GLASS AS A BUILDING ELEMENT – A SUSTAINABLE APPROACH:

A STUDY OF AN EXISTING ACADEMIC BUILDING

A Thesis

by

SWAPNIL SHRIRAM JORI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Construction Management

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Approved by:

Co-Chairs of Committee,	Mohammed Haque
	Liliana Beltran
Committee Member,	Boong Yeol Ryoo
Head of Department,	Joe Horlen

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ABSTRACT

Glass as a Building Element – A Sustainable Approach:

A Study of an Existing Academic Building.

(December 2010)

Swapnil Shriram Jori, B.Arch., Pune University, India

Co-Chairs of Advisory Committee: Dr. Mohammed Haque
Dr. Liliana Beltran

In the aspects of global sustainability, buildings are known to be one of the largest energy consumers. Though sustainable building construction through technological advances is helping in achieving environment friendly buildings, a considerable amount of energy is also being consumed by existing buildings. While many factors at all different stages of building life are responsible for this, the building material is one of the most important considerations. Glass being the most sensitive building material can lead to high energy consumption in the building if used in an improper way. This study takes this factor into account, and tries to investigate the potential of energy savings in buildings through the simple and basic considerations in design. An energy analysis model of an existing academic building in College Station, Texas was developed using Design Builder computer simulation software. This model was then analyzed for the total amount of energy consumption in the base case. The existing building model was then modified by replacing the glass used for external fenestrations. Latest building

codes and standards for the site location, glass properties, and parametric simulation results were taken into consideration. Again the model was simulated for annual energy consumption and the results are noted. This formed the first option for the retrofitting scenario. A hypothetical redesign scenario was also established in which the revision of building orientation was taken into consideration. The building was re-oriented to suit the weather conditions and recommendations by Advanced Energy Design Guidelines (30% energy savings over ASHRAE Standard 90.1-1999). The building was then simulated for annual energy consumption. A comparative analysis was performed between the three cases and the study concluded by showing 23% savings in the annual fuel consumption, 23.35% reduction in CO_2 emission of the building and 25% reduction in annual solar heat gain under Modified case 1. Modified case 2, however, did not show any further savings due to the form of the building (almost square). However, modified case 1 settings emitted 31.8% more CO_2 over the Energy Star office building in Texas. This methodology sets up a set of guidelines which can be followed while investigating a building for minimum annual energy consumption.

DEDICATION

For My Parents

SHRIRAM KUNDALIK JORI and SUREKHA SHRIRAM JORI

for their strong support, immense love and undying faith in me.

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NOMENCLATURE

WWR	Window to Wall Ratio
SHGC	Solar Heat Gain Coefficient
DHW	Domestic Hot Water
HVAC	Heating Ventilation and Air Conditioning
SDD	Summer Design Day
WDD	Winter Design Day
DOE	Department of Energy
AEDG	Advanced Energy Design Guidelines
T_{vis}	Light Transmission
kBtu	Thousand British thermal units
IECC	International Energy Conservation Code
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers

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1. INTRODUCTION

In today's context of sustainability and green buildings, building materials have become an important entity for the built environment. Recent globalization, industrialization, and emerging affluence of broad population segments are driving a construction boom throughout the world.

Glass is fast becoming one of the most rapidly used building materials over the world. During the industrial revolution, the availability of glass as a mass product at a considerably lowered price alongside new construction possibilities in steel and concrete allowed larger glazed areas to be realized (Bahaj *et al*., 2008). Sustainability in any building material is an important factor driving its usage and methods of use, in various ways. The skin of the building is the interface between the external and internal environment. Thus, the excessive and incoherent usage of glass in the building envelope in many cases has led to inefficient buildings. Such buildings are unable to capture and integrate the basic requirements of sustainability due to no proper considerations of the set of conditions in which the building is situated.

This thesis follows the style of *International Journal of Construction Education and Research*.

Glass and the manner of which it is used, thus plays an important role in affecting the degree of energy consumption, comfort and thus the sustainability of a building.

"Highly glazed buildings constructed in Europe and America within the modern architecture movement at the beginning of the 20th century soon revealed negative effects in terms of indoor comfort" (Bahaj *et al.*, 2008). Particularly in existing older generation of buildings, which cause a large part of the emission percentage and global sustainability, the process of redesigning the glazed components of facades to a better level of efficiency is essential. This can offer us a considerable scope to balance the overall national energy requirement and the carbon emissions of building.

1.1 Research objective

The endeavor is to investigate the potential of a building towards annual energy optimization by the impact of change of external glazing system and further change in the orientation of the building.

1.2 Research hypothesis

Total amount of energy consumption in a building reduces by improving the glass properties of the external glazing system and by making further changes in the building orientation to suit the best recommendations for site location.

Let $\mu 1$ = Total annual energy consumption in the existing case (basecase scenario)

Let $\mu 2$ = Total annual energy consumption of the building after improving the glass properties (modified case 1)

Let $\mu 3$ = Total annual energy consumption of the building after further change in the orientation (modified case 2)

Thus, the expected outcome or hypothesis is: $\mu 3 < \mu 2 < \mu 1$

1.3 Expected benefits

The outcome will benefit us in following ways

1. A set methodology to be followed while selecting glass for a particular building
2. Minimized total annual energy consumption in building
3. Reduction in solar heat gains
4. Minimized CO_2 emission of the building

1.4 Significance of study

This study is significant to architects, owners, developers, designers, and students by helping to understand the various factors guiding the usage of glass in building facades. It is also helpful in understanding the process for decision making while selecting appropriate glass for a particular project. The impact of glass and orientation on the overall energy consumption of the building can also be understood from this study.

1.5 Scope and limitations

The study is centered on understanding glass as a building material and factors associated with its usage. Many advanced technical solutions to intelligent facade designs are developing fast for contemporary buildings which are being built. However, this study is limited the simple solutions for energy optimization, outlining guidelines which determine the extents and types of glass utilized in the facade. The study is limited to only the external facades and envelope of the building and the resulting efficiency. For the purpose of this study, internal division of spaces shall not be considered for energy simulation purposes. The factors discussed are merely derived from the construction practices in College Station. This study does not deal with the operational issues of lighting and HVAC in the building.

1.6 Definitions

Occupancy density – It is the total number of people present per unit of area.

U-value – It is a measure of the rate of non-solar heat gain or loss through a material or assembly. U-values help in measuring how well a material allows heat to pass through. The lower the U-value, the greater a product's resistance to heat flow and the better its insulating value.

R-value – It is the ability of a material to resist heat transfer. The higher the R-value, the greater is the resistance of the material.

Solar Heat Gain Coefficient (SHGC) - The fraction of external solar radiation that is admitted through a window or skylight, both directly transmitted, and absorbed and subsequently released inward. The lower a window's SHGC, the less solar heat it transmits, and the greater its shading ability.

Visible transmittance - $T_{vis\text{-}glass}$ indicates the percentage of the visible portion of the solar spectrum that is transmitted through a given glass product.

Window-to-Wall Ratio (WWR) - A window to wall ratio is the measure of the percentage area of a building's exterior envelope that is made up of glazing, such as windows.

British thermal unit (Btu) - The amount of heat energy required to raise the temperature of one pound of water by 1°F at one atmosphere pressure.

Lighting Power Density (LPD) – It is the total watts per square foot for a given occupancy/space type.

Solar gain – It is the amount of energy that a building absorbs due to solar energy striking its exterior and conducting to the interior or passing through windows and being absorbed by materials in the building.

Internal gain - The heat produced by sources of heat in a building (occupants, appliances, lighting, etc).

Parametric analysis – the values generated by DesignBuilder, a software tool, to understand building performance under various heads such as total energy consumption, heating capacity, cooling capacity, comfort level, total carbon-di-oxide emission, total fuel consumption etc., with respect to various components of the building.

External infiltration – heat changes (in and out) through air infiltration (non-unintentional air entry through cracks and holes in building fabric).

Fuel breakdown – Heat generation: total fuel consumption due to operation of heat generators such as boilers and heat pumps; Lighting: electricity consumed by general and task/display lights; Room electricity: electricity consumed by room equipment other than lights (computers, laptops, equipments, printers, fax machines).

Low emissivity glass (low-e glass) - Glass that has a low-emissivity coating applied to it in order to control heat transfer through windows.

Heat gain - The amount of heat introduced to a space from all heat producing sources, such as building occupants, lights, appliances, and from the environment, mainly solar energy.

Heat loss – It is the amount of heat that flows from the building interior, through the building envelope to the outside environment.

Summer design day (SDD) – It is the hottest day in the year i.e. 15th July.

Winter design day (WDD) – It is the coldest day in the year i.e. 15th January.

2. LITERATURE REVIEW

2.1 Glass – an important building material

Discovered over 2000 years ago (Kanjilal, 2006), glass as a construction material has gained immense popularity in the building industry today. Figures 1, 2, 3, and 4 shows varied uses of glass as window, envelop, screen and structural element respectively.

Figure 1. Glass window
(Approved window systems ltd.)

Figure 2. Glass envelop
http://archilogy.com/johnsons-glass-house/

Figure 3. Glass screen
http://www.clearliving.co.ukimagesprod uctsscreensscreens-06.jpg

Figure 4. Glass – a structural element
http://www.galinsky.com/buildings/applefifthavenue /index.html

“Now that this material can fulfil nearly any task in a modern building envelope, it has been made possible to overcome the antagonism between the human basic need for protection from the outside world and the demand for natural daylight” (Elstner, 2009).

But, beyond its basic functionality, it is the versatility in usage which has allowed glass to surpass other building materials. This versatility is due to qualities like varying thickness, transparency, malleability, lightweight with unique strength and durability as well as manufacturing ease. In buildings, due to these qualities, glass has progressed from a mere ‘filler’ material to one which is very important in creating open, naturally lighted, light architecture and creative design solutions. .

During the industrial revolution the availability of glass as a mass product at a considerably lowered price alongside new construction possibilities in steel and concrete allowed larger glazed areas to be realized. However, highly glazed buildings constructed in Europe and America within the modern architecture movement at the beginning of the 20th century soon revealed negative effects in terms of indoor comfort (Bahaj *et al*., 2008). Thus, especially in recent times, excessive and incoherent use of glass has led to inefficient and high energy consuming buildings.

2.2 Glass – Used and misused

The building is a construct of a number of components enabling the creation of an enclosure space detached from the natural setting. Of these components, glass is the main material used in the facade fenestrations. Glass thus is one of the most crucial as the climate moderator and becomes the medium through which the internal space is exposed to the external elements.

While the glass is frequently used for its functionality, in the recent times, its usage to create an 'iconic' identity has increased (Aboulnaga M, 2006). This is being seen in various regions around the globe wherein the design of a building lays more importance on creating an opulent gesture than a functional space. Dubai, United Arab Emirates (UAE) is one of the notable examples of this phenomenon. While studies show that windows normally represent about 25–40% of the wall area of effectively designed daylight buildings, in some buildings, it reached up to 80–100% in fully glazed ones (Aboulnaga M, 2006). In the recent times it has become a trend in Dubai where an excessive number of buildings constructed in the past decade with a vast majority of which are almost entirely externally glazed.

Figure 5. Glazed buildings in Dubai
(Reprinted from Renewable Energy 31, pg 634)

Studies were conducted by Universal Space Studios in Al-Ain, UAE to analyze the performance of buildings based on the facades and the percentage of glazing in the envelopes of the building. A set of 15 buildings was selected demonstrating the spectrum of various ways in which glazing was incorporated in the façade system (Aboulnaga M, 2006). It was observed that the ones with low performance values had a large percentage of glazing in the facades, and consequently showed higher light transmission, shading co-efficient, and reflection values leading to a higher percentage of heat gain (Aboulnaga M, 2006). These examples were classified as low performance mainly due to the improper type of glazing.

Mumbai is another city where a large number of commercial buildings springing up are enveloped by a high percentage of glazing. Reacting to its extreme hot and humid climate, the interiors are generally becoming uncomfortable and overheated spaces with incessant glaring and usability problems. The dust and polluted environment in a metro like Mumbai affects the light transmission property of glass, and also contributes to maintenance issues of these glazed enveloped structures. Following figure 37 shows a completely glazed building in Bandra Kurla Complex, Mumbai.

Figure 6. Glazed ICICI Building – Mumbai
http://commons.wikimedia.org/wiki/File:Icicibandra_kurla_complex.png

In these two cases, the intrinsic climate conditions are particularly hot and the excessive glazing has affected the usability of the internal environments. In summers, with strong sunlight and corresponding intensity of heat, the glazing tended to cause uncomfortable overheated atmospheres within the built forms, consequently compelling the need for installation of high end air conditioning systems to cool the air within the zones. Similarly in cold conditions, heating equipment was required to maintain a comfortable workable internal space.

However, extensive utilization of heating and cooling facilities in order to compensate for the negative effects caused by large glazed areas implicitly leads to high energy consumption and, increasingly, high maintenance and electricity costs (Bahaj et al., 2008). Therefore it is important to couple aesthetics of a structure with efficiency to achieve sustainability, which is becoming one of the most essential issues in the contemporary context.

2.3 Energy saving in buildings: A significant part of building sustainability

According to Joseph Van Belleghem (2001), buildings have a tremendous impact on our lives and the Environment. Buildings use 1/3 rd of our total energy, 2/3 rd of our electricity, and 12% of our freshwater withdrawals. They are responsible for 30% of greenhouse gas emissions while generating construction and demolition waste of 136 million tons annually in the U.S.1. Buildings are a tremendous consumer of our resources using an estimated 3 billion tons of raw materials annually to construct buildings worldwide (Belleghem, 2001).

Buildings in all their phases, namely manufacturing of materials, transportation, construction, operation, maintenance, renovation, and demolition, contribute largely to the imbalance in environment. Therefore efficient design to save on energy consumption and consequently the costs, is a crucial issue in building sustainability.

2.4 Design factors driving the energy consumption in a building

There are several interrelated factors which when considered concurrently, can help to bring about a higher level of energy efficiency in a building. The annual energy consumption of a building can be a significant indication of the efficiency level of the building. Essentially, it is made up of the total fuel consumed for lighting, systems and equipment, heat generation, domestic hot water and other utilities which are involved in operational stage of the building.

The façade forms the interface between the external conditions and internal atmosphere. This research focuses on the aspects of façade which significantly guide the usage of energy i.e. mainly the glazing and the orientation.

2.4.1 Glazing

Studies show that in developing countries particularly, the majority of buildings which will be standing in 2050 have already been built (Buildings and Climate Change, 2009). Thus it can be said that, not only in new buildings, but old buildings also, type of glass chosen or changed is an important aspect of energy saving.

By far, the greatest proportion of energy is used during a building's operational phase. Though figures vary from building to building, studies suggest that over 80 percent of greenhouse gas emissions take place during this phase to meet various energy needs such as heating, ventilation, and air conditioning (HVAC), water heating, lighting, entertainment, and telecommunications (Junnila, 2004; Suzuki and Oka, 1998; Adalberth et al, 2001).

Nowadays there are also specific codes and energy standards that buildings are supposed to adhere to. Glass is one of the main façade components. 'Since glazing systems permit natural light and heat into a building, they present a significant potential energy savings (World Commission on Environment and Development, 1987).' Therefore, the studied redesigning of glazing in the facades, considering associated aspects will be a significant step in optimization of energy usage of the structures. In addition, it would be an interesting to check the potential that an existing building has towards minimizing the total energy consumption.

Properties of glass

Role of glass as an important building material has already been discussed in the earlier part of the study. The properties of glass, however, can be studied in terms of U-value, SHGC, T_{vis}, and R-value before selecting a particular type of glass. 'Modern construction entails that all exterior windows contain at least two parallel panes of glass, with insulating cavities in between. The cavity contains either air or an inert gas such as argon or krypton (Silverstein, 2007).' The infill gas makes a significant difference in thermal regulation. Argon and krypton infill suppress convection better than air, but are impractical options due to their high initial energy costs (Silverstein, 2007). ‘For further thermal protection, low-emissivity (low-e) coatings on one or more glass surfaces help prevent excessive heat gains by blocking wavelengths outside the spectrum of visible light. All of these glass components contribute to lessening the electricity load on the building and therefore reducing CO2 emissions (Silverstein, 2007).’ Double-glazed, argon-filled or krypton filled windows would not make up for the energy spent to produce them (Menzies, 2005a). The addition of a low-e coating may have an energy payback period of merely one month, and a financial payback period of five years or less (Menzies, 2005a) making it a better investment.

