All-Weather Energy Efficient Design for Buildings in Pakistan

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This thesis is dedicated to my mother for making me be who I am, my father for supporting me all the way and all those who made it possible for me till day and in future

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Abstract

There are several ways and tools for saving energy. If the sole objective is to limit and save the costs for energy consumption, the best option is to find a way to make the whole structure energy smart and improve not only the energy efficiency of some single component but treat the whole building as one unit.

The target of the thesis is to determine how to minimize energy consumption of the building. There are multiple aspects which has direct influence on the energy consumption and it is tedius to consider all of them at once, therefore through a careful literature review and qualitative analysis few features of energy efficient design are considered for analysis and simulations.In this thesis a reference building is planned and designed using simulation tool Design Builder with the least conceivable energy consumption. The theoratical portion of the thesis covers the core features and facets of energy efficient design using articles and literature. Several options gathered from experts opinions and literature review are considered for each feature. After covering the thoeratical portion, as per simulation software results and cost/benefit analysis best alternative solution with minimum energy consumption and high cost/benefit ratio is selected.

The results showed a vast improvement in terms of energy and cost. The building with energy efficient design consumes 60% less energy relative to the base case. Finally it can be concluded that the process of designing energy efficient residential buildings is not a ‘one-man’s show’. Architects, developers, interior designers and clients are the other actors who can bring a change in the design practice.

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Chapter 1

Introduction

1.1 Background

The emergent construction industry has foremost effect on the socio-economic characteristics of the society as it is one of the leading consumers of natural resources especially energy (Geng et al., 2017). The largest share of that energy is consumed by buildings. Precisely, more than 1/3rd of total global energy is consumed which is a huge portion and proves that buildings are significant contributors to energy problem and require necessary actions (Sohail and Qureshi, 2011; Mastrucci et al., 2017; Ahmad et al., 2014). The present natural resources which form major energy sources in Pakistan are oil, coal, and natural gas. The consumption of such fossil fuels elevates the level of greenhouse gases in the environment. Further, their reserves are limited meaning they cannot be produced at the same rate as they are being consumed (Ionescu et al., 2015).

The major consumers of energy in a particular building are heating, air conditioning (in intense climate), water warming and refrigeration. The minmum portion of energy consumed in buildings are for lighting, laundry, cooking and operating various electronics (Sohail and Qureshi, 2011). In regions like Middle East and Malaysia where temperatures are high throughout the year, buildings are designed as per climate to reduce heat gain by installing HVAC systems which ofcourse improve indoor environment (Zain et al., 2007). So is the case with northern parts with cold climate such as regions of north China and Canada (North America) where temperature is low throughout the year. Design for these regions attempts to minimize the heat loss for which efficient heating systems are installed (Pacheco et al., 2012). Most of the energy efficient design techniques are either focused on hot or cold climate and not the both, the later is achieved through other means (i.e. use of natural resources) (Xu et al., 2013). It is very important when creating an energy efficient building design for all weather conditions to keep in mind that the main focus is to achieve high thermal comfort while keeping the energy consumption to a minimum level (Feng, 2004). The goal is to provide the occupants with comfortable surrounding and solutions that consume fewer resources, conserve energy, use less water and materials and also contribute to a great indoor experience (Karimpour et al., 2015).

As Pakistan is located on the tropic of cancer, it has a continental type of climate which shows extreme variations in temperature on both daily and seasonal scales. The highest temperature during summers can exceed above 47^{o}C in plains while it falls below zero degrees in winters in areas towards far north and Baluchistan (NDMC, 2014). The objective of research will be to form a suitable energy efficient design which will cater for climatic conditions in the country and to introduce the probable means of improving the effectiveness and effeciency of energy conserving structures in Pakistan.

1.2 Research Objectives

1. To gather and analyze the energy efficient features for hot and cold climate.
2. To integrate energy efficient designs for both hot and cold climates.
3. To simulate and validate the proposed design for its effectiveness.

1.3 Significance of This Study

To materialize the situation of energy efficiency adequate methods are needed in the domestic sector because major part of the country's energy resources are being consumed by the residential buildings (Ahmad et al., 2014), see *Figure 1-1* for detailed sector wise usage of energy in Pakistan. Reduction in demand for heating and cooling occurs due to energy efficient design of buildings (Pacheco et al., 2012; Yu et al., 2009). Building energy simulation plays a vital role in building energy efficiency and is a useful tool for energy efficient designs and planning of buildings (Lam et al., 2008).

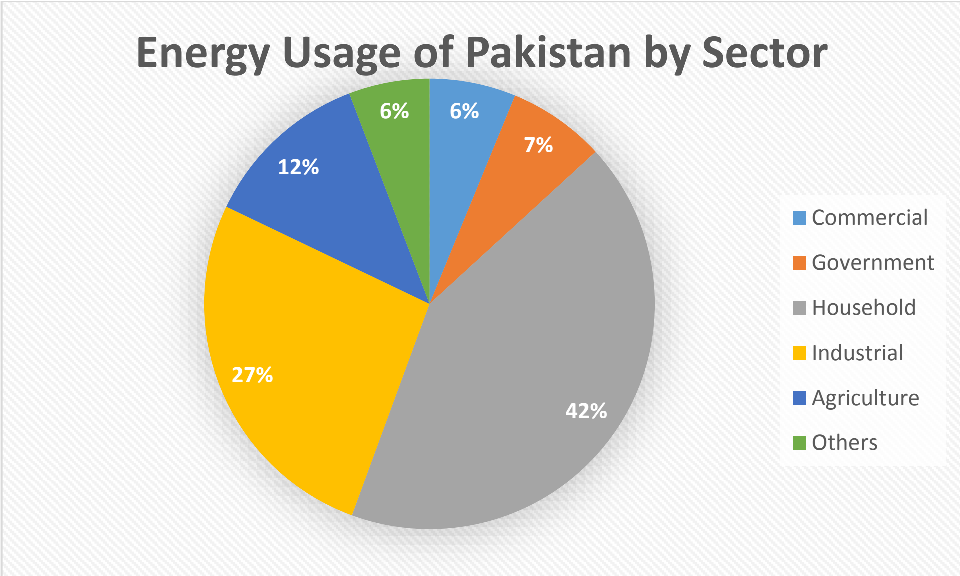

Figure 1-1: Energy usage by sector (Seema, 2013)

The amount of energy used by the people of Pakistan to create a comfortable environment around them consumes majority portion of the natural resources. The parameters for that comfortable environment are suitable HVAC system to maintain the comfortable level of temperature and humidity in the space, air quality, lighting, ergonomics and their effects on occupants or residents (Ahmad et al., 2014).

