This is to certify that the

Final Year Project Titled

# GREEN BUILDING RETROFIT – BIM BASED ANALYSIS

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# ABSTRACT

Buildings consume up to 50% of the total energy demand in Pakistan. Due to an increase in lifestyle, this consumption continues to grow, further fueling the energy crisis, which is not only a source of discomfort for the nation but is costing the country billions annually. Almost 30% of energy can be conserved through energy efficient housing, but unfortunately for Pakistan, there is no housing policy regarding energy efficiency in effect today. There has been a renewed interest in building efficiency energy throughout the world, and this research aims to bring it to Pakistan as well. Instead of targeting new buildings, this research seeks to improve the envelope thermal performance of the 99% of existing buildings to bring about a significant change in the energy consumption. An educational institute in NUST was chosen, and the methodology used involves simple passive retrofitting techniques such as double glazed windows and thermal insulation sheets, easily available to the general income quintile population of Pakistan. The results were simulated using the robust engine of DesignBuilder. The methodology helped achieve a 20.2% reduction in annual energy consumption with an economic payback period of 2.3 years. The research also aimed to reduce GHG emissions to some extent.

# DEDICATION

*This thesis is dedicated to our parents.*

*And to the future of energy conservation in Pakistan.*

# ACKNOWLEDGEMENT

We are thankful to Almighty Allah, Who gave us the courage and strength to complete this research. We would like to pay a debt of gratitude to our advisor, Dr. Jamaluddin Thaheem, for his profound encouragement to complete this research, which was a great support throughout this journey. We sincerely appreciate the valuable time, motivation, and personal support he provided for this research. We are also incredibly grateful to our co-advisor Lecturer Bilal Ayub for his sincere guidance in all regards. The guidance and support from Mr. Jibran Hashmi (CEO ENCON) were vital, above all, for the success of this research. We would also like to pay our earnest and honest gratitude to our parents and friends for their unconditional support, encouragement, prayers, and patience.

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background

There is a very strong correlation between energy and economic growth. Economic growth in Pakistan has been seriously hampered due to the energy crisis it's facing (Ahmed and Iftikhar-ul-Husnain, 2014). According to statistics, the average shortfall in the power sector was 4,000 Megawatts and has risen to 8,000 Megawatts of total demand for electricity in 2017 and nearly two billion cubic feet per day (BCFD) in the natural gas sector These power shortages cost Pakistan's economy a total of Rs 14 billion in 2015 (Mufti, 2016). Apart from the shortfall and its subsequent effect on the economy, energy sector is responsible for 52.9% of the 577 $MtCO_2$-eq green house gas emissions in Pakistan as estimated for the year 2020 (Zuberi et al., 2015), since 62.5% of the energy is contributed by thermal energy (Awan and Khan, 2014). Buildings consume up to half of this total energy demand, with the domestic sector leading with 43% consumption and the commercial sector consuming 7% (as predicted for the years 2012-2013) (Sohail and Qureshi, 2010) as shown in figure 1.

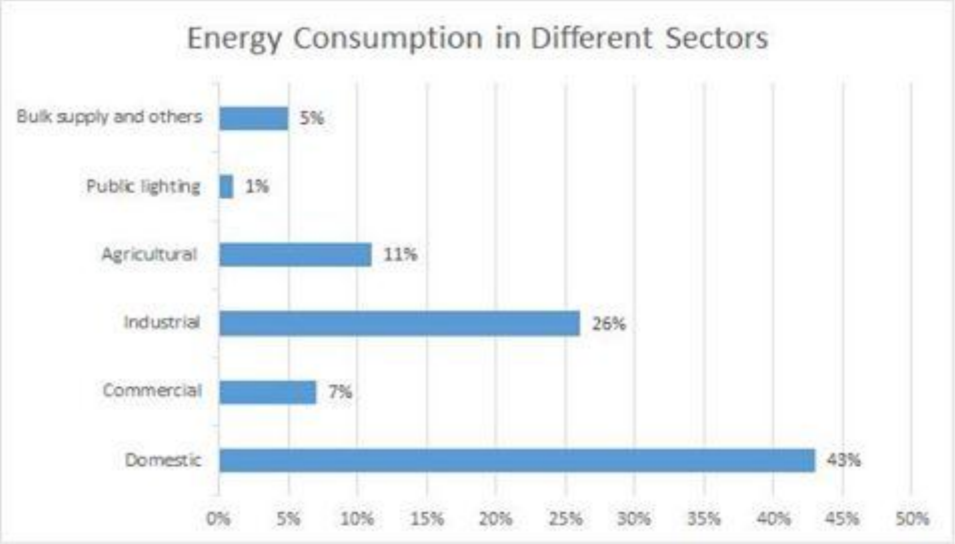


**Figure 2 - Energy consumption in different sectors of Pakistan for the years 2012-2013**

In this present situation, the potential of energy conservation in the construction industry cannot be neglected since it can yield significant results. Zainordin et al. (2012) says that 30% or even more in energy costs can be saved through energy smart or a green building. ENERCON – The national energy conservation centre in Pakistan identifies this need and has developed guidelines for energy efficient buildings. However no such effort reflects in the national housing policy that was formulated in 2001 and has not been revised yet, while on the other hand Europe is working towards refurbishments of existing buildings in a bid to reduce their green house gas emissions by about 88-91%. No doubt construction of zero-energy buildings will help reduce energy consumption but they only account for 1% of a city’s built environment in any given year. Whereas the number of existing buildings is more and they will still be in function till 2025 or even 2050. Their high rate of energy performance cannot be overlooked and cost effective retrofits need to be conducted to achieve an overall decrease in energy consumption in the construction sector (Huang et al., 2012).

### 1.1.1 Retrofitting

A person usually spends 70-90% of their lifetime in buildings. Energy-efficient or green building retrofitting is a huge contribution to the sustainability of the society. Existing green building standards are also enacted for local environmental benefits. Energy efficient buildings, whether retrofitted or new are ones that optimize the energy consumption associated with the typical uses of the building including the heating and cooling energy needs while maintaining the envisaged temperature. Buildings are energy extensive throughout their whole life cycle; therefore preserving the existing structures has more potential to save energy and reduce GHG emissions while incurring less cost than completely relying on new energy efficient or green buildings (Hupp, 2009). However, retrofitting can at times be more challenging. There is a plethora of retrofit techniques available. The optimal combination of such techniques can be chosen through cost and energy effective analysis and simulations.

### 1.1.2 BIM based simulations and analysis

A building information model is an intelligent, data rich, object oriented and parametric digital representation of a building facility. Using the model, appropriate data according to the needs of users can be extracted and analyzed to generate information that is then used to make decisions and improve the process of delivering the facility. It can help reduce costs with traditional sustainability analysis since all the information will be simply available as a byproduct of the standard design process (Azhar et al., 2009). BIM allows thorough exploration of the potential and alternative retrofitting techniques by comparing building performance through building performance, sustainability and cost analysis. BIM based sustainability analysis also provides satisfaction to consumers due to the easy interpretation of the data produced.

## 1.2 Reasons for selecting the project

Keeping in view how desperately our country needs to overcome energy shortfalls and conserve energy, and that buildings consume a significant amount of energy, we decided to come up with something that would help in overcoming this shortfall to some extent. We see that due to rapid urbanization in Pakistan and a need to improve lifestyle, occupants have been demanding higher level of indoor comfort which has led to an increase in the heating and cooling loads. Heating and cooling needs account for the majority of energy consumption in a building. Almost 50% reduction in cooling loads has been known to be achieved through retrofitting (Kharseh and Al-Khawaja, 2016). Retrofitting of the existing stock of buildings will create buildings that target both energy and environmental sustainability which is vital to help deal with the growing energy crisis, environmental degradation and depletion of valuable natural resources foreshadowing Pakistan. Such retrofitted buildings after a certain payback period prove to be more cost efficient than non retrofitted buildings. Using BIM for sustainability assessment will help increase its incorporation in the AEC industry, benefitting all the stakeholders involved in a project.

## 1.3 Aims and objectives

We aim to achieve the following objectives through this project:

a. To identify energy inefficiencies in an existing infrastructure.

b. Determine proposed retrofitting measures in lieu of the inefficiencies.

c. To create a building information model and conduct cost estimation and energy analysis.

d. To determine the optimal retrofit solution based on economical, environmental and social viability.

## 1.4 Areas of application

This research can be applied to all civil engineering works, however in this project our main focus will be on building projects. The methodology followed to determine the optimal retrofit solution can be adopted for any civil engineering project. The model that will be developed can be used throughout the life cycle of the project for energy analysis, cost estimation, facilities management, clash detection, as well as other BIM applications. Its ability to address all these applications through 3-D visualization will enable it to be incorporated in the construction industry of Pakistan for sustainable development and building operations and management.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 General

### 2.1.1 Retrofitting

Retrofitting refers to the provision of any facility or an accessory to an existing structure to serve a specific purpose. Retrofitting of buildings is conducted to protect the resources and environment. Retrofitting design covers a broad and diverse range of activities and choices. It does not mean installation of latest, expensive equipment; rather it is a philosophy of design that focuses on making designs friendlier to the environment, creating opportunities to significantly reduce global energy consumption.

### 2.1.2 Green, sustainable buildings and energy efficient buildings

Green building is a structure that is responsible and resource-efficient throughout its lifecycle. Green buildings are sustainable, but they tend to focus more on designs that make use of solar energy, effective day lighting and natural ventilation, recycling of waste or its treatment and reduction in consumption. Whereas sustainable buildings are a subset of sustainable development and balance, throughout its lifecycle, the three factors of sustainability: environmental, economic and social. On the other hand, energy efficient buildings spare energy utilization without any bargains made on profitability level, comfort and strength of tenants (Alwaer and Clements-Croome, 2010).

## 2.2 Key performance indicators for sustainability assessment

### 2.2.1 Sustainability assessment factors

Assessing building performance is complex since different criteria in a building have differing interests and requirements. Sustainability assessment covers the overlapping dimensions of environmental, economic and social factors, as shown in figure 2.

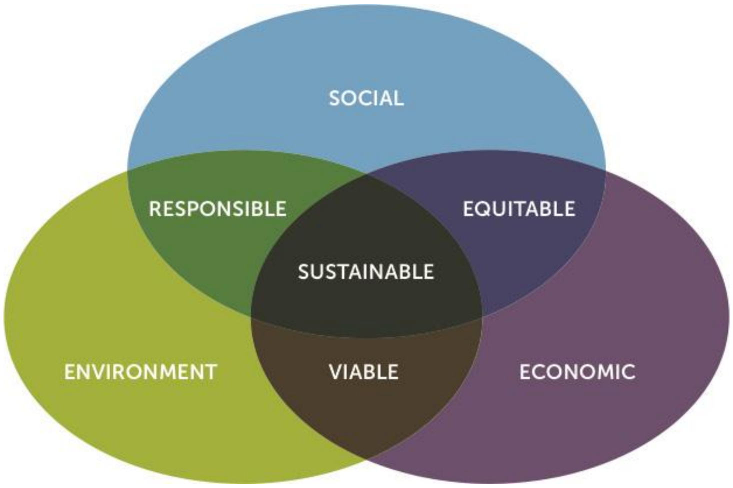


**Figure 3 - Main sustainability factors**

An intelligent, sustalnable building's emphasis should be in achieving the best combination of these values, rather than on using purely advanced technologies (Alwaer and Clements-Croome, 2010).

The following formula (conceptual) was developed in 2007 for the sustainability assessment of a building throughout its life cycle (Klöpffer et al., 2007). This formula further supports the relationship between the three factors of sustainability.

LCSA = LCA + LCC + LCSA

Where LCSA – Life Cycle Sustainability Assessment
LCA – Environmental Life Cycle Assessment
LCC – Life Cycle Costing
LCSA – Social Life Cycle Assessment

Buildings have exceptionally long life cycles. Due to the incorporation of hundreds of individual products, adopting LCA becomes a tedious and complicated job. Indicators need to be selected and their subsequent parameters to form the framework for any assessment. These are a combination of different quantifiable parameters or variables. Indicators need to be defined in an unambiguous, clear and correct way before assigning their relevance to different parameters (Bragança et al., 2010).