A study done by Menzies et al. (2005), compares the long-term cost, in money and energy of several common glass configurations. Following Table 1 shows the U-values and embodied energy for common window specifications (source, Menzies, 2005a). It concludes that the optimum glass specification is the one whose U-value effects the greatest net energy savings (Silverstein, 2007).

Table 1. U-values and embodied energy for common window specifications
(Reprinted from a Study of Glazing Design for Energy Savings in Sustainable Construction)

Window Type (glazing, infill, coating)	Specification[a]	Glazing Unit[b] U-value (W/m^2K)	Add'l Embodied Energy/Window [MJ]
Double, air, no coating	4 - 20Air - 4	2.76	standard specification
Double, air, low-e	4e - 20Air - 4	1.58	8.42
Double, argon, low-e	4e - 16Ar - 4	1.31	8.43
Double, krypton, low-e	4e - 12Kr - e4	0.94	525.04
Triple, argon, low-e	4e - 16Ar - 4 - 16Ar - e4	0.65	161.56
Triple, krypton, low-e	4e - 12Kr - 4 - 12Kr - e4	0.52	1167.14

[a]Glass specification details the width of glass pane (in mm), width of gap (mm) and infill gas, and width of second glas pane (mm). 4e represents a 4mm glass pane with one low-emissivity coating.

[b]U-value is for complete glazing unit, including glass panes, inert gas and low-e coating.

2.4.2 Orientation

The sun travels from the east to west through south and correspondingly the intensity of the sun varies as per the time of day. Orientation mainly plays a part in controlling the quality and intensity of both heat as well as light allowed within the building. In any building, in design/redesign stage, its particular facades, its functional spaces, etc. can be efficiently served when they are oriented towards appropriate directions. "The simple orientation of a building can save a significant portion of a building's energy use at no extra cost (Environmental Buildings and Energy Efficiency)". But appropriately, if a building is oriented depending on the climatic conditions of the site, it can minimize or maximize heat gain as per requirement. This would help in reducing the dependence on artificial systems and increase efficiency.

3. RESEARCH METHOD

This thesis utilizes an existing educational building as a case study. The building information in different forms has been collected from various sources mentioned under data collection section. A computer model replicating the existing scenario has been generated using computer software. This model was then simulated for the annual energy consumption. Further modifications are performed by taking into consideration the current energy design guidelines and building codes for the selected location. The building is again simulated to derive results for the modified cases. The two modified cases are based on two scenarios: Retrofit scenario and a hypothetical New Building scenario. A comparative analysis is then conducted to investigate the potential of the selected building towards energy savings and increase in the comfort levels under different scenarios.

3.1 Building selection and description

For this particular study purpose, Langford Building A, College of Architecture, at Texas A&M University Campus has been selected.

Location: This building falls under existing educational buildings and is located in the city of College Station, Texas, United States of America. Following are the coordinates of the location: Lat = 30° 36′ 5″ N, Long = 96° 18′ 52″ W. Figure 7 shows the map of the location of the city.

Selection criteria: The building used single pane clear glass and it is oriented at 45^0N. This created a strong possibility that the building will show high potential towards energy efficiency. Also, easy accessibility for data collection, regular visits, access to interior spaces, time-bound study, and understanding various functions in the building are the other reasons behind selecting this particular building.

Figure 7. Location of College Station, Texas, USA
http://www.bestplaces.net/city/College_Station-TX.aspx

Building character: This building was constructed in the year 1975 (HKS Architects, 1975). It uses reinforced cement concrete and glass as the major construction materials for the structure and fenestrations respectively. Building photographs were taken from interiors and exteriors in order to visualize various spaces. Figure 2 shows the North external view and Figure 3 shows the South external view of the building.

Space planning: This building incorporates various departments such as Architecture, Construction Science, Landscape, Land Development and Urban Design, and Visualization. There are computer labs, offices, studios, classrooms, meeting rooms, seminar halls, corridors, and lobby spaces along with cafeteria, and restrooms. All these spaces are connected by staircases and an elevator. Rooms are distributed on four floors with an atrium space in the centre which allows natural light from North, to enter the building through skylights. Figures 4 and 5 show the interior views of the atrium space and overlooking corridors. To sum up, it is a mix-use educational building.

Figure 8. North external view

Figure 9. South external view

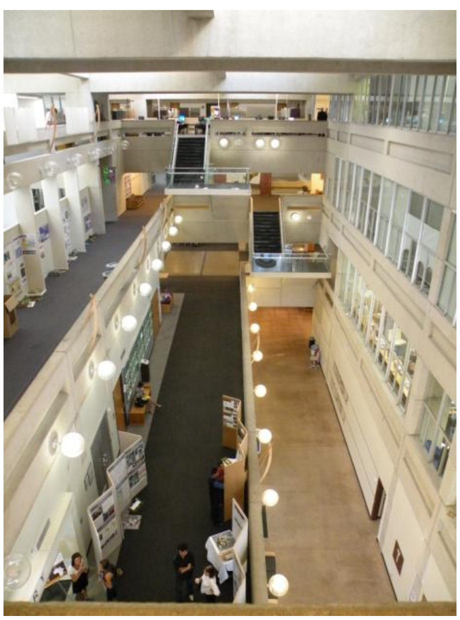


Figure 10. Atrium space – View 1

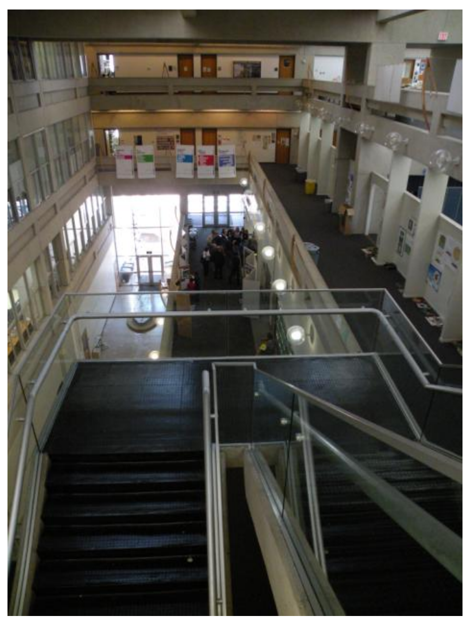


Figure 11. Atrium space – View 2

3.2 Data collection

Data collection took place after the selection of the building for the study. The blue prints and the complete set of original working drawings of Langford A Building has been collected from the Physical Plant at Texas A&M University. Table 2 shows the floor area tabulations for Langford, Building A (General data and criteria, sheet A-1, HKS). The five floor plans in the AutoCAD file format have been collected from the Facilities Coordination Department, Texas A&M University. Refer Appendix A for all the floor plans of the building. These overall drawings (plans, sections, and elevations) were used to study the building geometry and specifications.

Table 2. Floor area tabulations

Floor	**Area (sq. ft)**
First	23,832
Second	24,283
Third	27,524
Fourth	20,304
Total	95,943

For this particular study, DesignBuilder, a software tool, has been used for building simulation purposes. The pre-release Beta Test version 2.3.5.011 was used. DesignBuilder uses EnergyPlus 5.0 for performing energy simulation calculations.

Since this thesis is analyzing the existing building for the overall energy use, it was very essential to derive all the parameters and material properties in the existing scenario. Then only it would have been possible to generate a computer three dimensional model of the building, in order to develop the existing case in the software tool. For this purpose, various calculations were carried out to derive the existing Lighting Power Density (LPD), Occupancy, Occupancy Schedule, and Window to Wall Ratio (WWR). Refer Appendix A.

Lighting Power Density (LPD)

Each floor of the building has been divided into two zones i.e. Open Floor Plan and Atrium. Accordingly, different LPDs were calculated for each of them. Table 3 shows the calculated LPD for each type of space in the building.

Table 3. Lighting Power Densities in Langford Building A

Typical space	**Lighting Power Density (W/sq.ft)**
Computer Lab	3.28
Studio	2.84
Office	2.52
Corridor	2.62
Restroom	2.63
Lobby	1.80
Central Atrium	0.30

Occupancy

The College of Architecture cluster is divided into three buildings i.e. Langford A, B and C. The current number of students is 1900 and faculty and staff is around 180 (www.arch.tamu.edu). However, actual users of Langford Building A are less due to the presence of Langford Buildings B and C. For this reason, the total number of occupants in the Langford A Building were counted randomly on Wednesday, September 8th, 2010 at 1.00 pm. This gives an approximate occupancy value. The overall occupancy density was calculated as 0.007181 (people/sq.ft). Table 4 shows the occupancy and occupancy density on each floor of the building.

Table 4. Building occupancy

Floor	**Occupancy (sq.ft/person)**	**Occupancy density (people/sq.ft)**
First	127.44	0.007846
Second	126.47	0.007907
Third	162.86	0.006140
Forth	144.00	0.006944

Occupancy schedule

For a typical week, classes and lectures are conducted during weekdays whereas weekends are holidays. The peak occupancy schedule is during weekdays from 8.00 am to 6.00 pm. After 6.00 pm, the occupancy is approximately 1/3rd of the peak time occupancy, till midnight. The building almost remains empty from midnight till 8.00 am. During weekends, occupancy remains 1/3rd. Irrespective of the occupancy; the lights remain turned on 24 hours a day. For the input purpose of the software tool, typical occupancy schedule has been developed (Table 5). The fraction values of the occupancy are used according to the software restrictions.

Table 5. Occupancy schedule

Period: 1st Jan-31st Dec	**Time**	**Occupancy fraction**
Weekdays	8.00 am – 6.00 pm	1.00
	6.00 pm – 12.00 am	0.33
	12.00 am – 8.00 am	0.00
Weekends	24 hours	0.33

Window to Wall Ratio (WWR)

For this particular study, understanding the percentage of the glass used in the external fenestrations was very important. For hot regions, excessive amount of glass used leads to the solar heat gain in the building interiors. Thus, the scope for the improvement in the interior conditions of the building depends on the amount of glass used externally. DesignBuilder, the computer tool requires the Window to Wall ratio to be inputted. In order to achieve this value, WWR was calculated manually by using areas of glazed and non-glazed surfaces of the four facades of the building. The calculated value of the overall WWR is 0.6. Table 6 gives the WWR for each floor of the building.

Table 6. Window to Wall Ratio for each floor

Floor	**Window to Wall ratio**
First	0.68
Second	0.75

Table 6 Continued

Floor	Window to Wall ratio
Third	0.50
Forth	0.55
Overall	0.60

3.3 Energy analysis model development

The experiment has been conducted by using DesignBuilder computer program and by considering the above mentioned existing conditions of the building. Initial step was to generate a three dimensional computer model of the building. For this purpose, AutoCAD drawings were used to follow the exact geometry of the building. A model was then generated and appropriate building materials were selected for the building elements from the DesignBuilder (simulation tool) library and with reference to the blue prints of the building. The four floors of the building were treated as four “blocks” by the simulation tool. Each block (floor) is comprised of two “zones,” one being the open floor plan and the other is the central atrium. The central atrium connects all the four levels (Appendix B). The building has been originally designed with heavy and distinctive external shading devices. These shading devices comprise of staircase blocks, mechanical shafts, vertical and angular fins, and horizontal projections. These were modeled as “component blocks” in the simulation tool. The component blocks are not considered by the simulation tool while performing energy calculations. However, they play an important role in solar calculations by casting shadows on the building through the course of the day. The existing skylights facing north were placed over the atrium space in the computer model. The energy simulation model of the building is then rendered for true visualization purposes. Figure 12 and 13 shows the screen captured images of the North and South external view of the building respectively.

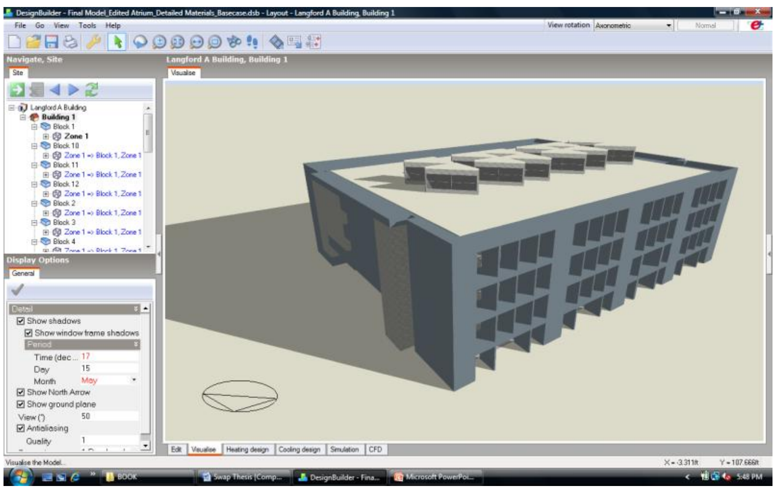


Figure 12. North view of energy simulation model

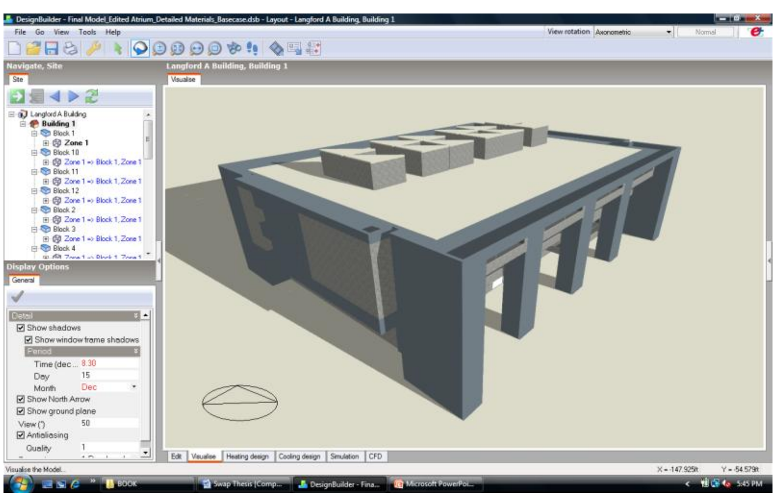


Figure 13. South view of energy simulation model

3.4 Basecase

First step was to understand the performance of the existing building (basecase) under different factors. DesignBuilder offers various data input tabs so that the user can model and develop the exact scenario as it would be in the designed building. For the base case, the physical characteristics of the existing building were derived and the best fit options were selected in the software tool. This was done in order to develop a realistic study rather than a virtual one. Table 7 describes various data input tabs along with the various parameters which were set for the simulation of the existing building.

Table 7. Data input for base case

Data input tab	**Category**	**Selection**
Site	Location	College Station Easterwood
	Region	Texas, USA
	Orientation	315^o
	Mandatory energy code	IECC-2000
Activity	Sector	Higher Education Universities
	Occupancy density	0.007181 (people/sq.ft)
	Schedule	Compact schedule
	Heating setpoint	70 (^{o}F)
	Cooling setpoint	78 (^{o}F)
	Target illuminance	27.87 (fc)
	Lighting power density (LPD)	2.5 (W/sq.ft)
	Computers + Office equipment	ON- 2.78 (W/sq.ft)

Table 7 Continued

Data input tab	**Category**	**Selection**
Construction	Sector	Mass concrete construction
	External Walls	Mass concrete reinforcement
	Roof	Flat roof
	Sub-surfaces (walls)	Gypsum plaster board with lightweight metallic cladding
	Component blocks	High density concrete
Openings	Glazing type	Single clear 6mm thick
	Layout	Horizontal strip, 60% glazed
	Type	Continuous horizontal
	Window to Wall percent	60%
	Frame	Aluminum window frame
	Window shading	Blind-with low reflectivity
Lighting	General lighting	ON
	Lighting energy	0.09 (W/sq.ft/fc)
HVAC	Template	Fan-coil unit
	Mechanical ventilation	ON
	Heating	ON
	Cooling	ON
	Domestic hot water (DHW)	ON
	Natural ventilation	OFF

3.4.1 Simulation results

This Basecase model was then run for the various output results with respect to heating, cooling, and simulation. The accuracy, completion, and time for simulation depend on the complexity of the model, level of simulation, and the computer system. This particular building model was complex and required a high performance computer system to carry out accurate calculations. Accordingly, only annual level simulations were performed to simplify the process. DesignBuilder performs calculations for each parameter of the building and gives the outputs for the same. However, only those outputs related with exterior glazing were considered and analyzed.

