 is better (has the highest temperature difference of 9.4 ˚C from clear glass) followed by DG2 (temperature difference of 8.7 ˚C) with respect to clear glass. Both the units are filled with argon gas. The effect of argon with respect to air has satisfied performance, for the clear glass on both sides filled with argon and air has the temperature difference as 8.7 and 5.3 respectively that is 1.46 times more in case of argon gas as compared to air. About 64 % more reduction in heat as compared with air. DG11 and DG13 have the capacity of lowering the temperature nearly same as of DG1. Performance of DG9 is the lowest. The temperature differences of all the combinations are presented in figure 5.7.

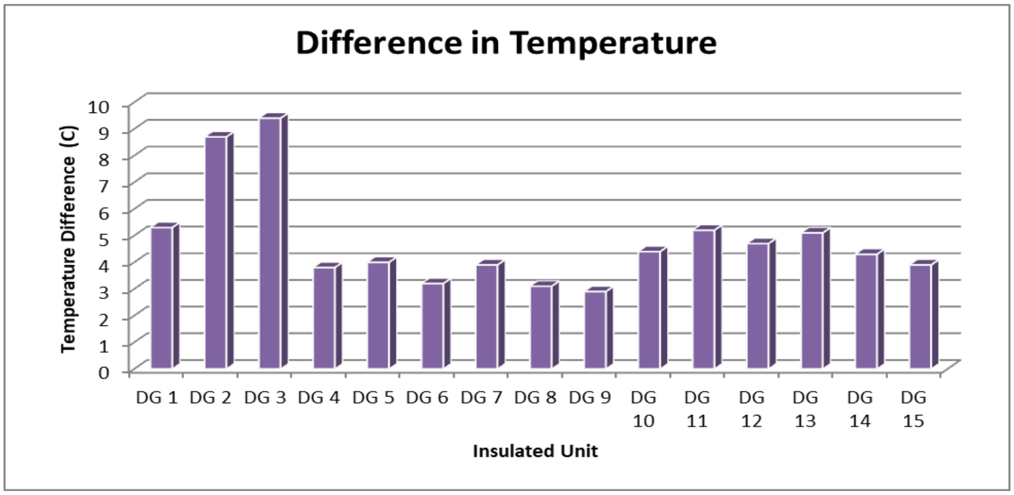


Figure 5.7 Difference in temperature with respect to clear glass

5.4. Empirical calculation for Energy Consumption

The energy consumed in lowering the temperature of the space was calculated keeping the 3 star AC, the room size 12 feet x 12 feet x 10 feet, is 14.49 Wh. Reflecting the same for all the combinations, the conservation in energy consumption is presented in figure 5.8.

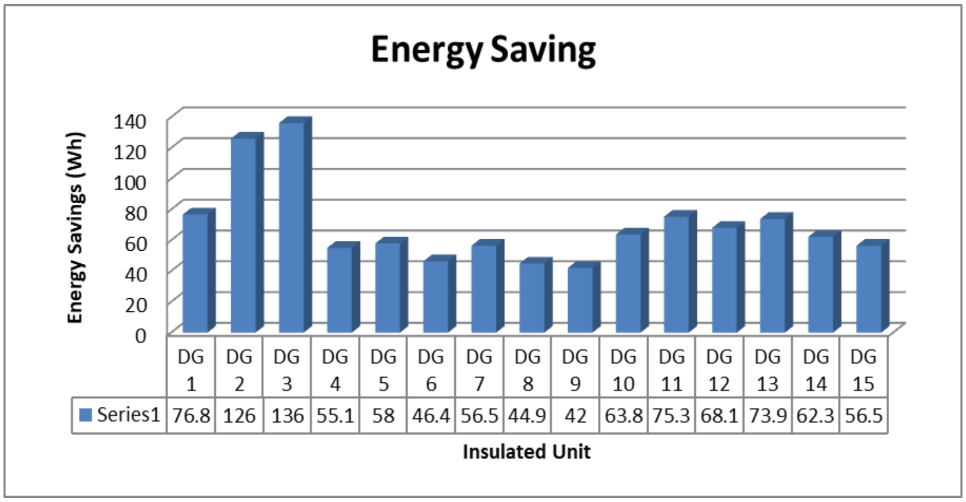


Figure 5.8 Energy saving annually with respect to clear glass

The difference of temperature (Δt in ˚C) for the various specified timings has been calculated and the average of the day for the maximum and minimum is recorded for the time span from 11th June, 2021 to 30th June, 2021.

For 15th June, 2021, being the hottest day, the difference in temperature from outside to inside is studied precisely and observed that the temperature control that is difference between outside and inside of the room falls in the range of 10.67 ˚C and 8.5 ˚C. The outside maximum temperature and minimum for the day was 33˚C and 30.87 ˚C respectively which reduces to about 23 ◦C figure 5.9.

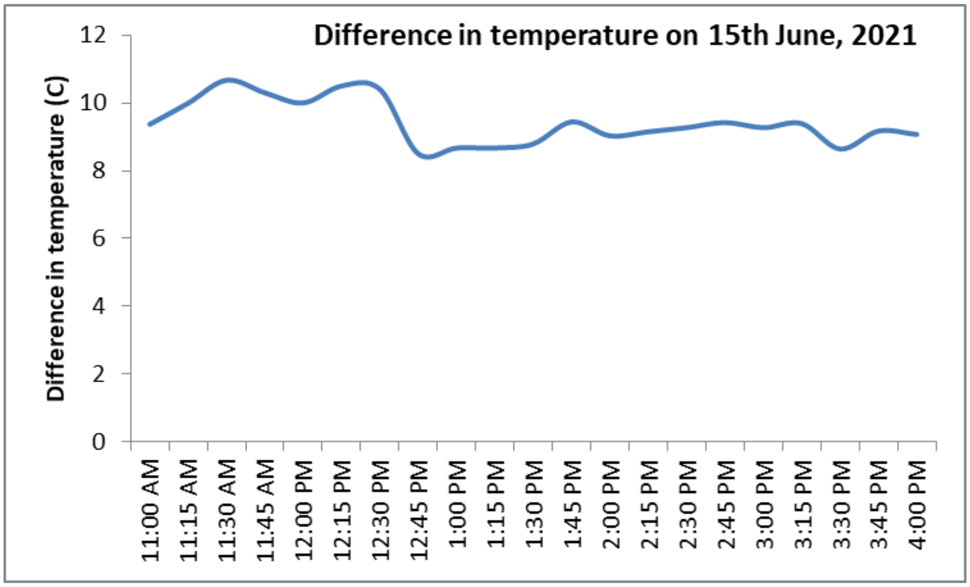


Figure 5.9Difference in temperatures for 15th June, 2021

For the entire time span from 10 - 30 June, 2021, the maximum average Δt day wise has been shown in figure 5.10. The difference maximum of 12.9˚C which shows the capacity of the DG3 that the fenestration can cut the temperature maximum by 12.9˚C and electric consumption can be lowered.

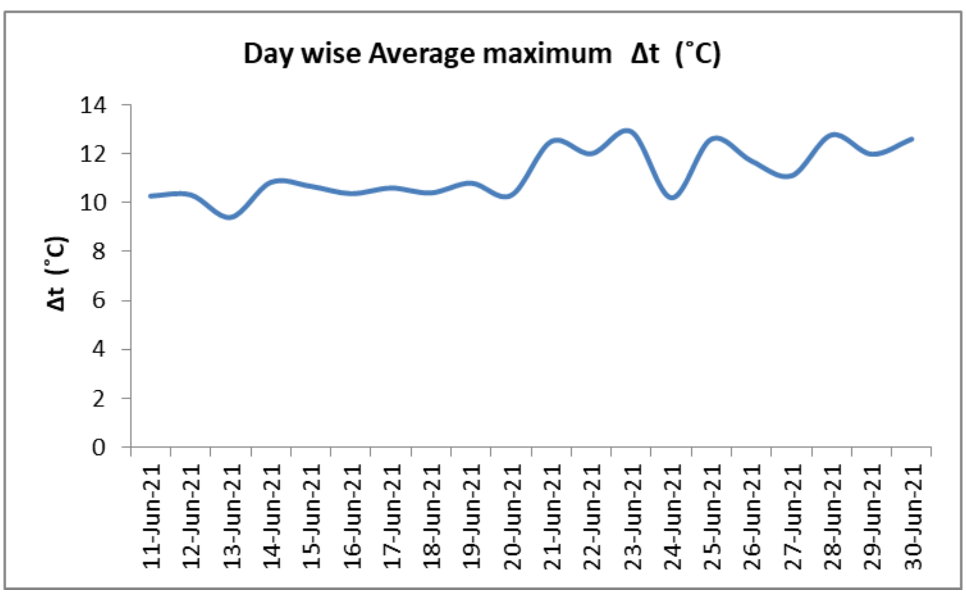


Figure 5.10Day wise maximum and minimum temperature difference

5.5. Simulation result analysis

5.5.1 For period of 10th June, 2021 to 30th June, 2021

With the aid of Design builder software, the room is modeled, the properties used are shown in figure 5.11. Energy plus engine is utilized for the simulation and output taken.

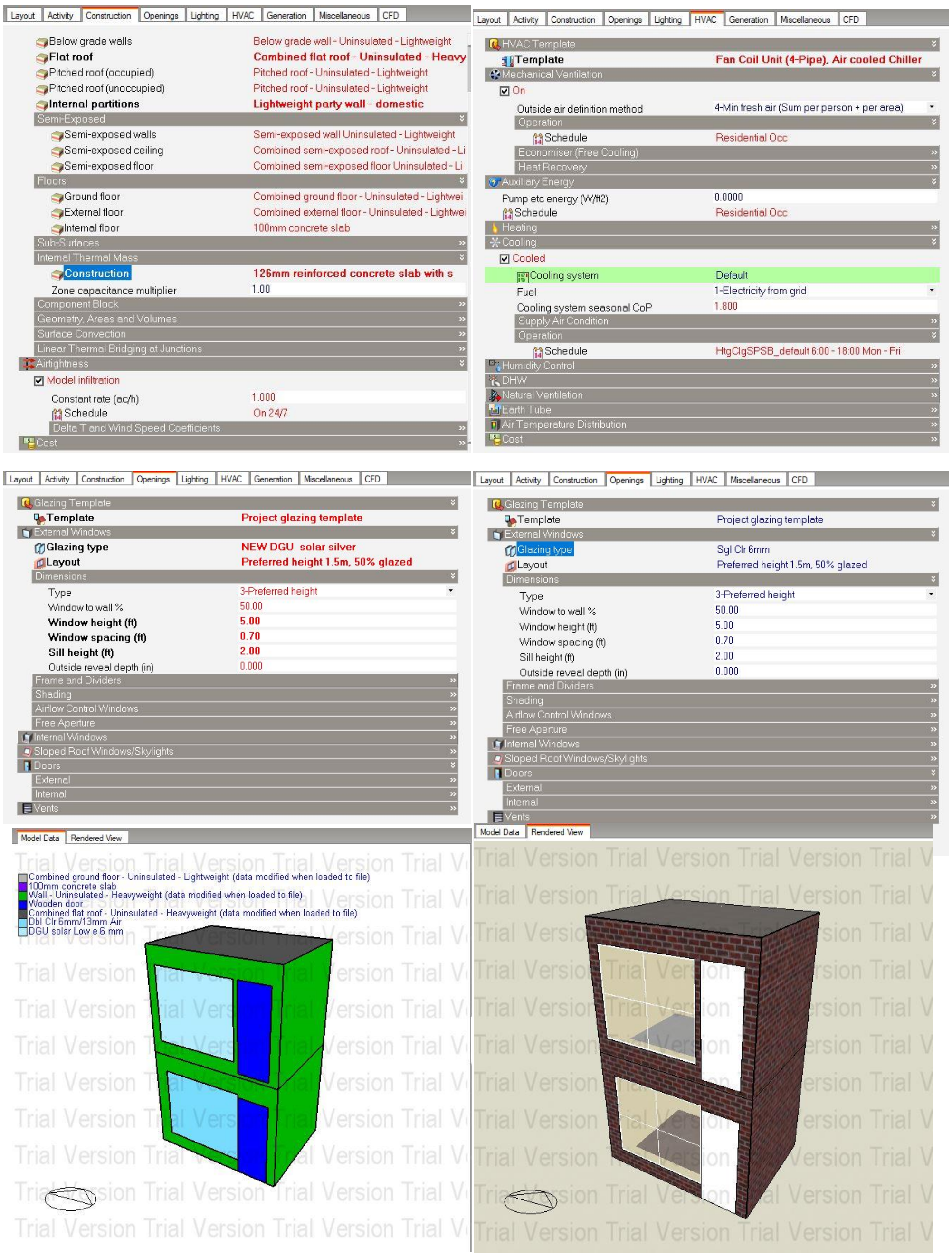


Figure 5.11Properties of model for Simulation

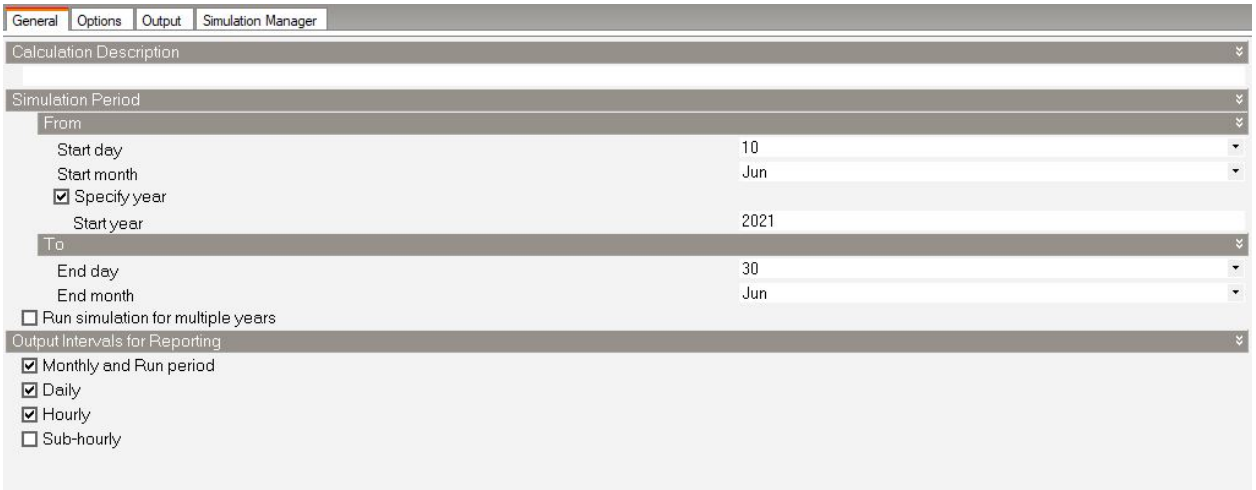


Figure 5.12 Simulation period for the model

The output was simulated for the same period as the installation in house was tested, the simulation period was shown in figure 5.12 and the output window was shown in figure 5.13. Simulation was performed for the time period of 10th June, 2021 to 30th June, 2021.