### 2.2.2 Building rating and certification systems

Building rating and certification systems transform sustainable goals into performance indicators and support the sustainable design by helping evaluate the overall performance. Three major rating systems form the basis for approaches used throughout the world:

- LEED (Leadership in Energy and Environmental Design) - developed by the USA;
- BREEAM (Building Research Establishment Environmental Research Method) - developed by the UK;
- SBTool (Sustainable Building challenge framework) – developed by the alliance of 20 countries.

These three systems offer different approaches but address the important common issues such as the life cycle costs, energy efficiencies, consumption of resources, materials and water efficiencies and indoor environment (Bragança et al., 2010). Ascione et al., 2015

### 2.2.3 Environmental sustainability indicators

The most common indicators for environmental sustainability assessment are climate change, emissions to the air, water and soil, water efficiency and resources depletion (Braganca et al., 2010).

### 2.2.4 Economic sustainability indicators

Robust LCC data requires careful selection of indicators and parameters. LCC uses present value technique and quantifies all the costs involved during the building's lifecycle, from investment to operating costs. This quantification allows for the selection of the optimal materials, operating energy cost, cost saving and payback period, minimizing the lifecycle cost of the building (Moore and Morrissey, 2014). Through life cycle based assessment, long term benefits of occupants can be achieved by the selection of optimal proposal that maximizes net savings (Ali and Al Nsairat, 2009). Hence the leading indicators for economic sustainability are LCC values, which are further divided into parameters, such as the cost of retrofitting, building size, occupant behavior, occupancy rates, the lifespan of building and maintenance frequency (Moore and Morrissey, 2014).

### 2.2.5 Social sustainability indicators

Due to dense variety in priorities and views of stakeholders concerning social factors, the identification of social indicators is not as easy as that of environmental and economic indicators (AlMahmoud and Doloi, 2012). According to Alwaer and Clements-Croome (2010), following are the common social sustainability indicators: usability, functionality and aesthetic aspects; indoor environment quality; health and well being; safety and security; no of occupants.

## 2.3 Energy systems in a building

Table 1 shows the main energy systems in a building. Each one of these have the potential for efficiency and energy conservation (Ahmed and Iftikhar-ul-Husnain, 2014; UN-HABITAT, 2010)

**Table 1 - Buildings energy systems**

| |
|---|
| **Building envelope** |
| **Lighting** |
| **Heating, ventilation and air conditioning** |
| **Mechanical and electrical systems** |
| **Service water heating** |

## 2.4 Potential conservation areas

ENERCON, in collaboration with UN-HABITAT produced estimates of energy conservation potential in the main energy systems of a building. Table 2 enlists these potentials (Ahmed and Iftikhar-ul-Husnain, 2014).

**Table 2 - Potential energy conservation areas**

| Conservation areas | Saving potential (%) |
|---|---|
| Building envelope | 40 |
| Lighting potential | 29 |
| High efficiency lighting | 72 |
| Fluorescent tube ballasts | 83 |
| Lamp fixtures | 50 |
| HVAC | 35 |
| Printer, copiers, computers | 19, 10, 2 |

## 2.5 Energy systems – passive retrofitting techniques

### 2.5.1 Building envelope

Building energy performance can be improved either by implementing active retrofit or passive retrofit strategies. There has been a great deal of renewed interest in passive building energy efficiency strategies in the recent years. These are categorized as improvements in the building envelope elements through thermal insulation, i.e. retrofitting with building elements having better thermal performance (Ascione et al., 2015). These passive techniques do not utilize energy and reduce the cooling and heating loads without compromising the indoor environment quality, making them a sustainable approach (Kulkarni et al., 2011).

A building envelope is a layer that separates the indoor environment of a building from the outdoors, controlling its quality despite the transitory outdoors. Principle components making up the building envelope include the roof, walls, and glazing. Strategies such as thermal insulation in walls, reflective and double glazing in windows and green roofs resulted in energy savings of up to 31% and peak load savings of 37% in apartment buildings situated in hot and humid climates by the implementation of passive energy efficient strategies (Cheung et al., 2005).

Since a properly designed building envelope significantly reduces HVAC loads and subsequently, the energy usage, building envelope standards in the UK have been revised over the years, upgrading and improving the code requirements on building envelopes significantly (Sadineni et al., 2011). This revision greatly stresses the need for energy conservation and also the need for its implementation in developing countries including Pakistan, where the energy crisis during summer seasons is primarily due to the increased cooling loads.

### 2.5.2 Roofs

Roofs are highly susceptible to solar radiation and receive the most amount in summers when compared to other building elements, contributing to uncomfortable indoor environments for occupants and high temperatures. Buildings with large roof area contribute as much as 50% heat gain (Kulkarni et al., 2011) and 60% thermal energy leakages, hence having the potential to save both heating and cooling loads if proper retrofit measures are implemented (Sadineni et al., 2011).

The impact of solar radiation on the roof can be reduced by providing shading and humidity through vegetation and insulation through a layer of polystyrene (these two techniques will be applied in this project).

### 2.5.3 Walls

Walls provide both thermal and acoustic comfort to the indoor environment of a building, making them a principle component of the building envelope. When retrofitting walls, care must be taken so as not to alter or modify the aesthetics, both interior and exterior, of the building. Thermal resistance (R-value) of walls is crucial in effecting the building energy consumption. Greater thermal resistance (higher R-value) enhances air tightness and thermal performance of the walls, resulting in reduced heating and cooling loads (Sadineni et al., 2011).

### 2.5.4 Windows

The openings in the building envelope play a vital role in the thermal comfort, illumination, and aesthetics of a building. Thermal conductivity (U-value), solar heat gain coefficient (SHGC) and orientation all play a significant role in energy savings. To balance between savings in terms of reduced loads and cost of retrofitting, orientation needs to be accounted for in energy analysis.

Single glazing can be retrofitted with double glazing to decrease the U-value. The edge components or the window frames should minimize thermal bridges (a bridge that has higher heat transfer than the surrounding elements thereby reducing thermal insulation of the envelope) and infiltration losses (Sadenini et al., 2011).

### 2.5.5 Thermal resistance and conductivity

Thermal conductivity or K-value is a measure of how efficiently heat flows through a material, regardless of its thickness. A low thermal conductivity means heat will flow through a material slowly; hence the material has a better thermal performance. K-value is measured in watts per meter-Kelvin (W/mK).

Thermal resistance or R-value is a measure of the resistance to heat flow through a given thickness of the material. A high thermal resistance means heat is restricted to flow through a material; hence the material has a better thermal performance. R-value is measured in meters squared Kelvin per watt ($m^2K/W$) and is calculated by dividing the thickness of the material (measured in meters) by the K-value. R-value allows simple and easy comparison between insulating materials, provided their thicknesses and K-values are known. However, since real buildings are made up of multiple components and although the thermal resistance can be calculated by adding up the values, it only takes into account the conduction of heat, not the radiation and convection. For this reason, U-values are used which take into account all the different mechanisms of heat loss.

U-value indicates the ease of heat flow through a given thickness of the material. It takes into account conduction, convection and radiation losses of heat and is the reciprocal of the total thermal resistance of components, including thermal resistance of the inside and outside surfaces of elements according to the respective temperatures. In other words, the calculation of U-values is not simple, but the value is more accurate when comparing the insulating capabilities of materials. The lower the U-value, the better the building component is as a heat insulator. It is measured in watts per meter squared Kelvin ($W/m^2K$).

## 2.5 Building Information Modeling (BIM)

### 2.5.1 Introduction

The term Building Information Modeling came forward in early 2002 to describe the virtual design, construction and facilities management (Chuang et al., 2011) but the actual concept dates back to almost three decades (Eastman et al., 2011).A building information model specifies the geometry and spatial relationships of buildings, location information, quantities and material properties of building elements, cost estimates, material inventories and project schedule. In other words, a BIM model demonstrates the complete life cycle of a building (Bazjanac, 2006). This demonstration enables quantities and shared properties of materials to be readily extracted, and scopes of work to be easily isolated and defined. AIA (American Institute of Architects) has defined BIM as a model-based technology together with a project information database that is accessible and shareable with various project participants (Nguyen et al., 2010). The information within BIM objects benefits all the design and construction processes. BIM data can be presented in both 3D model form as well as the conventional 2D construction drawing form. BIM applications can also be integrated with other computer applications for purposes such as project management, construction estimation, and scheduling. Architecture, Engineering, and Construction (AEC) firms have implemented BIM to a large extent owing to the long-term benefits and huge productivity gains that come with it (Nguyen et al., 2010). BIM represents the process of development, and use of a computer simulation emulating the planning, design, construction, and operation of a building facility (Azhar et al., 2008). A BIM model carries all required information related to the building, including its aesthetic and functional properties and project life cycle information, in a combination of “smart objects” (CRC Construction Innovation, 2007).

### 2.5.2 Green BIM

In the SmartMarket report, McGraw-Hill Construction (2010) provided an in-depth discussion over the green BIM practice approaches in the construction industry. Green BIM is the use of BIM tools to achieve sustainability and improved building performance objectives on a project (McGraw-Hill Construction, 2010). Wu and Issa (2015) points out that green BIM is the synergies of BIM and green building, which is used to help achieve green objectives and to improve sustainable outcomes of the building development. Alawini et al. (2013) mentions the green BIM as a tool that is created to help construction design industry efficiently integrate sustainable components, especially in energy efficiency application, into the building project lifecycle.

### 2.5.3 BIM and sustainability analysis

BIM aids in complex building performance analysis to ensure an optimized sustainable building design (Azhar et al., 2009). It allows for multi-disciplinary information to be superimposed within one model, allowing performance analysis to be performed throughout (Schueter and Thessling, 2008). Sustainability or energy efficiency, in particular, is a key measure of building performance and several programs have been adopted to certify buildings regarding sustainability (Hetherington et al., 2010).

The use of energy and sustainability analysis has considerably affected the traditional design, construction, and operation stages of buildings. This is to ensure that target energy savings and CO2 emissions are achieved and to do so, several approaches and technologies have been developed. On the other hand, achieving the CO2 emission target requires better monitoring of building performance and sharing accurate information among the stakeholders. Among the used technologies is the use of BIM to model energy usage, thermal flows, lighting patterns and other sustainability measures (Motawa and Carter, 2013)

#### 2.5.3.1 BIM in comparison to conventional tools

Building model allows for evaluation of energy. Although evaluation can be done using traditional 2D tools, such as graphic representations of conventional CAD or object-CAD solutions since they require a separate energy analysis to be performed at the end of the design process, the main problem lies in the integration between these packages. Multiple data entry occurs (Motawa and Carter, 2013) and a great deal of human intervention and interpretation is required for considerations of changes in building features over the lifecycle (due to maintenance and operation activities) rendering the analysis too costly and time-consuming. It also ends up reducing the opportunities for early modifications that could improve the building’s energy performance (Azhar et. al, 2009).

On the other hand, BIM model represents the building as an integrated database of coordinated information. The integration with performance analysis tools greatly simplifies the often cumbersome and challenging analysis, giving architects an easy access to tools providing immediate feedback on retrofit and otherwise designs alternatives (Azhar et al., 2009). The technologies and the ICT frameworks integrated into it support all the stakeholders’ collaboration over projects life-cycle by providing facilities to insert, extract, update or modify information in the BIM model. The applications in BIM also produce more usable data and information for visualizations and simulation than the conventional 2D tools (Motawa and Carter, 2013).A building information model specifies the geometry and spatial relationships of buildings, location information, quantities and material properties of building elements which can be exported to a building simulation tool. The typical output from the simulation tools includes thermal analysis, lighting or shading analysis, acoustic and cost analysis (Motawa and Carter, 2013).