Heating and cooling

The heating design details were calculated by the DesignBuilder for the Winter Design Day i.e. January 15th (coolest day) and cooling design details were calculated for Summer Design Day i.e. July 15th (hottest day). Since the building has been installed with 6mm single clear glass, the heat gains and losses are expected to be high as far as external glazing is concerned. Figure 14 shows the heat gains and losses from various physical elements of the building as performed on January 15th (Winter Design Day).

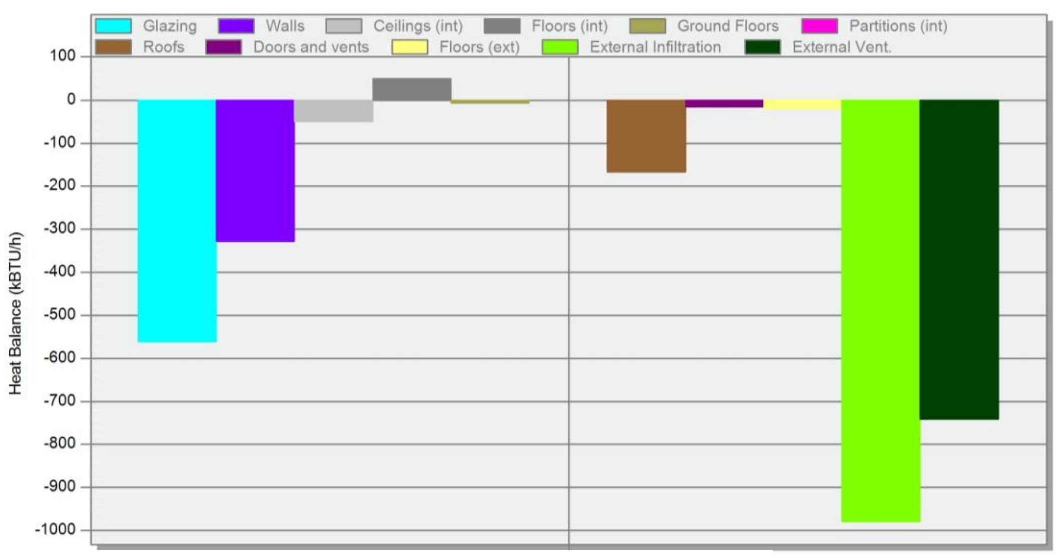
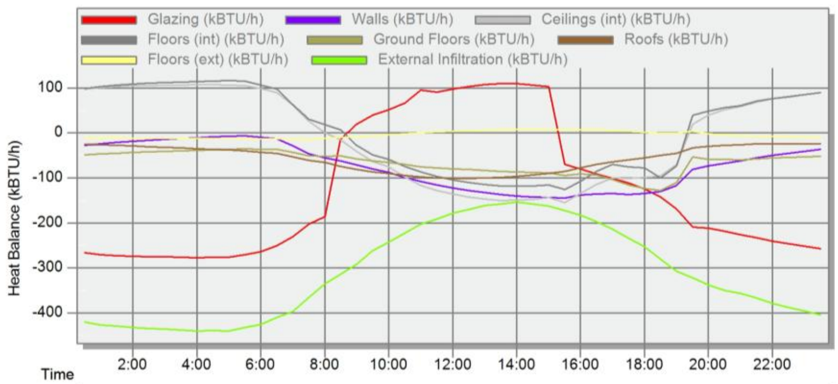


Figure 14. Heat balance – 15th January – Basecase

As it can be seen from figure 14, Glazing accounts for a total heat loss of 562.41 kBtu/h. This value is high because of the use of single pane clear glass. Also, for the Summer Design Day (15th July) glazing plays an important role in the heat gains and losses of the building through the course of the day. Figure 15 shows the Heat balance graph of the building on July 15th.

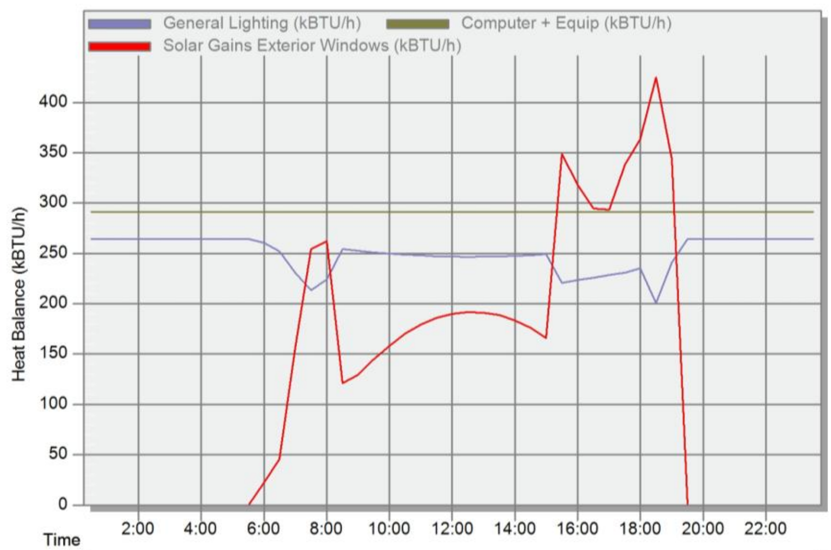


Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Glazing (kBTU/h)	-274.32	-277.23	-263.74	-186.25	52.27	97.74	109.49	-79.66	-125.14	-212.01	-240.54
Walls (kBTU/h)	-18.57	-10.37	-9.12	-55.27	-87.95	-121.94	-139.96	-138.50	-134.72	-73.05	-49.78
Ceilings (int) (kBTU/h)	104.77	107.20	98.75	0.74	-75.72	-136.16	-148.94	-134.92	-99.21	39.74	75.78
Floors (int) (kBTU/h)	108.95	114.33	106.17	18.47	-58.87	-104.34	-117.62	-107.62	-77.82	48.07	76.73
Ground Floors (kBTU/h)	-43.60	-38.45	-36.12	-52.49	-65.49	-79.43	-86.77	-91.44	-123.70	-58.30	-55.83
Roofs (kBTU/h)	-29.03	-34.84	-42.72	-65.67	-89.82	-101.11	-96.13	-77.17	-54.90	-29.61	-23.86
Floors (ext) (kBTU/h)	-11.48	-12.21	-12.96	-12.39	-4.11	3.86	8.10	7.63	1.63	-1.71	-7.89
External Infiltration (kBTU/h)	-432.87	-439.90	-426.11	-335.97	-243.10	-178.55	-153.61	-182.25	-253.35	-337.52	-379.40

Figure 15. Heat balance – 15th July – Basecase

Above figure 15 is the software tool output which clearly shows that the majority of the heat flow from external atmosphere to internal during day time through glazing is from 8:30 am to 3:15 pm. The tabulated information in the diagram shows the values of heat gains and losses through different physical elements of the building over a time period of 24 hours. The extent and type of glazing is responsible for the extremes of the heat gains and losses in the building. There is a high rate of external infiltration due to temperature difference between the external and internal conditions. As stated in the

DesignBuilder tutorials, fabric and ventilation data (above figures 14 and 15) only show the total heat flow to the building from the glazing, frame and divider of exterior glazing excluding transmitted short-wave solar radiation. The solar gains output gives the short-wave solar radiation transmission through all external windows. With reference to the tutorial, for a bare window, this transmitted radiation consists of solar radiation passing through the glass and diffused radiation from the outside source, if present. Figure 16 shows the sub-hourly heat balance information in terms of general lighting, computer, and equipment and solar gains through exterior windows on 15th July. The unit of measurement is kBtu/h.



General Lighting (kBTU/h)	264.17	264.17	260.74	223.91	250.00	246.93	247.69	223.70	235.47	264.17	264.17
Computer + Equip (kBTU/h)	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37
Solar Gains Exterior Windows (kBTU/h)	0.00	0.00	22.93	261.98	158.15	189.98	183.55	318.32	363.25	0.00	0.00

Figure 16. Internal heat gains – 15th July – Basecase

The peak values during morning and evening time indicates that there is direct solar penetration in the building causing high amount of solar heat gains. When sun is at east and west direction, the sun angle is low and enters directly into the building interiors (Appendix C). Throughout the day, the solar gains stay above 100 kBtu/h and touching the peak value of over 400 kBtu/h during the sunset.

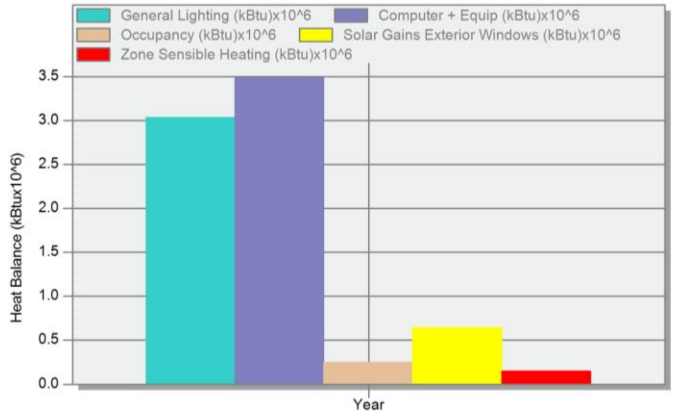
Since the building is located in hot climate zone, the cooling requirements are almost double as compared to the heating requirements. Table 8 shows the total heating and cooling design capacities for the basecase simulations.

Table 8. Energy loads for basecase

Type	**Loads (kBtu/h)**
Heating	3392.55
Cooling	7773.70

Annual simulations

Figure 17 shows the total annual internal gains for five categories. With reference to the DesignBuilder tutorials, these categories are: General Lighting - heat gain due to common lighting; Computer and Equipment - heat gain due to computer and other IT - related equipment; Occupancy – sensible gain due to occupants; Solar Gains Exterior Windows – short-wave solar radiation transmission through all external windows; Zone Sensible Heating – it is the sensible heating effect of any air introduced into the building through HVAC system. The data for annual simulations is available at building level only.



General Lighting (kBtu)x10^6	3.03
Computer + Equip (kBtu)x10^6	3.49
Occupancy (kBtu)x10^6	0.25
Solar Gains Exterior Windows (kBtu)x10^6	0.64
Zone Sensible Heating (kBtu)x10^6	0.15

Figure 17. Annual internal gains – Basecase

Total fuel consumption for one year for the building is given by Figure 18 below. Fuel was in the form of Electricity. Thus, the total consumption of electricity for the base case was 8.235 x 10^6 kBtu/h.year. Figure 19 talks about the fuel breakdown into five categories as per their consumption. According to DesignBuilder tutorial, Room Electricity is the electricity consumed by room equipment other than lights (computers, equipments); Lighting is the electricity consumed by general and task lights; Heat Generation is the total fuel consumption due to operation of heat generations such as boilers and heat pumps.

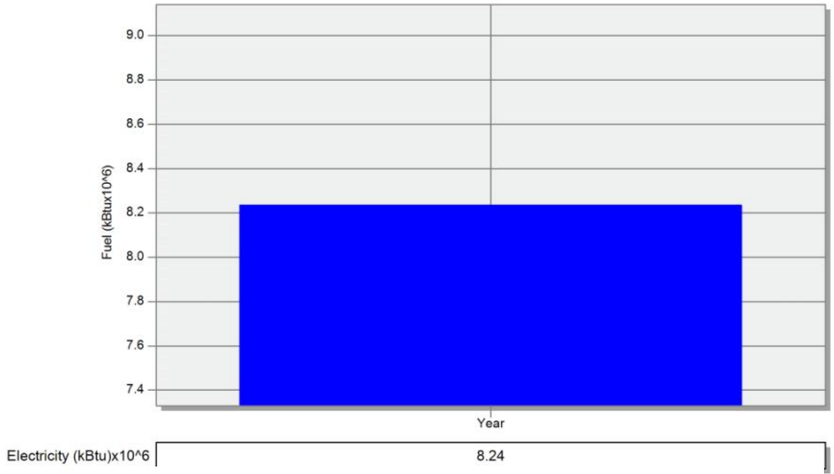


Figure 18 . Total fuel consumption – Basecase

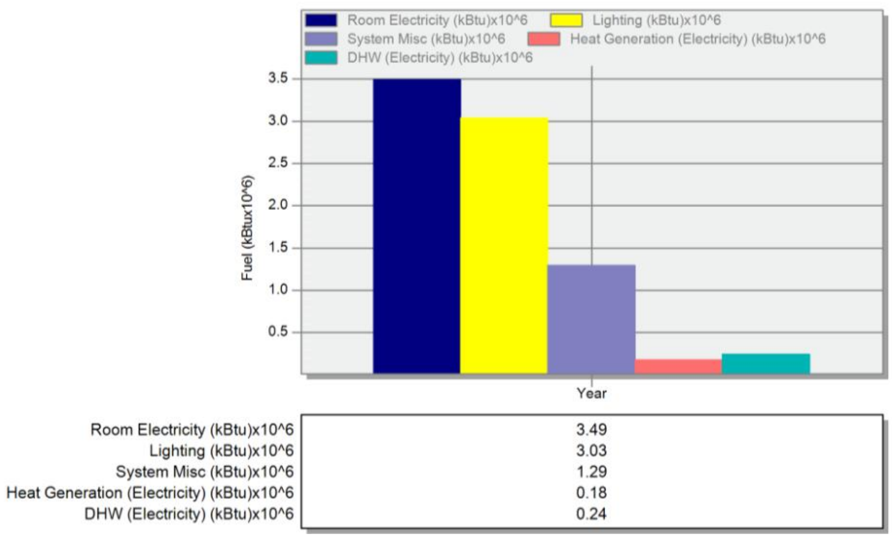


Figure 19 . Fuel breakdown - Basecase

The Carbon Di Oxide emission of the building must be taken into consideration. Figure 20 gives the total CO_2 emissions of the building in the existing case. It is 3.645 x 10^6 lb/year. According to Energy Star Program, a typical office building in Texas is responsible for emission of 30 lbs of CO_2 per square feet. Thus, this building covering

95,943 sq.ft of area should be responsible for 2.87 x 10^6 lb/year of CO_2 emission, but it is much higher. There is high scope to reduce this CO2 emission value.

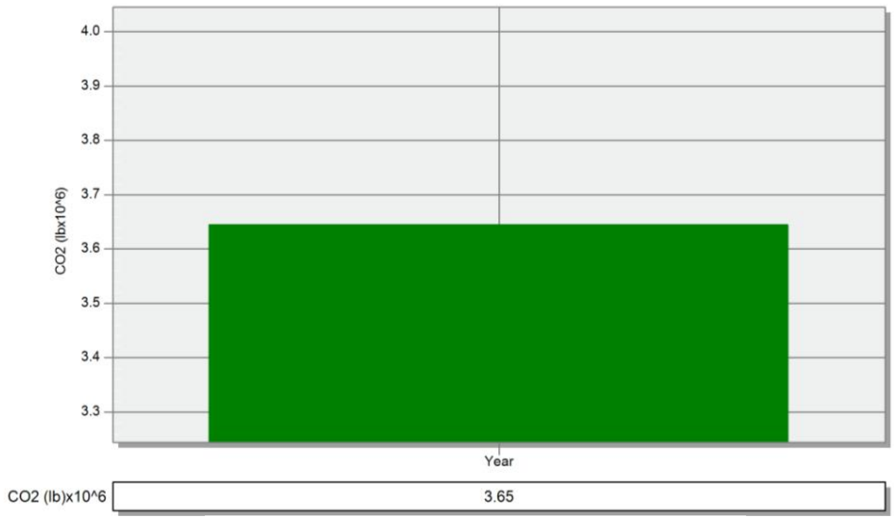


Figure 20 . Total CO_2 emission - Basecase

3.5 Modified Case 1 – Retrofit scenario

The second step was to investigate the effect of change in the exterior glazing over the energy consumption of the existing building. This approach helped in taking minimum retrofitting efforts to make the existing conditions better. For this particular process, four types of glass were shortlisted based on the literature review, market availability (Appendix D), and specifications as per Advanced Energy Design Guidelines (AEDG) and American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). The physical properties of glass such as U-value, R-value, Solar Heat Gain Coefficient (SHGC) and Light Transmission ($T_{vis)}$ needs to be taken into consideration before selecting a particular type of glass for a particular project. The building performance depends basically on these values since glass is the main source of entry for the daylight into the building interiors. Figure 21 shows the eight climate zones indentified by United States Department of Energy (DOE). Based on these climate zones Advanced Energy Design Guidelines (AEDG) gives a set of recommendations for achieving energy efficiency for any building.