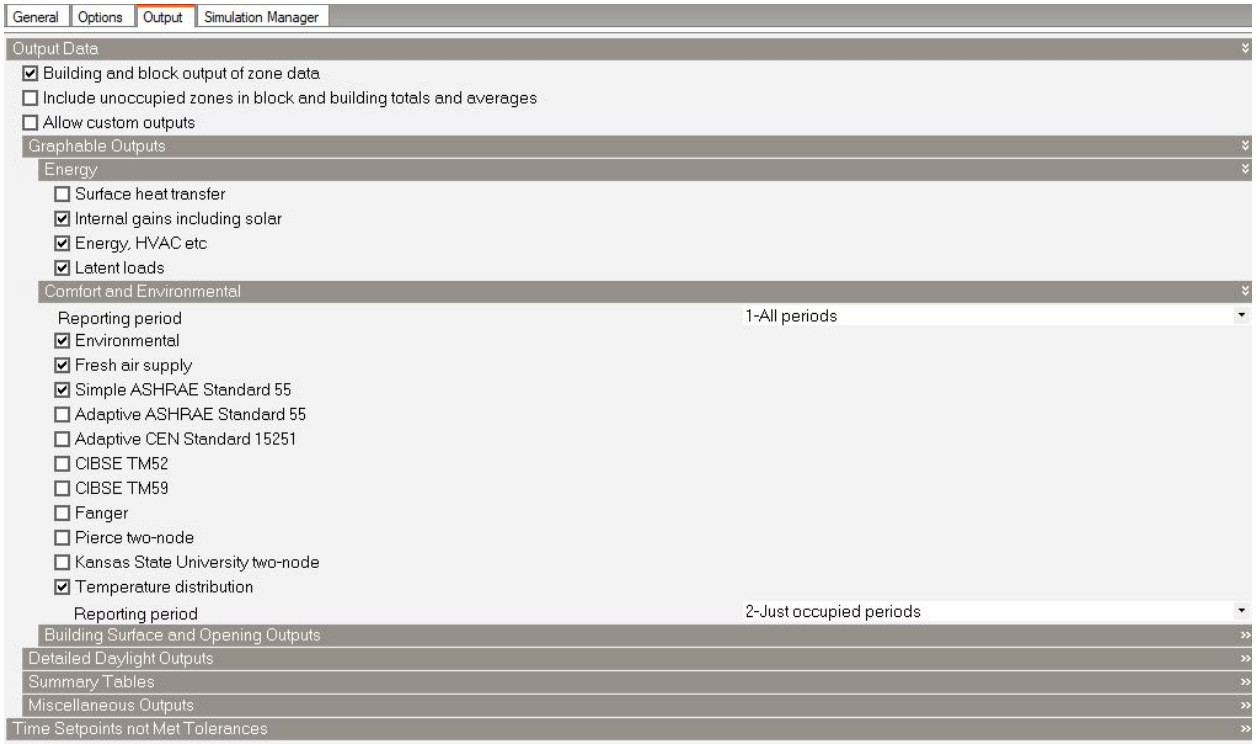


Figure 5.13Output for the model

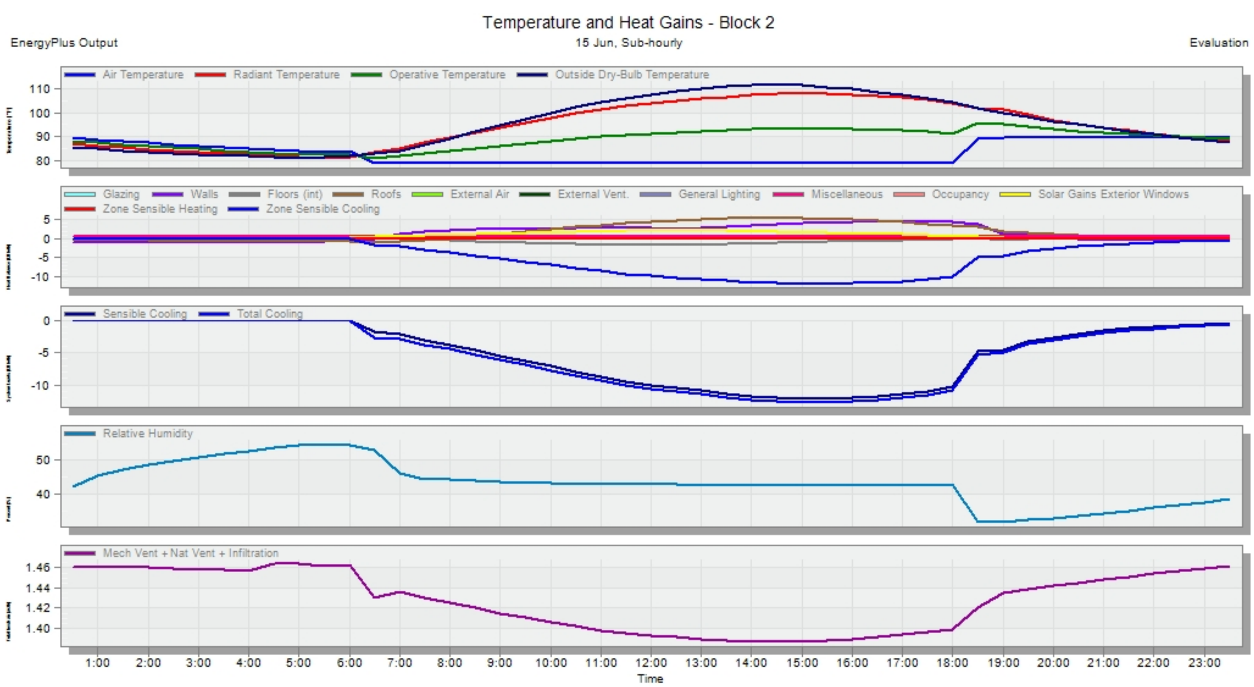


Figure 5.14Temperature and Heat gain of clear glass

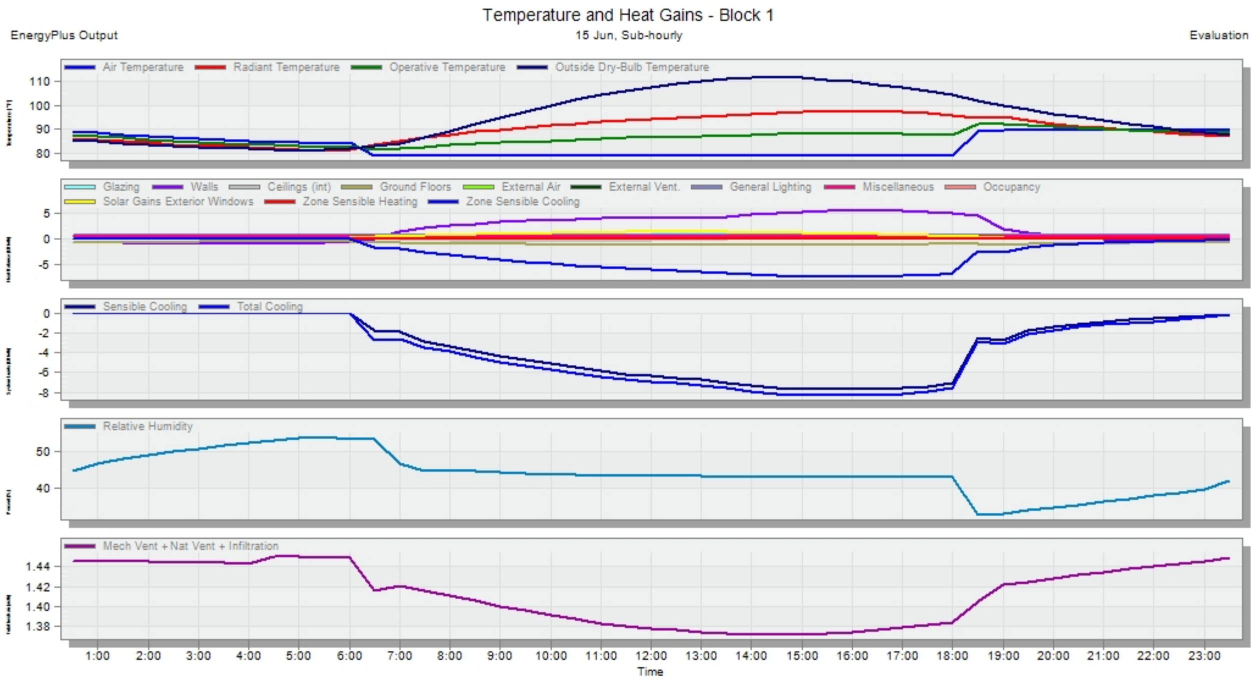


Figure 5.15Temperature and Heat gain of DGU

Energy plus 9.4 has been used as simulation engine, from figure 5.14 and 5.15 on 15th June, 2021, considered the hottest day, it was observed that the radiant temperature (red colour line) shows considerable reduction in case of DGU than clear glass window formation.

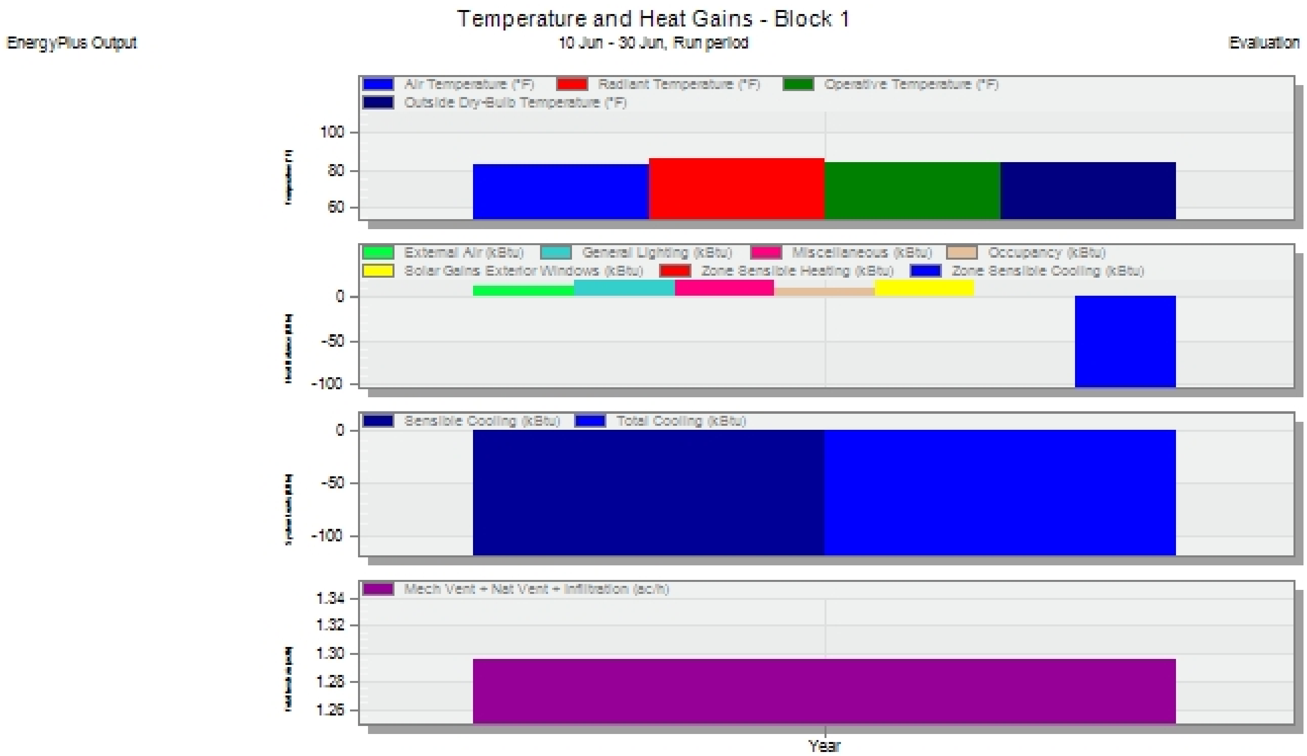
EnergyPlus Output

Temperature and Heat Gains - Block 2

10 Jun - 30 Jun, Run period

Evaluation

Air Temperature (°F)	82.02
Radiant Temperature (°F)	88.20
Operative Temperature (°F)	85.11
Outside Dry-Bulb Temperature (°F)	84.16
External Air (kBtu)	15.11
General Lighting (kBtu)	154.40
Miscellaneous (kBtu)	192.59
Occupancy (kBtu)	9.87
Solar Gains Exterior Windows (kBtu)	77.87
Zone Sensible Heating (kBtu)	0.04
Zone Sensible Cooling (kBtu)	-1105.63
Sensible Cooling (kBtu)	-1107.55
Total Cooling (kBtu)	-1332.57
Mech Vent + Nat Vent + Infiltration (ac/h)	1.30



Air Temperature (°F)	82.61
Radiant Temperature (°F)	85.68
Operative Temperature (°F)	84.15
Outside Dry-Bulb Temperature (°F)	84.16
External Air (kBtu)	11.26
General Lighting (kBtu)	154.40
Miscellaneous (kBtu)	192.59
Occupancy (kBtu)	9.69
Solar Gains Exterior Windows (kBtu)	298.13
Zone Sensible Heating (kBtu)	0.20
Zone Sensible Cooling (kBtu)	-659.10
Sensible Cooling (kBtu)	-658.87
Total Cooling (kBtu)	-837.34
Mech Vent + Nat Vent + Infiltration (ac/h)	1.30

Figure 5.16Solar gains from exterior windows

The energy consumption for sensible cooling (blue colour line in third graph) with DGU was much lesser than clear glass. These two factors were important to provide thermal comfort to the user. Considering the 20 days tenure from 10th to 30th June, 2021, the solar gain from exterior windows has been presented in figure 5.16 for clear glass and DGU.

From figure 5.16, it was observed that the solar gain from exterior windows for clear glass and DGU was 298.13 KBtu and 77.87 Kbtu respectively. There was considerable reduction in solar ingress which was reduced by 3.83 times. The sensible cooling also reduced by 1.68 times for DGU than clear glass window formation. The sensible cooling was reduced by 40.4 % when replaced with DGU. The results was promising through simulations for the run period of 10 to 30th June, 2021. There will be considerable saving on retrofitting the performance DG3.

Validation from the insitu ad simulation results showed the performance of DG3 a promising double glazing unit which can be utilized for the composite climate. The error between actual and simulated was not more than 6.89 %. The variation results might be due to opening and closing patterns [67].

5.5.2 Annual Simulation from 1st January, 2021 to 30th December, 2021

To understand the impact of the DG3 for the entire year, the temperature and heat gain for full year was shown in figure 5.17 where block 1 represents DGU and block 2 represents clear glass. The maximum and minimum reduction in solar gain through exterior windows was 483.3 KBtu and 177.65 respectively with respect to clear glass which makes the space cool and requires less cooling load and even cooling unit with lower capacity can be worked out and net incremental savings can be carried out on cooling equipment.