### 2.5.4 BIM and economic viability

Decisions made in a project are mainly dependent on their economic and environmental viability. Unfortunately, on the majority of projects in Pakistan, cost estimation or quantity take-off is still performed manually or by using a basic software. A building information model creates relationships between objects by using parametric object modeling technology, giving it the advantage of parametric change, allowing it to accommodate and coordinate changes and maintain a level of consistency while doing so. The relationships created not only include physical and functional characteristics but also project life cycle information. Schedules of components are easily obtained from the model, throughout its lifecycle and quantity of materials and their subsequent costs, and lifecycle costs can be directly determined (Azhar et al., 2009). By employing the present value technique, alternative investments can be quantified using LCC, and optimal retrofitting configuration can be selected. The LCC analysis will include energy costs related to operations, payback period and cost saving. The cost estimation using BIM requires up to 80% less time and is accurate within 3% as compared to traditional estimates. With a slight increase of 2% in the upfront building cost, about 20% of this initial value can be achieved in the form of life cycle savings (Azhar et al., 2011). Another analysis used to determine the best alternative is the return on investment (ROI) analysis. It compares the anticipated gain to the cost of investment,

$$\text{ROI} = \text{anticipated earning/cost}$$

According to research, the average BIM ROI ranges from 634% - 1633%, clearly outlining its valuable economic benefits (Azhar, 2011).

### 2.5.5 BIM and social sustainability

BIM integrates sustainable measures information from all disciplines into a single model, making it a highly efficient tool for assessing building performance. BIM’s integrated design and the holistic approach are particularly important for social sustainability assessment. Though BIM may not directly assess social sustainability, it helps to evaluate some parameters associated with it which eventually affect social sustainability (Azhar et al., 2011). Photorealistic visualizations and fly-through offered by BIM allows stakeholders to see what the building will look like prior construction, in this case retrofitting and their satisfaction can be assessed which has a vital role in social sustainability (Cory, 2015). BIM models can also be used to assess safety hazards by applying automated safety rules (Zhang et al., 2013), wherein occupational safety is one of the parameters involved in social sustainability as aforementioned in 2.2.5.

### 2.5.6 DesignBuilder

Providing comfortable, high quality and sustainable energy-efficient buildings require balancing many different criteria. The design of such buildings should be in compliance with building regulations, have minimum upfront costs and optimize the lifecycle energy costs while also reducing adverse environmental impacts. DesignBuilder is a 3-D modular tool that assists the design of such buildings by integrating a set of high productivity tools divided into ten modules.

Across the globe, leading services engineers and energy modelers use DesignBuilder to determine building performance, as this software combines advanced energy simulation with fast and easy modeling technology. DesignBuilder allows for an easy comparison of retrofit alternatives and allows optimization of design efficiently, allows large and complex buildings to be modeled easily, uses a robust engine namely EnergyPlus, generates high quality rendered images and movies that communicate the results to clients in an easy to understand way.

DesignBuilder provides key performance indicators such thermal comfort, energy consumption, costs, and carbon emissions throughout the retrofit process. These key features make it a highly popular choice for conducting energy analysis.

# CHAPTER 3

## RESEARCH METHODOLOGY

### 3.1 General introduction

This chapter aims to define the methodology that has been followed throughout this project to meet the objectives that were defined.

### 3.2 Determination of sustainability frameworks

Determination of environmental, economic and social sustainability frameworks is necessary. These are to be integrated with DesignBuilder so as to achieve a complete picture of sustainability upon analysis. The frameworks to be used are obtained from thorough literature review and are per the rating systems accepted globally. The indicators and parameters in the frameworks were then given priority based on the majority behavior of people in Pakistan concerning energy efficient housing and buildings. More emphasis was placed on the cost of lifecycle and retrofitting costs and their effect on the aesthetics as compared to emissions since these factors mostly drive the stakeholders to implement the retrofitting measures. This was determined through surveys and interviews with contractors. Economic sustainability is the primary driving factor, followed by social and then environmental factors.

The frameworks are as shown in figures 3,4 and 5.

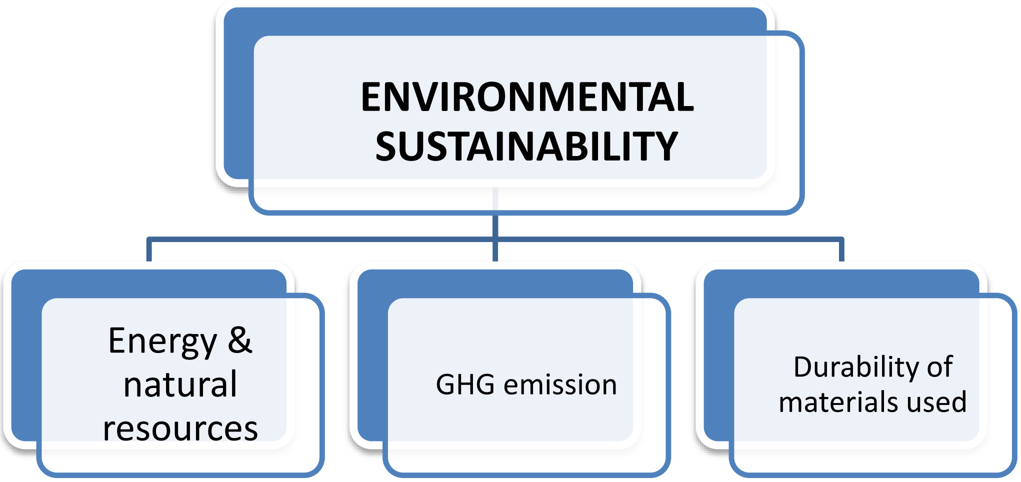


**Figure 4 - Selected environmental sustainability framework**

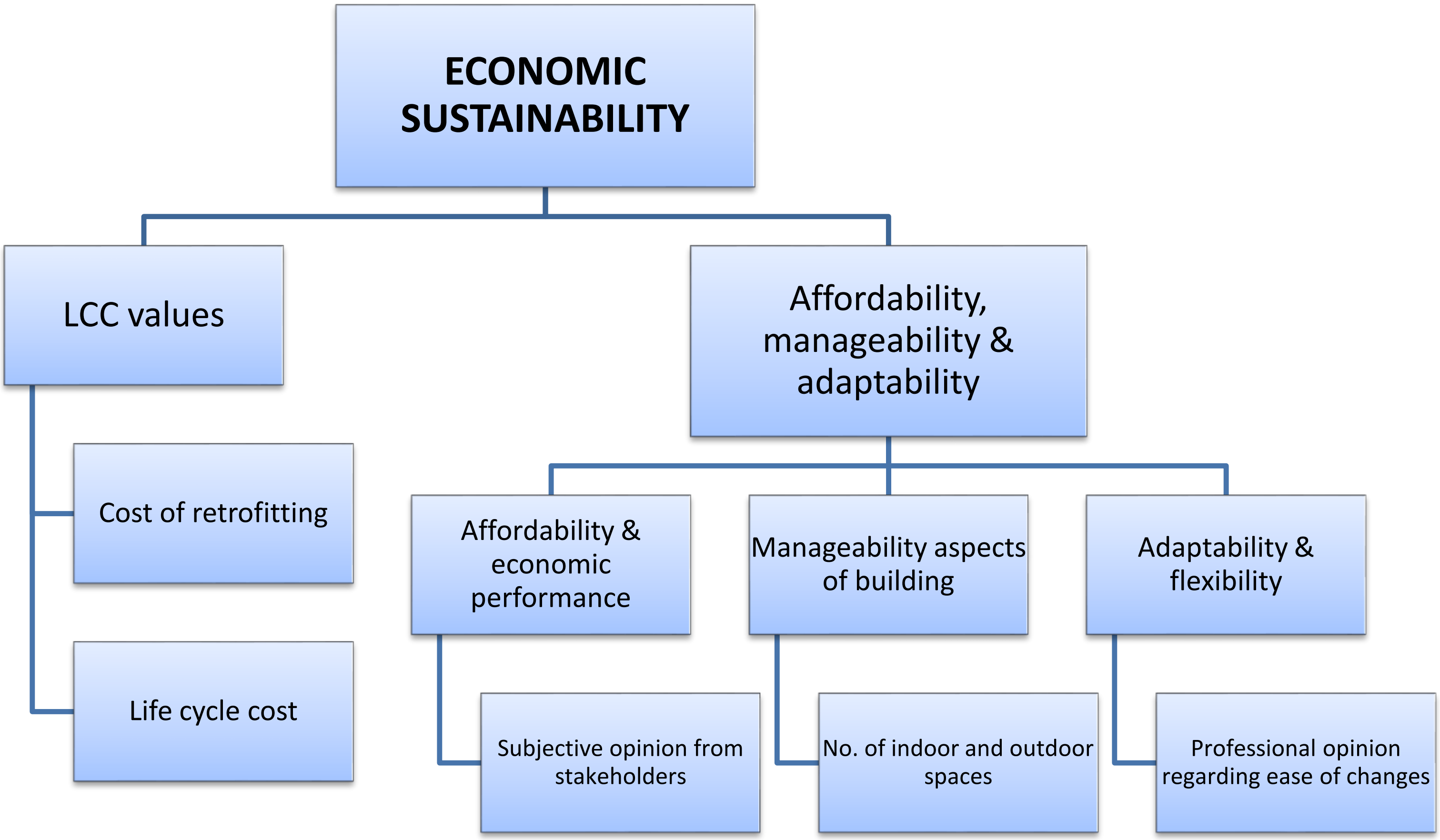


**Figure 5 - Selected economical sustainability framework**

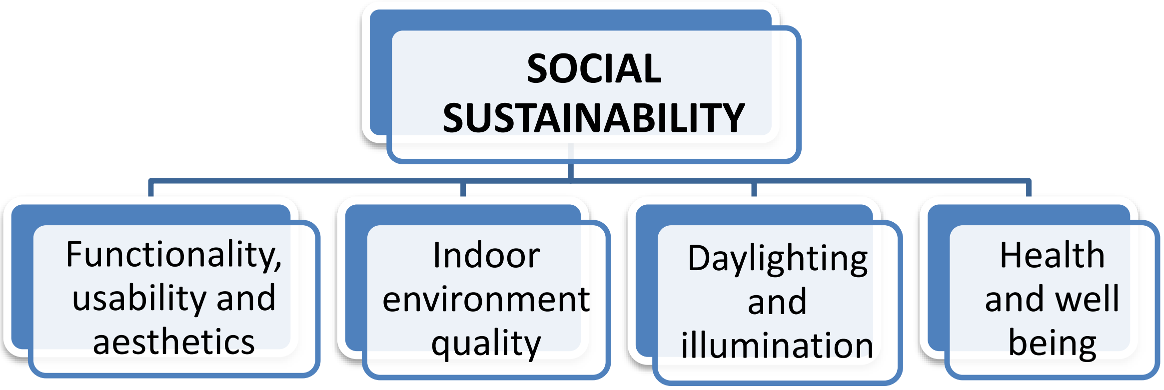


**Figure 6 - Selected social sustainability framework**

These indicators and parameters are quantifiable using the model that will be simulated in DesignBuilder and hence are in accordance with our objective of conducting sustainability analysis using a BIM.

## 3.3 Case study selection

For the research to be conducted, a real life building needs to be selected. We selected the Institute of Geographic and Information Systems (IGIS) located in NUST H-12, Islamabad. This building spans a total area of 20,924 sq. ft and is spread over three-storey. Since availability of building drawings, utility bills and visit permits are a key factor in selecting the building; IGIS was an ideal choice as it allowed all three. Drawings, BOQs, utility bills were obtained from PMO and in-situ monitoring was easily permitted.

The choice of an educational institute was also influenced by the schedules of heating and cooling which follow a fixed pattern as compared to a residential building. The building chosen has already been constructed as energy efficient with air gaps in the walls. However, our study also aims to highlight the importance of analysis to determine where and how much of an element is required to improve thermal performance and in turn incur less cost.