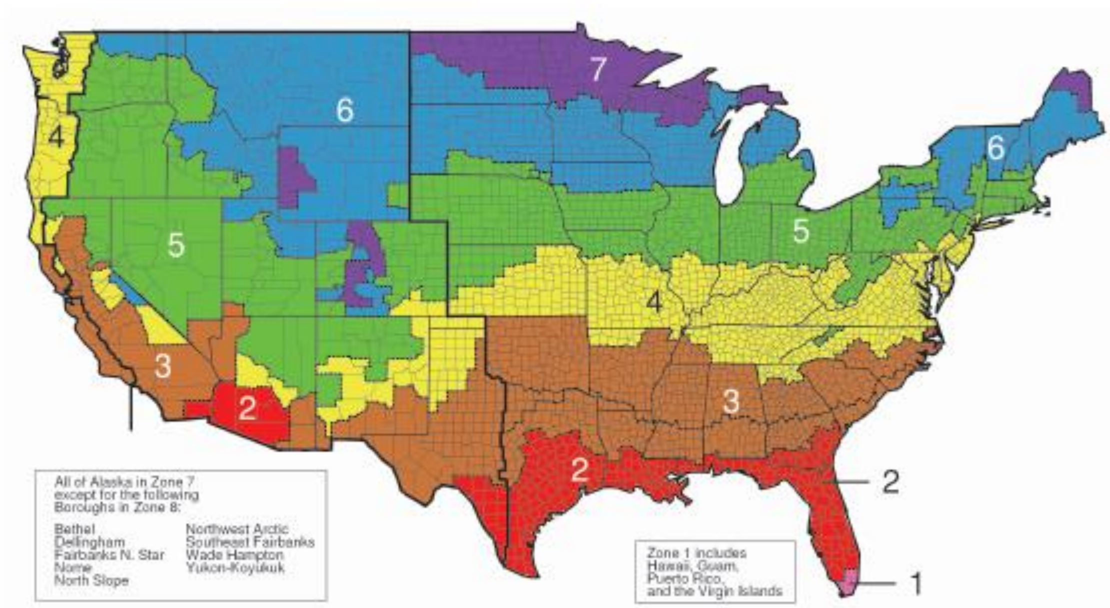


Figure 21. Climate zone map – U.S. Department of Energy
http://www.energycodes.gov

College Station (Brazos County) falls under zone two. Thus, the design recommendations of the AEDG were referred for this particular zone. ASHRAE Standards 90.1-2007 and Standard 189.1-2009 were also referred to derive the building requirements in terms of glass properties. Again, Zone 2A (standard 90.1-2007) was followed for location of College Station. Following table 9 gives the summary of the building requirements as per AEDG and ASHRAE.

Table 9. Specific standards for College Station, Texas

Elements	**AEDG**	**ASHRAE 90.1-2007**	**ASHRAE 189.1-2009**
WWR (%)	20 – 40	0 – 40	0 – 40
Fenestration (U-value)	0.45	0.75	0.75
Fenestration (SHGC)	0.31, N-0.44	0.25 all	0.25 all
LPD (W/ft2)	0.90	1.20	1.00

DesignBuilder can perform a Parametric Simulation where a particular element of the building (parameter) can be selected and simulations are run to understand its effect on the overall performance of the building. This is very useful at a conceptual or decision making stage to understand how the building performance is affected by variations in parameter. It was for the benefit of this study that a right glazing was selected amongst the four shortlisted types of glazing. Accordingly, a parametric simulation was run for each one of them and the readings were noted in form of a matrix. DesignBuilder has a database for all the building materials. After choosing the right composition of materials, the material properties were calculated. They were also included in the matrix. Table 10 shows the five types of glass (including the existing one), their physical properties which are mentioned above, and the parametric simulation results.

Table 10. Glass matrix – Properties and parametric simulations

	Glass properties: Values calculated by DesignBuilder				**Parametric analysis results: Langford A Building Period: 1st Jan – 31st Dec**		
	U-value (Btu/h.ft2.F)	**R-value**	**Solar heat gain co-effi. (SHGC)**	**Light transmission (T_{vis})**	**Total energy (kBtu x 10^6)**	**Total CO2 emission (lb x 10^6)**	**Absorbed solar gains (W/ft2 x 10^3)**
Single Clear 6mm glass (Existing case)	1.07	0.93	0.81	0.88	2.413	1.653	192.02
Single Clear Low-E 6mm glass	0.75	1.33	0.71	0.81	2.412	1.652	186.47
Double Clear Low-E 6mm/13mm Air gap	0.31	3.22	0.56	0.75	2.409	1.650	169.80
Double Clear Low-E 6mm/13mm Argon gap	0.26	3.84	0.56	0.75	2.409	1.650	169.80
Triple Clear Low-E 6mm/13mm Air gap	0.21	4.76	0.30	0.45	2.410	1.65	153.96

From the above matrix, it was clear that double clear low-e 6mm thick glass was much better in performance than the single pane 6mm clear glass (both normal and low-e). Triple clear low-e glass gives the lowest values for the U-value, SHGC, and absorbed solar gains by offering much higher resistance, but the visible light transmission (T_{vis}) is below fifty percent. As double low-e glass with air gap is way above the minimum requirements of the AEDG and ASHRAE and offers 3/4th of the visible light transmission, it has been selected to replace the glass in the basecase.

Table 11 gives the changes made in the data input tab for Modified Case 1. Rest of the information from Table 7 has been kept intact. As per Table 9 above, the LPD value has been lowered down to 0.9 W/sq.ft. Separate study shall be carried out to try various options for replacing the existing high wattage bulbs by the energy efficient products available in market.

Table 11. Changes in basecase

Category	**Selection**
Mandatory energy code	ASHRAE 90.1-2007
Lighting Power Density (LPD)	0.90 W/ft2 (table 7)
Target illuminance	30 fc
Glazing type	Double low-e clear glass 6mm thick with 13mm air gap
Window Shading	High reflectance diffusing blinds – low reflectivity
Lighting energy	0.03 W/ft2/fc

3.5.1. Simulation results

This modified model was again run for the retrofitting option for various output results with respect to heating, cooling, and simulation. The same outputs as noted in the basecase above were recorded for comparative analysis purpose.

Heating and cooling

Again, the heating design details and cooling design details were calculated by DesignBuilder for Winter Design Day (15th January) and Summer Design Day (15th July) respectively. Figures 22 and 23 show the DesignBuilder output for the Fabric and Ventilation values of the building elements on these two particular days. On the Winter Design Day, the heat loss through the glazing is 515.51 kBtu/h, whereas on the Summer Design Day, it is 961.95 kBtu/h.

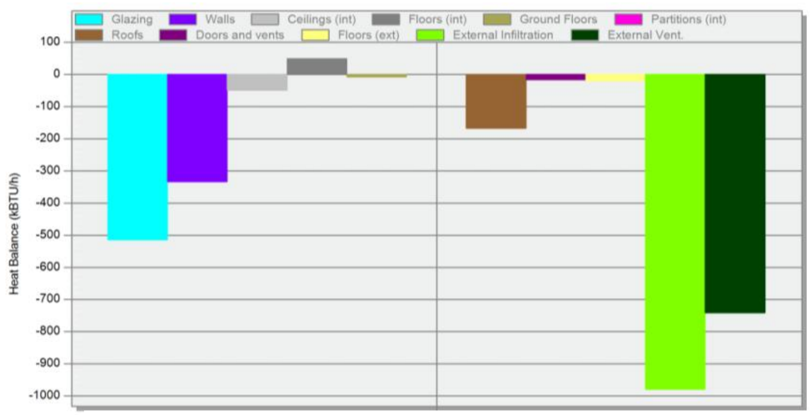
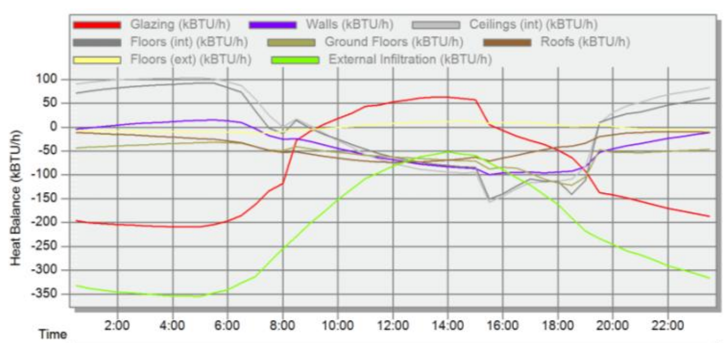


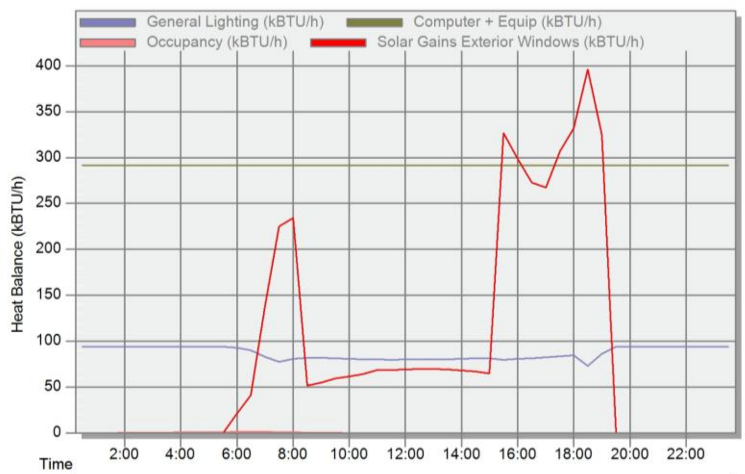
Figure 22. Heat balance – 15th January – Modified case 1



Glazing (kBTU/h)	-204.60	-208.85	-197.26	-117.59	17.87	52.75	63.31	-6.80	-48.12	-142.09	-170.57
Walls (kBTU/h)	4.36	11.75	13.04	-25.61	-44.22	-68.70	-83.26	-96.12	-94.27	-45.17	-23.61
Ceilings (int) (kBTU/h)	99.26	102.78	95.48	0.46	-28.04	-75.83	-94.23	-144.54	-112.96	30.89	68.04
Floors (int) (kBTU/h)	82.61	89.95	83.16	-13.49	-25.48	-62.43	-80.64	-140.27	-113.59	20.18	46.04
Ground Floors (kBTU/h)	-39.13	-34.56	-32.90	-49.07	-52.69	-62.41	-68.89	-84.37	-117.10	-52.42	-50.48
Roofs (kBTU/h)	-15.01	-20.90	-28.92	-52.83	-64.81	-73.47	-68.86	-64.65	-41.42	-15.60	-9.38
Floors (ext) (kBTU/h)	-8.67	-9.44	-10.26	-9.84	-0.48	7.75	11.97	10.11	4.55	1.39	-4.94
External Infiltration (kBTU/h)	-345.53	-353.90	-341.49	-254.48	-152.02	-81.55	-52.25	-88.64	-161.90	-245.42	-290.68

Figure 23. Heat balance – 15th July – Modified case 1

Figure 24 gives the sub-hourly heat balance in terms of general lighting, computer, and equipment and solar gains through exterior windows and the unit of measurement is kBtu/h. The maximum solar gains occur at the start and end of the day from East and West sun position. From 8:30 am to 3:00 pm, the solar heat gain stays comfortably below 100 kBtu/h while touching the maximum value of 331.58 kBtu/h. In this case, there is reduction in the solar heat gain due to the use of double pane of low emissivity glass.



General Lighting (kBTU/h)	94.09	94.09	92.95	80.77	80.64	79.85	80.61	80.70	84.59	94.09	94.09
Computer + Equip (kBTU/h)	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37
Occupancy (kBTU/h)	0.02	0.62	1.16	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Solar Gains Exterior Windows (kBTU/h)	0.00	0.00	20.98	234.16	61.54	69.05	68.17	298.53	331.58	0.00	0.00

Figure 24. Internal heat gains – 15th July – Modified case 1

Due to the improper orientation, two facades get direct exposure to east and west sun position. This was the important reason for high heat gains during peak times. Table 12 shows the total heating and cooling design capacities for the modified case 1 simulations.

Table 12. Energy loads – Modified case 1

Type	Loads (kBtu/h)
Heating	3343.17
Cooling	7671.22

Annual simulations

Figure 25 gives the internal gains of the building in the modified case 1, for a period of one year. The majority of the gains are from the computers and office equipments whereas general lighting is second major contributor to the internal gains of the building.

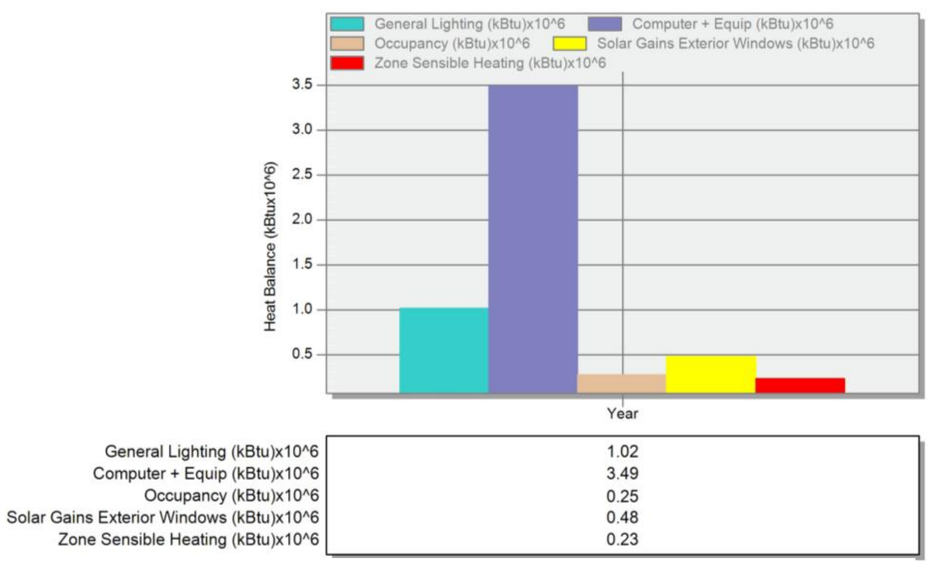


Figure 25. Annual internal gains – Modified case 1

Figure 26 gives the total fuel consumption in the modified case 1. Thus, the annual consumption of electricity is 6.32 x 10^6 kBtu/h. This fuel is consumed under five categories shown in Figure 27. It gives the breakdown of the fuel (electricity) over a period of one year. Room electricity had the largest share of the total fuel which was 3.49×10^6 kBtu/h. Lighting and System Miscellaneous shared almost the same amount of fuel.