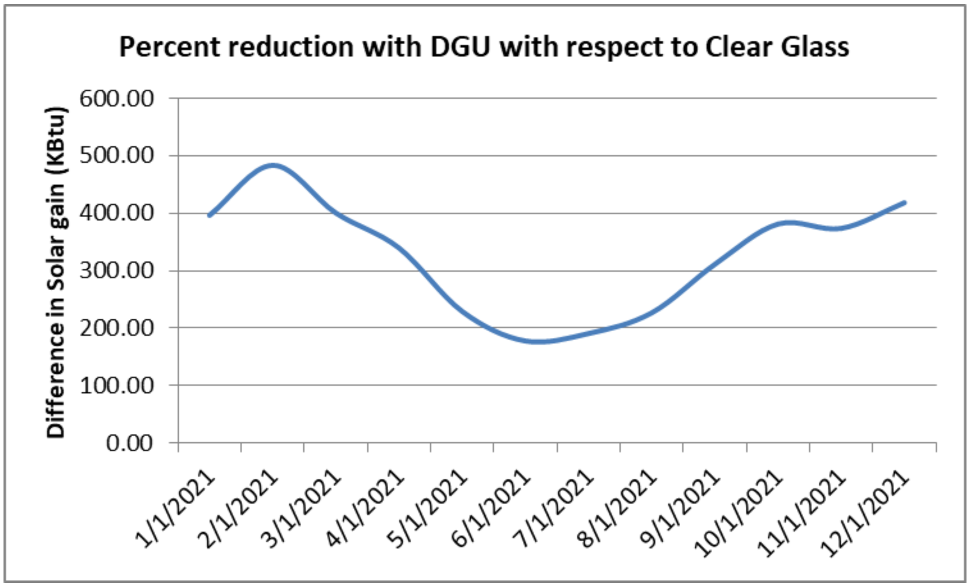


Figure 5.17Difference in solar gains with respect to clear Glass

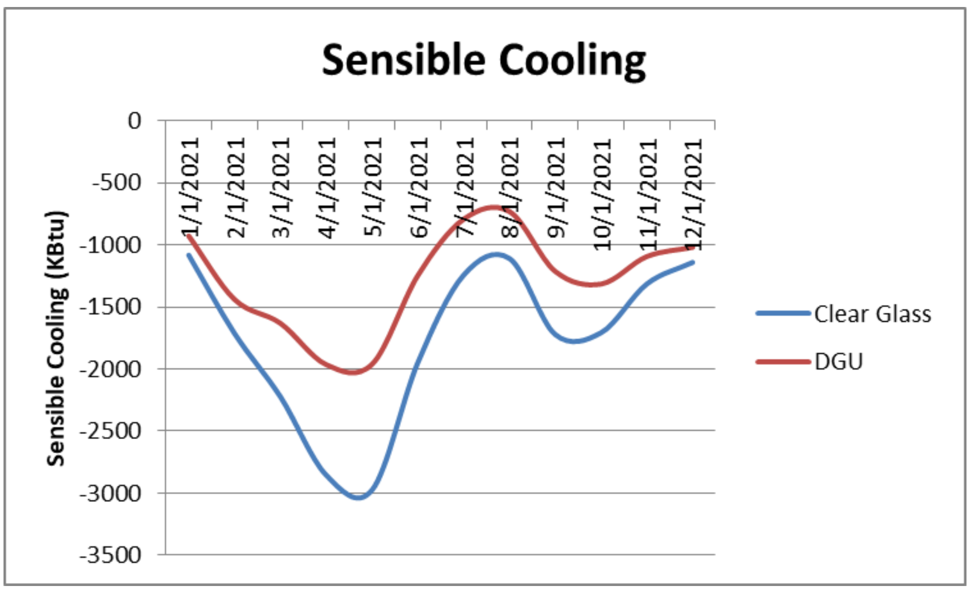


Figure 5.18Sensible cooling

Sensible cooling for the full year analysis through Energy plus simulation for clear glass and DGU is -21033.26 KBtu and -15338.28 KBtu respectively. DGU saves over the sensible cooling load by 5694.98 KBtu which was 27.08 % with respect to clear glass for full year. The reduction was for all the months of summer season and transition period, with maximum of 56.69 % (for month of July). The percent reduction for all months in summer season is presented in figure 5.19. The benefit was high in the summer season that was from May to September.

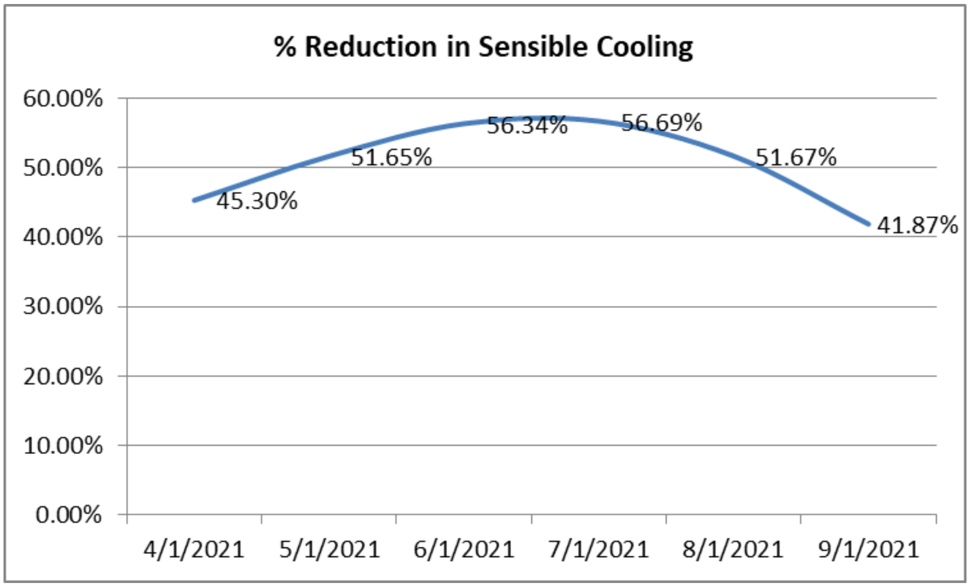


Figure 5.19Percent reduction in sensible cooling with DGU on Clear glass

5.6. Economic Analysis

The initial cost of the performance window formation was more as compared to traditional window made up of typically clear glass which proves to be energy inefficient. The initial cost of DGU used and found much better results was about Rs. 200/Sft which was about 2.82 times the cost of traditional window and one of the crucial factor for decision making at the owners end. Seeing the results, it was cleared that utilizing DGU with argon gas has considerable benefits in terms of lowering electricity consumption in the residential building. The savings in cooling loads are in the range of 25% to 40.4 % annually. The initial cost of the DGU window formation was about 15% - 20% more than the traditional window (clear glass). The initial excess cost can be saved as discussed here under

5.6.1 Net Incremental Cost

The cost due to installation of DGU with respect to clear glass traditional window formation will result in lesser capacity cooling equipment. The net incremental cost is incremental cost (cost of Energy Conservation Measures, ECM) minus the cost reduction in system resizing (because of the load reduction). As in the residential buildings, the reduction was possible in case of lower capacity air conditioner unit. For 3 star AC, saving of Rs. 7510 for 0.5 ton as shown in figure 5.20.

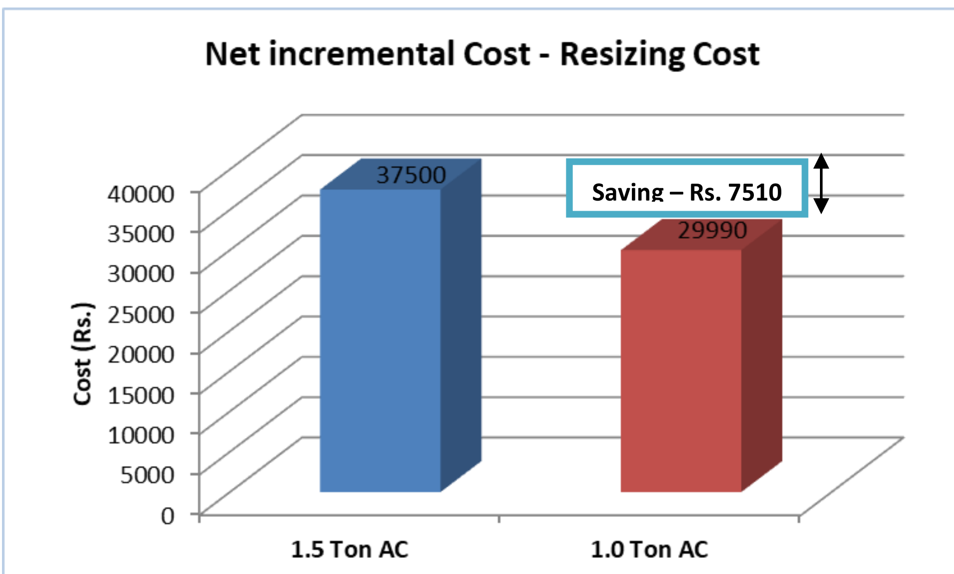


Figure 5.20 Net incremental costs

5.6.2 Operational Savings

The energy consumption was lowered and results in lesser electricity bills contribute towards operational savings with respect to ECM. Means after implementation in designing phase or in retrofitting of the ECM, the HVAC system that was operation of air-conditioner in terms of cooling loads will be lesser used and contributing to the reduction in energy consumption. In the study, the 3 star AC was used for the study and operational for 5 hours at set point of 26 ◦C. there was operational savings as shown in figure 5.21.

Running Cost with Traditional Window		
EER(Energy Efficiency Ratio)=cooling capacity of ac/power consumed by ac.		
Assuming the ac to be a 3 star rated, its Energy Efficiency Ratio (EER)=	2.7	
3 Star AC Power consumption per ton	3.517	kW
For 1.5 ton AC ,power consumption of ac =cooling capacity/EER	1.954	
Assuming 60 % of the total on time compressor unit is on.	60%	60
Energy consumption per hour of running =	1.172	Units
Running Hours	8	hours
Energy consumption for 8 hour of running	9.379	Units
Months and days @ average 30 days	300	days
Energy consumption for 300 days or 10 months of running	2813.600	Units
Charge per unit	9	Rs.
Electricity Bill @ 9 Rs	25322.4	Rs.

Running Cost with DG3 Fenestration		
EER(Energy Efficiency Ratio)=cooling capacity of ac/power consumed by ac.		
Assuming the ac to be a 3 star rated, its Energy Efficiency Ratio (EER)=	2.7	
3 Star AC Power consumption per ton	3.517	kW
For 1.5 ton AC ,power consumption of ac =cooling capacity/EER	1.954	
Assuming 60 % of the total on time compressor unit is on.	60%	60
Energy consumption per hour of running =	1.172	Units
Running Hours (can lowered due to less heat inside the room @ 20%)	5	hours
Energy consumption for 5 hour of running	5.862	Units
Months and days @ average 30 days	300	days
Energy consumption for 300 days or 10 months of running	1758.500	Units
Charge per unit	9	Rs.
Electricity Bill @ 9 Rs	15826.5	Rs.

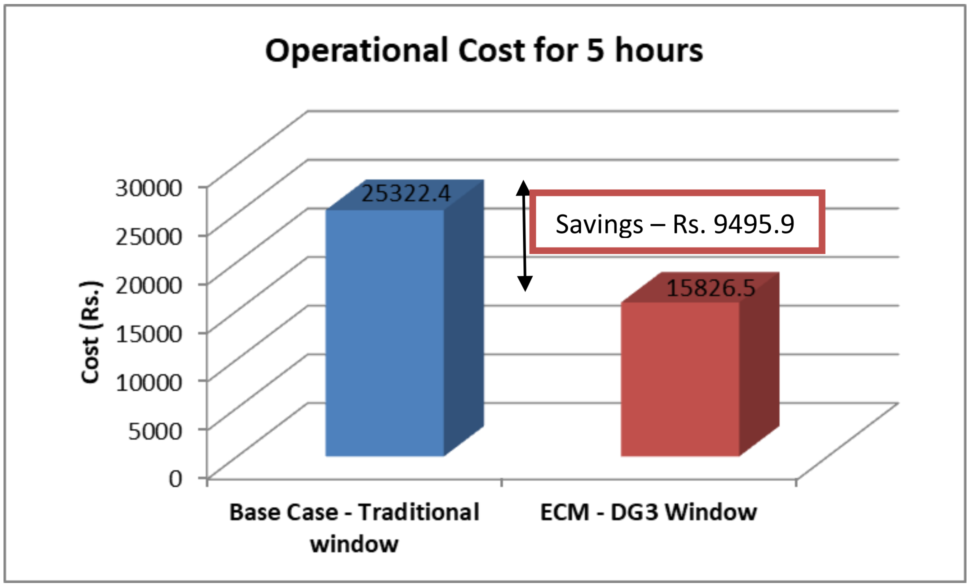


Figure 5.21Operational Cost

This shows the saving of Rs. 17005.9 as shown in figure 5.22 on operational working and net incremental cost.

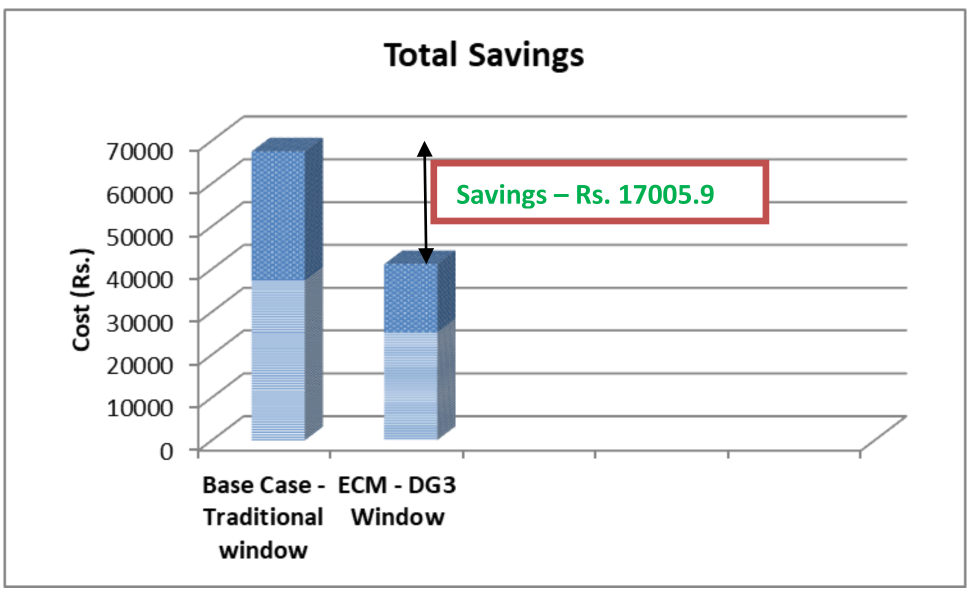


Figure 5.22Total savings

These savings will offset the payback period in less than one and half season and the owner will have ample benefits such as noise reduction, heat reduction, cooling loads which mean cutting the electricity bills, large windows to connect outside environment.