## 3.4 Building performance assessment

The performance of the building envelope needs to be diagnosed and an energy audit needs to be conducted to understand the quantity and quality of energy uses in buildings, by identifying areas with energy saving potentials. This is necessary before we can decide on the retrofitting measures as they are highly dependent on the initial assessment of the building envelope. We will be combining in-situ monitoring and documental information to conduct the energy diagnosis and the following steps were followed for performing this energy audit.

### 3.4.1 Identify building specifications

The following table 3 shows the details of the selected building.

**Table 3 - Building details**

| FACTOR | VALUE |
|---|---|
| Building area ($m^2$) | 20,924 sq . ft |
| Designing outdoor temperature | $40^0$ c (max) and $2^0$ c (min) |
| Occupancy times | 8 am – 9 pm |
| HVAC times | Followed per the schedules designed for DesignBuilder |

### 3.4.2 Audit of the building envelope

The audit of the building envelope can be carried out by quantifying the total heat transfer coefficient of the envelope (the U-values) and analyzing thermographs obtained from infrared thermography.

### 3.4.2.1 Heat transfer coefficients

Heat transfer coefficients or thermal transmittances or U-values describe how well heat gets transferred or the rate of transfer of heat through a square meter of a structure. The higher the U-values, more heat getting transferred and hence worse the performance of the envelope of the building. Low values indicate high levels of insulation and hence better thermal performance of the envelope. Rather than relying on individual properties of elements, U-values help assess the behavior of composite materials (Ascione et al., 2015).

$$U = 1/R \text{ where } R = \text{thermal resistivity}$$

$$U = k/L \text{ where } k = \text{thermal conductivity coefficient, } L = \text{thickness}$$

SI units of U-value are $W/m^2K$

Thicknesses of the materials were obtained from BOQs of the building and on-site assessment and their corresponding k-values were obtained from standard values. Table 4 shows the U-values obtained for the primary components of the building envelope.

**Table 4 - U-values of windows**

| Component | U-value ($W/m^2K$) |
|---|---|
| Aluminium without thermal breaks – 5 mm clear single glazed tinted | 4.473 |
| Roof | 2.323 |
| Walls | 1.046 |

### 3.4.2.2 In-situ monitoring

In-situ monitoring involves walk through assessment and infrared thermography. Walk through assessment helped analyze the building structure first hand and identify areas with energy saving potentials which set a base for retrofitting techniques.

During the initial walk through, windows and floors were analyzed and areas with the greatest energy saving potential.

All the windows were single glazed with no air insulation provided. However, the connection between the frame and glass was air tightened. Windows in the library were found to be tinted using a tinting sheet and glass on the curtain walls was covered with reflective film to reduce penetration of light, as shown in figure 6. For simplicity, all windows were assumed to be tinted, as in table 4.

**Figure 7 (a) Air tightened glass and frame, (b) Tinted sheet**

Infrared thermography (figure 7) allowed the identification of major heat losses, missing or damaged insulation in the walls and roofs. It also helped identify air leakages and infiltrations around the window frames, as shown in figure 8. Such air leakages are usually one of the main causes of thermal discomfort for occupants. This was carried out using a SeekThermal camera and the imaging was obtained in both the winter and summer seasons.

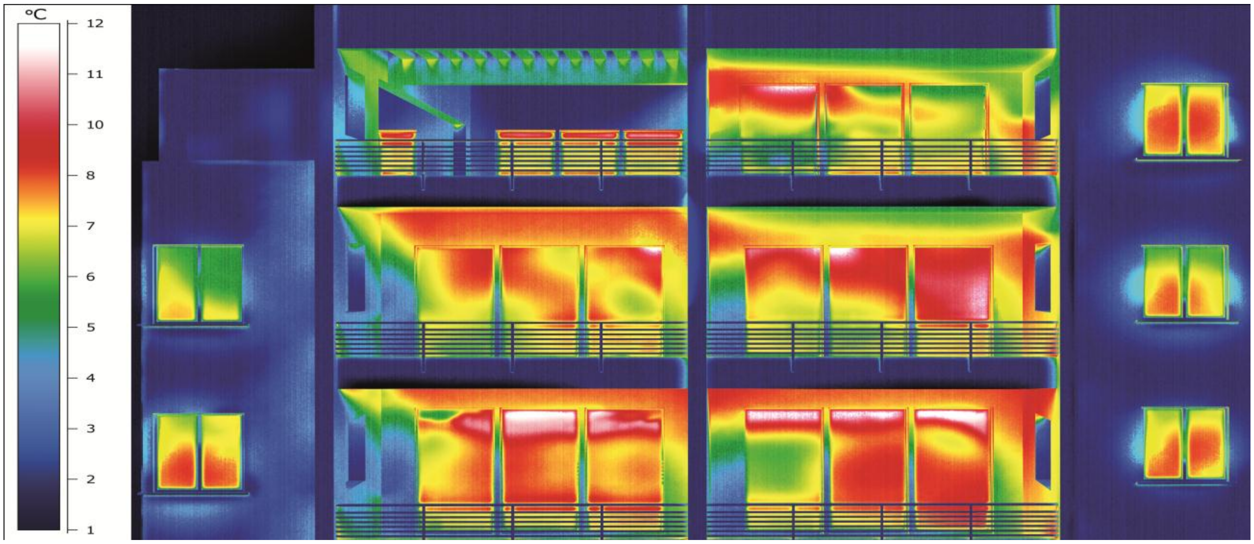


**Figure 8 Thermal imaging of an apartment building (general)**

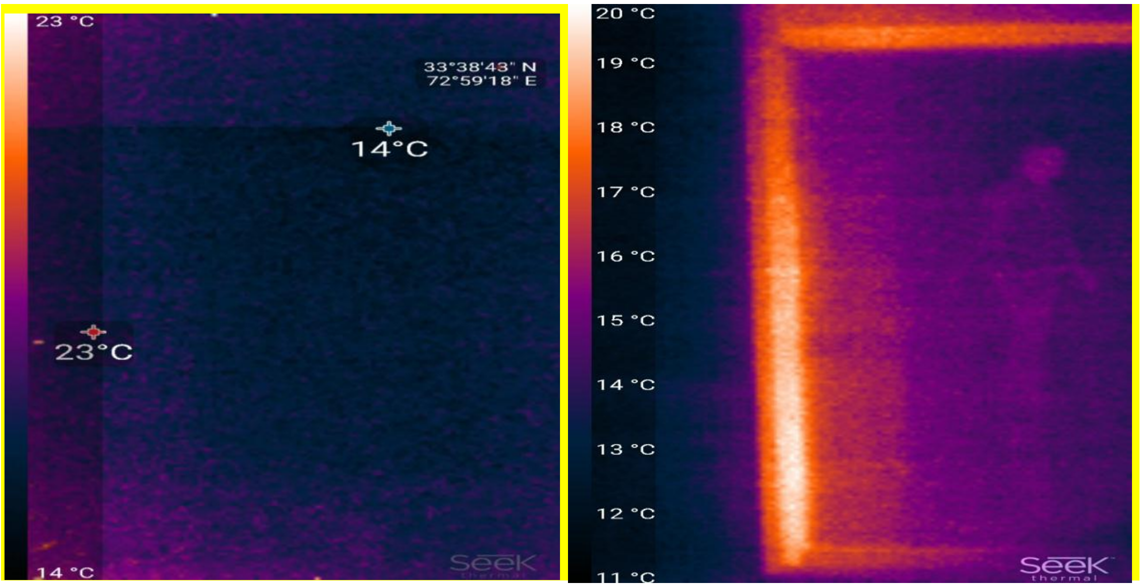


**Figure 9 Thermal imaging of windows in IGIS**

Main heating and cooling is done through the HVAC while staff offices have individual split ACs.

Daylight illumination and ventilation is extensively used on the second floor owing to the presence of terraces, but these terraces are also a source of thermal discomfort.

## 3.5 BIM Model

The building was then modeled using DesignBuilder using the drawings obtained from the PMO office. Since it was building information modeling, the drawings required detailed information input.

Geographic data was set depicting the accurate location of the building. Weather data files were imported from the online weather database. Unfortunately, weather data files compatible with BIM and all software using BIM are not available for Islamabad. Hence files for Karachi, the only city of Pakistan whose complete data set was available were used. The complete spatial data allows the DesignBuilder to generate accurately the solar path which helped us determine which façade of the building required the most retrofitting, as shown in figure 9 and 10. By studying the solar path, it was determined that only 22 windows out of the total required retrofitting, since the rest of the windows were only exposed to full radiation for insignificant times throughout the day.

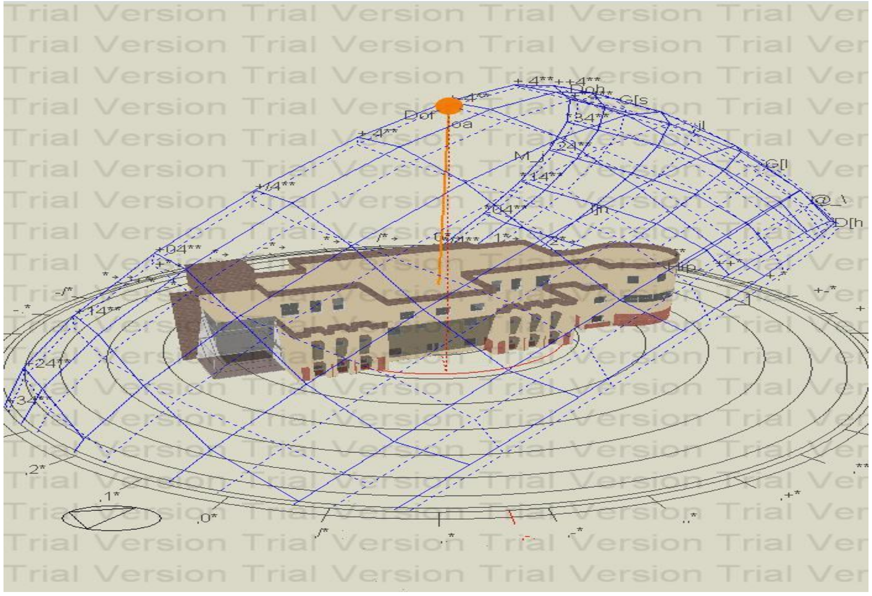


**Figure 10 South façade**

Figure 11 North façade

Each zone’s information modeling property was then set. The zones that had HVAC system were assigned their respective HVAC zones and the zones with split air conditioners were assigned their air conditioners.

Information such as the number of computers, appliances, printers and water heaters and most importantly, occupants was also assigned.

The schedule of the HVAC systems, occupancy, computers, appliances and water heaters for all seasons, days of the week, weekends, holidays and summer holidays were then individually created using compact schedules. These schedules define all the features of the schedule components in commands. Each compact schedule covers all the days of a year and have values for all 24 hours of all day types. This work is extensive and care must be taken as they highly influence the energy analysis result.

Each setting was carefully setting to best imitate the real life IGIS building environment.

After the baseline model was created, energy simulation was run and results were obtained that would then be used as a base for comparing and selecting the optimal retrofit combination.

Retrofit combinations that are mentioned in detail in 3.6 were then applied, with carefully selected data to represent accurate properties. Energy simulations were then run and results were obtained.

## 3.6 Building retrofits

### 3.6.1 Green roof:

When a building roof is completely or partly covered with vegetation, is known as a green roof.  We used the extensive type of green roof which allows for thin layers of vegetation and these can be easily planted on the roof top without any modifications to the roof structure. These extensive green roofs usually provide an added load of 125 – 150 kg/m2 which is within the acceptable limits of most buildings.

$$\text{U-value } (W/m^2K) = 1.433$$

### 3.6.2 Thermal insulation (roofs and walls)

Polystyrene sheets are commonly used in the Middle East and Asia. These insulation layers have the capability of reducing the load by up to 50% when compared to a building with no insulation, due to their close molecular structure. These polystyrene sheets have a life expectancy of up to 50 years and are lightweight, making them ideal for economic retrofitting.