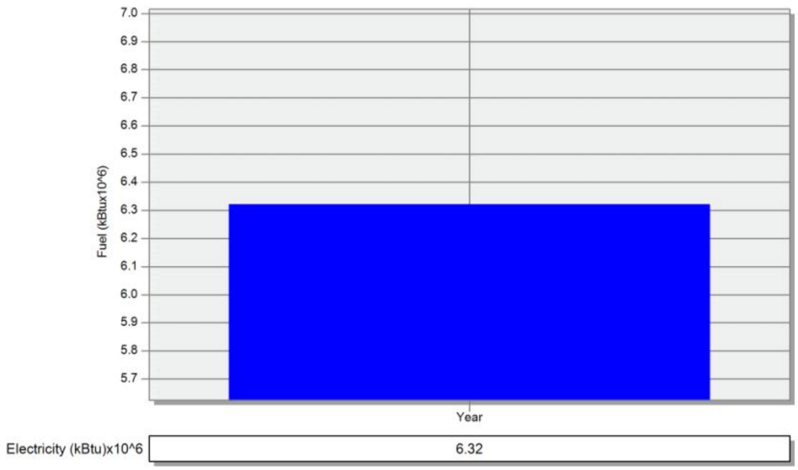


Figure 26. Total fuel consumption – Modified case 1

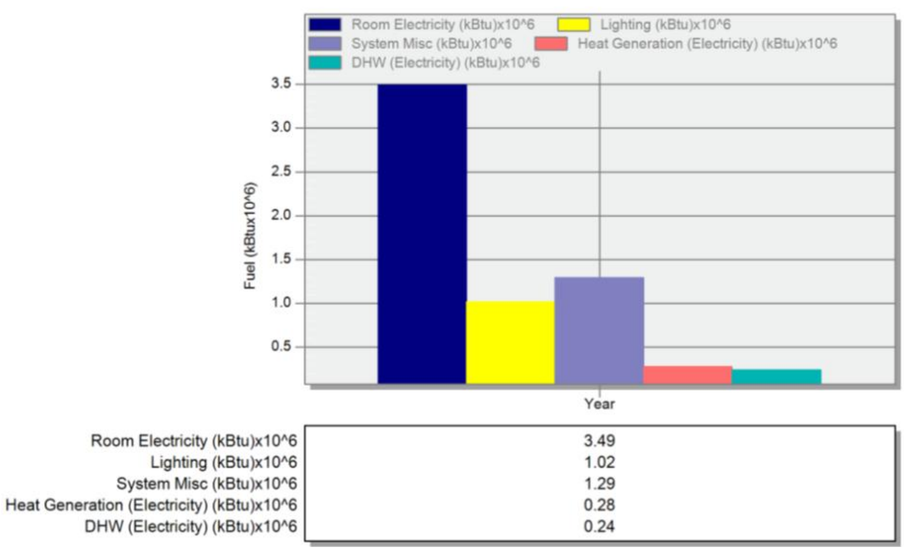


Figure 27. Fuel breakdown – Modified case 1

Figure 28 gives the total Carbon Di Oxide emission of the building in the modified case 1. It is 2.80 x 10^6 lb/year which is equal to 29.18 lbs/sq.ft. The Energy Star Office Building is said to have CO_2 emission of 22 lbs/sq.ft which is much less than the results in the Modified case 1.

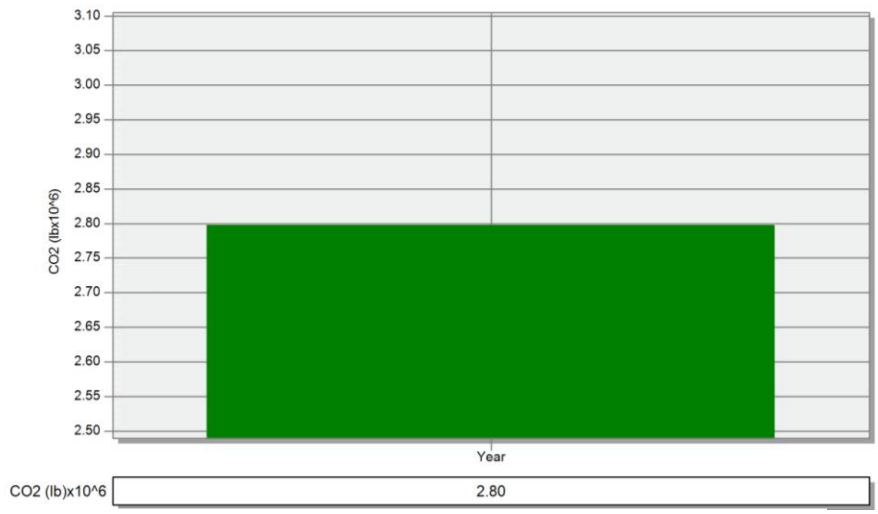


Figure 28. Total CO_2 emission – Modified case 1

3.6. Modified Case 2 – Redesign (hypothetical) scenario

Third step was to investigate the potential of the building for energy optimization with the impact of change in orientation. This was a hypothetical scenario. It was not a feasible and practical scenario, but the only intention was to understand role of orientation of a building with respect to its location and energy consumption. In the previously discussed literature review section, it was brought to light that the orientation of the building plays an important role in its annual energy consumption. The building layout needs to follow the best orientation recommendations for that particular climate zone. A process was carried out in order to investigate whether the existing orientation of the building is justified for minimum energy use or if there was a better alternative to it. To begin this process, the existing orientation of the building was derived from the site plan available in the blue prints. Figure 29 shows the orientation of the building as 315^0 to North and Figure 30 shows plan view of the building model orientation.

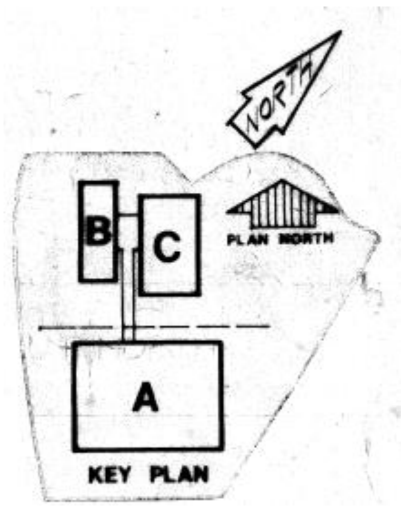


Figure 29. Site orientation – Reprinted from blue prints

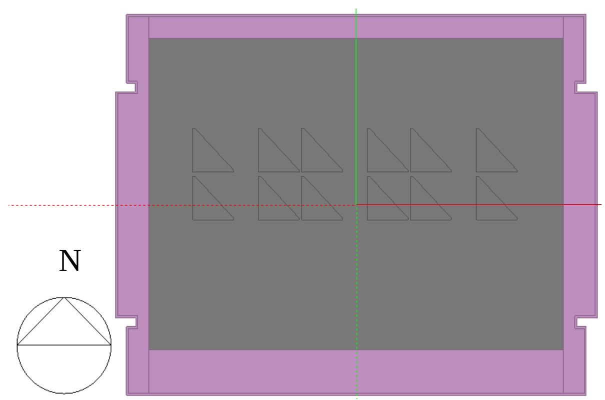


Figure 30. Site orientation – Building model – Plan view

Next task was to decide the best orientation for buildings in this particular location i.e. College Station (Brazos County). The Advanced Energy Design Guidelines (AEDG) was referred for the recommendations. According to the suggestions in AEDG, in hot climate zones, buildings suffer more harm from east and west facades than the north and south in terms of solar heat gain and glare. This is mainly because on the east and west, sun is at a lower angle and penetrates deep into the building interiors, whereas the sun angle is much higher when it is on the south side. Horizontal projections on the south face keep the sun away and vertical fins on east and west facades keep morning and evening sun in control. North façade does not need any shading devices since it does not receive direct sunlight. Figure 31 shows the AEDG recommendations for the orientation of building in a hot climate zone (zone 2 for Brazos County).

Figure 31. Orientation recommendations for zone 2 - AEDG

Langford A building follows the third orientation from left which is stated as BAD. The building is not elongated, so it can be hypothetically oriented as per the second option from left which is OKAY. It could be hypothetically said that if this building was oriented as per the second option from left in above figure 31, then it would have been more energy efficient. For this purpose, the modifications done in above section 3.5 – Modification Case 1, were kept intact, the orientation of the building was changed to 0^0 North, and energy simulations were run on DesignBuilder to calculate energy consumption details.

3.6.1. Simulation results

This modified model was again run for the redesign (hypothetical) option for various output results with respect to heating, cooling, and simulation. The same outputs as noted in the above two cases were recorded for comparative analysis purpose.

Heating and cooling

Figures 32 and 33 show the DesignBuilder output for the Heat Balance values of the building components on 15th January and 15th July respectively. On the Winter Design Day, the heat loss through the glazing is 519.24 kBtu/h, whereas on the Summer Design Day, it is 922.24 kBtu/h.

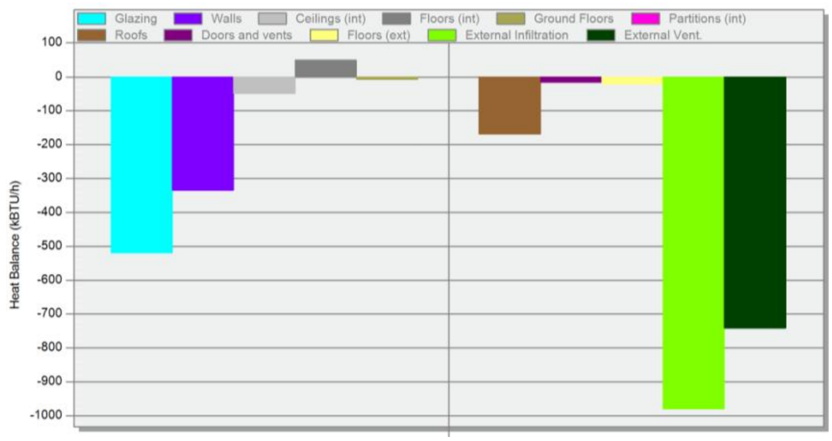
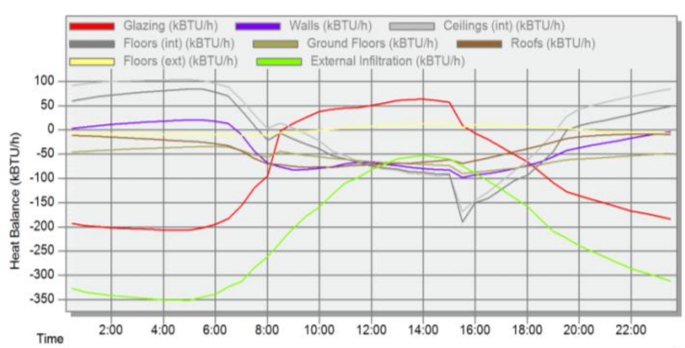


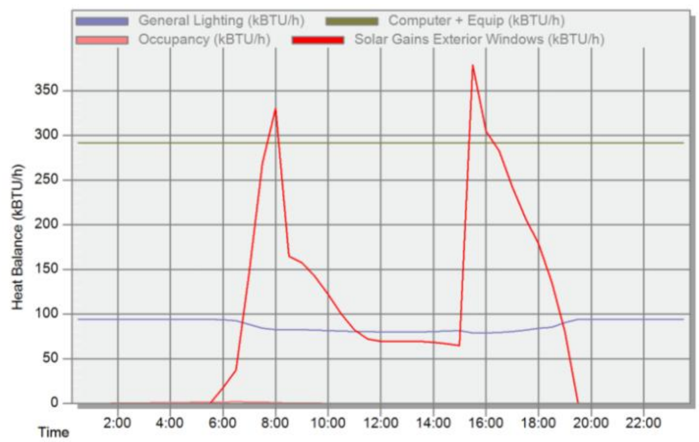
Figure 32. Heat balance – 15th January – Modified case 2



Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Glazing (kBTU/h)	-201.85	-206.45	-195.18	-95.62	38.23	50.29	63.02	-6.83	-65.44	-135.98	-167.15
Walls (kBTU/h)	11.04	17.91	17.75	-67.82	-78.71	-67.53	-79.50	-92.63	-73.52	-36.91	-17.01
Ceilings (int) (kBTU/h)	99.65	102.93	96.45	3.11	-22.78	-75.64	-90.97	-144.71	-63.15	42.00	69.06
Floors (int) (kBTU/h)	72.01	80.69	78.09	-21.34	-39.14	-74.39	-87.65	-150.12	-93.37	8.20	31.82
Ground Floors (kBTU/h)	-41.18	-36.73	-34.39	-56.24	-54.83	-65.29	-70.89	-86.96	-75.26	-60.11	-53.56
Roofs (kBTU/h)	-14.71	-20.66	-28.44	-69.59	-76.24	-71.96	-66.19	-63.62	-38.86	-14.31	-9.10
Floors (ext) (kBTU/h)	-8.57	-9.34	-10.05	-10.17	-0.43	7.75	12.05	10.75	6.58	0.55	-4.85
External Infiltration (kBTU/h)	-341.87	-350.69	-338.66	-261.70	-159.38	-81.76	-52.28	-88.99	-157.59	-238.78	-285.95

Figure 33. Heat balance – 15th July – Modified case 2

Figure 34 gives the sub-hourly heat balance graph for the whole building on July 15th and the unit of measurement is kBtu/h. The maximum solar gains occur at the start and end of the day from East and West sun position. The two steep curves indicate problem of excessive heat gain and glares from east and west building facades. In this case, due to the change in orientation of the building, only one façade faces east and west, so the exposure to sun is comparatively low. The south sun is blocked by the horizontal projections. However, the angular fins on the east and west side were unable to block the morning and evening sun, thus leading to high solar gains during peak times (Appendix C).



General Lighting (kBTU/h)	94.09	94.09	93.45	82.37	81.60	79.94	80.28	78.95	84.25	94.09	94.09
Computer + Equip (kBTU/h)	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37	291.37
Occupancy (kBTU/h)	0.16	0.84	1.49	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Solar Gains Exterior Windows (kBTU/h)	0.00	0.00	17.53	330.83	121.91	69.05	68.23	304.62	178.72	0.00	0.00

Figure 34. Internal heat gains – 15th July – Modified case 2

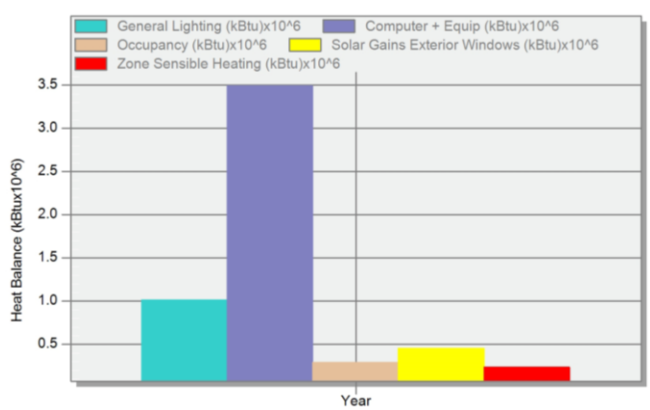
Table 13 shows the total heating and cooling design capacities for the modified case 2 simulations.

Table 13. Energy loads – Modified case 2

Type	**Loads (kBtu/h)**
Heating	3348.01
Cooling	7710.58

Annual simulations

The internal gains over a period of one year, in the Modified case 2, are given by Figure 35. The majority of the gains are from the computers and office equipments whereas general lighting still remains the second major contributor to the internal gains of the building.



General Lighting (kBtu)x10^6	1.01
Computer + Equip (kBtu)x10^6	3.49
Occupancy (kBtu)x10^6	0.25
Solar Gains Exterior Windows (kBtu)x10^6	0.45
Zone Sensible Heating (kBtu)x10^6	0.24

Figure 35. Annual internal gains – Modified case 2

The total fuel consumption in modified case 2 is given in Figure 36. Thus, the annual consumption of electricity is 6.322 x 10^6 kBtu/h. The breakdown of this value is given in Figure 37 under five sub categories over a period of one year. Room electricity consumed the total electricity which was 3.48 x 10^6 kBtu/h. Lighting and System Miscellaneous shared almost the same amount of fuel.