Chapter 6. Conclusion

6.1. General

The research purpose was to find an optimal glazing system that has potential to decrease the energy consumption in the building through changing the building envelope. Windows being the crucial element which if not properly placed or analyzed the outcome will be more energy consumption for the building and occupant has to pay much more energy bills. The double glazed units have evolved and showed the researchers the path to further explore as the behind mechanism of DGU was not established well and needs more careful investigation. Through the research program, this question has addressed and for composite climate, the feasible and suitable solution in the form of DGU has been tested and recommended to the society. Through the series of testing through laboratory, in-situ and simulation, the results revealed the following conclusions:-

- The less utilization of the energy efficient solutions proposed by researchers was possible due to lack of awareness to the occupant which has been seen through the survey in-person an globally conducted. More than 72 % occupants were not aware of the glass types and the potential behind savings in energy consumption. The same can be increased by trainings cum workshops especially to the frontlines such as Engineers, Architects and Contractors having rich experience in the building construction sector.

- Most of the projections through various researchers have been through simulation tools where there was deviation due to many reasons as mentioned in earlier section. Experimentation in real situation was required so as to make the occupant confident, thereby reference also adds. Out of 15 different combinations tested in the prototype, DG3 serves the best performance in curtailing the outside temperature to maximum average of 9.4 ◦C with respect to traditional glass with saving of 136 wh followed by DG2. The impact of argon gas was better than air in the gap which is approximately 64 % better performance in lowering the outside temperature.

- Out of 3 different DGU tested for sound/ noise level, DGU3 reduces the sound level of outside by 36.45 % in respect to DGU1 having PVB layer and DGU2 having acoustic layer. The DGU3 is cheaper than other two as well which makes DGU3 an economical viable solution to have peace inside the building.
- In-situ experiment showed the DG3 performance was better and reduces the temperature to 23 ◦C with difference in temperature to average maximum of 12.9 ◦C reduces to 39.1 % which was promising.
- After simulation using Energy Plus tool, for the period of 20 days of high summer shows the performance of DG3. The conclusion drawn here was that DG3 showed the cooling load reduced by 40.1 % with respect to traditional glass window. The solar gains drastically reduced by DG3 by 3.82 times that by traditional window. Annual simulation concluded the saving of 36.1 % of cooling loads in respect to traditional window.

6.2. Scope and limitation

Testing should be carried at faster speed and for most of the simulation results. The scope further exposes the work of actual validation in the building in the particular climatic zones. The full year actual readings should be monitored and compared with the simulated program so as to understand the parameters required for simulation closely on one end and the occupant behavior for drafting schedules on the other hand. Such experiments will help the refining of the software and the simulation results with negligible errors. The experiment program can be employed for all the possible directions.

6.3. Future scope

Residential sector usually have open to sky (OTS) provisions to provide the ventilation and natural light to all the possible location of the building so as to save energy consumption over artificial lighting. But these OTS were not properly designed, there is possibility of the research to work upon the initial designs and also the OTS can also be worked with different types of glazing so as to reduce the heat ingress from the top. Research is needed in the OTS sector as well in addition to the window design in developing countries.

Chapter 7. Recommendation Report

7.1. Purpose

The purpose of the research is to develop the most suitable windows that can be sustainable and has the potential to lower the energy consumption substantially.

7.2. Introduction

The energy consumption in the buildings is rising due to larger sized windows that play two major benefits. One is the window provides wellness and good health to occupants and second, it connects the outside to inside of the building. The windows plays crucial role in enhancing the energy demands due to cooling and heating loads. Thus, windows should be properly designed in view to energy consumption. Also a sustainable and efficient window helps in lowering the temperature from outside to inside and aesthetic look as well to the building.

7.3. Present scenario of windows

For the composite climate, the traditional window (clear glass 5 – 6 mm thickness) lets the heat ingress inside the building and enhances the cooling load of the building thereby energy consumption increases. As traditional windows are quite cheaper thus usually becomes the choice of building owner. Energy efficacy was demanded now a day as the energy consumption of the building is now a challenge versus its generation for the nation and developing countries such as India.

7.4. Proposed Solution

After the careful and intensive experiments from field, sustainable windows especially for residential houses are suggested as under-

1. Double glass pane (6 mm Solar Silver Low e glass + 12 mm argon gas + 6 mm clear glass) is recommended in the building towards south face and west face. Window to wall ratio recommended is 45% - 48%.
2. Double glass pane (6 mm clear glass + 12 mm argon gas + 6 mm clear glass) is recommended in the building towards east face. Window to wall ratio recommended is 45% - 48 %.
3. Double glass pane (6 mm clear glass + 12 mm air + 6 mm clear glass) is recommended in the building towards east face and north face. Window to wall ratio recommended is 45% - 48%.

Double glass pane / Double Glass Unit (DGU) were far better and energy efficient solution than traditional windows in many aspects and prove to a sustainable approach. Selecting the energy efficient window comprises of careful designing of the window panes from various types of glass as per parameters required for the building envelope. DGU composed of two glass panes with gap in between. The gap can be 12mm and filled with air and argon gas tio improve the thermal efficiency.

7.5. Recommendation

Author recommends the following window configurations

1. DGU (6 mm Solar Silver Low e glass + 12 mm argon gas + 6 mm clear glass) on south and south-west side as promising windows in terms of lowering heat ingress and sound level. The payback period is just one season that is one year. The initial cost is about 2.47 times than the traditional window pane.
2. DGU (6 mm clear glass + 12 mm argon gas + 6 mm clear glass) on east and west side of building. The payback period is about one year and initial cost is 2.3 times than traditional windows and performance is better on mentioned directions.

7.6. Description and Discussion of the proposed solution

Windows is a crucial component which leads heat ingress in the building envelope and responsible for increasing energy consumption if not properly designed as per various key parameters. By 2050, it is estimated that the energy consumption will reach by 8 times from 2012 energy consumption as reported by GBPN report. To slow down the energy consumption, windows should be carefully designed seeing key parameters such as sun path, direction facing, window to wall ratio etc. The traditional windows are widely used even today may be due to factors such as unawareness to occupant, initial high cost, not aware about energy savings potential by sustainable windows, payback period etc. There are various steps that can be taken in order to slow down the energy consumption in the building especially residential units which are usually not engineered.

- Training camps at minute usage by various agencies such as PEDA, PSPCL in Punjab.
- Energy analysis with saving potential of the window.
- Designing of the windows.
- Awareness to crucial parameters for saving potential windows and energy efficient solution.

A research project has been undertaken by author where following activities were carried

- Research literature review and review of existing model being used in the residential houses.
- To determine and identify the most suitable windows for the region of Punjab using analytical and experimental approach.
- To assess the impact of sustainable windows in to the residential house using IOT.

After experimentation using prototype in the region of Punjab, city Jalandhar, following windows is being recommended out of 15 types of windows taken for experimentation.

Name of window	Configuration
DGU1	6 mm Solar Silver Low e glass + 12 mm argon gas + 6 mm clear glass
DGU2	6 mm clear glass + 12 mm argon gas + 6 mm clear glass
DGU3	6 mm clear glass + 12 mm air + 6 mm clear glass

The better window configuration as per performance that is DGU is tested in the residential house in real time and found satisfactory results in comparison to traditional window.

7.7. Comparison

A comparative has been prepared from the study and presented as under-

Name of window	Temperature Difference (◦C)	Cost (per Square feet)	Savings per season (Kwh)	Payback period (Years)	Performance Drivers		
					VLT	SHGC	U-Value
DGU1	9.4	220	240.83	1.43	25	0.3	1.7
DGU2	8.7	200	220.23	1.33	68	0.33	1.8
DGU3	5.3	175	134.36	1.73	68	0.42	1.9

7.7.1 Explanation of the recommendation

Window configuration DGU1 is recommended which has the capacity to lower the inside temperature from higher outside temperature and more savings with very less payback period. The cost of the DGU1 is more than other recommendation but the savings is more than other alternatives and thus reduces the payback period. The argon gas has more impact than air in the gap between two window panes. The recommendation is solicited with the help of empirical approach, experimentation and simulation for the composite climate.

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Appendix

Appendix –A: Survey results

Records of survey from residential occupant in-person were as under

Client	Type of glass	Aware-ness	Thickness	Direction Facing	Issue 1	Issue 2
1	Tinted Glass	No	3-5mm	South	Heat	sound
2	tinted glass	yes	3-5mm	South	Heat	sound
3	Tinted Glass	No	3-5mm	South	Heat	Brittleness
4	Tinted Glass	No	3-5mm	North-East	No	
5	Tinted Glass	No	3-5mm	North	No	
6	Tinted Glass	No	3-5mm	South	Heat	sound
7	Annealed Glass	Yes	3-5mm	South	Heat	Glare
8	Tinted Glass	No	3-5mm	South	Heat	Glare
9	Tinted Glass	No	3-5mm	South	Heat	Glare
10	Tinted Glass	No	3-5mm	South	Heat	Glare
11	Tinted Glass	No	3-5mm	South	Heat	Transparency
12	Tinted Glass	No	3-5mm	South-West	Heat	sound
13	Annealed Glass	No	3-5mm	South	Heat	sound

14	Annealed Glass	No	3-5mm	South	Heat	sound
15	Tinted Glass	No	3-5mm	South-West	Heat	Transparency
16	Tinted Glass	No	3-5mm	North	No	
17	Annealed Glass	No	3-5mm	South	Heat	
18	Tinted Glass	No	3-5mm	South	Heat	Transparency
19	Tinted Glass	No	3-5mm	North-East	No	
20	Toughened Glass	No	10mm	North-East	No	
21	Annealed Glass	No	3-5mm	South	Heat	Glare
22	Tinted Glass	No	3-5mm	South-West	Heat	Glare
23	Annealed Glass	No	3-5mm	North-East	No	
24	Tinted Glass	yes	3-5mm	South	Heat	Transparency
25	Tinted Glass	No	3-5mm	North-East	No	
26	Annealed Glass	No	3-5mm	South	Heat	
27	Tinted Glass	yes	3-5mm	South	Heat	Glare
28	Tinted Glass	No	3-5mm	South-West	Heat	Glare
29	Annealed Glass	No	3-5mm	South	Heat	
30	Annealed Glass	No	3-5mm	South	Heat	Brittleness
31	Annealed Glass	No	3-5mm	North-East	No	
32	Tinted Glass	No	3-5mm	South	Heat	Glare
33	Tinted Glass	No	3-5mm	South	Heat	Glare
34	Annealed Glass	No	3-5mm	South-West	Heat	Glare

35	Tinted Glass	No	3-5mm	North	No	
36	Tinted Glass	No	3-5mm	South-West	Heat	
37	Annealed Glass	No	3-5mm	West	Heat	Transparency
38	Tinted Glass	yes	3-5mm	South	Heat	Glare
39	Tinted glass	No	3-5mm	West	Heat	
40	Tinted Glass	No	3-5mm	West	Heat	
41	Tinted Glass	No	3-5mm	North	No	
42	Tinted Glass	No	3-5mm	West	Heat	Less Light
43	Annealed Glass	No	3-5mm	West	Heat	Sound
44	Tinted Glass	No	3-5mm	West	Heat	
45	Annealed Glass	No	3-5mm	North	No	
46	Annealed Glass	No	3-5mm	South-West	Heat	
47	Annealed Glass	No	3-5mm	South-West	Heat	sound
48	Tinted Glass	No	3-5mm	South-West	Heat	Glare
49	Tinted Glass	No	3-5mm	South	Heat	sound
50	Annealed Glass	No	3-5mm	East	No	Less Light
51	Tinted Glass	No	3-5mm	South	Heat	sound
52	Annealed Glass	No	3-5mm	South-West	Heat	Glare
53	Annealed Glass	No	3-5mm	East	No	sound
54	Tinted Glass	No	3-5mm	North-East	No	
55	Annealed Glass	yes	8mm	South-West	Heat	

56	Annealed Glass	yes	10mm	South	Heat	sound
57	Annealed Glass	No	3-5mm	South-West	Heat	
58	Tinted Glass	No	6mm	North-East	No	
59	Tinted Glass	No	3-5mm	South-West	Heat	sound
60	Annealed Glass	No	10mm	South	Heat	sound
61	Annealed Glass	yes	10mm	South-West	Heat	sound
62	Annealed Glass	No	3-5mm	South	Heat	Glare
63	Tinted Glass	yes	3-5mm	South	Heat	
64	Tinted Glass	No	3-5mm	South	Heat	
65	Tinted Glass	No	6mm	South	Heat	Brittleness
66	Annealed Glass	yes	3-5mm	South	Heat	Brittleness
67	Annealed Glass	yes	3-5mm	North-East	No	
68	Tinted Glass	No	3-5mm	West	Heat	sound
69	Annealed Glass	No	3-5mm	West	Heat	Sound
70	Annealed Glass	No	3-5mm	South	Heat	sound
71	Annealed Glass	No	3-5mm	South	Heat	sound
72	Annealed Glass	No	3-5mm	South-West	Heat	Glare
73	Annealed Glass	No	8mm	West	Heat	
74	Tinted Glass	No	3-5mm	West	Heat	
75	Annealed Glass	No	3-5mm	West	Heat	Sound
76	Annealed Glass	No	3-5mm	South-West	Heat	sound

77	Toughened Glass	No	6mm	North-East	No	Less Light
78	Annealed Glass	yes	3-5mm	South-West	Heat	
79	Toughened Glass	No	6mm	North-East	No	
80	Annealed Glass	No	3-5mm	South	Heat	Sound
81	Annealed Glass	No	3-5mm	South-West	Heat	
82	Tinted Glass	No	3-5mm	South-West	Heat	Brittleness
83	Tinted Glass	No	3-5mm	East	No	Sound
84	Annealed Glass	No	3-5mm	West	Heat	
85	Tinted Glass	No	3-5mm	North-East	No	
86	Annealed Glass	No	3-5mm	West	Heat	Sound
87	Annealed Glass	No	3-5mm	North-East	No	Sound
88	Annealed Glass	yes	3-5mm	West	Heat	
89	Annealed Glass	No	3-5mm	West	Heat	Brittleness
90	Annealed Glass	No	3-5mm	South	Heat	Sound
91	Annealed Glass	No	3-5mm	North-East	No	
92	Annealed Glass	No	3-5mm	West	Heat	
93	Toughened Glass	yes	8mm	West	Heat	Less Light
94	Annealed Glass	No	3-5mm	West	Heat	Brittleness
95	Tinted Glass	No	3-5mm	South-West	Heat	Brittleness
96	Annealed Glass	yes	3-5mm	West	Heat	Less Light
97	Tinted Glass	No	3-5mm	South-West	Heat	

98	Tinted glass	yes	3-5mm	South-West	Heat	
99	Tinted Glass	No	3-5mm	South-West	Heat	sound
100	Tinted Glass	No	3-5mm	South	Heat	Glare
101	Annealed Glass	No	3-5mm	South	Heat	Glare
102	Annealed glass	No	3-5mm	South	Heat	Glare
103	Annealed Glass	No	3-5mm	West	Heat	Less Light
104	Tinted glass	No	3-5mm	West	Heat	
105	Annealed Glass	No	3-5mm	West	Heat	Less Light
106	Tinted glass	yes	6mm	West	Heat	
107	Tinted glass	yes	3-5mm	West	Heat	Less Light
108	Tinted glass	No	6mm	West	Heat	Sound
109	Annealed Glass	yes	3-5mm	North	No	
110	Annealed Glass	No	6mm	West	Heat	
111	Annealed Glass	No	3-5mm	South	Heat	sound
112	Annealed Glass	yes	3-5mm	North-East	No	sound
113	Toughened Glass	yes	6mm	North-East	No	Less Light
114	Tinted Glass	yes	3-5mm	South	Heat	Glare
115	Tinted Glass	yes	3-5mm	North	No	
116	Toughened Glass	yes	6mm	West	Heat	
117	Tinted Glass	No	3-5mm	South	Heat	sound
118	Tinted Glass	yes	6mm	West	Heat	