For use on roofs, a waterproof layer was first added, then 3 inches in polystyrene followed by wire mesh and screed. The composite U-value is;

$$\text{U-value } (W/m^2K) = 0.467$$

For use on walls, 2 inches of polystyrene on the interior face, covered by either gypsum board, the composite U-value being;

$$\text{U-value } (W/m^2K) = 0.648$$

Or covered by wall paper, the composite U-value being;

$$\text{U-value } (W/m^2K) = 0.683$$

### 3.6.3 Double glazed, low e value

Windows play a vital role in the thermal activity of the building, and to reduce any thermal leakages we used the double glazed low e value glass with a 13 mm vacuum between the two glasses. A low e value glass basically helps in reducing the heat loss/gain from the windows as it has a see through metallic coating which allows the inside heat to stay inside, while reflecting the heat from the Sun, thus preventing any indoor heat loss or gain. These low e value glass are used on the interior face of the interior glass. This combination greatly reduces the thermal leakages.

$$\text{U-value } (W/m^2K) = 1.628$$

# CHAPTER 4

## ANALYSIS AND RESULTS

### 4.1 General

Building performance analysis is conducted using the input data from energy audits from DesignBuilder and through building utility bills. Reliable estimation and quantification of energy benefits is necessary for prioritizing the retrofit measures. The performance were evaluated by energy simulation and modeling. The simulation plays an important role in analyzing the performance of different retrofit measures, since different models and tools offer different prediction reliabilities with different uncertainties.

Economic analysis facilitates the comparison between different retrofit alternatives, indicating whether the following represents a tradeoff between capital investments and benefits. This economic analysis is also used to determine the pay-back period as it plays a key role in convincing the customer.

### 4.2 Trials/Combinations

A total of seven trials were conducted and the results were analyzed. The combinations/trials are as shown in table 5. For each trial, heating loads, cooling loads and GHG emissions were simulated. The cooling loads were simulated for April, June and October and the results of June were used. These were then compared with the base model results to determine the reduction in heating and cooling loads and the emission of GHG.

There were numerous combinations of retrofitting measures possible, but the combinations selected are the ones that will produce significant results and comparisons. Note that trail 2 and trial 7 are almost identical, except that in trial 2 (and all other trials), all the windows were retrofitted; while in trial 7 only 22 windows (decided on the basis of the solar path) were retrofitted. This will demonstrate the need for the use of carefully simulated energy and cost analysis.

**Table 5 Retrofit combinations**

| TRIAL | DETAILS |
|---|---|
| 1 | **Insulation sheet on roof and double glazed low e** |
| 2 | **Insulation sheet on roof and wall, and double glazed low e** |
| 3 | **Green roof, Insulation sheet on wall and double glazed low e** |
| 4 | **Double glazed low e and Insulation sheet on walls** |
| 5 | **Insulation sheet on roof and wall (without gypsum), double glazed low e** |
| 6 | **Insulation sheet on roof and wall** |
| 7 | **Insulation sheet on roof and wall, and selected double glazed low e** |

## 4.3 Optimal retrofit measure

After comparing the results, it was found that trial 2 and trial 7 produced the most optimal results, i.e. they reduced heating and cooling loads more than the other trials. The energy efficiencies obtained were as shown in table 6

| Trial | Energy efficiency |
|---|---|
| 2 | 21.35% |
| 7 | 20.2% |

Note that despite having retrofitted only 22 windows, trial 7 saved almost the same amount of energy as trial 2. This strengthens the need for conducting energy analysis using robust software as opposed to baselessly applying retrofitting measures on every element, which not only has a high initial cost, but also a longer payback period.

EnergyPlus results for the base model and trial 7 are attached in Annex A.

## 4.4 Cost benefit analysis

Without considering the economic analysis, optimal retrofit combination cannot be selected. Since payback period is the primary factor that influences the stakeholder, it is necessary that it be calculated. Keeping in mind the economic sustainability framework, cost of retrofitting and life cycle costs (in terms of reduction in heating and cooling loads) were determined and used to calculate the payback period.

Total cost of retrofitting for trial 7 after carrying out the energy analysis was a total of almost **Rs. 18 lacs**. This cost included the thick polystyrene sheets on the roof with waterproofing and cement on top of the sheets in order to protect them. This cost also includes the cost of retrofitting the windows with double glazed low e value glass and aluminum frame with thermal breaks and retrofitting the walls with polystyrene sheets and gypsum boards in order to protect the sheets.

Due to significant reduction of **20.2%** in the energy consumption, the yearly bill (including both the heating and cooling loads) was reduced from **Rs. 3,858,163** to **Rs. 3,078,814**, thus saving an amount of **Rs. 779,348.**

Calculating Payback Period:

| Initial investment on retrofitting the roof, walls and windows (A) | Savings (B) | Payback Period (A/B) |
|---|---|---|
| **Rs. 1,786,530** | **Rs. 779,348** | **2.3 yrs** |

## 4.5 Conclusion

Retrofitting of commercial, residential and office buildings is influenced by various parameters, making it a highly complex process. Simulating the results using DesignBuilder made it possible to analyze the issues involving this process. It also helps develop an assessment methodology which takes into account the economic, social and environmental criteria. A retrofitting project should not only be chosen in regard to its thermal performance, but also it’s economic feasibility and durability and aesthetics.

For a country like Pakistan, it is best to use simple techniques rather than opting for new and active retrofitting techniques. By the use of simple, passive retrofitting techniques that can be afforded by a wide range of general income quintile population, this methodology can be adopted easily in Pakistan and this will widely help curb the ever growing energy crisis in Pakistan and to some extent, the environmental degradation too.

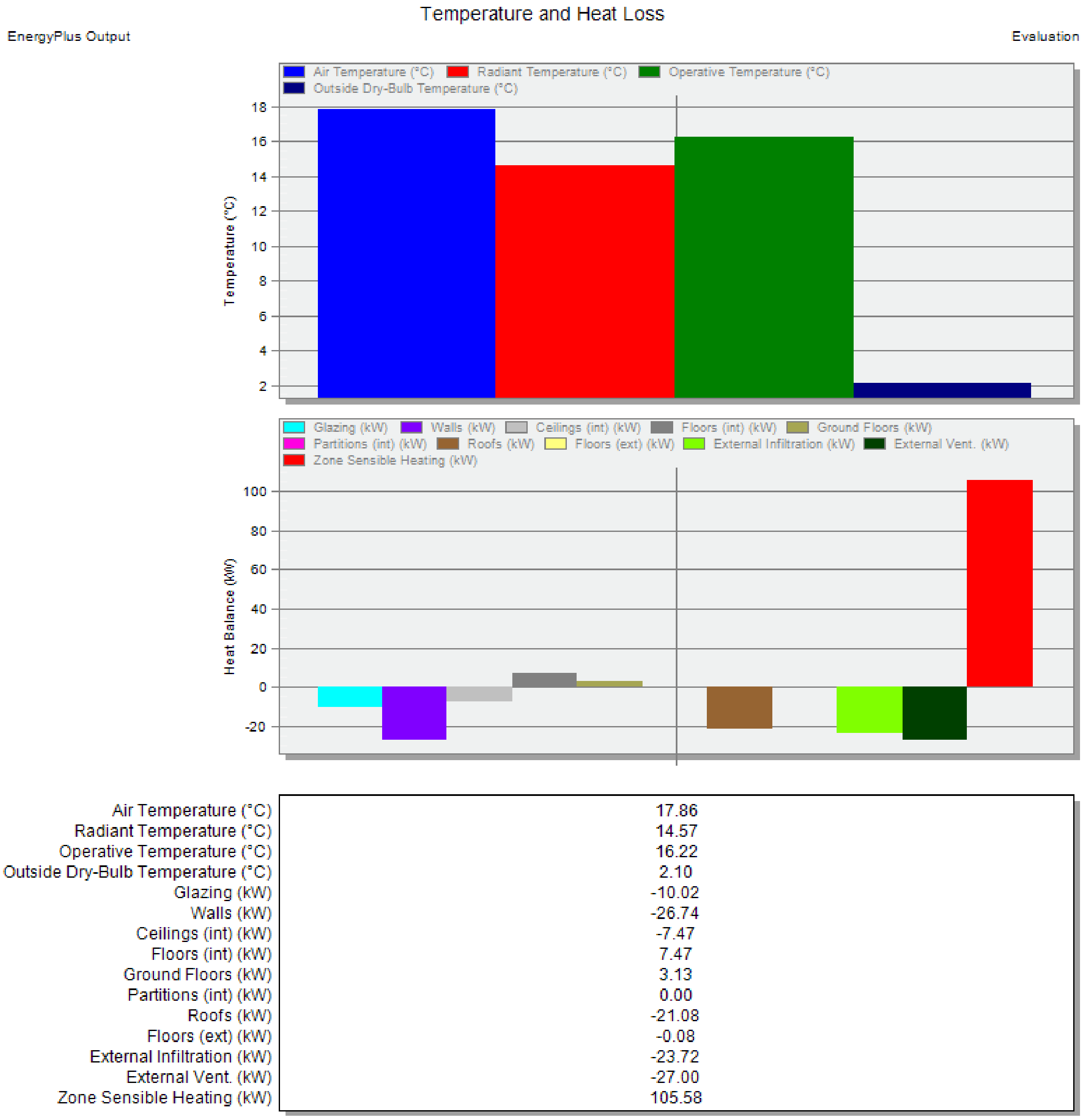
The following conclusions were drawn from the simulation results:

- The application of polystyrene sheets on the roof, use of polystyrene sheets on the walls with gypsum boards and double glazed low e glass with 13 mm vacuum gap and thermal gaps in the aluminum frames on 22 windows proved to be the best retrofit combination.
- Application of these measures reduced the heating and cooling loads by 20.2% yearly.
- A payback period of only 2.3 years was obtained. This suggests that within 2.3 years, the initial cost invested on retrofitting will be returned in the form of yearly utility bills savings due to a reduction in the heating and cooling loads.
- GHG emissions were reduced from a maximum of 8137.88 kg to 7984.05 kg after the implementation of these retrofitting techniques.
- The retrofitting measures used are durable with low maintenance and replacement costs, their life expectancy being up to 50 years.