With energy optimized designs and tools, there is considerable reduction in the comsumption of electricity as well as the usage of cooling plant. This should be area of interest in any energy efficiency program for fully air-conditioned buildings. It was establish that passive solar designs would have large energy effeciency potential in cold climate but for hot climates that have far-reaching cooling requirements, priority should be to achieve a considerable equity between the constructive solar heat during the winter and the over and above summer cooling load penalty (Lam et al., 2008).

Factors like solar heat gain in hot climatic condition, loss of heat in cold climate, and natural ventilation during intermediate weather conditions must be kept in mind while designing energy-efficient residential buildings for all seasons and conditions. The heat conduction of building differs in summer and winter, therefore heat and moisture transfer must be taken in account while providing ventilation systems in a certain building. Consideration of solar heat gain in hot weather conditions, effective insulation in cold climate and natural conduction during the intermediate seasonal varion is important in the design of energy efficient buildings (Feng, 2004).

Spatial and temporal factors are among the most important factors in conservation of energy therefore energy efficient building must be planned and executed as per these factors. More cooling will be required in the cities in the southern parts of Pakistan i.e. Multan & Karachi rather than heating compared to cities situated in Baluchistan or north of the country (Ahmad et al., 2014). A lot of money can be saved by addressing this energy crisis in Pakistan through the introduction of energy efficient designs in construction (Sheikh, 2010).

Pakistan is among the few countries which is under worst energy and water crises in recent decades. Residential, industrial and commercial buildings consume major portions of Pakistan’s energy and water recourses. Hence, meeting this daily water and energy requirements has become more challenging. This all can be fixed if decision is taken to convert existing built environment into a sustainable one (Asif, 2009). To achieve water efficiency, energy efficiency, minimize, and conserve the use of natural resources in places of living and work, the country has to adapt to worldwide accepted best sustainable infrastructure. Nevertheless,friendly environment supporting building can be a healthy place to live and work, which ensures wellbeing of the building users by providing them access to natural air, light and views (Chandel et al., 2016).

Buildings have a major role in the sustainability through their phases of construction, pattern of development and the lifetime of their operation. With the increasing status, standards and needs of this century and with the increasing population the expansion of buildings and their constructions are growing rapidly and sustainable development and design needs to be established for growing economies(Zeng et al., 2011).

This concept of energy efficient buildings is providing the vision for setting long-term sustainable goals in developing and developed countries. Moreover, these wiser decisions for the use of resources more sensibly has helped developing nation to attain the status of developed countries without depleting and exhausting their natural resources (Asif, 2009).

1.4 Scope

Creating an energy conserving state is a gradual evolution which may take decades but is most adequate in terms of time and economy (Badescu, 2007). The time is now for Pakistan to improvize energy-conservation policies, practices and tools like the developed world already has. In order to face rising energy crisis with its related impacts on local environment it is necessary to pace up the development of energy efficient buildings and provide with examples for others to follow. Introduction of new techniques, methods and materials in buildings designs will facilitate the country in improving and optimizing the current energy resourses (Sohail and Qureshi, 2011).

The energy deficiency in Pakistan is being covered through extensive load-shedding in summers and winters (Sheikh, 2010). Some possible solutions can be to build new energy sources like Coal power plants, dams and renewable energy power projects i.e. Solar fields & windmills, but these projects take time at least 2 to 6 years to complete and also major budgets, depending upon the nature of the project. Considering the time and dire need of energy, the only option left is to conservate energy in the most effective and efficient way possible (Chaudhry et al., 2009).

Above are the reasons to work fast on developing energy efficient buildings in Pakistan to deal with the energy crisis situation in country and reducing its effects on the sorroundings. To reduce the present energy overburden in the country, innovations in the new building design are required to move towards energy efficiency. These innovations may include implementation of building energy efficiency codes, energy-efficient building materials, electrical appliances and improved architectural designs.

1.5 Advantages

- Less operating costs and high asset value
- Less waste generation
- Conserves natural resources
- Inhabitants get healthier and productive environment
- Reduction of greenhouse gas emissions and carbon footprint

Chapter 2

Literature Review

2.1 What does Energy Efficient Building mean?

In basic words, energy efficient building can be characterized as the structures/buildings which utilizes the provided energy effectively (Wang et al., 2009). The main theme of the energy efficient building is to minimize the amount of energy without affecting the comfort level. It does not imply to consume less energy. Instead it complies energy optimization economicaly (Nair et al., 2010).

Energy efficient building does not only optimize the energy, but also uses new technology to use the energy in better ways. For instance, insulationg of a building will consume less energy for heating and cooling to maintain a comfortable temperature. Installation of fluorescent, LED lights and use of natural skylights decreases energy requirement with same level of comfort compared with using traditional high-volt lightbulbs. Energy efficient technology helps in improving the utility of energy in efficient manner (Hee et al., 2015).

Energy consumption in buildings and its associated adverse impacts is a big concern for the evironment. Around 40% of total carbon emission and energy consumption is due to Buildings. These buildings are meant to exist and are used for several decades for multiple purposes. Therefore stakeholders associated to building industry holds an important responsibility for implementing strategies and policies to increase energy efficiency and minimize carbon emissions in order to mitigate the worst impacts of climate change (Tokbolat et al., 2013; Yildiz and Güngör, 2009; Yang et al., 2008).

Keeping in view the energy consumption, building sector proves to be a key energy end user in the years ahead. Proper building energy efficient designs and conservation program should be used to reduce the demand of energy (Lam et al., 2008).

The “Energy Efficient Building” is generally defined by a high level of insulation, windows with energy efficiency and a low level of heat exchange. There is no formal definition of these buildings. The most general definition says a construction with an energy performance higher than the standard building effeciency is termed as energy efficient building (Ionescu et al., 2015).

2.2 Why Energy Efficient Building?

The generation of convential energy using non renewable natural resources such as oil, gas and hyde is 99% in pakistan while the rest of 1% consitutes renewable natural resources. This is also one of the reason that Pakistan is an energy-deficient country because the potential of producing energy from natural renewable resources is higher than that of convential energy (Sheikh, 2010).

Due to economic uprise , the global energy consumption has been increased significantly in recent years. The world’s total energy consumption growth rate has reached to about 6% which was the highest rate since 1973 (Xu et al., 2013). The fossil fuels are fading rapidly. The usage of natural resources and the increased energy demands have forced designers, planners and policy makers to look for alternative way of optimizing energy (Chaudhry et al., 2009).