119	Annealed Glass	No	3-5mm	South	Heat	Glare
120	Annealed Glass	yes	3-5mm	South	Heat	sound
121	Annealed Glass	yes	3-5mm	West	Heat	
122	Tinted Glass	yes	3-5mm	South	Heat	sound
123	Annealed Glass	No	3-5mm	North	No	
124	Annealed Glass	yes	3-5mm	West	Heat	
125	Annealed Glass	No	3-5mm	West	Heat	
126	Tinted Glass	yes	3-5mm	South	Heat	sound
127	Annealed Glass	yes	3-5mm	South	Heat	sound
128	Annealed Glass	yes	3-5mm	South-West	Heat	
129	Tinted Glass	No	6mm	South-West	Heat	
130	Annealed Glass	yes	3-5mm	South-West	Heat	
131	Annealed Glass	No	6mm	South-West	Heat	sound
132	Annealed Glass	No	3-5mm	South-West	Heat	Brittleness
133	Annealed Glass	No	3-5mm	East	No	Privacy
134	Tinted Glass	No	6mm	West	Heat	
135	Annealed Glass	yes	3-5mm	West	Heat	
136	Annealed Glass	yes	3-5mm	South-East	Heat	Brittleness
137	Annealed Glass	yes	3-5mm	South-West	Heat	Brittleness
138	Toughened Glass	yes	6mm	South-East	Heat	Less Light
139	Tinted Glass	yes	10mm	East	No	sound

140	Toughened Glass	yes	6mm	West	Heat	
141	Annealed Glass	No	3-5mm	West	Heat	Sound
142	Annealed Glass	No	3-5mm	South	Heat	sound
143	Annealed Glass	No	3-5mm	South	Heat	sound
144	Annealed Glass	No	3-5mm	South-West	Heat	Glare
145	Annealed Glass	No	6mm	West	Heat	
146	Tinted Glass	No	3-5mm	West	Heat	
147	Annealed Glass	No	3-5mm	West	Heat	Sound
148	Annealed Glass	No	3-5mm	South-West	Heat	sound
149	Toughened Glass	No	6mm	North-East	No	Less Light
150	Annealed Glass	yes	3-5mm	South-West	Heat	
151	Toughened Glass	No	6mm	North-East	No	
152	Annealed Glass	No	3-5mm	South	Heat	Sound
153	Annealed Glass	No	3-5mm	South-West	Heat	
154	Annealed Glass	No	3-5mm	South-West	Heat	Brittleness
155	Toughened Glass	No	3-5mm	East	No	Sound
156	Annealed Glass	No	6mm	West	Heat	
157	Annealed Glass	No	3-5mm	South-West	Heat	
158	Tinted Glass	No	3-5mm	South-West	Heat	sound
159	Tinted Glass	No	3-5mm	South-West	Heat	Glare
160	Tinted Glass	No	3-5mm	South	Heat	sound

161	Annealed Glass	No	6mm	East	No	Less Light
162	Tinted Glass	No	3-5mm	South	Heat	sound
163	Annealed Glass	No	3-5mm	South-West	Heat	Glare
164	Annealed Glass	No	3-5mm	East	No	sound
165	Tinted Glass	No	3-5mm	North-East	No	
166	Annealed Glass	yes	8mm	South-West	Heat	
167	Annealed Glass	yes	3-5mm	South	Heat	sound
168	Annealed Glass	No	3-5mm	South-West	Heat	
169	Toughened Glass	No	6mm	North-East	No	
170	Tinted Glass	No	3-5mm	South-West	Heat	sound
171	Annealed Glass	No	10mm	South	Heat	sound
172	Tinted Glass	yes	10mm	South-West	Heat	sound
173	Annealed Glass	No	3-5mm	South	Heat	Glare
174	Tinted Glass	yes	3-5mm	South	Heat	
175	Tinted Glass	No	3-5mm	South	Heat	
176	Tinted Glass	No	3-5mm	South	Heat	Transparency
177	Tinted Glass	No	3-5mm	South-West	Heat	sound
178	Annealed Glass	No	3-5mm	South	Heat	sound
179	Annealed Glass	No	3-5mm	South	Heat	sound
180	Tinted Glass	yes	3-5mm	South-West	Heat	Transparency
181	Tinted Glass	No	3-5mm	North	No	

182	Toughened Glass	No	3-5mm	South	Heat	
183	Tinted Glass	yes	3-5mm	South	Heat	Transparency
184	Tinted Glass	No	3-5mm	North-East	No	
185	Toughened Glass	No	10mm	North-East	No	
186	Annealed Glass	No	3-5mm	South	Heat	Glare
187	Tinted Glass	No	3-5mm	South-West	Heat	Glare
188	Annealed Glass	No	3-5mm	North-East	No	
189	Tinted Glass	yes	6mm	South	Heat	Transparency
190	Tinted Glass	No	3-5mm	North-East	No	
191	Annealed Glass	No	3-5mm	South	Heat	
192	Tinted Glass	yes	3-5mm	South	Heat	Glare
193	Toughened Glass	yes	3-5mm	South-West	Heat	Glare
194	Annealed Glass	No	3-5mm	South	Heat	
195	Annealed Glass	No	3-5mm	South	Heat	Brittleness
196	Annealed Glass	No	3-5mm	North-East	No	
197	Tinted Glass	No	3-5mm	South	Heat	Glare
198	Tinted Glass	No	3-5mm	South	Heat	Glare
199	Annealed Glass	No	3-5mm	West	Heat	Less Light
200	Annealed Glass	No	6mm	West	Heat	Sound
201	Tinted Glass	No	3-5mm	West	Heat	
202	Annealed Glass	No	3-5mm	North	No	

203	Tinted Glass	No	3-5mm	South-West	Heat	
204	Toughened Glass	No	3-5mm	South-West	Heat	sound
205	Tinted Glass	No	3-5mm	South-West	Heat	Glare
206	Tinted Glass	No	3-5mm	South	Heat	sound
207	Annealed Glass	No	3-5mm	East	No	Less Light
208	Tinted Glass	No	3-5mm	South	Heat	sound
209	Annealed Glass	No	3-5mm	South-West	Heat	Glare
210	Annealed Glass	No	3-5mm	East	No	sound
211	Tinted Glass	No	3-5mm	North-East	No	
212	Annealed Glass	yes	8mm	South-West	Heat	
213	Annealed Glass	yes	10mm	South	Heat	sound
214	Annealed Glass	No	3-5mm	South-West	Heat	
215	Tinted Glass	No	6mm	North-East	No	
216	Tinted Glass	No	3-5mm	South-West	Heat	sound
217	Annealed Glass	No	10mm	South	Heat	sound
218	Annealed Glass	yes	3-5mm	South	Heat	sound
219	Annealed Glass	yes	3-5mm	West	Heat	
220	Tinted Glass	yes	3-5mm	South	Heat	sound
221	Annealed Glass	No	3-5mm	North	No	
222	Tinted Glass	yes	3-5mm	West	Heat	
223	Annealed Glass	No	3-5mm	West	Heat	

224	Tinted Glass	yes	3-5mm	South	Heat	sound
225	Annealed Glass	yes	3-5mm	South	Heat	sound
226	Annealed Glass	yes	3-5mm	South-West	Heat	
227	Tinted Glass	No	6mm	South-West	Heat	
228	Annealed Glass	yes	3-5mm	South-West	Heat	
229	Annealed Glass	No	6mm	South-West	Heat	sound
230	Annealed Glass	No	3-5mm	South-West	Heat	Brittleness
231	Annealed Glass	No	3-5mm	East	No	Privacy
232	Tinted Glass	No	6mm	West	Heat	
233	Annealed Glass	yes	3-5mm	West	Heat	
234	Annealed Glass	yes	3-5mm	South-East	Heat	Brittleness
235	Annealed Glass	yes	3-5mm	West	Heat	
236	Annealed Glass	No	3-5mm	West	Heat	
237	Tinted Glass	yes	3-5mm	South	Heat	sound
238	Annealed Glass	yes	3-5mm	South	Heat	sound
239	Annealed Glass	yes	3-5mm	South-West	Heat	
240	Tinted Glass	No	6mm	South-West	Heat	

DGU Code	Surface 1 (Outside)	Gap (mm)	Type	Surface 2 (Inside)	One side Temperature (C) at center of glass	Other Side Temperature (C) at center of glass	Difference in Temperature (C) at center of glass
DG 1	6 mm clear glass	12	Air	6 mm clear glass	39.6	34.3	5.3
DG 2	6 mm clear glass	12	Argon gas	6 mm clear glass	41	32.3	8.7
DG 3	**6 mm Solar Silver Low e glass**	**12**	**Argon gas**	**6 mm clear glass**	41.2	31.8	9.4
DG 4	6 mm clear glass	12	Air	6 mm Golden Brownish Low e glass	39	35.2	3.8
DG 5	6 mm clear glass	12	Air	6 mm Silver glass Low e	38.4	34.4	4
DG 6	6 mm clear glass	12	Air	6 mm Neutral Grey Low e glass	39.3	36.1	3.2
DG 7	6 mm clear glass	12	Air	6 mm Dark Blue Low e glass	39	35.1	3.9
DG 8	6 mm clear glass	12	Air	6 mm Neutral Low e glass	39.2	36.1	3.1
DG 9	6 mm clear glass	12	Air	6 mm clear Neutral Low e glass	39.3	36.4	2.9
DG 10	6 mm Golden Brownish Low e glass	12	Air	6 mm clear glass	39.8	35.4	4.4
DG 11	6 mm Silver glass Low e	12	Air	6 mm clear glass	39.5	34.3	5.2
DG 12	6 mm Neutral Grey Low e glass	12	Air	6 mm clear glass	39.5	34.8	4.7
DG 13	6 mm Dark Blue Low e glass	12	Air	6 mm clear glass	35.4	30.3	5.1
DG 14	6 mm Neutral Low e glass	12	Air	6 mm clear glass	36.4	32.1	4.3
DG 15	6 mm clear Neutral Low e glass	12	Air	6 mm clear glass	38.2	34.3	3.9

S.No	Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)		
			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)
1	11-Jun	11:00 AM	38	29	9	12-Jun	11:00 AM	34.1	24.71	9.39	13-Jun	11:00 AM	32.2	23	9.2	14-Jun	11:00 AM	33.3	24.6	8.7	15-Jun	11:00 AM	32.2	22.83	9.37
2	11-Jun	11:15 AM	38.6	30.08	8.52	12-Jun	11:15 AM	33.3	24.3	9	13-Jun	11:15 AM	32	23.6	8.4	14-Jun	11:15 AM	32.6	24.02	8.58	15-Jun	11:15 AM	32	22.01	9.99
3	11-Jun	11:30 AM	38.5	30	8.5	12-Jun	11:30 AM	33.3	24	9.3	13-Jun	11:30 AM	31.4	22	9.4	14-Jun	11:30 AM	32.5	23.78	8.72	15-Jun	11:30 AM	32.7	22.03	10.67
4	11-Jun	11:45 AM	38.47	29.94	8.53	12-Jun	11:45 AM	34	24.6	9.4	13-Jun	11:45 AM	30.5	21.2	9.3	14-Jun	11:45 AM	33.4	23.63	9.77	15-Jun	11:45 AM	32.4	22.1	10.3
5	11-Jun	12:00 PM	38	30	8	12-Jun	12:00 PM	36	25.9	10.1	13-Jun	12:00 PM	29.5	22	7.5	14-Jun	12:00 PM	34.3	23.7	10.6	15-Jun	12:00 PM	33	23	10
6	11-Jun	12:15 PM	38.17	29.6	8.57	12-Jun	12:15 PM	35	25.6	9.4	13-Jun	12:15 PM	30.4	22.2	8.2	14-Jun	12:15 PM	33.3	23.09	10.21	15-Jun	12:15 PM	32.5	22	10.5
7	11-Jun	12:30 PM	38.07	29	9.07	12-Jun	12:30 PM	34.2	23.88	10.32	13-Jun	12:30 PM	29	23	6	14-Jun	12:30 PM	33.7	22.87	10.83	15-Jun	12:30 PM	32.6	22.2	10.4
8	11-Jun	12:45 PM	37.97	29	8.97	12-Jun	12:45 PM	32.77	23.8	8.97	13-Jun	12:45 PM	29	23.2	5.8	14-Jun	12:45 PM	32	22.65	9.35	15-Jun	12:45 PM	31	22.5	8.5
9	11-Jun	1:00 PM	38.07	28.92	9.15	12-Jun	1:00 PM	32.87	25	7.87	13-Jun	1:00 PM	28.27	23	5.27	14-Jun	1:00 PM	32.07	22.6	9.47	15-Jun	1:00 PM	30.87	22.2	8.67
10	11-Jun	1:15 PM	38.17	28.9	9.27	12-Jun	1:15 PM	32.97	24.18	8.79	13-Jun	1:15 PM	28.37	22.7	5.67	14-Jun	1:15 PM	32.17	23.23	8.94	15-Jun	1:15 PM	30.97	22.3	8.67
11	11-Jun	1:30 PM	38.27	28	10.27	12-Jun	1:30 PM	33.07	24	9.07	13-Jun	1:30 PM	28.47	22	6.47	14-Jun	1:30 PM	32.27	23.43	8.84	15-Jun	1:30 PM	31.07	22.28	8.79
12	11-Jun	1:45 PM	38.37	29	9.37	12-Jun	1:45 PM	33.17	24	9.17	13-Jun	1:45 PM	28.57	22.5	6.07	14-Jun	1:45 PM	32.37	23.53	8.84	15-Jun	1:45 PM	31.7	22.26	9.44
13	11-Jun	2:00 PM	38.47	29.08	9.39	12-Jun	2:00 PM	33.27	23.9	9.37	13-Jun	2:00 PM	28.67	23	5.67	14-Jun	2:00 PM	32.47	23.2	9.27	15-Jun	2:00 PM	31.27	22.24	9.03
14	11-Jun	2:15 PM	38.6	29.09	9.51	12-Jun	2:15 PM	33.4	23.4	10	13-Jun	2:15 PM	28.8	23.2	5.6	14-Jun	2:15 PM	32.6	23.52	9.08	15-Jun	2:15 PM	31.4	22.25	9.15
15	11-Jun	2:30 PM	38.72	29.33	9.39	12-Jun	2:30 PM	33.52	24	9.52	13-Jun	2:30 PM	28.92	23	5.92	14-Jun	2:30 PM	32	23.52	8.48	15-Jun	2:30 PM	31.52	22.25	9.27
16	11-Jun	2:45 PM	38.6	29	9.6	12-Jun	2:45 PM	33	23.89	9.11	13-Jun	2:45 PM	28.8	22	6.8	14-Jun	2:45 PM	32.6	23.28	9.32	15-Jun	2:45 PM	31.43	22.01	9.42
17	11-Jun	3:00 PM	38.6	29	9.6	12-Jun	3:00 PM	33.4	23.5	9.9	13-Jun	3:00 PM	28.3	22.2	6.1	14-Jun	3:00 PM	32.6	23.16	9.44	15-Jun	3:00 PM	31.4	22.13	9.27
18	11-Jun	3:15 PM	38.72	29.63	9.09	12-Jun	3:15 PM	33.53	23.6	9.93	13-Jun	3:15 PM	28.88	22.3	6.58	14-Jun	3:15 PM	32.72	23.16	9.56	15-Jun	3:15 PM	31.52	22.13	9.39
19	11-Jun	3:30 PM	38.74	29.5	9.24	12-Jun	3:30 PM	33.54	24.15	9.39	13-Jun	3:30 PM	29	22.5	6.5	14-Jun	3:30 PM	32.74	23.3	9.44	15-Jun	3:30 PM	31.54	22.9	8.64
20	11-Jun	3:45 PM	39.3	29.4	9.9	12-Jun	3:45 PM	34.1	24.81	9.29	13-Jun	3:45 PM	30.2	22.7	7.5	14-Jun	3:45 PM	32	23.74	8.26	15-Jun	3:45 PM	32.1	22.93	9.17
21	11-Jun	4:00 PM	39.2	29	10.2	12-Jun	4:00 PM	34	24.81	9.19	13-Jun	4:00 PM	30	22.6	7.4	14-Jun	4:00 PM	32.2	23.76	8.44	15-Jun	4:00 PM	32	22.93	9.07
Maximum Δt (˚C)			39.3	30.08	10.27			36	25.9	10.32			32.2	23.6	9.4			34.3	24.6	10.83			33	23	10.67
Minimum Δt (˚C)			37.97	28	8			32.77	23.4	7.87			28.27	21.2	5.27			32	22.6	8.26			30.87	22	8.5

Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)		
		Outside	Inside	∆t (˚C)			Outside	Inside	∆t (˚C)			Outside	Inside	∆t (˚C)			Outside	Inside	∆t (˚C)			Outside	Inside	∆t (˚C)
16-Jun	11:00 AM	35.7	26.3	9.4	17-Jun	11:00 AM	32	26.3	5.7	18-Jun	11:00 AM	31.2	26.3	4.9	19-Jun	11:00 AM	32	26.3	5.7	20-Jun	11:00 AM	34.1	25.11	8.99
16-Jun	11:15 AM	35	26	9	17-Jun	11:15 AM	33.2	26	7.2	18-Jun	11:15 AM	32	26	6	19-Jun	11:15 AM	33.2	26	7.2	20-Jun	11:15 AM	33.9	24.29	9.61
16-Jun	11:30 AM	35.3	25.74	9.56	17-Jun	11:30 AM	34	25.74	8.26	18-Jun	11:30 AM	33.9	25.74	8.16	19-Jun	11:30 AM	34	25.74	8.26	20-Jun	11:30 AM	33.8	24.51	9.29
16-Jun	11:45 AM	35	25.7	9.3	17-Jun	11:45 AM	34.2	25.7	8.5	18-Jun	11:45 AM	34.2	25.7	8.5	19-Jun	11:45 AM	34.2	25.7	8.5	20-Jun	11:45 AM	33.3	24.38	8.92
16-Jun	12:00 PM	35.3	26	9.3	17-Jun	12:00 PM	35.3	26	9.3	18-Jun	12:00 PM	35.3	25.3	10	19-Jun	12:00 PM	35.3	26	9.3	20-Jun	12:00 PM	33	24.9	8.1
16-Jun	12:15 PM	34.57	25.71	8.86	17-Jun	12:15 PM	35.2	25.71	9.49	18-Jun	12:15 PM	35.3	25.71	9.59	19-Jun	12:15 PM	35.2	25.71	9.49	20-Jun	12:15 PM	33.37	24.28	9.09
16-Jun	12:30 PM	34.47	25	9.47	17-Jun	12:30 PM	34.3	25.2	9.1	18-Jun	12:30 PM	35.7	25.3	10.4	19-Jun	12:30 PM	34.3	25.2	9.1	20-Jun	12:30 PM	34	24.7	9.3
16-Jun	12:45 PM	34.37	24.5	9.87	17-Jun	12:45 PM	34.37	24.5	9.87	18-Jun	12:45 PM	35	25	10	19-Jun	12:45 PM	34.37	24.5	9.87	20-Jun	12:45 PM	34.2	23.9	10.3
16-Jun	1:00 PM	34.47	24.1	10.37	17-Jun	1:00 PM	34.7	24.1	10.6	18-Jun	1:00 PM	34.7	25.2	9.5	19-Jun	1:00 PM	34.7	24.1	10.6	20-Jun	1:00 PM	33.3	23.67	9.63
16-Jun	1:15 PM	34.57	24.7	9.87	17-Jun	1:15 PM	34.2	24.7	9.5	18-Jun	1:15 PM	34.2	24.7	9.5	19-Jun	1:15 PM	34.2	24.7	9.5	20-Jun	1:15 PM	32.9	24.175	8.725
16-Jun	1:30 PM	34.67	25	9.67	17-Jun	1:30 PM	34.5	24.9	9.6	18-Jun	1:30 PM	34.5	24.9	9.6	19-Jun	1:30 PM	34.5	24.9	9.6	20-Jun	1:30 PM	33.47	24.56	8.91
16-Jun	1:45 PM	34.77	25	9.77	17-Jun	1:45 PM	34.77	24.6	10.17	18-Jun	1:45 PM	34.77	24.6	10.17	19-Jun	1:45 PM	34.77	24.6	10.17	20-Jun	1:45 PM	33.57	24.54	9.03
16-Jun	2:00 PM	34.87	25.95	8.92	17-Jun	2:00 PM	34.87	25.95	8.92	18-Jun	2:00 PM	34.87	25.2	9.67	19-Jun	2:00 PM	34.87	24.3	10.57	20-Jun	2:00 PM	33.67	24.52	9.15
16-Jun	2:15 PM	35	25.96	9.04	17-Jun	2:15 PM	35.04	25.96	9.08	18-Jun	2:15 PM	35.04	25.5	9.54	19-Jun	2:15 PM	35.04	24.5	10.54	20-Jun	2:15 PM	33.8	24.53	9.27
16-Jun	2:30 PM	35.12	25.96	9.16	17-Jun	2:30 PM	35.12	25.96	9.16	18-Jun	2:30 PM	35.12	25.96	9.16	19-Jun	2:30 PM	35.12	24.6	10.52	20-Jun	2:30 PM	33.92	24.53	9.39
16-Jun	2:45 PM	35	25.72	9.28	17-Jun	2:45 PM	35	25.72	9.28	18-Jun	2:45 PM	35	25.72	9.28	19-Jun	2:45 PM	35	24.2	10.8	20-Jun	2:45 PM	33.8	24.29	9.51
16-Jun	3:00 PM	35	25.84	9.16	17-Jun	3:00 PM	35	25.84	9.16	18-Jun	3:00 PM	35	25.4	9.6	19-Jun	3:00 PM	35	24.5	10.5	20-Jun	3:00 PM	33.8	24.41	9.39
16-Jun	3:15 PM	35.12	25.84	9.28	17-Jun	3:15 PM	35.12	25.84	9.28	18-Jun	3:15 PM	35.12	25.6	9.52	19-Jun	3:15 PM	35.12	25.84	9.28	20-Jun	3:15 PM	33.92	24.41	9.51
16-Jun	3:30 PM	35.14	25.98	9.16	17-Jun	3:30 PM	35.14	25.98	9.16	18-Jun	3:30 PM	35.14	25.1	10.04	19-Jun	3:30 PM	35.14	25.02	10.12	20-Jun	3:30 PM	33.94	24.55	9.39
16-Jun	3:45 PM	35.7	26.64	9.06	17-Jun	3:45 PM	35.7	26.64	9.06	18-Jun	3:45 PM	35.7	25.4	10.3	19-Jun	3:45 PM	35.7	25.3	10.4	20-Jun	3:45 PM	34.5	25.21	9.29
16-Jun	4:00 PM	35.6	26.64	8.96	17-Jun	4:00 PM	35.6	26.64	8.96	18-Jun	4:00 PM	35.6	25.2	10.4	19-Jun	4:00 PM	35.6	25.5	10.1	44367	4:00 PM	34.4	25.21	9.19
		35.7	26.64	10.37			35.7	26.64	10.6			35.7	26.3	10.4			35.7	26.3	10.8			34.5	25.21	10.3
		34.37	24.1	8.86			32	24.1	5.7			31.2	24.6	4.9			32	24.1	5.7			32.9	23.67	8.1

Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)		
		Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)
21-Jun	11:00 AM	35.8	25.81	9.99	22-Jun	11:00 AM	36.5	27.85	8.65	23-Jun	11:00 AM	36.9	28.53	8.37	24-Jun	11:00 AM	31.2	21.93	9.27	25-Jun	11:00 AM	35.4	26.23	9.17
21-Jun	11:15 AM	36	24.99	11.01	22-Jun	11:15 AM	37	27.27	9.73	23-Jun	11:15 AM	37.4	27.9	9.5	24-Jun	11:15 AM	31.7	22.6	9.1	25-Jun	11:15 AM	35.7	26.8	8.9
21-Jun	11:30 AM	37.3	24.91	12.39	22-Jun	11:30 AM	38.3	27	11.3	23-Jun	11:30 AM	38	27.8	10.2	24-Jun	11:30 AM	32.01	22.9	9.11	25-Jun	11:30 AM	36.02	27.6	8.42
21-Jun	11:45 AM	37	26.3	10.7	22-Jun	11:45 AM	38	27.4	10.6	23-Jun	11:45 AM	39.9	27	12.9	24-Jun	11:45 AM	32.2	23.9	8.3	25-Jun	11:45 AM	36.9	27.9	9
21-Jun	12:00 PM	38.8	27	11.8	22-Jun	12:00 PM	39.2	28	11.2	23-Jun	12:00 PM	40	29	11	24-Jun	12:00 PM	33.8	24.01	9.79	25-Jun	12:00 PM	37.8	28	9.8
21-Jun	12:15 PM	37.8	25.3	12.5	22-Jun	12:15 PM	39.3	27.3	12	23-Jun	12:15 PM	40.8	28.5	12.3	24-Jun	12:15 PM	33.2	23.9	9.3	25-Jun	12:15 PM	38.01	26.8	11.21
21-Jun	12:30 PM	36	24.97	11.03	22-Jun	12:30 PM	38	26.51	11.49	23-Jun	12:30 PM	40.5	28.1	12.4	24-Jun	12:30 PM	33.1	23.1	10	25-Jun	12:30 PM	37.9	25.3	12.6
21-Jun	12:45 PM	35.6	24.07	11.53	22-Jun	12:45 PM	38.02	26.28	11.74	23-Jun	12:45 PM	40.9	28.3	12.6	24-Jun	12:45 PM	32.7	22.5	10.2	25-Jun	12:45 PM	36.3	25.8	10.5
21-Jun	1:00 PM	34.3	24.36	9.94	22-Jun	1:00 PM	37.2	26.76	10.44	23-Jun	1:00 PM	40	28.63	11.37	24-Jun	1:00 PM	31.8	22	9.8	25-Jun	1:00 PM	35.88	25.6	10.28
21-Jun	1:15 PM	33.6	24.84	8.76	22-Jun	1:15 PM	36	26.72	9.28	23-Jun	1:15 PM	41	28.34	12.66	24-Jun	1:15 PM	30.42	21.75	8.67	25-Jun	1:15 PM	35.91	25.45	10.46
21-Jun	1:30 PM	33	25.26	7.74	22-Jun	1:30 PM	35.9	26.68	9.22	23-Jun	1:30 PM	41.02	28.5	12.52	24-Jun	1:30 PM	30.17	21.38	8.79	25-Jun	1:30 PM	34.37	25.3	9.07
21-Jun	1:45 PM	33.7	25.24	8.46	22-Jun	1:45 PM	35.57	26.78	8.79	23-Jun	1:45 PM	41.3	28.4	12.9	24-Jun	1:45 PM	30.27	21.36	8.91	25-Jun	1:45 PM	34.5	25.9	8.6
21-Jun	2:00 PM	34	25.22	8.78	22-Jun	2:00 PM	35.67	26.76	8.91	23-Jun	2:00 PM	41.2	28.5	12.7	24-Jun	2:00 PM	30.37	21.34	9.03	25-Jun	2:00 PM	34.8	25.3	9.5
21-Jun	2:15 PM	33.9	25.23	8.67	22-Jun	2:15 PM	35.1	26.1	9	23-Jun	2:15 PM	40.99	28.1	12.89	24-Jun	2:15 PM	30.5	21.35	9.15	25-Jun	2:15 PM	34.7	25.53	9.17
21-Jun	2:30 PM	33	25.23	7.77	22-Jun	2:30 PM	35.6	26	9.6	23-Jun	2:30 PM	40.2	27.95	12.25	24-Jun	2:30 PM	30.62	21.35	9.27	25-Jun	2:30 PM	34.82	25.75	9.07
21-Jun	2:45 PM	33.3	24.9	8.4	22-Jun	2:45 PM	35.8	26.53	9.27	23-Jun	2:45 PM	39.6	27.72	11.88	24-Jun	2:45 PM	30.53	21.13	9.4	25-Jun	2:45 PM	33.9	25.43	8.47
21-Jun	3:00 PM	34.5	25.11	9.39	22-Jun	3:00 PM	35.8	26.41	9.39	23-Jun	3:00 PM	39.4	27.83	11.57	24-Jun	3:00 PM	30.5	21.23	9.27	25-Jun	3:00 PM	34.7	25.4	9.3
21-Jun	3:15 PM	34.3	25.11	9.19	22-Jun	3:15 PM	35.82	26.41	9.41	23-Jun	3:15 PM	39	27.84	11.16	24-Jun	3:15 PM	30.62	21.25	9.37	25-Jun	3:15 PM	34.5	25.55	8.95
21-Jun	3:30 PM	34.64	25.25	9.39	22-Jun	3:30 PM	36.04	26.65	9.39	23-Jun	3:30 PM	38.4	28.07	10.33	24-Jun	3:30 PM	30.74	21.47	9.27	25-Jun	3:30 PM	34.94	25.9	9.04
21-Jun	3:45 PM	34.4	25.91	8.49	22-Jun	3:45 PM	36.52	26.99	9.53	23-Jun	3:45 PM	37.4	28.63	8.77	24-Jun	3:45 PM	31.2	22.03	9.17	25-Jun	3:45 PM	35.4	26.33	9.07
21-Jun	4:00 PM	34.1	25.91	8.19	22-Jun	4:00 PM	36.4	27.01	9.39	23-Jun	4:00 PM	37.2	28.63	8.57	24-Jun	4:00 PM	31.1	22.03	9.07	25-Jun	4:00 PM	35.3	26.2	9.1
		38.8	27	12.5			39.3	28	12			41.3	29	12.9			33.8	24.01	10.2			38.01	28	12.6
		33	24.07	7.74			35.1	26	8.65			36.9	27	8.37			30.17	21.13	8.3			33.9	25.3	8.42