# ANEX A

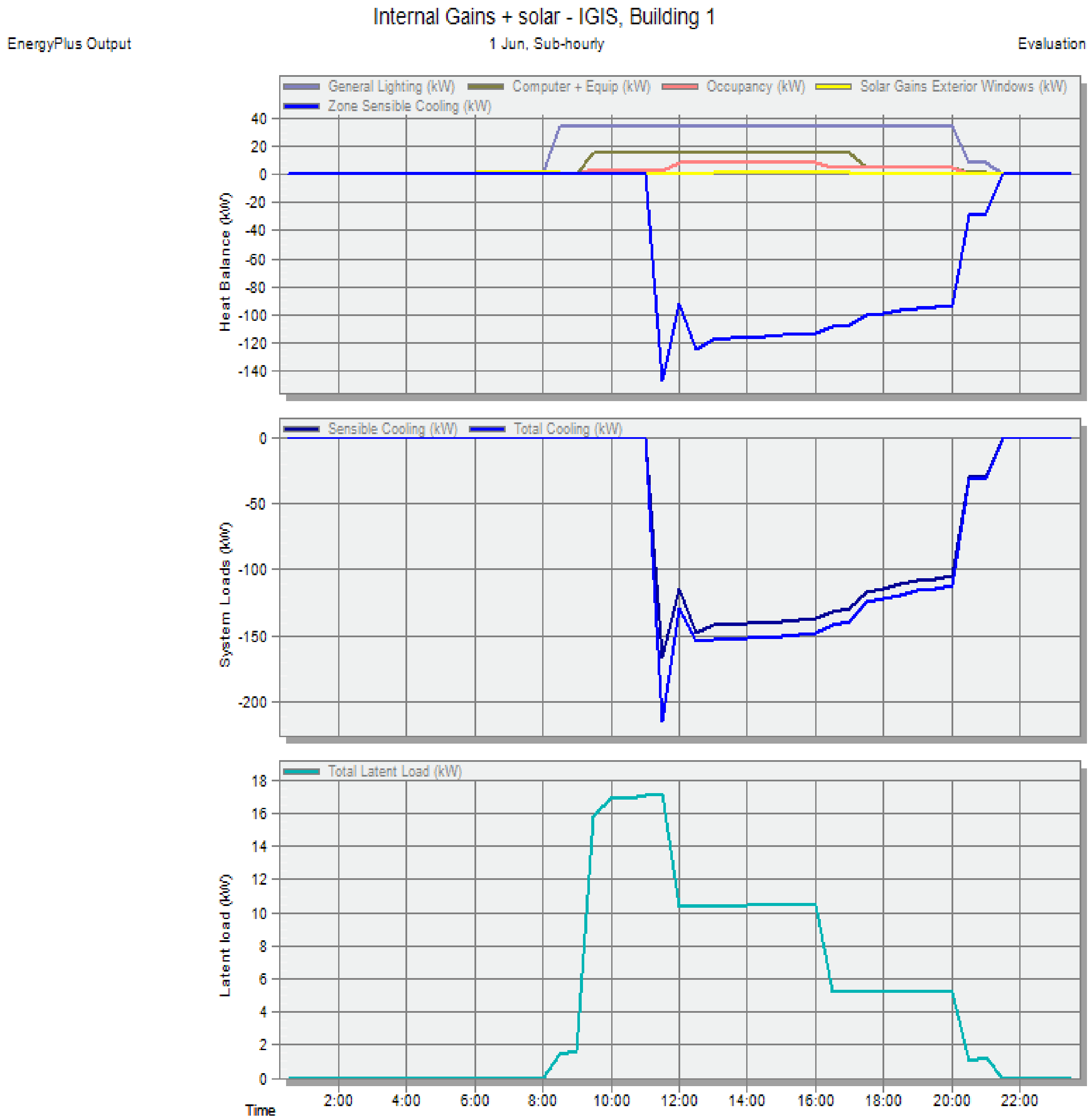
## 1 BASE MODEL RESULTS

### 1.1 Heating loads



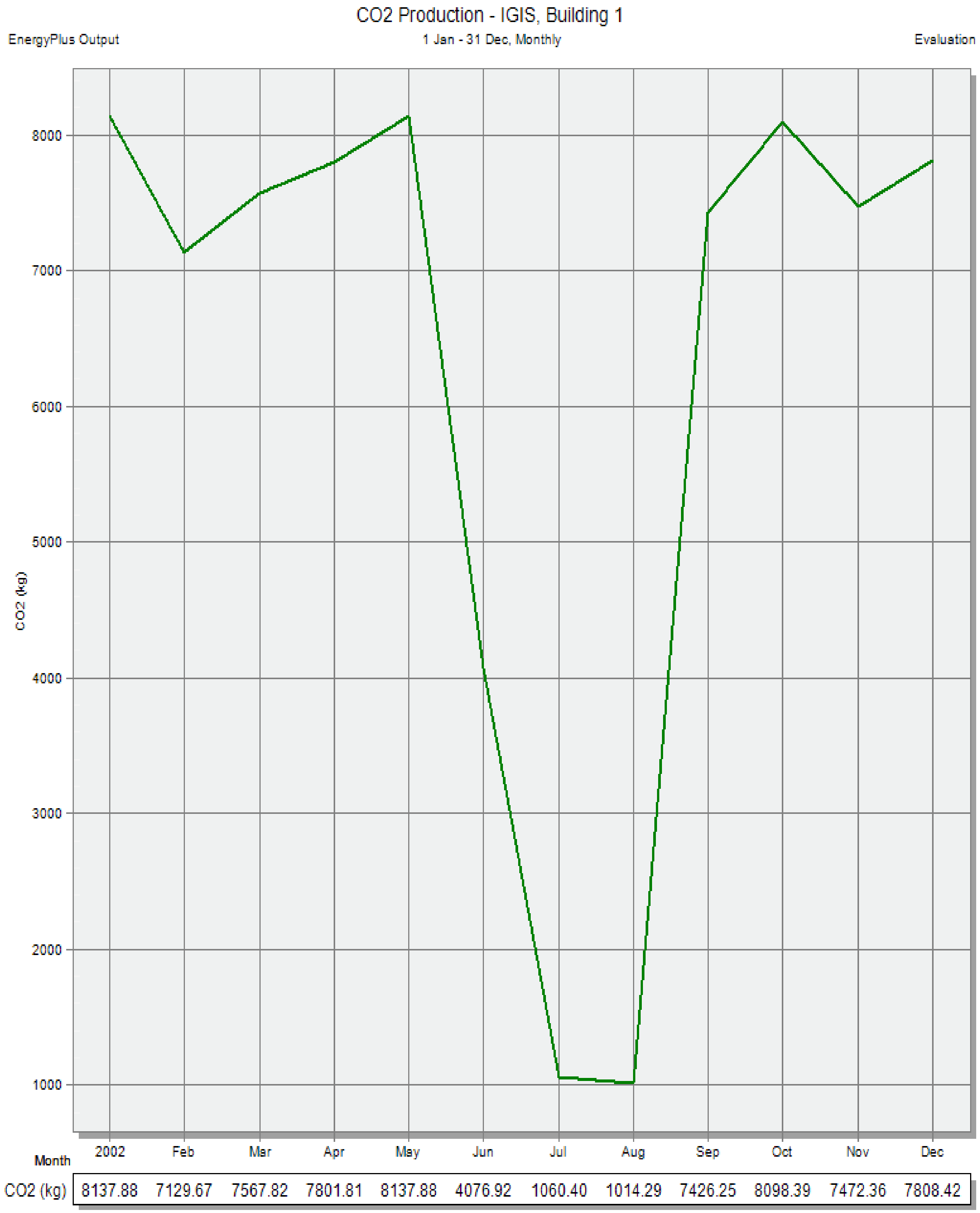
| | |
|---|---|
| Air Temperature (°C) | 17.86 |
| Radiant Temperature (°C) | 14.57 |
| Operative Temperature (°C) | 16.22 |
| Outside Dry-Bulb Temperature (°C) | 2.10 |
| Glazing (kW) | -10.02 |
| Walls (kW) | -26.74 |
| Ceilings (int) (kW) | -7.47 |
| Floors (int) (kW) | 7.47 |
| Ground Floors (kW) | 3.13 |
| Partitions (int) (kW) | 0.00 |
| Roofs (kW) | -21.08 |
| Floors (ext) (kW) | -0.08 |
| External Infiltration (kW) | -23.72 |
| External Vent. (kW) | -27.00 |
| Zone Sensible Heating (kW) | 105.58 |

## 1.2 Cooling loads



| | 2:00 | 4:00 | 6:00 | 8:00 | 10:00 | 12:00 | 14:00 | 16:00 | 18:00 | 20:00 | 22:00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| General Lighting (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 33.97 | 33.97 | 33.97 | 33.97 | 33.97 | 33.97 | 0.00 |
| Computer + Equip (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 15.27 | 15.27 | 15.27 | 15.27 | 5.09 | 5.09 | 0.00 |
| Occupancy (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 2.34 | 9.02 | 8.96 | 8.94 | 4.50 | 4.52 | 0.00 |
| Solar Gains Exterior Windows (kW) | 0.00 | 0.00 | 0.93 | 1.03 | 0.83 | 0.77 | 1.14 | 1.11 | 0.52 | 0.00 | 0.00 |
| Zone Sensible Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -91.78 | -116.11 | -112.93 | -99.07 | -93.11 | 0.00 |
| Sensible Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -113.87 | -140.69 | -136.37 | -114.08 | -104.40 | 0.00 |
| Total Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -129.09 | -151.54 | -147.11 | -121.73 | -111.99 | 0.00 |
| Total Latent Load (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 17.03 | 10.34 | 10.41 | 10.43 | 5.18 | 5.16 | 0.00 |

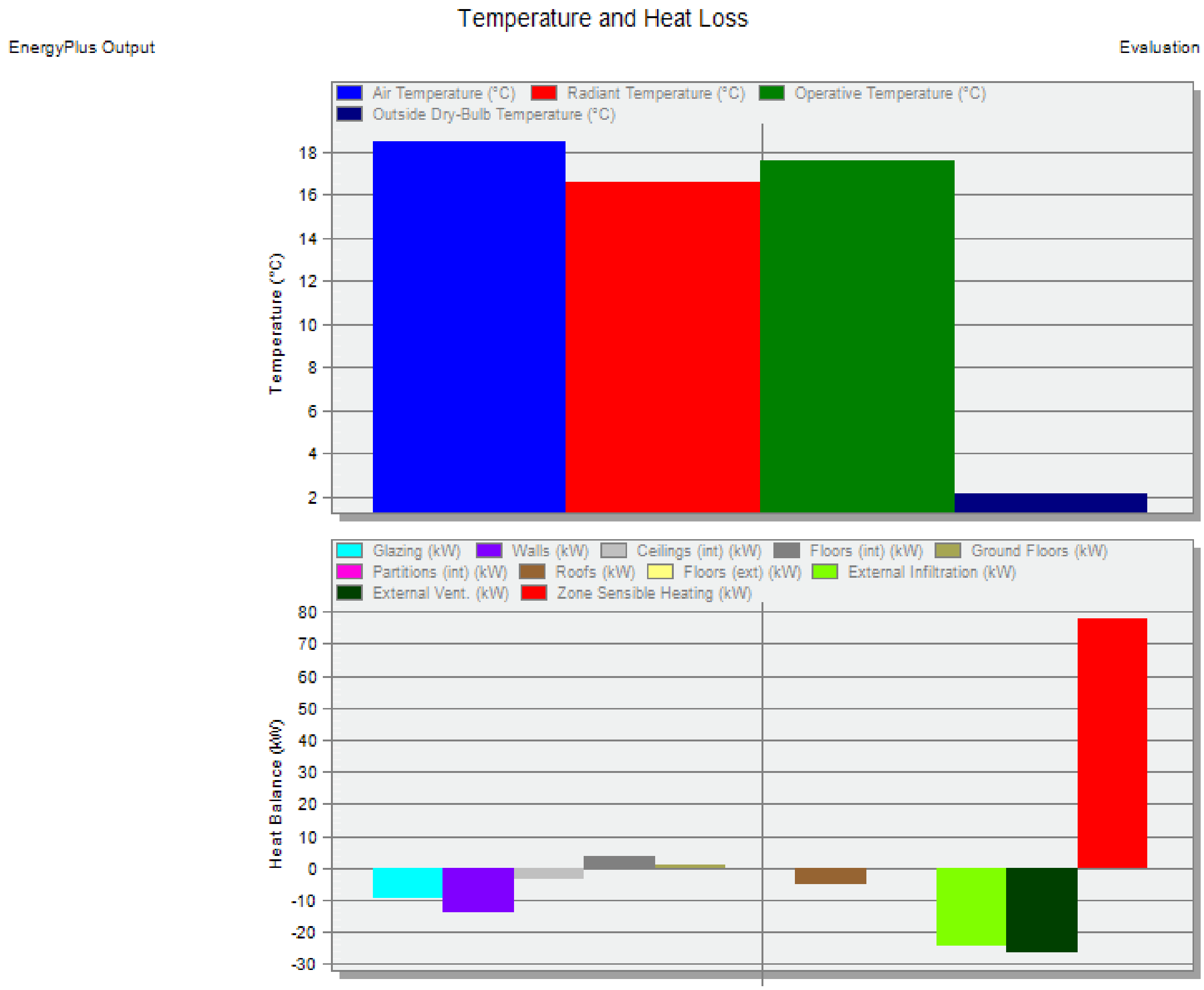
## 1.3 GHG emissions



| Month | 2002 | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO2 (kg) | 8137.88 | 7129.67 | 7567.82 | 7801.81 | 8137.88 | 4076.92 | 1060.40 | 1014.29 | 7426.25 | 8098.39 | 7472.36 | 7808.42 |