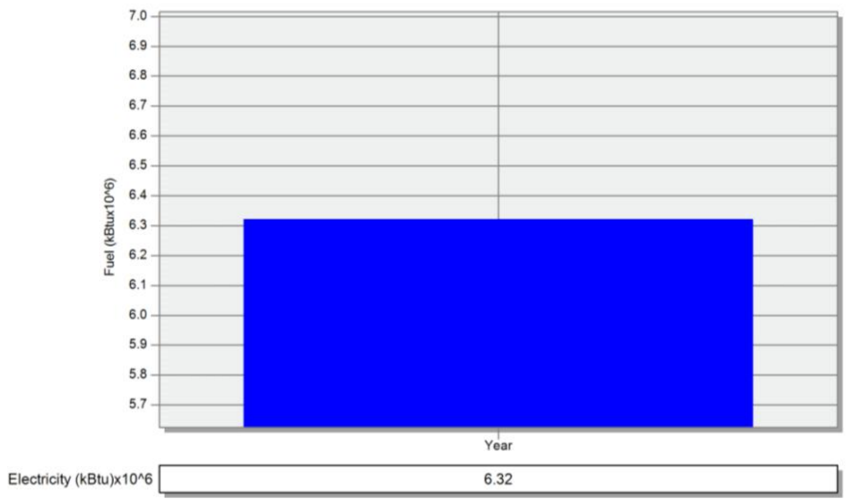


Figure 36. Total fuel consumption – Modified case 2

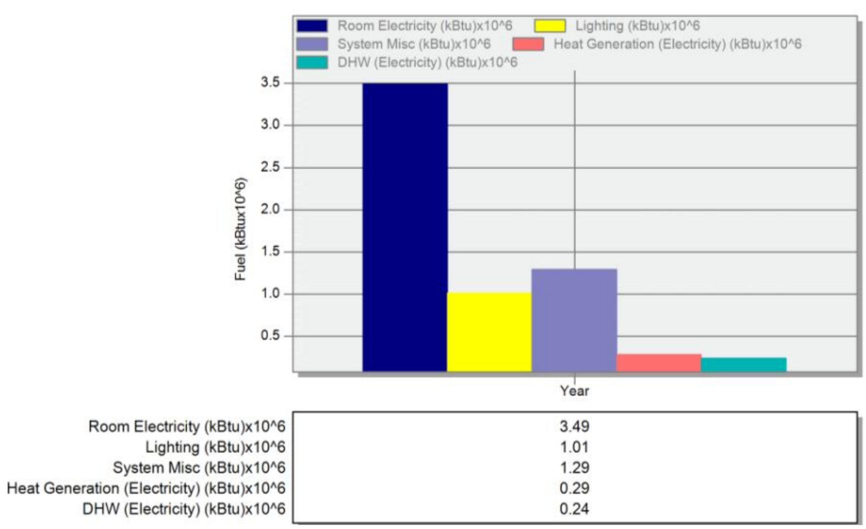


Figure 37. Fuel breakdown – Modified case 2

The total carbon dioxide emission remains the same as it was in the section 3.5 Modified case 1 above. The total amount of carbon di oxide emission over a period of one year is 2.80 x 10^6 lb/year and is given by Figure 38 below.

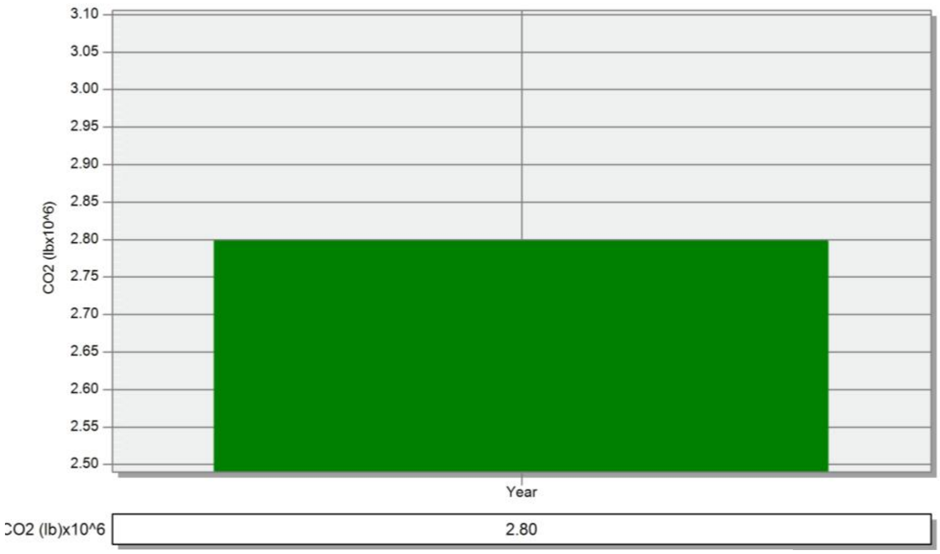


Figure 38. Total CO_2 emission – Modified case 2

4. FINDINGS

The results derived from the above experiment mentioned under section 3 of Research Method were summarized and a comparative analysis between the three cases was done. These three cases were Basecase (existing scenario), Modified case 1 (retrofit scenario) and Modified case 2 (redesign scenario). The following discussion is carried out based on the DesignBuilder outputs for various components.

4.1 Heat losses

Table 14. Heat loss summary

Scenario	**Total heat loss through Glazing (10^6 kBtu/h)**		**Difference (%)**	
	WDD	**SDD**	**WDD**	**SDD**
Existing case	562.41	1399.39	-	-
Modified case 1	515.51	961.95	Less by 8.33 %	Less by 31.25%
Modified case 2	519.24	922.96	Less by 7.67 %	Less by 34.04%

As it can be seen from above table 14, use of double low-e 6mm thick glass system with air gap in the modified case 1 reduces the heat losses from the interior of the building to the outside atmosphere by 8.33% on winter design day and by 31.25% on summer design day. Change in orientation of the building, however, would not have had any considerable impact on the heat losses of the building than those in modified case 1. These reductions in heat losses would certainly minimize the loads on annual heating and cooling systems of the building.

4.2 Solar heat gain

Table 15. Solar heat gain summary as on 15th July (SDD)

	Solar heat gains through exterior windows – 15th July (kBtu/h)						
Time of the day	6.00	8.00	10.00	12.00	14.00	16.00	18.00
Existing case	22.93	261.98	158.15	189.98	183.35	318.32	363.25
Modified case 1	20.98	234.16	61.54	69.05	68.17	298.53	331.58
Modified case 2	17.53	330.8	121.91	69.05	68.23	304.62	178.72

Table 15 gives the exact values of the solar heat gains from the exterior windows for the summer design day. The values are noted at an interval of two hours through the whole day. The table clearly shows that the absorption of heat gain is much lower when the existing single clear 6mm glass in replaced by double pane clear low-e glass in the modified case 1. This is due to the lower U-value and SHGC of the selected glass along with its high resistance (R-value). In the existing case, figure 10 shows that the spans of excessive heat gains during morning and evening are quite high. This is because originally the building is at 45^0 to north. This causes two facades of the building to face east and west direction (along with use of single clear glass pane 6mm thick). The lower sun angles directly hits two sides of the building causing excessive solar heat gains. When the glass and orientation of the building was changed, the resistance towards the solar heat gain was comparatively higher. Refer Appendix C for details.

4.3 Annual internal gains

General lighting accounted for a high internal gain value of 3.03 x 10^6 kBtu annually in the existing case. This is majorly because the building in existing condition uses a high lighting power density of approximately 2.5 W/ft2. When this was changed to 0.9 W/ft2 in the modified case 1, the internal heat gain due to general lighting was lowered to 1.02 x 10^6 kBtu (a total reduction of 33%). Also, the annual solar heat gain was reduced by 25% in the modified case 1 and almost by 30% in the modified case 2. The internal gains from occupancy and computers remain almost the same due to no action. Following table 16 gives a summary of the above discussion.

Table 16. Summary of internal heat gains – Annually

Scenario	**General lighting (kBtu x 10^6)**	**Computer equipment (kBtu x 10^6)**	**Occupancy (kBtu x 10^6)**	**Solar gains through exterior windows (kBtu x 10^6)**
Existing case	3.03	3.49	0.25	0.64
Modified case 1	1.02	3.49	0.25	0.48
Modified case 2	1.01	3.49	0.25	0.45

4.4 Annual fuel consumption

Table 17. Annual fuel consumption

Scenario	**Electricity consumption (kBtu x 10^6)**
Existing case	8.235
Modified case 1	6.320
Modified case 2	6.322

Above table 17 shows clearly that the modified cases help in achieving 23% savings in the annual consumption of fuel i.e. building electricity. This is majorly due to the decreased load on heating and cooling systems of the building. As the total fuel consumption is reduced, the annual amount spent for the consumption of electricity will be much lower. However, there is no difference in the annual fuel consumption in the modified case 1 and 2.

4.5 Annual CO_2 emissions

Table 18. Annual CO_2 emission

Scenario	**CO_2 emission (lb x 10^6/year)**	**CO_2 emission (lbs/sq.ft)**
Existing case	3.645	38
Modified case 1	2.797	29
Modified case 2	2.798	29

Table 19. Carbon emissions: Energy Star Program

	Typical office building (lbs CO_2/sq.ft)	**Energy Star office building (lbs CO_2/sq.ft)**
Texas	30	22
California	20	15

The above table 18 shows that the annual carbon di oxide emission of the building is reduced by 23.35% when the existing single clear 6mm thick glass is replaced by double low-e 6mm thick glass with 13 mm air gap in between. On the other hand, the building with replaced glass when orientated to the north, does not contribute to any further reduction in the CO_2 emission than in model case 1. Table 19 gives the Energy Star Program specified carbon emissions from office building energy use for Texas and California. The comparison shows that the existing building is emitting 26% more CO_2 than the typical office building in Texas. Even after applying modifications, the building is responsible for emitting 31.8% more CO_2 over the Energy Star office building in Texas.

The above findings help us to conclude that the replacement of existing single pane clear 6mm glass by high performance double low-e 6mm clear glass (with 13mm air gap) gives higher energy efficiency in existing Langford Building A. However, due to the form of the building (almost square), the change in orientation does not really affect the overall energy consumption in the building in terms of annual Carbon Di Oxide emission and the electricity consumption of the building.

5. CONCLUSION

5.1 Summary of findings

The above experiment, results, and comparison between three cases showed that the annual solar heat gain was reduced by 25% when the existing glass was replaced by high performance double pane low-e clear glass. The solar gains were further reduced by 5% when the building was reoriented hypothetically to suit the recommendations laid by AEDG. Reduction in the lighting power density resulted in 33% lower internal gains caused by general lighting. 23% saving was achieved in the total annual fuel consumption when the existing glass was replaced. Also, this helped in reducing the total annual Carbon-di-Oxide emission of the building by 23.35%. However, further noticeable savings were not achieved when the building was hypothetically reoriented as per the AEDG. This was basically due to the form of the building. Since the building is (almost) square, there is almost equal exposure of each façade towards the sun. This causes the total amount of energy consumption in the building to remain same as compared to that of the modified case 1. The modified case 1 emitted 31.8% more CO_2 than the Energy Star office building in Texas.

Thus, the hypothesis is partially accepted and partially rejected. The total annual energy consumption of the building after further change in the orientation (modified case 2) is almost equal to the total annual energy consumption of the building when the existing glass was replaced (modified case 1). Thus, the equation is:

$(\mu 3 \cong \mu 2) < \mu 1$

5.2 Future research

This particular study leaves a scope for further investigation in future and can be done with respect to following points:

- The energy analysis model can be taken to EnergyPlus 6.0 for the purpose of in-depth analysis and intense simulation results.
- To study other important building components falling under Lighting Systems, Heating Ventilation and Air Conditioning (HVAC), and Computational Fluid Dynamics (CFD) in detail and study their impact on the overall energy consumption of the building.
- To study each façade of the existing building separately and design external shading devices keeping components such as daylighting, solar heat gain and glare in mind.
- The dynamic nature of the facades (moving facades) can also be studied to understand their behavior under building and site conditions.

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APPENDIX A

Table 20. Tabulation chart showing Lighting Power Density (LPD)

Typical space	**Total area (sq.ft)**	**Total light fixtures (no.)**	**Fixture type**	**Total wattage**	**LPD (W/sq.ft)**
Computer Lab	1092.50	104	T-8 (32 w ea.)	3328	3.03
Studio	2634.34	234	T-8 (32 w ea.)	7488	2.84
Office	101.32	08	T-8 (32 w ea.)	256	2.52
Restroom	145.92	12	T-8 (32 w ea.)	384	2.63
Corridor	778.79	64	T-8 (32 w ea.)	2048	2.62
Lobby	531.90	20	White incandescent (60 w ea.)	1200	2.25
Atrium (1st floor)	1993	13	White incandescent (60 w ea.)	780	0.40
Atrium (2nd floor)	2826.75	16	White incandescent (60 w ea.)	960	0.34
Atrium (3rd floor)	3101.47	12	White incandescent (60 w ea.)	720	0.23
Atrium (4th floor)	3101.47	0	-	-	0.0