One of the method is to introduce energy efficiency into the building design. Energy efficient buildings will play a decisive role in reducing overall energy consumption and costs, since, worldwide, the residential and commercial sectors use almost 40% of final energy in the world and 76% of this energy is used to create comfort level in buildings heating, ventilation and air conditioning systems (see *Figure 2-1*). Due to longlast life of buildings, it is necessarty to enhance the energy efficiency of the HVAC systems (Oldewurtel et al., 2012; Morrissey et al., 2011).

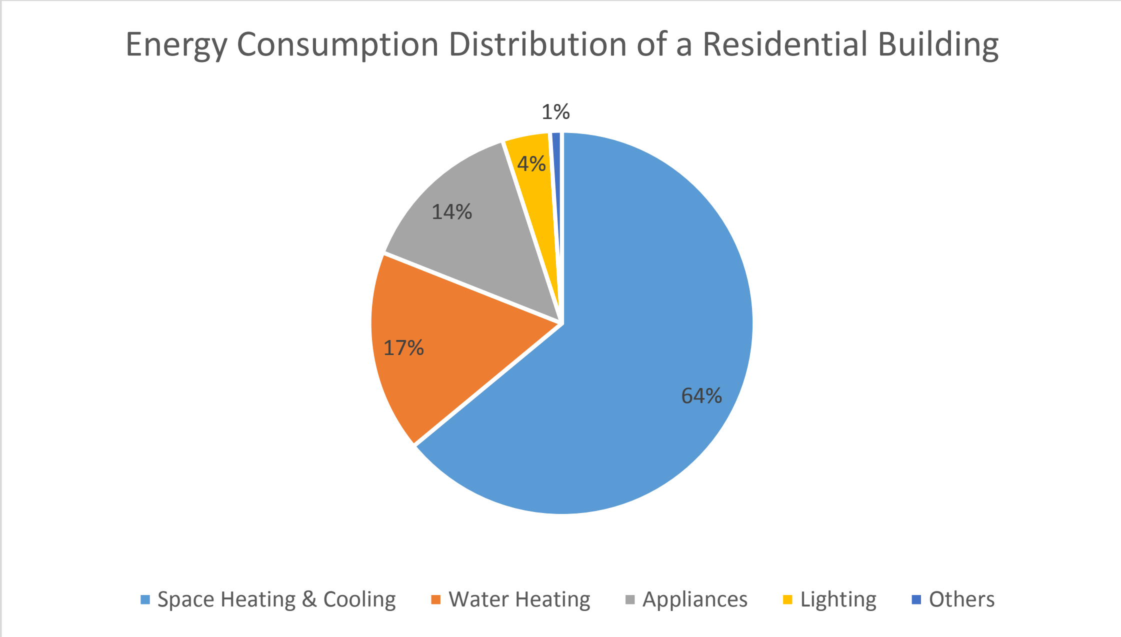

Figure 2-1: Energy consumption distribution of a residential building ((PWGSC), 2011)

As mentioned earlier Pakistan is an energy deficient country and to fulfil that demand there is a need to develop more energy sources, but that is time consuming and has no positive impact on the environment. A better solution to the situation will be rapid development in energy-efficient buildings which is only way to cope with extreme energy crisis and associated environmental impact in Pakistan. Innovations and inventions in the building-design will help the country in reducing its energy crisis. These innovations include improvized architectural designs, energy-efficient materials, technology and strict implementation of building energy efficiency policies (Sohail and Qureshi, 2011). Also, Considering greenhouse gas effect due to emissions from fossils fuels, the construction of energy efficient building can provide a way out in dealing with rising temperature problems. Proper designing and planning of energy efficient building is certainly the one of the important approach to counter the climatic problem (Jomehzadeh et al., 2016; Wang et al., 2009).

Traditionally, architects design a building as per client requirement considerting space and function. In designing process, they seldom consider energy efficiency because they pay much more attention to the aesthetics as they got no awareness regading energy effieciency (Zeng et al., 2011). It is critical to analyze that improvement of the energy efficiency in the buildings can be done through advanced mechanical systems ,advanced technologies and design decisions that affect operation and management (Sozer, 2010).

Evidently, the end user is benefitted with energy efficient design methods. A building design based on energy saving criteria improves economy throughout the life of the building because of its lower energy usage, furthermore it compensates for the greater initial investment. Due to designs, reduction of CO_2 emissions into the atmosphere which is added value service to the end user (Pacheco et al., 2012).

2.3 Energy Efficient Building Design Features

In past years, evident efforts and policies have been introduced to ehance energy efficiency and reduce energy consumption. The concept of energy efficiency in buildings transforms the energy supply needed to achieve favourable environmental conditions that reduces energy consumption. The conceptual design phase of a building is the suitable time to integrate energy efficient strategies. During construction phase, it can minimize certain execution costs as compared to when they are installed in successive stages of construction (Akadiri et al., 2012). A thorough literature review comprising of different journals, books, researches and related websites were considered to find out the basic principles for designing energy efficient buildings. Table 2-1 shows the list of aspects for energy efficient buildings that has been obtained from the literature review.

Table 2-1: Energy efficiency features from literature

Authors	Features of Energy Efficiency in Building						
	Windows	Solar Shading	Lighting	Air-Conditioning System	Ventilation System	Building Envelope	Building Orientation
(Feng, 2004)	●			●	●	●	
(Gaterell and McEvoy, 2005)	●			●		●	
(Badescu, 2007)				●	●		
(Lam et al., 2008)	●	●	●	●	●	●	●
(Yang et al., 2008)	●	●	●	●		●	●
(Haase and Amato, 2009)	●	●	●	●	●	●	●
(Wang et al., 2009)	●		●		●	●	●
(D'Orazio et al., 2010)	●	●		●	●	●	
(Castleton et al., 2010)				●	●	●	
(Nair et al., 2010)	●					●	
(Sozer, 2010)	●	●	●	●	●	●	●
(Chan et al., 2010)				●	●	●	●
(Nielsen and Drivsholm, 2010)					●		
(Yıldız and Arsan, 2011)	●	●		●	●	●	●
(Zeng et al., 2011)	●			●	●	●	
(Morrissey et al., 2011)	●			●	●	●	●
(Yıldız and Arsan, 2011)	●	●	●	●	●	●	
(David et al., 2011)	●	●	●	●	●		●
(Pacheco et al., 2012)	●	●	●	●	●	●	●
(Jaffal et al., 2012)		●		●		●	
(Tokbolat et al., 2013)	●	●	●	●	●	●	●