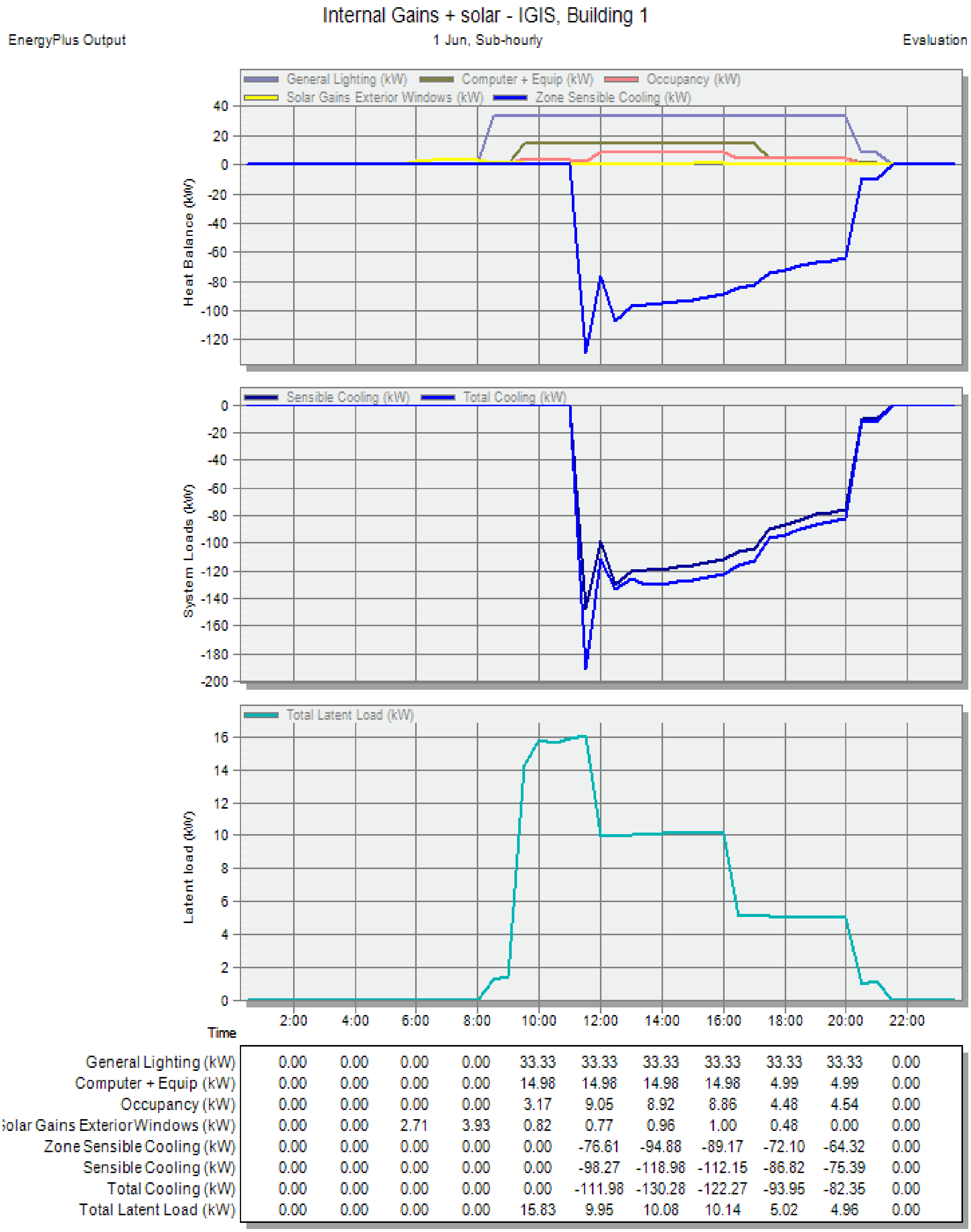
# 2. TRIAL 7 RESULTS

## 2.1 Heating loads



| | |
|---|---|
| Air Temperature (°C) | 18.50 |
| Radiant Temperature (°C) | 16.58 |
| Operative Temperature (°C) | 17.54 |
| Outside Dry-Bulb Temperature (°C) | 2.10 |
| Glazing (kW) | -9.27 |
| Walls (kW) | -13.93 |
| Ceilings (int) (kW) | -3.52 |
| Floors (int) (kW) | 3.53 |
| Ground Floors (kW) | 1.06 |
| Partitions (int) (kW) | 0.01 |
| Roofs (kW) | -4.92 |
| Floors (ext) (kW) | -0.10 |
| External Infiltration (kW) | -24.21 |
| External Vent. (kW) | -26.48 |
| Zone Sensible Heating (kW) | 77.88 |

## 2.2 Cooling loads



Internal Gains + solar - IGIS, Building 1

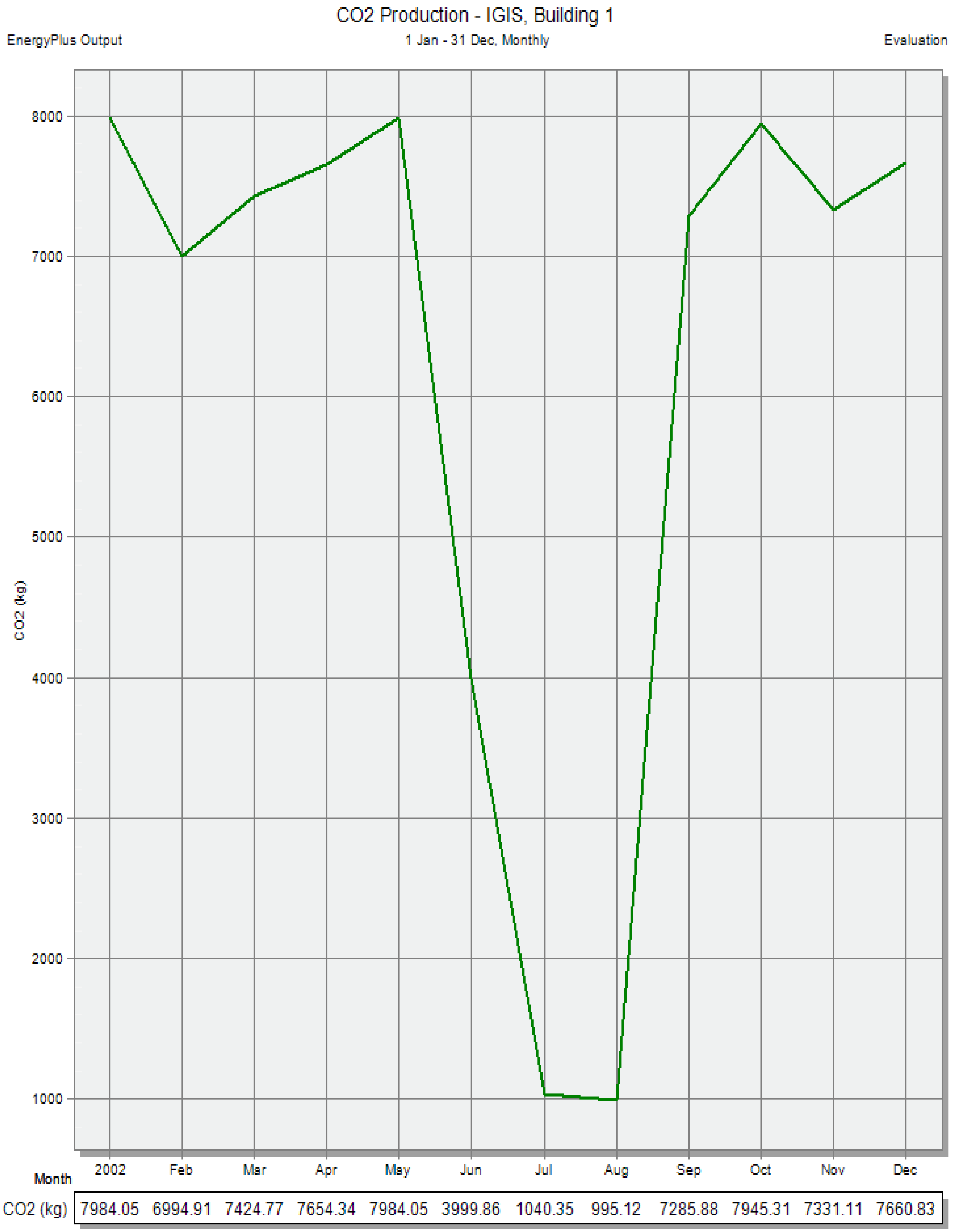
EnergyPlus Output

1 Jun, Sub-hourly

Evaluation

| Time | 2:00 | 4:00 | 6:00 | 8:00 | 10:00 | 12:00 | 14:00 | 16:00 | 18:00 | 20:00 | 22:00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| General Lighting (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 0.00 |
| Computer + Equip (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 14.98 | 14.98 | 14.98 | 14.98 | 4.99 | 4.99 | 0.00 |
| Occupancy (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 3.17 | 9.05 | 8.92 | 8.86 | 4.48 | 4.54 | 0.00 |
| olar Gains Exterior Windows (kW) | 0.00 | 0.00 | 2.71 | 3.93 | 0.82 | 0.77 | 0.96 | 1.00 | 0.48 | 0.00 | 0.00 |
| Zone Sensible Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -76.61 | -94.88 | -89.17 | -72.10 | -64.32 | 0.00 |
| Sensible Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -98.27 | -118.98 | -112.15 | -86.82 | -75.39 | 0.00 |
| Total Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -111.98 | -130.28 | -122.27 | -93.95 | -82.35 | 0.00 |
| Total Latent Load (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 15.83 | 9.95 | 10.08 | 10.14 | 5.02 | 4.96 | 0.00 |