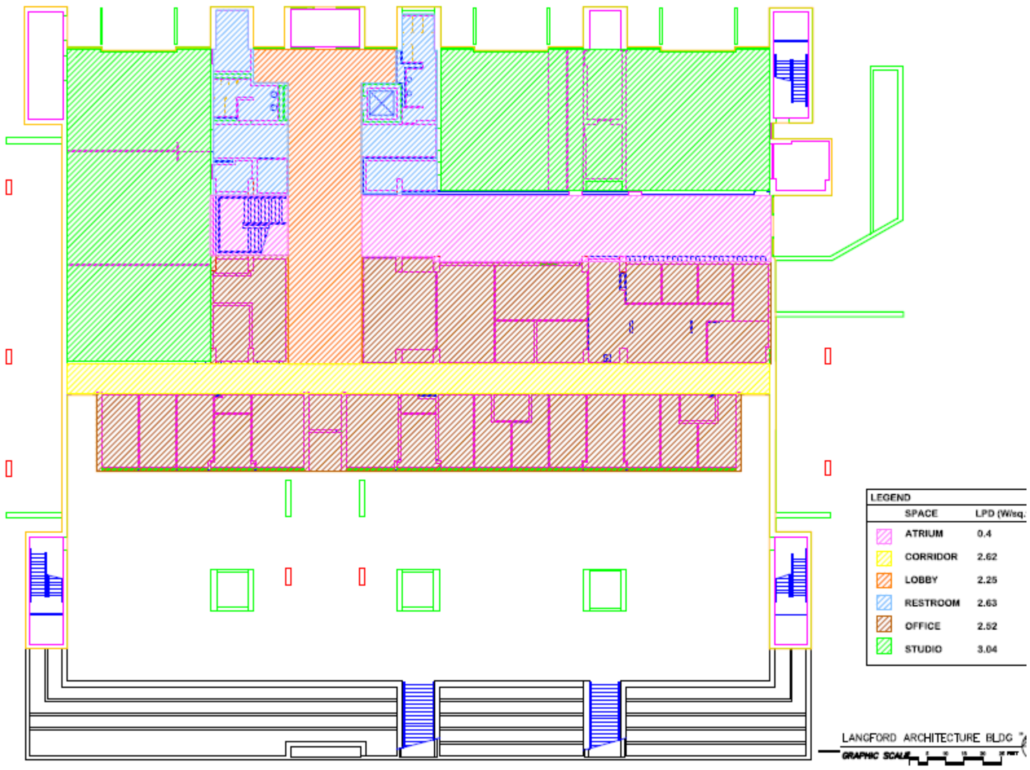


Figure 39. First floor plan

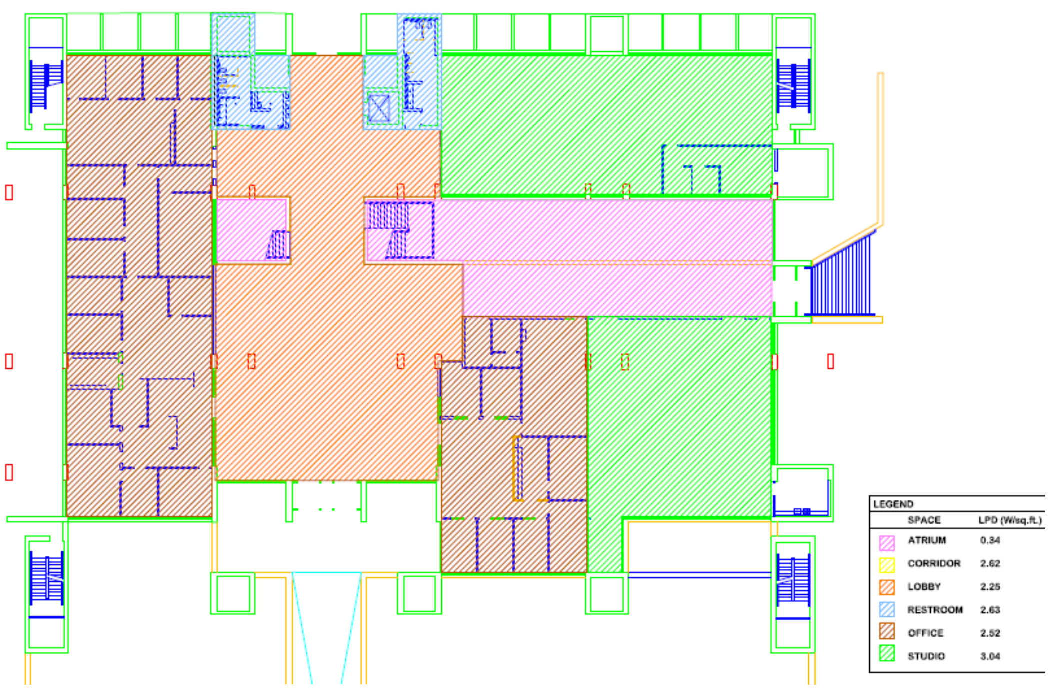


Figure 40. Second floor plan

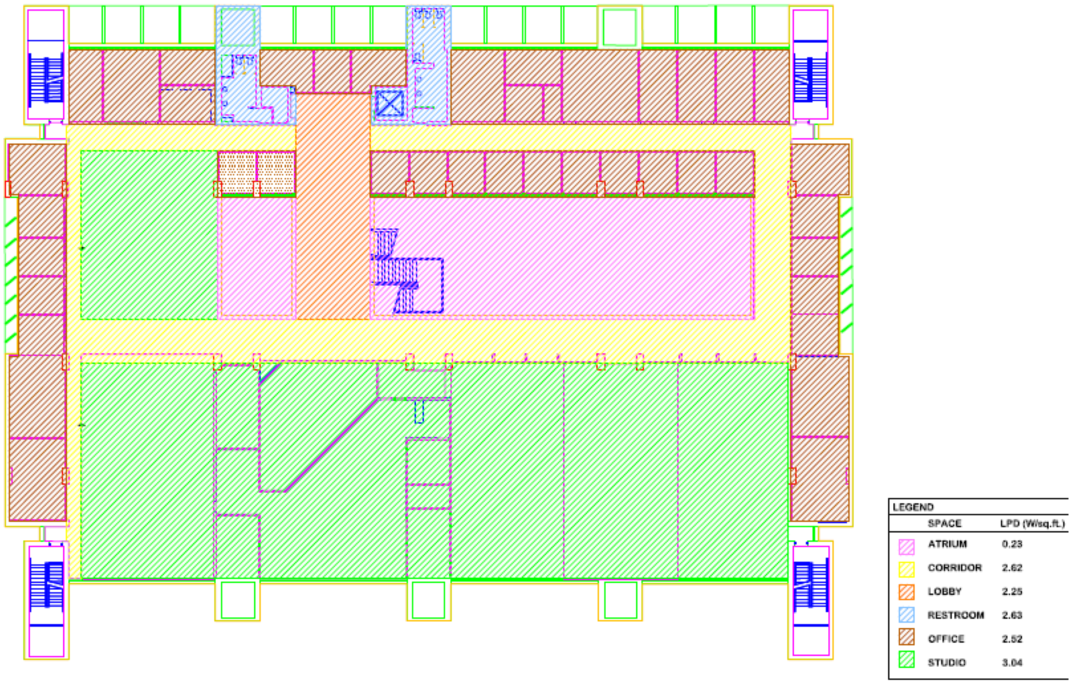


Figure 41. Third floor plan

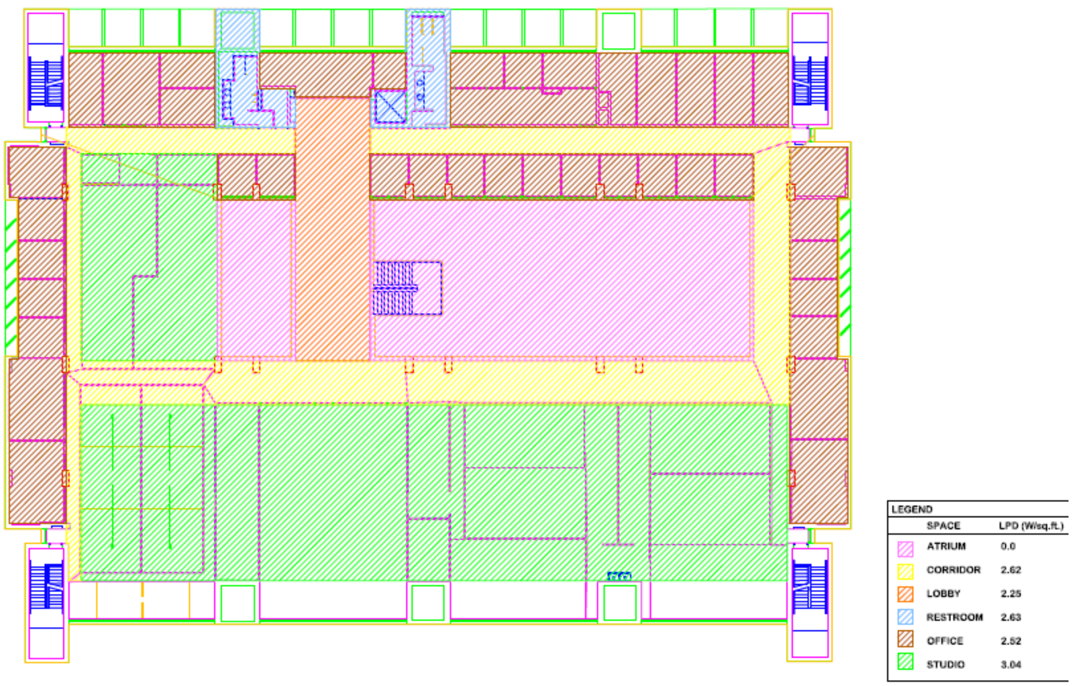


Figure 42. Fourth floor plan

Table 21: Tabulation chart showing occupancy: Wednesday, 09/08/2010 at 1:00 pm

Floor	**Total area (sq.ft)**	**Number of occupants**	**Occupancy (sq.ft/person)**	**Occupancy density (people/sq.ft)**
First	23,832	187	127.44	0.007846
Second	24,283	192	126.47	0.007907
Third	27,524	169	162.86	0.006140
Forth	20,304	141	144.00	0.006944
Total	95,943	689	139.25	0.007181

Table 22: Tabulation chart showing Window to Wall Ratio

Floor	**Total glass area (sq.ft)**	**Total wall area (sq.ft)**	**Window to Wall ratio**
First	3828.90	5601.81	0.68
Second	4713.00	6222.00	0.75
Third	3605.00	7215.10	0.50
Forth	4230.36	7654.60	0.55
Total	16,377.26	26,693.51	0.60

APPENDIX B

Computer modeling of the central atrium space:

The existing central atrium space of the Langford Building A is in a stepped profile. The corridors at each floor overlook into the central space on one longitudinal side and on the other side, the wall runs continuously. This atrium space is provided with skylights at the roof level. Similar model was developed in DesignBuilder and simulations were run. However, due to the complex geometry of the building due to the atrium space, simulations were not run smoothly and error occurred. For this purpose, an alternative technique was applied. Instead of stepped profile of the atrium, a rectangular profile was developed. Figure shows the two thumb nail sections of the atrium space.

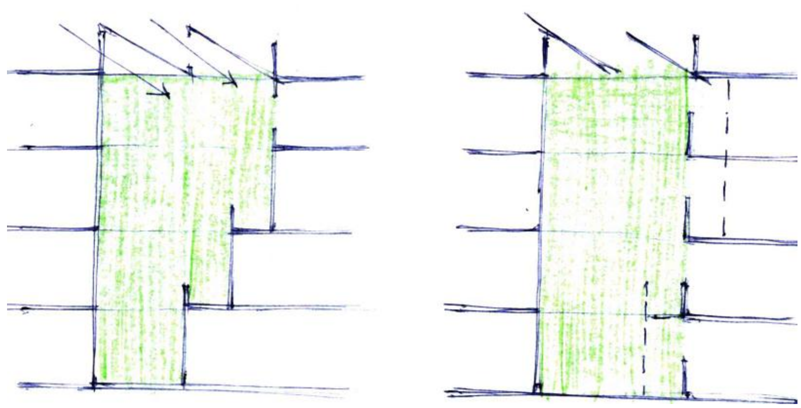


Figure 43: Sections showing atrium in existing and modeled case

The structural wall of the second floor was run continuously till the top and the overall volume of the central atrium space was kept the same approximately. This simplified the computer model comparatively and the simulations were run without any errors.