(GhaffarianHoseini et al., 2013)	●	●	●	●	●	●	●
(Xu et al., 2013)	●	●	●	●	●	●	
(Grynning et al., 2013)	●	●	●	●	●		
(Bellia et al., 2013)	●	●	●	●		●	●
(Schulze and Eicker, 2013)	●	●	●	●	●		●
(Al-Obaidi et al., 2014)		●		●	●	●	
(Echenagucia et al., 2015)	●	●	●	●	●	●	●
(Dudzińska and Kotowicz, 2015)	●	●	●	●	●	●	
(Latha et al., 2015)	●	●	●	●	●	●	●
(Manso and Castro-Gomes, 2015)		●		●		●	
(Mohamed et al., 2015)						●	●
(Hee et al., 2015)	●	●	●	●	●		●
(Jomehzadeh et al., 2016)				●	●		
(Chandel et al., 2016)	●	●	●	●	●	●	●
(Hemsath, 2016)	●	●		●		●	●
(Cuce, 2017)	●		●			●	
(Lee et al., 2017)	●		●			●	●
Frequency	**30**	**24**	**21**	**33**	**28**	**32**	**21**
Literature Score	**45.60**	**36.48**	**31.92**	**50.16**	**42.56**	**48.64**	**31.92**

All these mentioned factors have effect on the energy usage and indoor ambience of the building, and it is necessary to choose correct properties and the best probable combination of these features of the energy efficient building to gain maximum benefits, but due to the many possible combinations and limited time available selected few will be considered for further analysis in this thesis.

Table 2-2: Analysis of energy efficiency features

S.No	Factor	Literature Score	Normalized Score	Cumulative score	Rank	
4	Air-Conditioning System	50.16	0.174603175	0.174603175	1	
6	Building Envelope	48.64	0.169312169	0.343915344	2	
1	Windows	45.6	0.158730159	0.502645503	3	50%
5	Ventilation System	42.56	0.148148148	0.650793651	4	
2	Solar Shading	36.48	0.126984127	0.777777778	5	
3	Lighting	31.92	0.111111111	0.888888889	6	80%
7	Building Orientation	31.92	0.111111111	1	7	

After performing content analysis on these energy efficient features, we have got 3 features at 50% accumulated score and 6 features at 80% accumulated score as you can see in Table 2-2.

2.3.1 Windows

The main source of solar heat gain is through windows and skylights(Lam et al., 2008) and also one of the major component for the heat loses (Yildiz and Güngör, 2009) therefore it is a major design consideration. The remarkable impact of buildings on energy consumption is a consequence of poor structural features and improper thermal insulation characteristics of existing building such as windows, which are the main cause of energy loss from building envelope (Cuce, 2017).

The magnitude of sunlight that enters a building through the windows depends on various factors such as the latitude, climate, daylight, incident angle of solar radiation, obstruction created by other buildings around it, and the energy reflected by neighboring elements (Pacheco et al., 2012). These mentioned attributes connect the window feature to the building orientation which will be discussed later in the thesis.

Energy can be saved in a Building without window, but it is not recommended due to the certain benefits such as visual comfort and the biological effect of natural light. Selecting a window design for a building is complicated when energy saving and daylighting aspects of a building are both considered simultaneously. Hence, window design plays important role in energy efficient building design (Hee et al., 2015).

The aim of minimizing the energy need for heating, cooling and lighting of the building can be achieved by varying some window design variables. These variables are number, position, shape, window-to-wall ratio and type of windows (Echenagucia et al., 2015).

2.3.2 Solar Shading

The solar radiation which falls on the building is controlled by solar shading on building facade. This gives positive impact when building façade cavities consist of the elements that transfer the radiation to the inside of the building. The usage of shading tools can prove helpful at certain times of the year though they are counter-productive at other times (Pacheco et al., 2012).

In areas with hot climate, shading strategy is very efficeint in order to improve ambience of the room. The cooling load and improvement inside the building and visual comfort conditions can be achieved by the use of shading devices (Sozer, 2010).

The main purpose of a shading system is to shield building transparent envelope from solar radiation in hot weather, thus reducing overheating by creating hinderance in the way of unwanted energy. Solar shadings can save energy for the cooling system, while it tends to increase in energy requirements for both heating and lighting systems. The energy demand can be minimized using these energy solutions (Bellia et al., 2013).

Solar shading systems is important because it lowers the energy demands more than as compared to unshaded windows (Grynning et al., 2013). Thermal and visual point of view assesses the effectiveness of solar shades. Solar shading is the design feature which reduces the indoor temprature of the the building which further decrease the demand of air condition (David et al., 2011).

2.3.3 Lighting

The lighting tools contributes to indoor source of heat. The availability of daylight inside the room means internal source of heat is reduced(Echenagucia et al., 2015; Schulze and Eicker, 2013; Haase and Amato, 2009). Energy efficient lighting shall be introduced because it can reduce considerable amount of electricity use as well cooling plant .In hot weather conditions, it should be a vital option in any energy efficient building to avoid use of heavy energy consumption systems such as HVAC systems (Latha et al., 2015; Lam et al., 2008).

A preposition is floating around in few countries that state should ensure solar features on official government buildings to decrease the requirement of energy resources (Chandel et al., 2016).

The effective use of daylight and efficient lights will also results in reduction energy demand of a building (Hee et al., 2015). Natural lighting is essential when it comes to reduction in energy demand and consumption as lighting is a major portion of total energy consumption in buildings, so replacing it natural light such as the sun can reduction in energy demand and load. Effective solar protection and a suitable level of natural lighting should be considered for optimum design (David et al., 2011).

2.3.4 Air-Conditioning System

Air conditioning is compulsory for sustaining thermal comfort in indoors. Air-conditioning is a major consumer of the energy in a building or facility. Its consumption can exceed more than half of the building total energy used and almost 25% of the total national energy use (Chua et al., 2013). The more use of air conditioning the more chances of serious peak electricity load problem to utilities and the cost of electricity may rise(Santamouris et al., 2007). With constant economic growth, there is a mounting desire for more comfortable indoor built environment, particularly in cold season space heating and cooling comfort in hot seasons (Lam et al., 2008). These loads are having a negative impact on CO_2 emissions, as well as on demand of energy supply (Chan et al., 2010).