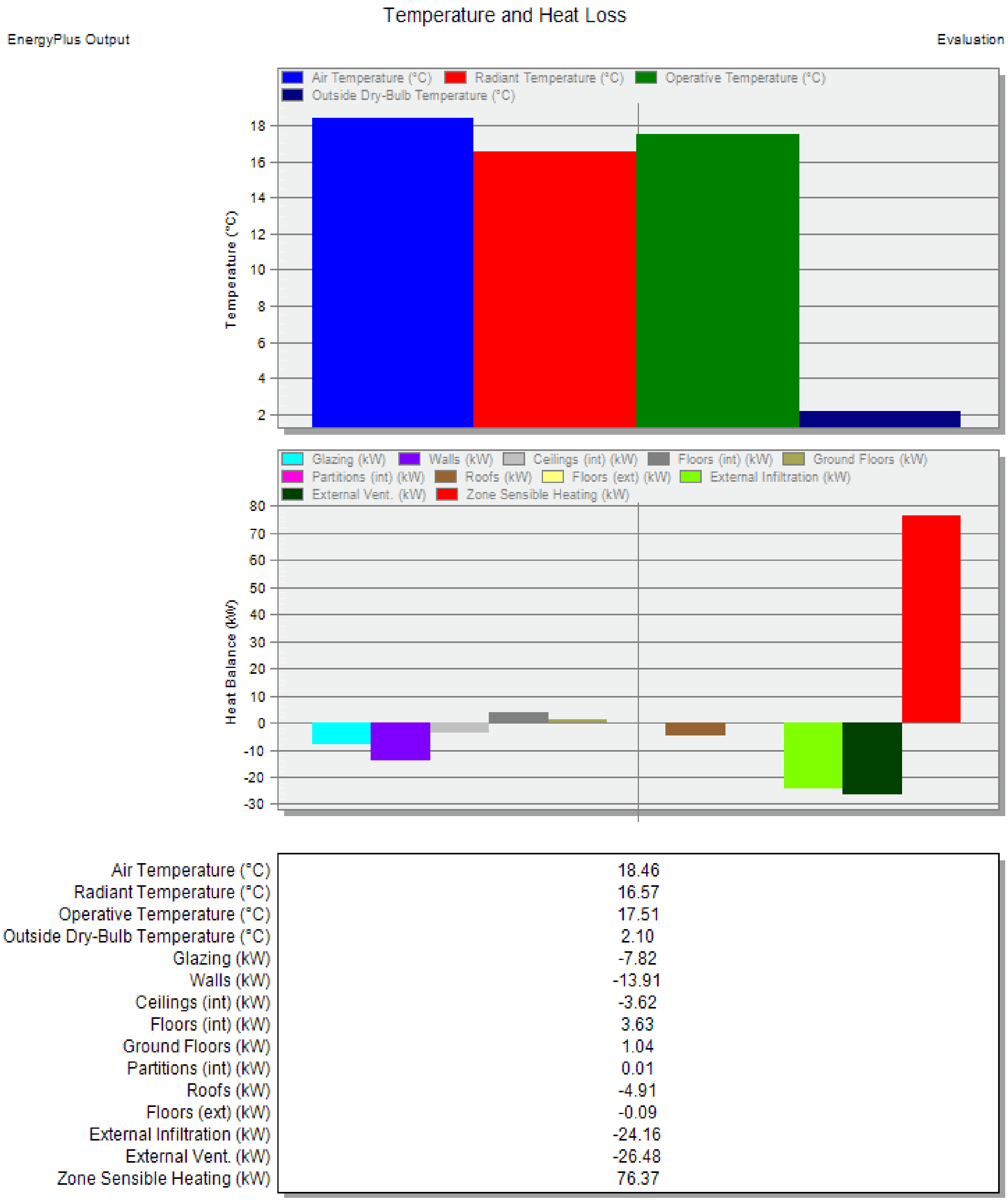
## 2.3 GHG emissions



| Month | 2002 | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO2 (kg) | 7984.05 | 6994.91 | 7424.77 | 7654.34 | 7984.05 | 3999.86 | 1040.35 | 995.12 | 7285.88 | 7945.31 | 7331.11 | 7660.83 |

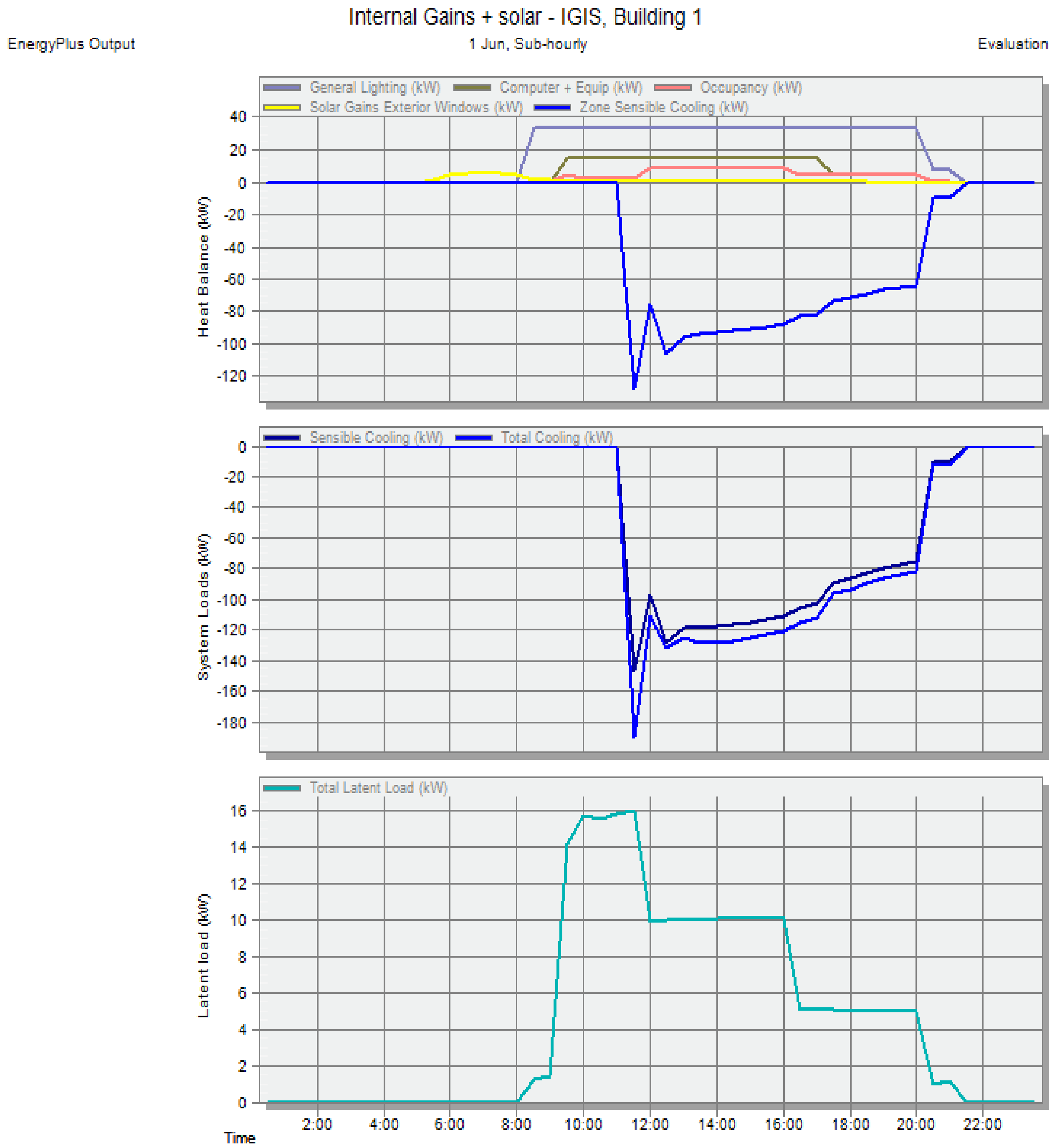
# 3. TRIAL 2 RESULTS

## 3.1 Heating loads



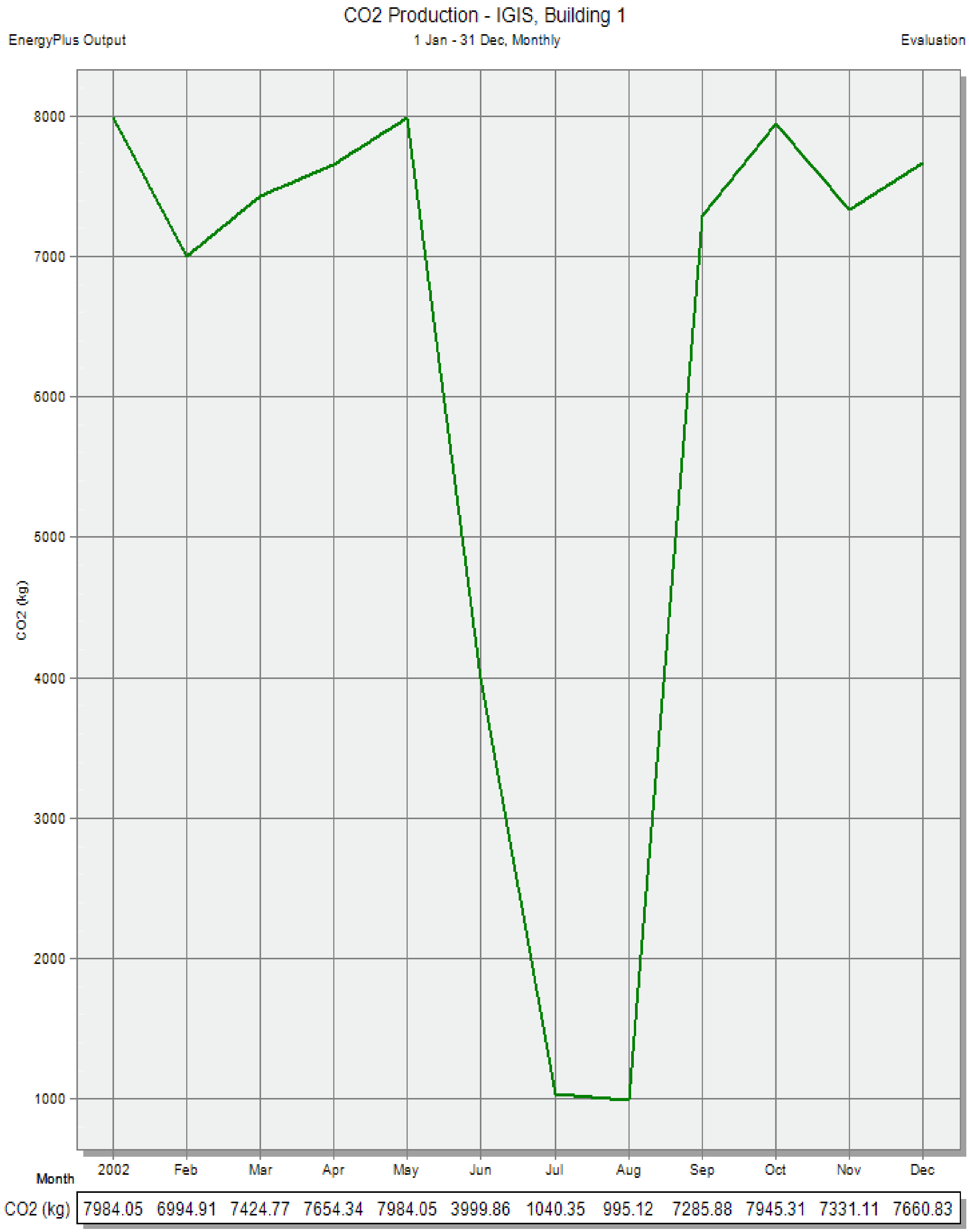
| | |
|---|---|
| Air Temperature (°C) | 18.46 |
| Radiant Temperature (°C) | 16.57 |
| Operative Temperature (°C) | 17.51 |
| Outside Dry-Bulb Temperature (°C) | 2.10 |
| Glazing (kW) | -7.82 |
| Walls (kW) | -13.91 |
| Ceilings (int) (kW) | -3.62 |
| Floors (int) (kW) | 3.63 |
| Ground Floors (kW) | 1.04 |
| Partitions (int) (kW) | 0.01 |
| Roofs (kW) | -4.91 |
| Floors (ext) (kW) | -0.09 |
| External Infiltration (kW) | -24.16 |
| External Vent. (kW) | -26.48 |
| Zone Sensible Heating (kW) | 76.37 |

## 3.2 Cooling loads


Internal Gains + solar - IGIS, Building 1

| Time | 2:00 | 4:00 | 6:00 | 8:00 | 10:00 | 12:00 | 14:00 | 16:00 | 18:00 | 20:00 | 22:00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| General Lighting (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 33.33 | 0.00 |
| Computer + Equip (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 14.98 | 14.98 | 14.98 | 14.98 | 4.99 | 4.99 | 0.00 |
| Occupancy (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 3.20 | 9.05 | 8.92 | 8.86 | 4.48 | 4.54 | 0.00 |
| olar Gains ExteriorWindows (kW) | 0.00 | 0.00 | 4.95 | 4.83 | 0.99 | 0.94 | 1.05 | 0.97 | 0.42 | 0.00 | 0.00 |
| Zone Sensible Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -75.47 | -93.44 | -87.97 | -71.40 | -64.00 | 0.00 |
| Sensible Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -97.14 | -117.55 | -110.95 | -86.11 | -75.07 | 0.00 |
| Total Cooling (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -110.73 | -128.78 | -121.04 | -93.23 | -82.03 | 0.00 |
| Total Latent Load (kW) | 0.00 | 0.00 | 0.00 | 0.00 | 15.80 | 9.95 | 10.08 | 10.14 | 5.02 | 4.95 | 0.00 |

## 3.3 GHG emissions



| Month | 2002 | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO2 (kg) | 7984.05 | 6994.91 | 7424.77 | 7654.34 | 7984.05 | 3999.86 | 1040.35 | 995.12 | 7285.88 | 7945.31 | 7331.11 | 7660.83 |

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