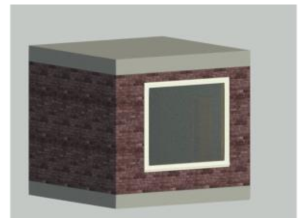
Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)			Date	Time	Temperature (˚C)		
		Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)			Outside	Inside	Δt (˚C)
26-Jun	11:00 AM	31	23.72	7.28	27-Jun	11:00 AM	35.5	27.73	7.77	28-Jun	11:00 AM	34.6	28.2	6.4	29-Jun	11:00 AM	38.01	29.51	8.5	30-Jun	11:00 AM	34.6	28.2	6.4
26-Jun	11:15 AM	31.8	23.14	8.66	27-Jun	11:15 AM	36	26.91	9.09	28-Jun	11:15 AM	35.6	27.97	7.63	29-Jun	11:15 AM	38.7	28.69	10.01	30-Jun	11:15 AM	35.6	27.97	7.63
26-Jun	11:30 AM	33	22.8	10.2	27-Jun	11:30 AM	37.03	26.9	10.13	28-Jun	11:30 AM	36.2	27.7	8.5	29-Jun	11:30 AM	39.02	28.68	10.34	30-Jun	11:30 AM	36.2	27.7	8.5
26-Jun	11:45 AM	33.2	23.54	9.66	27-Jun	11:45 AM	37.4	26.3	11.1	28-Jun	11:45 AM	38	27.47	10.53	29-Jun	11:45 AM	39.3	28.67	10.63	30-Jun	11:45 AM	38.9	27.47	11.43
26-Jun	12:00 PM	33.9	24.7	9.2	27-Jun	12:00 PM	38.8	27.7	11.1	28-Jun	12:00 PM	40.8	28.03	12.77	29-Jun	12:00 PM	41.7	29.9	11.8	30-Jun	12:00 PM	40.9	28.3	12.6
26-Jun	12:15 PM	34.02	23.6	10.42	27-Jun	12:15 PM	37.3	27.5	9.8	28-Jun	12:15 PM	36.46	27.33	9.13	29-Jun	12:15 PM	40.4	28.97	11.43	30-Jun	12:15 PM	38	28.03	9.97
26-Jun	12:30 PM	34.4	22.8	11.6	27-Jun	12:30 PM	36.27	27.4	8.87	28-Jun	12:30 PM	36.57	27.32	9.25	29-Jun	12:30 PM	40.3	29.18	11.12	30-Jun	12:30 PM	37.9	27.68	10.22
26-Jun	12:45 PM	34	22.3	11.7	27-Jun	12:45 PM	35.96	26.8	9.16	28-Jun	12:45 PM	36.26	26.89	9.37	29-Jun	12:45 PM	39.4	28.97	10.43	30-Jun	12:45 PM	37.23	27.47	9.76
26-Jun	1:00 PM	34.4	22.85	11.55	27-Jun	1:00 PM	35.3	26.5	8.8	28-Jun	1:00 PM	36.06	26.97	9.09	29-Jun	1:00 PM	37.64	28.86	8.78	30-Jun	1:00 PM	37.5	27.35	10.15
26-Jun	1:15 PM	33.43	23	10.43	27-Jun	1:15 PM	35.81	26.3	9.51	28-Jun	1:15 PM	36.11	26.1	10.01	29-Jun	1:15 PM	37.03	28.91	8.12	30-Jun	1:15 PM	37.4	27.41	9.99
26-Jun	1:30 PM	33.02	23.01	10.01	27-Jun	1:30 PM	35.2	26.24	8.96	28-Jun	1:30 PM	35.4	26.3	9.1	29-Jun	1:30 PM	37.76	28.85	8.91	30-Jun	1:30 PM	36.26	27.35	8.91
26-Jun	1:45 PM	32.6	22.65	9.95	27-Jun	1:45 PM	35.96	27.05	8.91	28-Jun	1:45 PM	35.7	26	9.7	29-Jun	1:45 PM	38	26.02	11.98	30-Jun	1:45 PM	36.03	27.33	8.7
26-Jun	2:00 PM	32.01	22.63	9.38	27-Jun	2:00 PM	36.23	27.03	9.2	28-Jun	2:00 PM	36.36	27.35	9.01	29-Jun	2:00 PM	37.96	27	10.96	30-Jun	2:00 PM	36.46	27.31	9.15
26-Jun	2:15 PM	31.8	23	8.8	27-Jun	2:15 PM	36.3	27.15	9.15	28-Jun	2:15 PM	36.6	27.47	9.13	29-Jun	2:15 PM	38.2	27.09	11.11	30-Jun	2:15 PM	36.7	27	9.7
26-Jun	2:30 PM	31	22.64	8.36	27-Jun	2:30 PM	36.42	27.15	9.27	28-Jun	2:30 PM	36.72	27.47	9.25	29-Jun	2:30 PM	38.03	27.1	10.93	30-Jun	2:30 PM	36.82	27.43	9.39
26-Jun	2:45 PM	30.8	22.4	8.4	27-Jun	2:45 PM	36.5	26.91	9.59	28-Jun	2:45 PM	36.9	27.23	9.67	29-Jun	2:45 PM	38.2	27.5	10.7	30-Jun	2:45 PM	36.9	27.19	9.71
26-Jun	3:00 PM	31.2	22.5	8.7	27-Jun	3:00 PM	36.3	27.03	9.27	28-Jun	3:00 PM	37	26.8	10.2	29-Jun	3:00 PM	38.2	28.03	10.17	30-Jun	3:00 PM	36.7	27.31	9.39
26-Jun	3:15 PM	30.9	22.65	8.25	27-Jun	3:15 PM	36.9	27.03	9.87	28-Jun	3:15 PM	37.3	27	10.3	29-Jun	3:15 PM	38.4	26.8	11.6	30-Jun	3:15 PM	36.82	27.31	9.51
26-Jun	3:30 PM	31.8	22.28	9.52	27-Jun	3:30 PM	36.3	27.03	9.27	28-Jun	3:30 PM	37.7	26.8	10.9	29-Jun	3:30 PM	38.2	27.3	10.9	30-Jun	3:30 PM	36.7	27.31	9.39
26-Jun	3:45 PM	32.01	22.86	9.15	27-Jun	3:45 PM	36.9	27.83	9.07	28-Jun	3:45 PM	38	27.69	10.31	29-Jun	3:45 PM	38.9	27.7	11.2	30-Jun	3:45 PM	37.4	28.11	9.29
26-Jun	4:00 PM	32.4	22.9	9.5	27-Jun	4:00 PM	37.03	27.83	9.2	28-Jun	4:00 PM	38.1	27.71	10.39	29-Jun	4:00 PM	38.8	27.3	11.5	30-Jun	4:00 PM	37.02	28.11	8.91
		34.4	24.7	11.7			38.8	27.83	11.1			40.8	28.2	12.77			41.7	29.9	11.98			40.9	28.3	12.6
		30.8	22.28	7.28			35.2	26.24	7.77			34.6	26	6.4			37.03	26.02	8.12			34.6	27	6.4

Appendix –B Photos of the work

Photos of the work carried during research were as under -

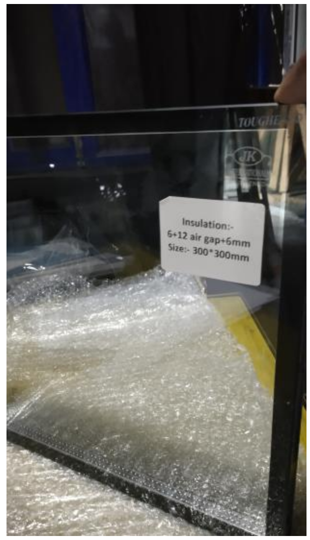
Photos of Sound level window formations



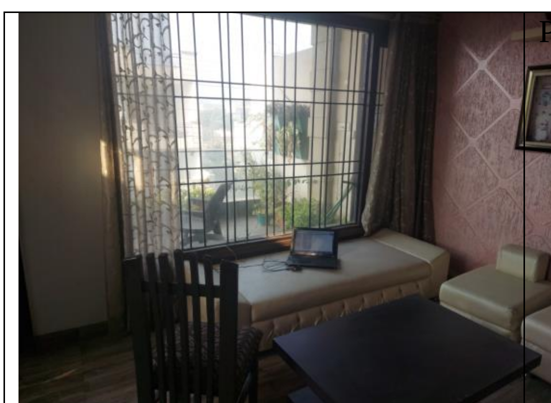


Picture 1: DGU2 Picture 2: DGU 3 Picture 3: Simulated model

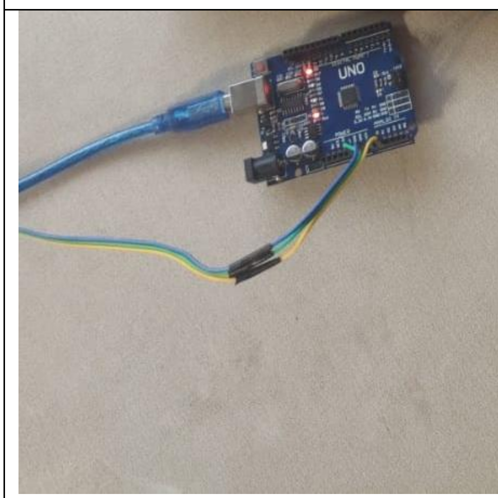
Picture 4: Different types of glass



Picture 5: DG1 Picture 6: DG2 Picture 7: Sound level prototype



Picture 8: Actual at site

	Picture 9: Actual at site
	Picture 10: Actual at site

Appendix –C: Conferences attended

S.No	Title of the paper with author names	Name of conference	Date
1	Evaluation of glass in Reducing Electricity Consumption in Built Environment Using Sustainable Windows. Amit kumar Dhir, Dr. Pushpendra Kumar Sharma	International Conference on "Sustainable Construction (ICSC 2021)"	15th June, 2021
2	Economic societal approach to sustainability for domestic sector in mitigating electricity consumption.	Recent advances in Fundamental and Applied Sciences, RAFAS-2021	25-26th June, 2021
3	Reducing Electricity Consumption in Built Environment using Sustainably Designed Fenestration	International Conference on Experimentation and Progression in Engineering, Research and Technology, EXPERT 2019	15th November, 2019

4	The Variance in Assessment and Simulation for Effect of Double Glass Unit in Built Environment	International Conference on Materials for Emerging technologies (ICMET-21)	18- 19 Feb, 2022
5	Economic Computation and Simulation for Different Window Formations in Reducing Energy Consumption in Building Sector	International Conference on Materials for Emerging technologies (ICMET-21)	18- 19 Feb, 2022

St. PETER'S INSTITUTE OF HIGHER EDUCATION & RESEARCH

DEPARTMENT OF CIVIL ENGINEERING

CERTIFICATE

Amit Kumar Dhir of Lovely Professional University has participated in the Online International Conference on "Sustainable Construction (ICSC 2021)" organized by Department of Civil Engineering,St. Peter's Institute of Higher Education and Research, Chennai, on 15.06.2021

Dr.P.Asha
Convenor

Certificate No. 225362

LOVELY PROFESSIONAL UNIVERSITY

Transforming Education Transforming India

Certificate of Participation

This is to certify that ***Mr. Amit Kumar Dhir***

of ***Lovely Professional University, Punjab***

has given poster presentation on ***Economical Societal Approach to Sustainability for Domestic Sector in Mitigating Electricity Consumption***

in the International Conference on "Recent Advances in Fundamental and Applied Sciences" (RAFAS 2021) held on June 25-26, 2021, organized by School of Chemical Engineering and Physical Sciences, Lovely Faculty of Technology and Sciences, Lovely Professional University, Punjab.

Date of Issue : 15-07-2021
Place of Issue: Phagwara (India)

Prepared by
(Administrative Officer-Records)

Organizing Secretary
(RAFAS 2021)

Convener
(RAFAS 2021

LOVELY FACULTY OF TECHNOLOGY AND SCIENCES

[Under the Aegis of Lovely Professional University, Jalandhar-Delhi G.T. Road, Phagwara (Punjab)]

Certificate No. 183246

Certificate of Recognition

This is to certify that Dr./Mr./Ms. **Amit**

from **Lovely Professional University**

presented a research paper titled **Reducing Electricity Consumption in Built Environments Using Sustainably Designed Fenestration**

in the ***International Conference on Experimentation and Progression in Engineering, Research and Technology (EXPERT - 2019)"*** *held on 15th and 16th of November 2019, organized by School of Civil Engineering at Lovely Professional University, Punjab, India.*

Date of Issue : 15-11-2019
Place of Issue: Phagwara (India)

Prepared by
(Administrative Officer-Records)

Chairmam
(EXPERT - 2019)

Organizing Secretary
(EXPERT - 2019)

DIVISION OF RESEARCH AND DEVELOPMENT

[Under the Aegis of Lovely Professional University, Jalandhar-Delhi G.T. Road, Phagwara (Punjab)]

Certificate No.240176

Certificate of Participation

This is to certify that **Mr. Amit Kumar Dhir** of **Lovely Professional University, Phagwara, Punjab, India** has presented paper on **The Variance in Assessment and Simulation for Effect of Double Glass Unit in Built Environment** in the **International Conference on Materials for Emerging Technologies (ICMET-21)** held on February 18-19, 2022, organized by Department of Research Impact and Outcome, Division of Research and Development, Lovely Professional University, Punjab.

Date of Issue: 16-03-2022
Place: Phagwara (Punjab), India

Prepared by (Administrative Officer-Records)	Dr. Vipul Srivastava Convener (ICMET-21)	Dr. Manish Vyas Organizing Secretary (ICMET-21)	Dr. Chander Prakash Co-Chairperson (ICMET-21)

DIVISION OF RESEARCH AND DEVELOPMENT

[Under the Aegis of Lovely Professional University, Jalandhar-Delhi G.T. Road, Phagwara (Punjab)]

Certificate No.240213

Certificate of Participation

This is to certify that **Mr. Amit Kumar Dhir** of **Lovely Professional University, Phagwara, Punjab, India** has presented paper on **Economic Computation and Simulation for Different Window Formations in Reducing Energy Consumption in Building Sector** in the **International Conference on Materials for Emerging Technologies (ICMET-21)** held on February 18-19, 2022, organized by Department of Research Impact and Outcome, Division of Research and Development, Lovely Professional University, Punjab.