There are a lot of active and passive solar designs have been developed for heating and cooling, but each system have their own boundaries (Chan et al., 2010). A promising alternative to reduce energy consumption are passive air-conditioning systems. In order to enhance the building overall performance; a combination of both renewable energy production techniques and more energy efficient air-conditioning methods are advised (GhaffarianHoseini et al., 2013; Jomehzadeh et al., 2016)

2.3.5 Ventilation System

Natural ventilation is sometimes termed as comfort ventilation which is based on the positive psychological effect on the occupant inside the building. Therefore, it is necessary to minimize the psychological consequences of humidity and improve the loss of body heat (Pacheco et al., 2012). The air flow is controlled by the mechanical ventiallation system which saves energy if the mean ventilation flow rate can be decreased below the required constant flow required. Ventilation rate reduction doesnot effect the indoor air quality(Nielsen and Drivsholm, 2010). The heat transfer process of building envelopes vary in winters and summer so it should be considered while providing natural ventilation(Feng, 2004). Natural ventilation has become a promising cooling strategy which reduces the problems caused by man made air conditioning systems(Jomehzadeh et al., 2016). Speed and prevailing direction of the wind during multiple seasons, are important aspects in natural ventilation design and analysis (Lam et al., 2008).

Cooling the building through natural ventilation is one of the countless ways to protect a building from overheating. A high number of night ventilation hours is especially recommended. The room with natural ventilation affects the interior microclimate (Jomehzadeh et al., 2016; Dudzińska and Kotowicz, 2015; Zeng et al., 2011). Ventilation is a very important attribute in enhancing thermal comfort, with or without use of advanced building materials. The buildings that lack ventilation systems in their envelope have the trapped heat in the building that degrades the thermal comfort of the occupants (Latha et al., 2015).

Natural ventilation and infiltration dictates the fresh air inside a residential building, while the same is done by mechanical ventilation system in public buildings (Xu et al., 2013). Ventilation is defined as “the increase in thermal comfort due to an increase in natural or mechanical air movement as a passive cooling strategy” (Haase and Amato, 2009).

2.3.6 Building Envelope

The building envelope most interesting concept in energy efficient building design. Envelopes plays a decisive role in the exposure of building to the elements which effect building efficiency. Envelopes can also play vital role in the structure of building as well as it can cover economic constraints (Echenagucia et al., 2015).

The building envelope serves as temprature control barrier between the interior and the outdoor environment which governs demand of energy to maintain an ambient environment inside building (Lee et al., 2017). Building envelope is the most effective indicator which includes several features such as wall to window ratio, roof materials properties, wall material properties, air leakage and sealing, natural airflow, placement, building alignment, day light portion, height and shape of building. Observance to these constraints will provide optimum day light, ventilation, heating and cooling and results in energy efficiency in almost every climatic conditions (Chandel et al., 2016). A climate responsive building envelope design should assist the design strategies and climatic conditions are governed by responsive optimal climate sensitive building envelope (Haase and Amato, 2009).

Accurate designing of building envelope can improve the heating and cooling objectives and increase energy efficiencies. The building envelope regulates the energy exchange which governs the overall energy performance of the building. (Sozer, 2010; Gaterell and McEvoy, 2005).

2.3.7 Building Orientation

Orientation is the most important factor in passive solar design of buildings (Pacheco et al., 2012). The thermal comfort can be optimized using energy effective building oreintation (Latha et al., 2015; Tokbolat et al., 2013). The Orientation of building is considered as a prominent cause for optimal performance of indoor environment and energy usage. The orientation of room is dictated by the postion and placement of window in the bedroom, while the house orientation is considered according to entrance facade direction(Wang et al., 2009).

Building placement and position directly effects the utility bills one has to pay due to reduction in heating and cooling load. Often lack of awareness of solar orientation of each home causes economic overburden over the life span. Most suitable positioning and placement can be easily implemented which provide low cost and high quality energy (Hemsath, 2016).

Energy requirements can be reduced upto 20% by maintaining optimal orientation of the buildings. building and window orientation is considered as vital in passive designs (Morrissey et al., 2011). The derived benefit extracted from optimum building orientation are the following:

- It is a cost efficient valid in the preliminary stages of project design.

- The energy demand is reduced.
- Complex passive systems utilization is considerably reduced.
- The performance of other sophisticated passive techniques is enhanced.
- The quantity of dailylight is increased along with reduction in enrgy demand.
- contribution of internal heating load of the building is reduced.
- The performance of solar collectors is improved.

Chapter 3

Research Methodology

This study was executed in three phases to achieve the research targets. In the first phase, an initial study was conducted to find the study gap. Fundamental objectives were also developed in this stage. Then in the second phase, a detailed literature review was performed concerning the established objectives and partial data was collected. The third and final phase covered data collection, analysis and a detailed discussion on the results of the energy efficient design.

3.1 Phase 1

Phase 1 consists of basic research steps such as selection of topic, development of research problem, and research objectives. Research papers, articles, conference papers help to find out study gaps in current research. At this phase, different questions like work already done on proposed topic, relevance to national need and basic advantages, etc. are answered.

3.2 Phase 2

After phase 1, detailed literature review is carried out to find out the features that can be altered and combined together in order to achieve the energy efficient design that goes with the climate conditions of Pakistan. Total of 7 featues are gathered from the literature. It is difficult to take into account all of the features, therefore through a careful literature review and frequency analysis few features of energy efficient design are considered for analysis and simulations. As per performed analysis 3 features at 50% accumalted score are selected, which are further used for analysis and simulations for creating an Energy Efficient Design.

3.3 Phase 3

In 3rd phase energy simulation with the help of Design Builder simulation software is carried out for buildings. From the literature review and cosultaion with different field experts 3 alternatives for each energy efficient feature are gathered and by systematically changing the values of these key design parameters in computer simulations, a database with a series of influence coefficients was developed, showing how building energy consumption will be affected by design changes. The calculated iteration results are analyzed considering the factors of extra initial investment, corresponding building energy consumption and the savings on electrcity utilized. With the help of these factors Benefit/Cost analysis is performed for the selection of final design parameters. Inshort, it summarizes the key research outcomes, provide the importance and various constraints of this research, and recommend building energy performance study of buildings for further research studies.