APPENDIX C

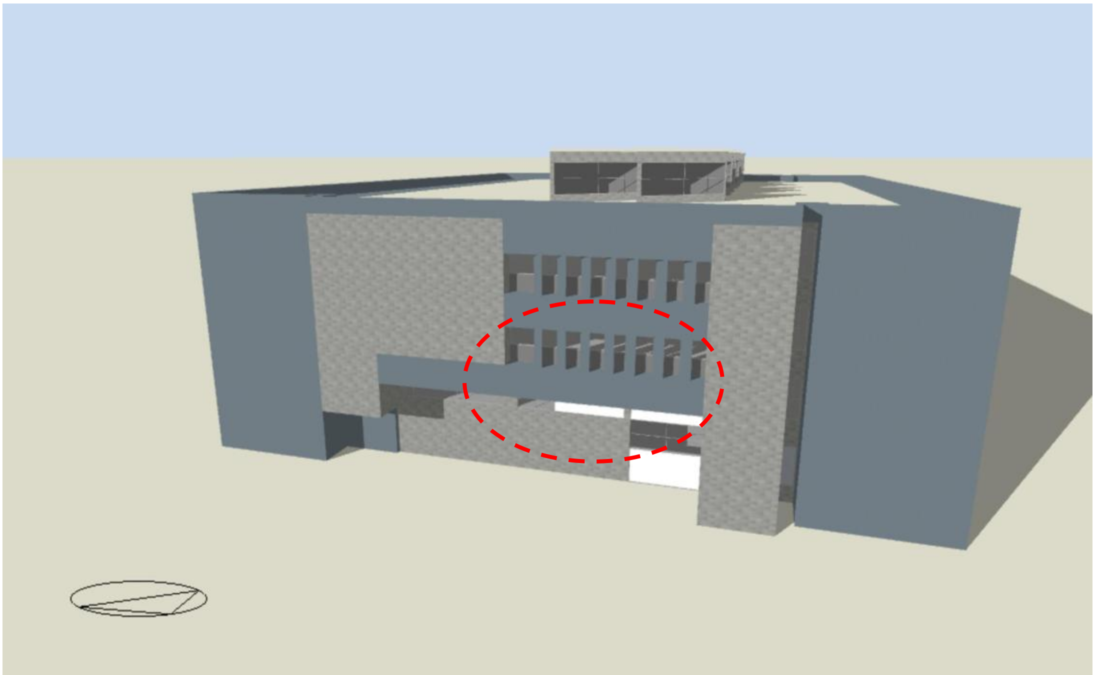


Figure 44. Sun penetration on 15th July at 7:00 am – North east façade, basecase

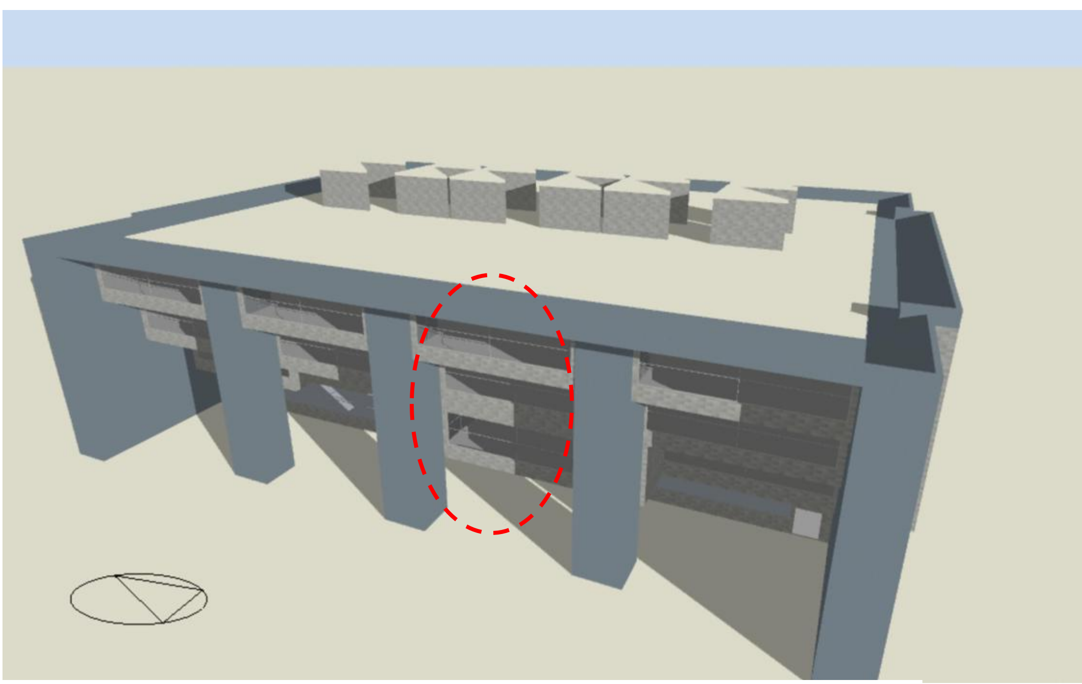


Figure 45. Sun penetration on 15th July at 7:00 am – South east façade, basecase

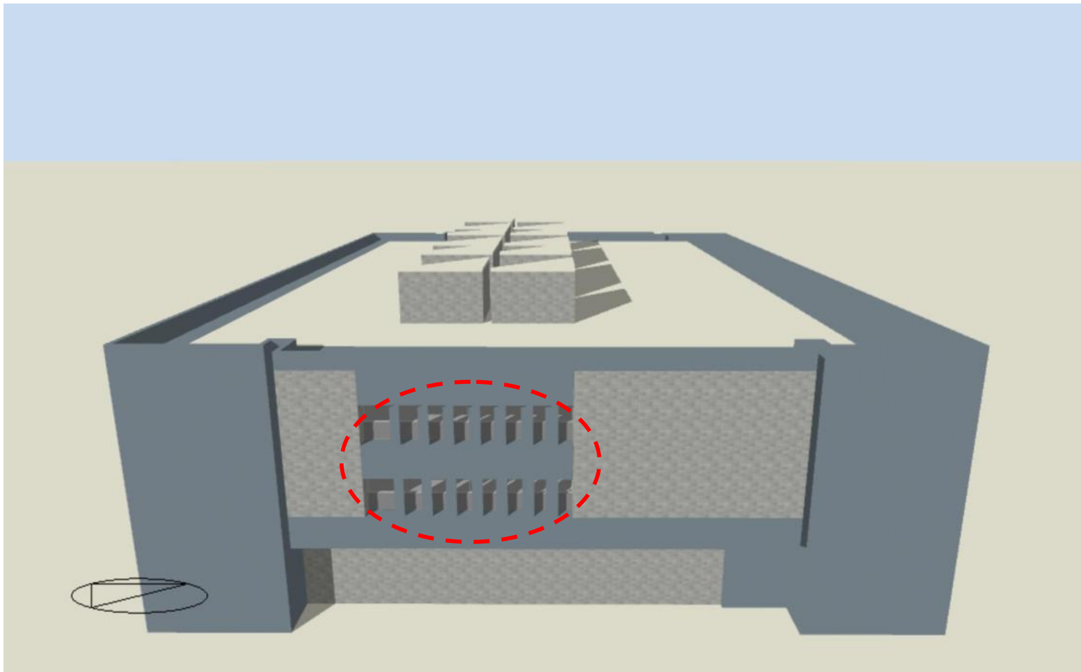


Figure 46. Sun penetration on 15th July at 4:00 pm – South west façade, basecase

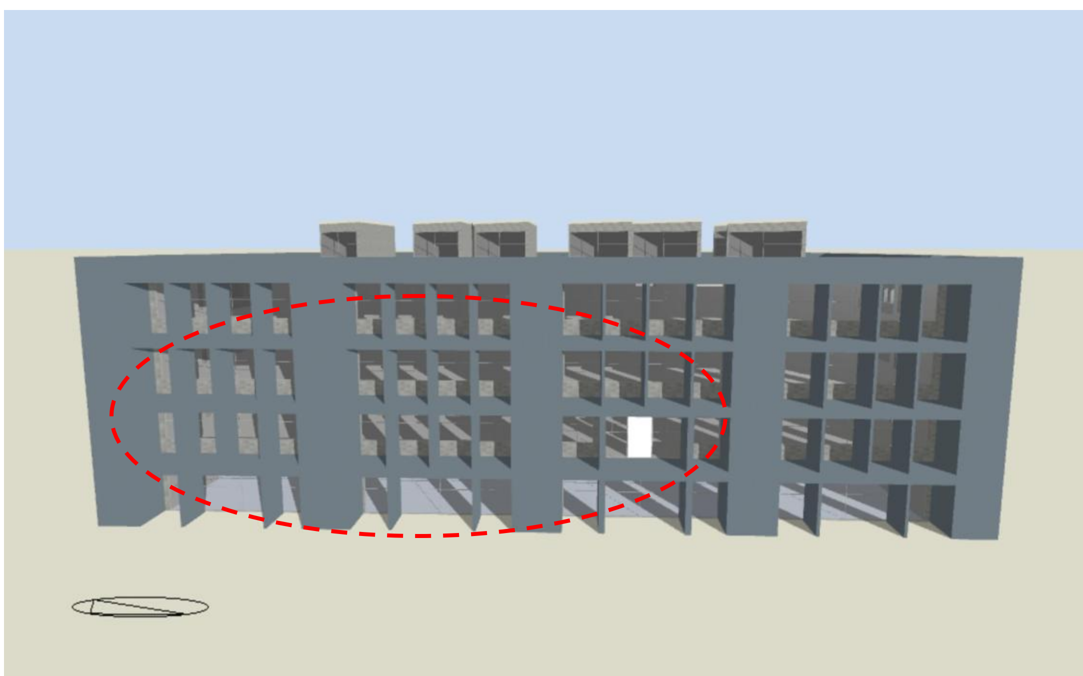


Figure 47. Sun penetration on 15th July at 6:00 pm - North west façade, basecase

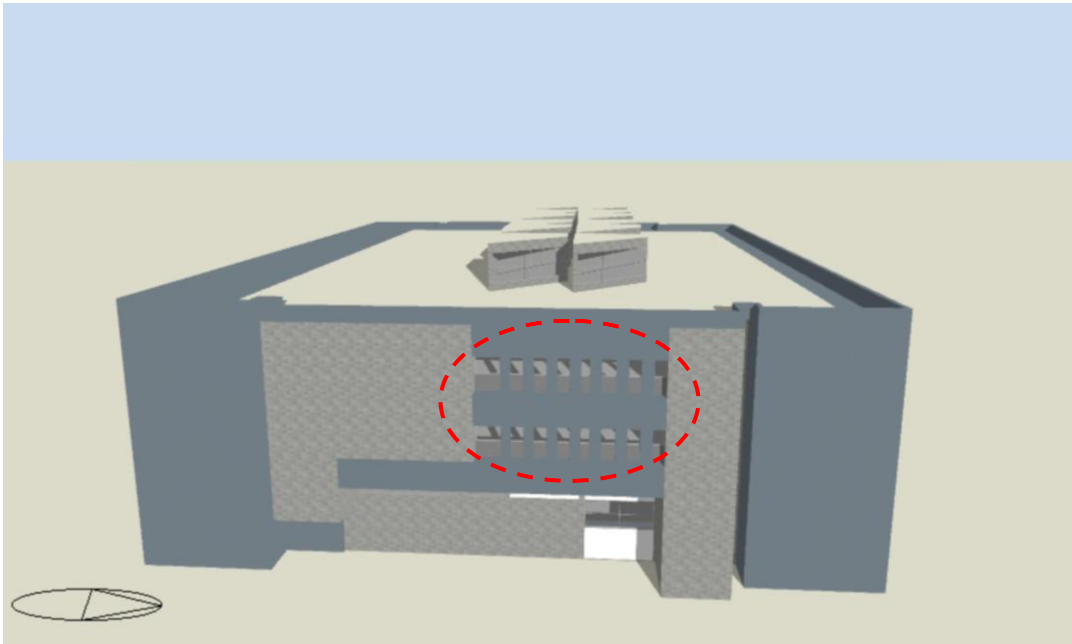


Figure 48. Sun penetration on 15th July at 7:00 am - East façade, modified case 2

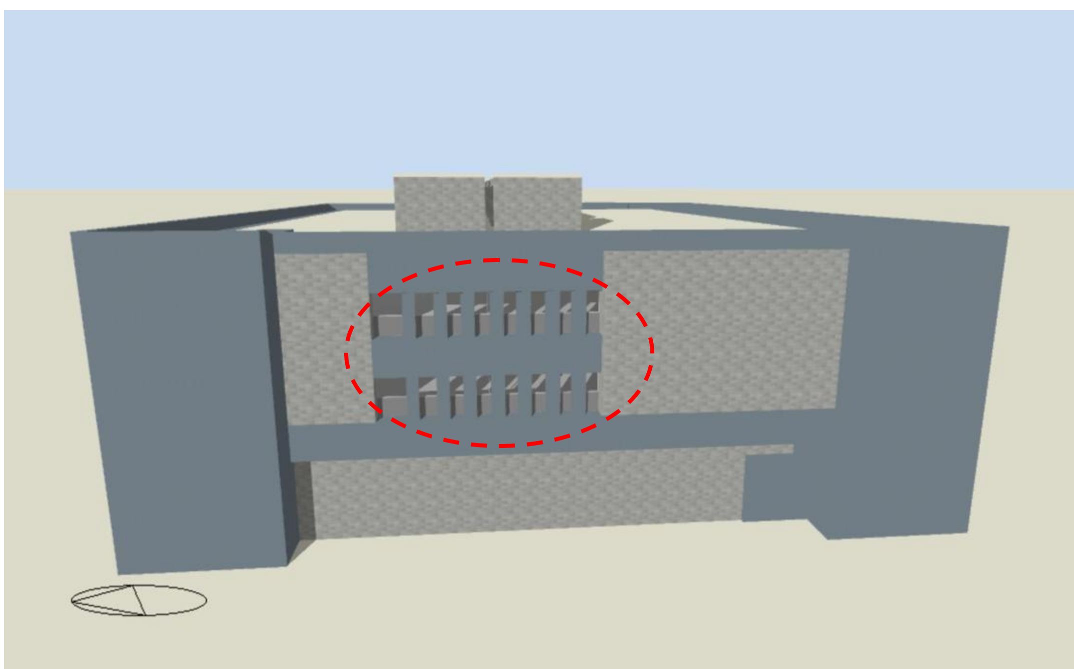
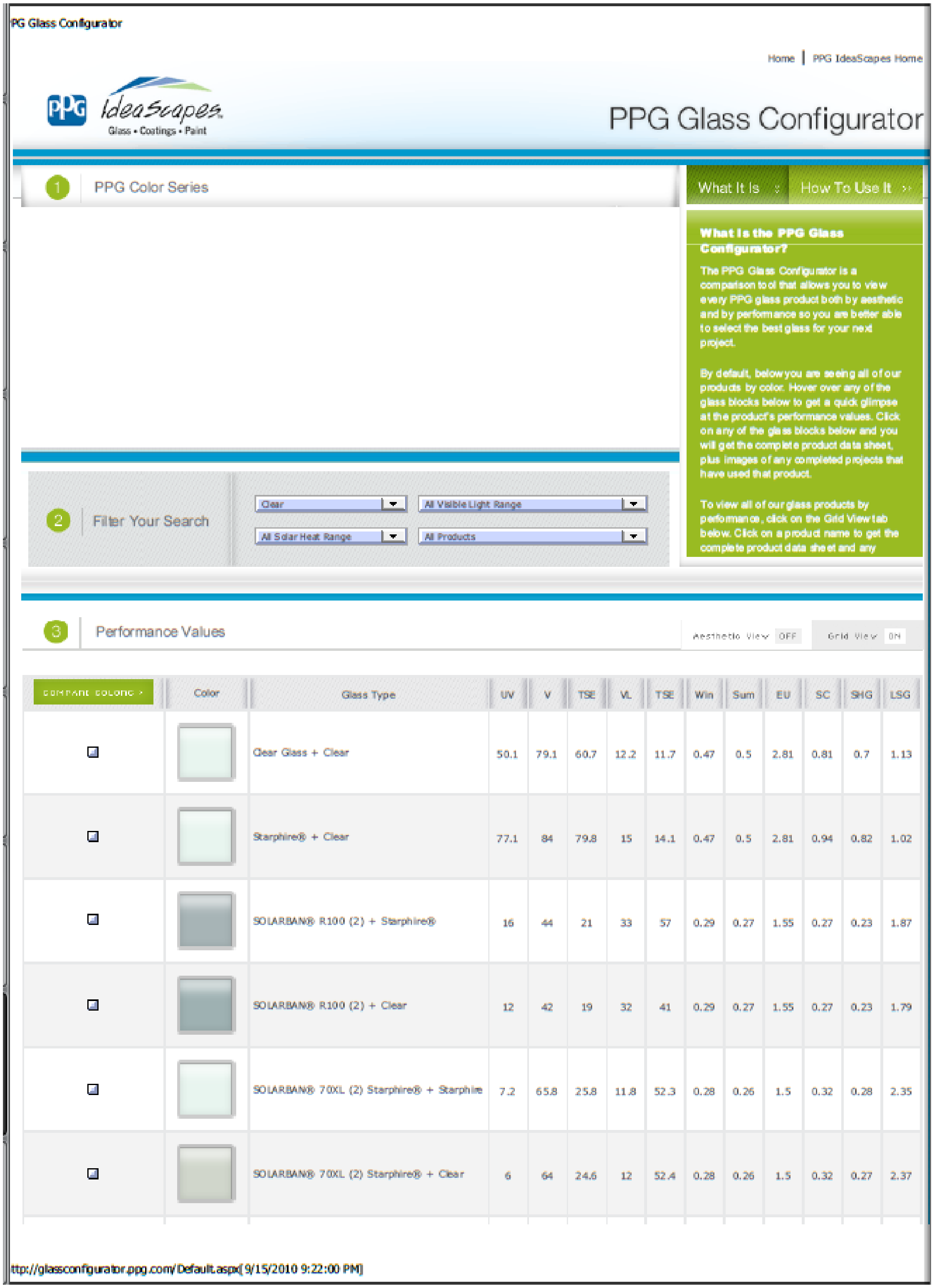


Figure 49. Sun penetration on 15th July at 6:00 pm - West façade, modified case 2

APPENDIX D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1 PPG Color Series

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2 Filter Your Search

Clear | All Visible Light Range | All Solar Heat Range | All Products

3 Performance Values

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COMPARE COLORS ›	Color	Glass Type	UV	V	TSE	VL	TSE	Win	Sum	EU	SC	SHG	LSG
☐		Clear Glass + Clear	50.1	79.1	60.7	12.2	11.7	0.47	0.5	2.81	0.81	0.7	1.13
☐		Starphire® + Clear	77.1	84	79.8	15	14.1	0.47	0.5	2.81	0.94	0.82	1.02
☐		SOLARBAN® R100 (2) + Starphire®	16	44	21	33	57	0.29	0.27	1.55	0.27	0.23	1.87
☐		SOLARBAN® R100 (2) + Clear	12	42	19	32	41	0.29	0.27	1.55	0.27	0.23	1.79
☐		SOLARBAN® 70XL (2) Starphire® + Starphire	7.2	65.8	25.8	11.8	52.3	0.28	0.26	1.5	0.32	0.28	2.35
☐		SOLARBAN® 70XL (2) Starphire® + Clear	6	64	24.6	12	52.4	0.28	0.26	1.5	0.32	0.27	2.37

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Figure 50: Glass specifications 1

PPG Glass Configurator

SOLARBAN® 60 (2) Clear + Clear	18.6	70	32.8	11	29.3	0.29	0.27	1.55	0.44	0.38	1.85
SOLARBAN® 60 (2) Starphire® + Starphire	25	74	38	11	42.4	0.29	0.27	1.55	0.46	0.4	1.85
SOLARBAN® 80 (2) Clear + Clear	13	48	19.5	33	37.7	0.29	0.27	1.52	0.28	0.24	1.98
SOLARBAN® 80 (2) Optiblue + Clear	9	34	14.8	19	28.3	0.29	0.27	1.52	0.23	0.2	1.70
SOLARBAN® 80 (2) Optiblue + Optiblue	7	24.5	11.4	18.6	28.2	0.29	0.27	1.52	0.23	0.2	1.23
Sungate® 400 (2) Clear + Clear	28.1	76.3	51	13.6	16	0.32	0.31	1.75	0.69	0.6	1.28
SUNGATE® 400 (2) Starphire® + Starphire	39	80	65	14	20	0.32	0.31	1.75	0.78	0.68	1.18
Clear + Sungate® 400 (3) Clear	28	76	51	14	17	0.32	0.31	1.75	0.73	0.63	1.21
Starphire® + SUNGATE® 400 (3) Starphire	39	80	65	14	22	0.32	0.31	1.75	0.83	0.72	1.11
Sungate 500 (2) + Clear	42	73.6	52.1	16.5	13.6	0.35	0.35	1.96	0.71	0.62	1.19

Notes

- Performance data is based on representative samples of factory production. Actual values may vary slightly due to variations in the production process.
- The performance data is based on a standard 1-inch (25mm) insulating glass unit with a ½-inch (13mm) airspace and two ¼-inch (6mm) lites. The interior lite is clear unless otherwise noted.
- Figures may vary due to manufacturing tolerances. All tabulated data is based on NFRC methodology using the LBNL Window 5.2 software.
- Transmittance (UV, V, TSE) and Reflectance (VL, TSE) values are based on spectrophotometric measurements and energy distribution of solar radiation.
- U-Value (UV) is the overall coefficient of heat transmittance or heat flow measured in BTU/hr.
- European U-Value (EU) is the overall coefficient of heat transmittance or heat flow measured in Watts/m2•°C, and is calculated using WinDat WIS version 3.0.1 software.
- Shading Coefficient (SC) is the ratio of the total amount of solar energy that passes through a glass relative to 1/8-inch (3.0mm) thick clear glass under the same design conditions.
- Solar Heat Gain Coefficient (SHG) represents the solar heat gain through the glass relative to the incident solar radiation.
- Light to Solar Gain (LSG) ratio is the ratio of visible light transmittance to solar heat gain coefficient.

Figure 51: Glass specifications 2

VITA

Name: Swapnil Shriram Jori

Address: Langford Building A, College of Architecture
3137 TAMU
College Station, TX, 77843-3137

Email Address: swapniljori@gmail.com

Education: M.S., Construction Management
Texas A&M University, 2010
Thesis – Glass as a Building Element – A Sustainable Approach:
A Study of an Existing Academic Building
Committee Chair: Dr. Mohammed Haque, Dr. Liliana Beltran

B.Arch., Pune University, India, 2007
Thesis – An Expression of Traditional Character in Contemporary
Architecture: Design of a Youth Development Center, India
Committee Chair: Ar. Aslam Kadri, Ar. Prajakta Baste

Accreditation: LEED Accredited Professional, LEED® AP NC v 2.2
Registered Architect, Council of Architecture, India

Work Experience: Architect, Asst. Estimator – Year: 2007-2008
Swastikarch Architects, Nashik, India.
Contact: swastikarch9@rediffmail.com

Intern Architect – Year: 2006
MICD Associates, Colombo, Sri Lanka.
Contact: micd@eol.lk

Computer skills: Building Information Modeling (BIM)
Ecotect 2010, Design Builder, HEED 3.0, eQUEST, Radiance
Microsoft Project, Primavera, WinEst, On-Screen Take off
AutoCAD, Revit Architecture, Revit Structure, Corel Draw, Photoshop