Date of Issue: 16-03-2022
Place: Phagwara (Punjab), India

Prepared by (Administrative Officer-Records)	Dr. Vipul Srivastava Convener (ICMET-21)	Dr. Manish Vyas Organizing Secretary (ICMET-21)	Dr. Chander Prakash Co-Chairperson (ICMET-21)

Appendix – D: Workshops attended

S.No	Name of workshop/ Program	Dates
1	Sustainable Practices in Built Environment – SBPE- 2021	26th December to 30th December, 2021
2	Awareness program on Energy conservation Building Code -2017	10th January, 2019
3	NPTEL online certification Glass in Buildings	July- October,2018
4	Glass Academy Foundation and NIT-tiruchirappalli	5 – 10th, December, 2016

GLASS ACADEMY

FACULTY DEVELOPMENT PROGRAMME

By

Glass Academy Foundation

In association with

National Institute of Technology, Tiruchirappalli

Certificate of Completion

This is to certify that

AMIT KUMAR DHIR

has successfully completed the Faculty Development Programme conducted by Glass Academy Foundation in association with National Institute of Technology, Tiruchirappalli between 5 - 10 December 2016

M. Balaji Chief Sevak Glass Academy Foundation	**Dr. G. Subbaiyan** NIT, Trichy Program - Co-ordinators	**Prof. P. Gopalakrishnan** NIT, Trichy Program - Co-ordinators	**Dr. Samson Mathew** NIT, Trichy Program - Co-ordinators
	Ar. C. N. Raghavendran Chairman Glass Academy Foundation	**Director** NIT, Trichy	

Elite

NPTEL Online Certification

(Funded by the Ministry of HRD, Govt. of India)

This certificate is awarded to

AMIT KUMAR DHIR

for successfully completing the course

Glass in buildings : Design and Applications

with a consolidated score of **71 %**

Online Assignments	21.31/25	Proctored Exam	50/75

Total number of candidates certified in this course: **247**

Prof. A. Ramesh
Chairman
Center for Continuing Education, IITM

Ar.C.N.Raghavendran
Chairman
Glass Academy Foundation

Prof. Andrew Thangaraj
NPTEL Coordinator
IIT Madras

Indian Institute of Technology Madras

Jul - Oct 2018
(12 week course)

GLASS ACADEMY

swayam

Roll No: NPTEL18CE27S21830111

To validate and check scores: http://nptel.ac.in/noc

No: *NIT/HMR/Arch/eWorkshop/SPBE-2021/P- 4*

NATIONAL INSTITUTE OF TECHNOLOGY HAMIRPUR

Certificate of Participation

This is to certify that Mr./Ms.

AMIT KUMAR DHIR

*has attended a five-day e-Workshop on "**Sustainable Practices in Built Environment (SPBE-2021)**" organized by Department of Architecture, National Institute of Technology Hamirpur from 26th Dec. 2021 – 30th Dec. 2021.*

Dr. Aniket Sharma
Coordinator,
Department of Architecture

Dr. Vandna Sharma
Convener & Head,
Department of Architecture

Appendix – E: Acceptance from the journals

S.No	Title of the paper with author names	Name of Journal/ conference	Published date	Issue no./ Vol no.	Indexing in Scopus/ Web of Science/ UGC-Care
1	Design Principle, Modernization and Techniques in Smart Electrical Grid system. Amit kumar Dhir, Dr. Pushpendra Kumar Sharma	CRC, Taylor and Francis	Oct 11, 2021	Accepted	Scopus
2	Performance Analysis of the sustainable Windows Glazing System for built environment. Amit kumar Dhir, Dr. Pushpendra Kumar Sharma	Springer	Jan 14, 2021	Accepted	Scopus
3	Economic Computation and Simulation for Different Window Formations in Reducing	--	Jan 14, 2021	Accepted	Scopus

	Energy Consumption in Building Sector. Amit kumar Dhir, Dr. Pushpendra Kumar Sharma				
4	Variance in Assessment and Simulation for Effect of Double Glass Unit in Built Environment. Amit kumar Dhir, Dr. Pushpendra Kumar Sharma	--	Jan 5, 2021	Accepted	Scopus

Dr. Krishan Arora
to me

9:55 AM (1 hour ago)

Dear Authors,

Greetings of the day!!

We are pleased to inform you that your chapter titled **"Evaluation of Sustainable Window for Energy mitigation in an Electrical Grid building" has been accepted** under the book title **"Design Principle, Modernization and Techniques in Smart Electrical Grid System, CRC Taylor & Francis"** in**CRC Taylor & Francis**. The current book is now processed by the production team of the publisher.

We are thankful for your contribution and cooperation.

Dr. Krishan Arora
Lead Editor
Smart Electrical Grid System: Design Principle,
Modernization, and Techniques

Request to fill and submit 'Manuscript Submission Checklist' (IGGEC-21) Phd ×

IGGEC-21 NITJ Fri, Jan 14, 3:30 PM (9 days ago)

to kreddy, Uma, harshal.nikhade1100, harshal, madhumita, Dharmendra, sanjeevktl1993, Sanjeev, Nadeem, Sonawaneswati, Harshit, suraj, SHIVANIGOUR, Ah

Dear Authors,

Your manuscript, submitted for the presentation in the "First Indian Geotechnical and Geo-environmental Engineering Conference (IGGEC-2021)", has been forwarded to the publisher (Springer Nature) for inclusion in the proceedings.

However, as per the requirement of the publisher, the authors are required to submit the 'Manuscript Submission Checklist' to be filled and signed by the corresponding author.

In view of this, you are requested to kindly complete the document duly filled and signed and send it to us using the google form link given below within three days.

Please find the list of papers forwarded to the publisher for possible inclusion in the proceedings. Kindly Rename your document with theme number and serial number (ex: Theme 1 Serial No1) of your paper as per the attached list herewith.

Link for Submission : https://forms.gle/mjyJdVA4Kx42huTo7

With Kind Regards;
(H. S. Chore)

International Conference on Materials for Emerging Technologies Fri, Jan 14, 10:50 PM (9 days ago)

to me

Dear Participant

We are happy to inform you that your abstract **"Economic Computation and Simulation for Different Window Formations in Reducing Energy Consumption in Building Sector"** has been accepted for its presentation at the International Conference on Materials for Emerging Technologies-2021 (ICMET-21). Kindly, Register for the conference using the link: https://conferences.lpu.in/icmet/RegistrationForm.aspx. Also, submit a full-length manuscript within the stipulated time limit. If you have already registered and submitted the full-length manuscript, kindly ignore it.
Your Abstract No. is MS-142.

Regards

Team, ICMET-21

International Conference on Materials for Emerging Technologies Wed, Jan 5, 4:19 PM

to me

Dear Participant

We are happy to inform you that your abstract "**Variance in Assessment and Simulation for Effect of Double Glass Unit in Built Environment**" has been accepted for its presentation at the International Conference on Materials for Emerging Technologies-2021 (ICMET-21).
Kindly, Register for the conference using the link: https://conferences.lpu.in/icmet/RegistrationForm.aspx. Also, submit a full-length manuscript within the stipulated time limit. If already registered and submitted the full-length manuscript, kindly ignore.
Your Abstract No. is MS-077.

Regards

Team, ICMET-21

Appendix – F: Paper published

S.No	Title of the paper with author names	Name of Journal/ conference	Published date	Issue no./ Vol no.	Indexing in Scopus/ Web of Science/ UGC-Care
1	Evaluation of glass in Reducing Electricity Consumption in Built Environment Using Sustainable Windows. Amit kumar Dhir, Dr. Pushpendra Kumar Sharma	International Conference on "Sustainable Construction (ICSC 2021)"	15th June, 2021		Conference
2	Economic societal approach to sustainability for domestic sector in mitigating electricity consumption.	Recent advances in Fundamental and Applied Sciences, RAFAS-2021	25-26th June, 2021		Conference
3	Reducing Electricity Consumption in Built Environment using Sustainably Designed Fenestration	International Conference on Experimentation and Progression in Engineering,	15th November, 2019		Conference

		Research and Technology, EXPERT 2019			
4	Mitigation of Energy Demands in Building Sector: A Review. Amit kumar Dhir, Dr. Pushpendra Kumar Sharma	IOSR Journal of Engineering (IOSR JEN)	30th May, 2019	ISSN (e): 2250-3021	UGC CARE List SL. No. 4814
5	A Evaluation For Role Of Suitable Glazing In Saving Energy. Amit kumar Dhir, Dr. Pushpendra Kumar Sharma.	Journal of Emerging Technologies and Innovative Research	January, 2019	ISSN-2349-5162	UGC CARE List SL. No. 63975

ISSN (e): 2250-3021
ISSN (p): 2278-8719

International Organization of Scientific Research

Is hereby honoring this certificate to

Amitkumar Dhir

In recognition of the Publication of Manuscript entitled

Mitigation of Energy Demands in Building Sector: A Review

Published in IOSR Jen, Special Issue / presented at the

International Conference on Sustainable Environment & Civil Engineering (ICSECE'19)

Organized by

Department of Civil Engineering, Easwari Engineering College, Bharathi Salai, Ramapuram, Chennai-600 089 Tamil Nadu, India

on 28th-29th March 2019

Editor in Chief
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IOSR Journal of Engineering (IOSR JEN) **www.iosrjen.org**
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PP 35-38

Mitigation of Energy Demands in Building Sector: A Review

Amitkumar Dhir[1], Dr. Pushpendra Kumar Sharma[2]
[1]*Research Scholar, School of Civil Engineering, Lovely professional University, Punjab, India.*
[2]*Associate Professor, School of Civil Engineering, Lovely professional University, Punjab, India.*

Abstract: *Most of the countries are struggling to pace increasing energy demands and carbon emissions globally. Residential sector has significant role to play as it contributes a share of 27% in energy consumption and 17% in carbon emissions as per WEO 2017. Further windows play a significant role in buildings to mitigate the energy requirements and to reduce carbon footprints. At present researchers have carried out numerous modifications in windows and rare of them are tested experimentally as well, still nothing has been devised concrete. Many improvements tested or suggested as HISG, VT, DGU etc have been presented herein. The focus of this paper is to highlight the inputs across universe and their challenges in implementation. Most efficient glazing used commercially is HISG though VT window also shows remarkable results. The scope of HISG is very much limited in residential market due to its high payback period of 33.7 years. Payback period of VT is 14.34 years. Windows have the potential to save half of the energy consumption provided that it should be carefully designed and checked experimentally. Though many reviews are available in literature yet there is an urgent need to upgrade windows along with cost analysis following guidelines being framed by many governments in their respective building code time to time. In the current review the authors have emphasized on need of investigation in regards to economical windows to reduce the payback period.*

Keywords: *Payback period, Daylight, Energy savings, Heat insulation solar glass, types of glass for windows.*

I. Introduction

Developing countries are emerging and their energy consumption is also on the higher side. Residential sector is consuming about 27% energy [1]. Globally the energy consumption trend shows 14 % growth between 2000 and 2014 [1], [2]. This growth in energy consumption is mainly due to population growth, urbanization and ownership of appliances. [3]. Also CO2 emissions from residential sector are about 17 % responsible in GHG effect [4]. Global energy needs will expand at the rate of 30% from present to 2040 [1]. The global demands of electricity would estimate to be increased by 40% by 2040.(World energy Outlook, 2017). To compensate these increasing demands, new policy and reforms are demanded in the building codes such as new wind power and solar PV panels [5] are to be utilized especially in china as per international energy agency report, 2017.

In the building, its envelope plays a pivotal role in energy mitigation and energy savings. This has been evidenced from the research studies that the windows and its frame that is fenestration can lower the energy consumption by 40 to 60 percent [5], [6]. About 60% of the heat is lost though windows, the day lighting effect can be utilized in order to reduce heat loss [6]. Windows should be carefully designed so to reduce solar heat from outside to inside along with to reduce heat loss from outside to inside and VLT should be optimum [5]. Choice of glass is of prime importance to take care of mentioned issues. The fenestration should be chosen effectively that works efficient and should have low U-value .

Various researchers have performed enormous studies and evidenced that the windows can minimize the energy consumption provided to be designed properly utilizing the parameters required as per site [7], [8]. This not only helps to minimize the energy but also can greatly control the emission of CO2 gases which is need of hour and is responsible for global warming. Many researches showed the reduction of CO2 emissions from the building and help in ecofriendly environment. This paper emphasis from the literature survey that the usage of glass can help the building to mitigate the energy demands and also ease the occupants to visual and cozy comforts [9].

II. Background

2.1 Type of Glasses

To ensure the reduction of heat loss through windows, the glass should be selected through various parameters that are as per climate, orientation of building, performance or intended function and efficiency.
To cater these needs glass industry has rolled and manufactures some of the majorly utilized glasses types are briefly discussed.

A Evaluation For Role Of Suitable Glazing In Saving Energy

Amit kumar Dhir[1], Dr. Pushpendra Kumar Sharma[2]

[1]*Assistant Professor, School of Polytechnic, Lovely professional University, Punjab, India.*

[2]*Associate Professor, School of Civil Engineering, Lovely professional University, Punjab, India.*

ABSTRACT

Most of the countries are struggling to pace increasing energy demands and carbon emissions globally. Residential sector has significant role to play as it contributes a share of 27% in energy consumption and 17% in carbon emissions as per WEO[1] 2017.Further windows play a significant role in buildings to mitigate the energy requirements and to reduce carbon footprints. At present researchers have carried out numerous modifications in windows and rare of them are tested experimentally as well, still nothing has been devised concrete. Many improvements tested or suggested as HISG, VT, DGU etc have been presented herein. The focus of this paper is to highlight the inputs across universeand their challenges in implementation. Most efficient glazing used commercially is HISG though VT window also shows remarkable results. The scope of HISG is very much limited in residential market due to its high payback period of 33.7 years. Payback period of VT is 14.34 years. Windows have the potential to save half of the energy consumption provided that it should be carefully designed and checked experimentally. Though many reviews are available in literature yet there is an urgent need to upgrade windows along with cost analysisfollowing guidelines being framed by many governments in their respective building code time to time. In the current review the authors have emphasized on need of investigation in regards to economical windows to reduce the payback period.

Keywords: Payback period, Daylight, Energy savings, Heat insulation solar glass, types of glass for windows.

INTRODUCTION

Developing countries are emerging and their energy consumption is also on the higher side. Residential sector is consuming about 27% energy(BEC, 2017). Globally the energy consumption trend shows14 % growth between 2000 and 2014(BEC, 2017),(IEA, 2017). This growth in energy consumption ismainly due to population growth, urbanization and ownership of appliances.(Payam Nejat;Fatemeh Jomehzadeh; Mohammad Mahdi Taheri;Mohammad Gohari;Muhd Zaimi Abd. Majid, 2015). Also CO_2 emissions from residential sector are about 17 % responsible in GHG[2] effect(Alessandra Pierucci , Alessandro Cannavale, Francesco Martellotta , Francesco Fiorito, 2018). Global energy needs will expandat the rate of 30% from present to 2040(BEC, 2017). The global demands of electricity would estimate to be increased by 40% by 2040.(World energy Outlook, 2017).To compensate these increasing demands, new policy and reforms are demanded in the building codes such as new wind power and solar PV panels(Akash Kumar Shukla, K. Sudhakar, Prashant Baredar, 2016) are to be utilized especially in china as per international energy agency report, 2017.

In the building, its envelope plays a pivotal role in energy mitigation and energy savings. This has been evidenced from the research studies that the windows and its frame that is fenestration can lower the energy consumption by 40 to 60 percent(Sharifah Nor Fairuz Syed Husin; Zarina Yasmin Hanur Harith, 2018),(Zhihua Zhou, Chendong Wang, Xinhao Sun, Feng Gao, Wei Feng, George Zillante, 2017). About 60% of the heat is lost though windows, the daylighting effect can be utilized in order to reduce heat loss(Jelle B.P.;Hynd A.;Gustavsen A.;arasteh D.;Goudey H, 2012). Windows should be carefully designed so to reduce solar heat from

[1] World Energy Outlook 2017

[2] Green House Gasses