Table 3-1: Tools & techniques and sources used for objectives

Objectives	Tools & techniques	Sources
Energy efficiency features	Detailed literature review	Journals, articles, reports and conference papers
Integrate energy efficient designs for both hot and cold climates.	Detailed literature review, consult with field experts & simulations	Journals, articles, reports, conference papers and software (DesignBuilder)
Validate Energy efficient design	Simulations	DesignBuilder & energy efficient quidelines provided by PGBC

The research will be carried out according to the sequence shown in *Figure 3-1*:

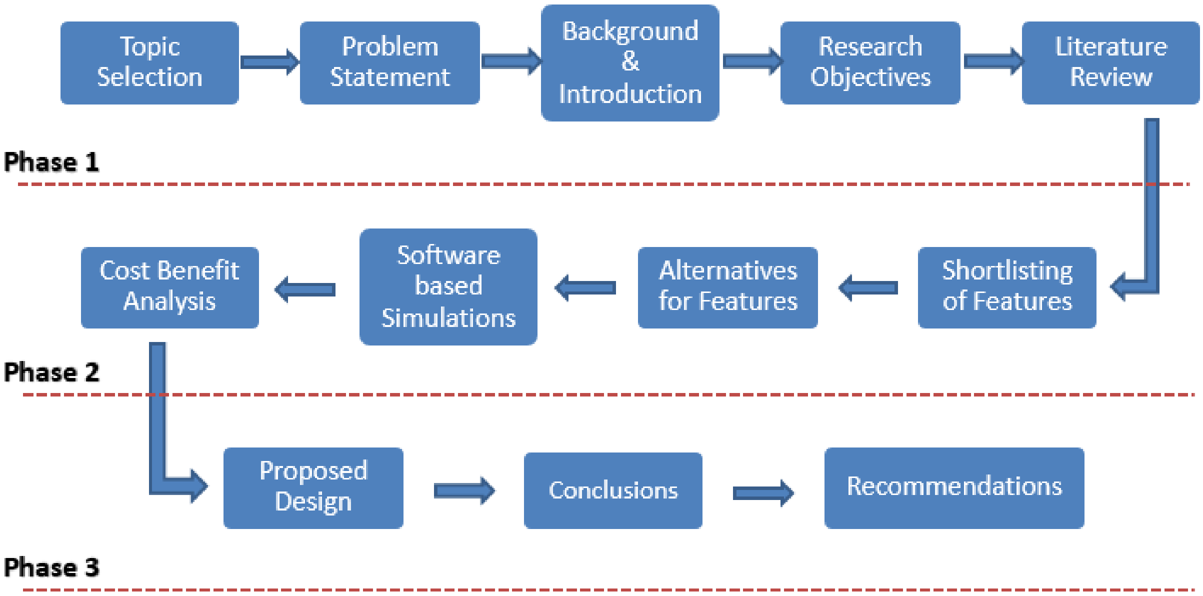

Figure 3-1: Research methodology

3.4 Simulation Software (DesignBuilder)

To create the building model which incorporates EnergyPlus database, DesignBuilder is the most popular software used. With the help of CAD drawings 3D model is developed, after that it was easy to insert basic materials, constructions and schedules since it comes with wide-ranging data templates for simulation inputs such as typical occupancy schedules, envelope construction options and lighting systems. DesignBuilder has a help panel that assists in providing tips and wizards that guides the user in creating thermal model. This is particularly useful for new users, as it helps them to have a better grip on the concepts of thermal modelling. It is generally easy to learn the basics of the software but a beginners short training or introductory workshop will pace up the learning process.

The interface of DesignBuilder starts with the setting of a location and the corresponding weather through a weather file after that integrated CAD interface is used for the creation of specific thermal building model geometry. This building geometry represents the definition of geometry needed for the simulation of the building's thermal performance. DesignBuilder provides a huge database of country or region specific templates for choice of parameters (such as materials and constructions). The other definable parameters are construction types, internal loads (with occupancy patterns/activities), openings (windows and doors), HVAC and lighting systems. After the completion of sleecting all input parameters, one can perform design simulations. In addition, one can authenticate most parts of the thermal model of the building in contrast to the energy code that applies to the locatity of that building.

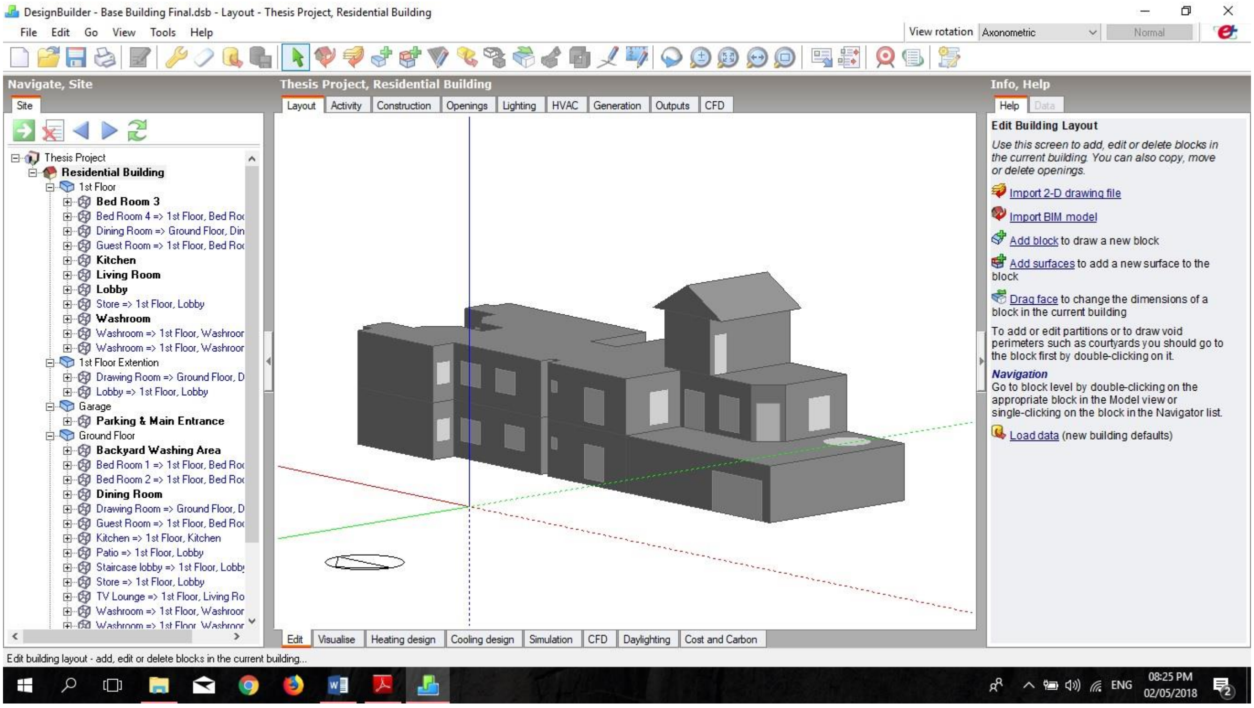

Figure 3-2: Screenshot of the energy model of the residential building in DesignBuilder

Chapter 4

Data Analysis, Results & Discussion

4.1 Base Building Model Description

4.1.1 Location

The selected base case is Located in Islamabad, Pakistan (33.6844° N, 73.0479° E). It was selected based on the availability of construction plans, materials and weather data; therefore, this assisted in accomplishing the work of this thesis. The temperature range in Islamabad is maximum 38°C in June to minimum 3°C in January. The result of this thesis will still hold true to other studies since normalised loads are used.

4.1.2 Specifications

The base case study is a typical 2-storey house to be constructed in Islamabad, which doesn't apply any building code requirement. It consists of four bedrooms, two guest rooms, two dining room, two main halls, and unconditioned places such as toilets, laundry room and storage rooms. A detailed description of the building and it's material are shown in Table 4-1. *Figure 4-1* shows the floor plan of ground and 1st floor respectively.

Table 4-1: Base residential building description

PARAMETERS	SPECIFICATIONS
NUMBER OF FLOORS	2
TOTAL AREA	490.12 m^2 (1 Kanal)
FLOOR HEIGHT	3.1 m
EXTERNAL WALL	25 mm Cement Plaster (inner & outer surface) 229 mm Brick Wall (English Bond)
ROOF	150 mm Concrete Slab
FENESTRATION	Single Glazing, operable, Aluminium frame windows
HVAC	Split Systems
SET POINT TEMPERATURE	26°C

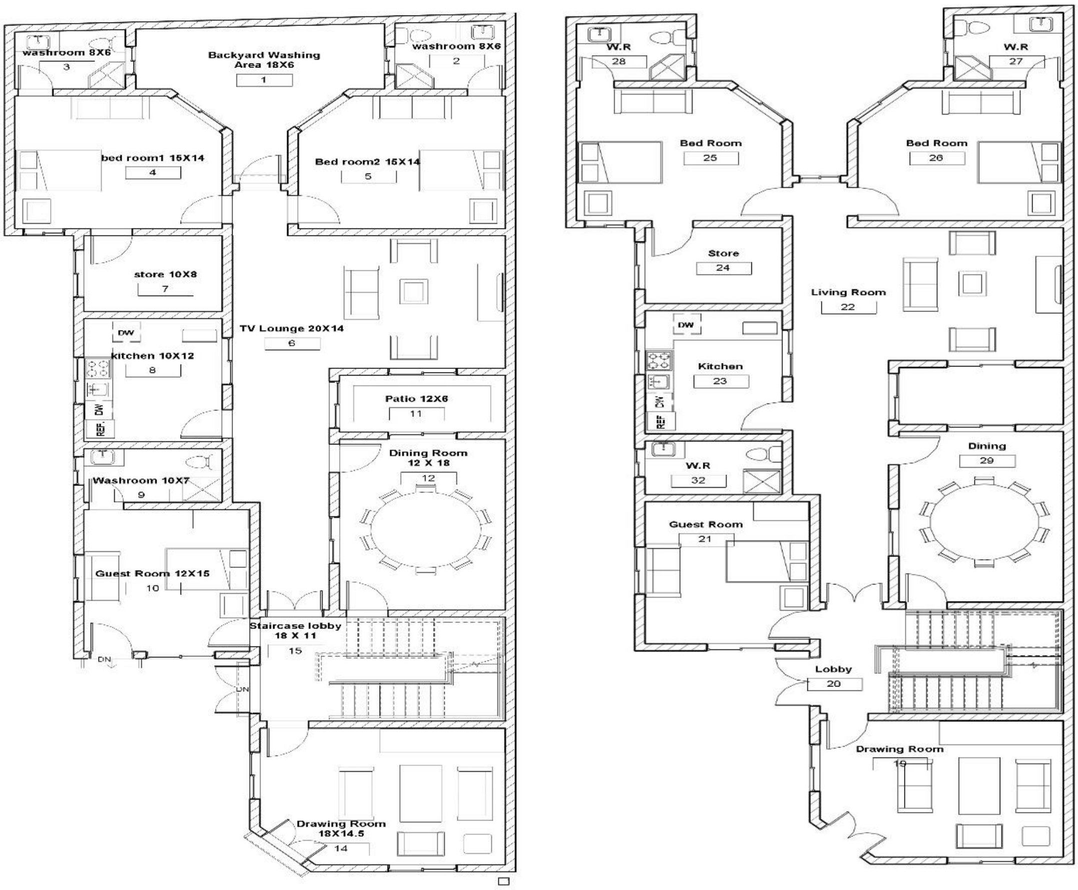

Figure 4-1: Ground-floor & first-floor plan of base building

4.2 Building Energy Analysis using DesignBuilder

After the completion of base building design, simulation is performed on the base building to calculate the base building energy consumption which is then further used to compare the results of the different scenarios created through changing the features specifications gathered from the literature and discussion with field experts. 3 alternatives are used for the each feature shortlisted from detailed literature review and interviews conducted from field experts are shown in *Figure 4-2*.

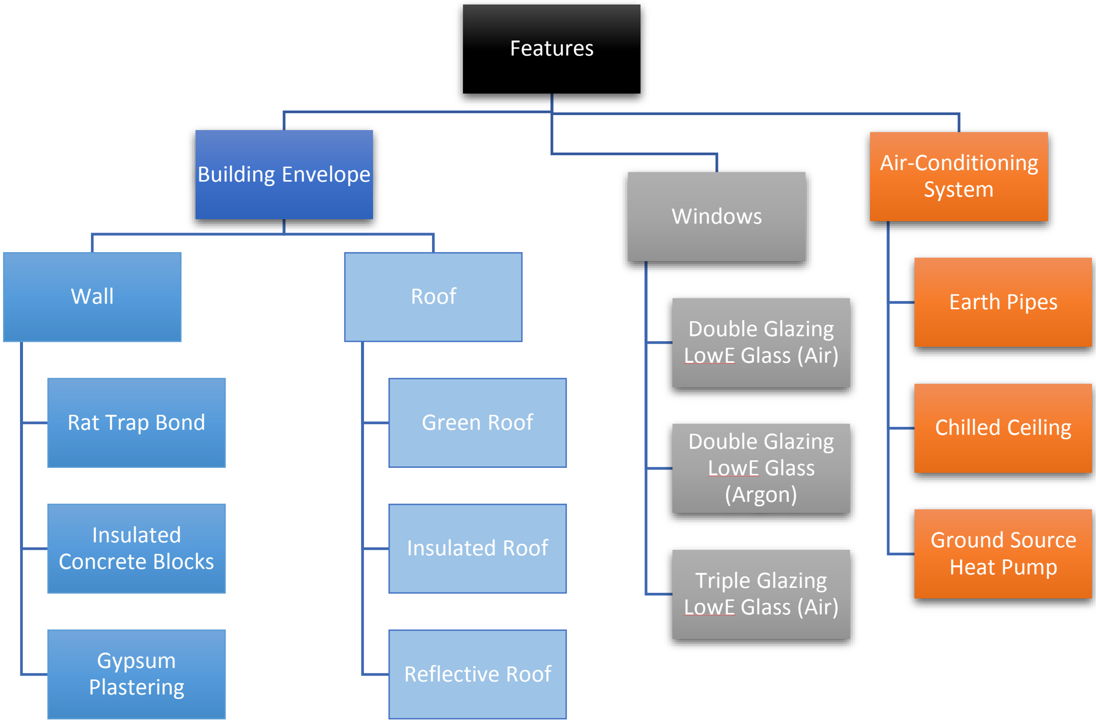

Figure 4-2: Alternative options for each feature

4.3 Thermal Transmittance (U-Value)

A measure of the heat transmission through a building part (such as a wall or window) or a given thickness of a material (such as insulation) with lower numbers indicating better insulating properties, the lower the value, the less heat transfer (Hammarberg and Roos, 2003).

4.4 Energy Efficiency Feature Alternatives

4.4.1 Walls

One main parameter can be used to characterize the performance of walls defined as U-Value by which it measures the heat loss or gain due to difference between indoor and outdoor temperatures. The lower this value is, the better the insulation performance. Table 4-2 shows the comparison for the different energy efficient options available for wall construction of the building with respect to their U-values, energy consumption, installation cost and advantages that benefits us for selecting that particular wall type.

Table 4-2: Comparison of different energy efficient options available for wall construction

Options	Rat Trap Bond	Insulated Concrete Blocks	Gypsum Plastering
Specifications	• 9” thick load bearing wall • Bricks arranged in such an order that creates cavity throughout the wall	• 40cm x 20cm x 20cm (8” thick) • Rows filled with insulation material • 10-12% Portland cement used	• Cement plaster on outer surfaces on both sides of wall is replaced with waterproof gypsum plastering
U-Value (W/m^2K)	1.519	0.724	1.586
Energy Consumption (kWh/m2)	175.71	170.53	170.61
Installation Cost (PKR)	952,000	1,456,000	1,456,000
Advantages	• 25% more load bearing capacity when compared to usual brick masonry work • Saving of upto 25% of bricks • 33% less of the total mortar used • Better thermal insulation properties between exterior and interior surfaces	• 10 ºC of minimum temperature difference is achieveable between the inner and outer surface • Reduced electrical energy usage for maintaining the temperature	• Low thermal conductivity • Great potential for reducing energy consumption, peak loads and can also reduce overheating of the building enevelope • 3 days required for water curing compared to 28 days for cement plaster meaning fast construction
References	(Marunmale and Attar, 2014; Prakash, 2013; Srivastava)	(Al-Jabri et al., 2005; Caruana et al., 2017; Huberman and Pearlmutter, 2008)	(Bicer and Kar, 2017; Zhu et al., 2009; Silva et al., 2007)

4.4.2 Roofs

The heat gain by the roof can be reduced by adding insulation below the roof membrane, installing a radiant barrier and installing a reflective coating to the roof. Applying such reflective coatings can save up 10%~50% of home energy and by which it can reflect about 82% of total sunlight (Simmons et al., 2008). Table 4-3 shows the comparison for the different energy efficient options available for roof construction of a residential building with respect to their U-values, energy consumption, installation cost and advantages that benefits us for selecting that particular roof type.

Table 4-3: Comparison of different energy efficient options available for roof construction

Options	Green Roof	Reflective Roof	Insulated Roof
Specifications	• 200mm thick layer of cultivated soil (exposed surface) • PVC flexible sheet (to avoid moisture infiltration) • 200mm thick concrete slab	• Aluminum sheets • 6mm thick expanded polystyrene • 200mm thick concrete slab	• 25mm thick roof tiles • 6mm thick expanded polystyrene • 200mm thick concrete slab • False ceiling (inner surface)
U-Value (W/m^2K)	0.639	0.342	0.496
Energy Consumption (kWh/m2)	162.03	160.88	161.36
Installation Cost (PKR)	805,375	1,155,950	786,425
Advantages	• Extension of roof life and a reduction of the urban heat island effect • Enhanced architectural interests, designs and biodiversity • Enables the roof to reduce the heat transfer to the building below • Keeps the building cool during daytime by absorbing heat and radiating it away during night.	• Reflects back most of the incident solar radiations i.e. heat • Lesser heat conduction into the building resulting in reduced cooling loads • Increased roof albedo (reflectance) of the roof surface of the building	• Low heat transference to lower structure • 1/3rd or less reduction of heat flux into the inside layers • Easily available and can also be used as a retrofitting technique
References	(Castleton et al., 2010; Jaffal et al., 2012; Zinzi and Agnoli, 2012)	(Akbari, 2003; Shen et al., 2011; Simmons et al., 2008)	(D'Orazio et al., 2010; Halwatura and Jayasinghe, 2008; Halwatura and Jayasinghe, 2009)

4.4.3 Windows

The aim of selecting a suitable window type is to minimize the heat gain through window and maximize the percentage of visible light for day lighting. Table 4-4 shows us the comparison between three different types of glass configurations all fixed in a UPVC window frame.

Table 4-4: Comparison of energy efficient windows glass options available

Options	Double LowE Glass (Air)	Double LowE Glass (Argon)	Triple LowE Glass (Air)
Specifications	• 2x 6mm LowE coated glass sheets • Sealed space in between with air trapped • UPVC frames	• Air in sealed space is replaced with inert gas Argon • UPVC frames	• 3x 6mm LowE coated glass sheets • 2x sealed spaces with air trapped • UPVC frames
U-Value (W/m^2K)	1.786	1.512	0.780
Energy Consumption (kWh/m2)	178.98	178.97	176.44
Installation Cost (PKR)	325,000	345,000	475,000
Advantages	• Air gap acts as a barrier and minimizes the flow of heat energy • The low-e coating enables reduced heat flow through the glass	• Argon has 34% lower thermal conductivity than air	• All the functions of double-glazed windows are performed by triple-glazed windows, but with more effectiveness
References	(Kaklauskas et al., 2006; Shen et al., 2011)	(Kaklauskas et al., 2006)	(Cho and Kim, 2017; Lohia and Dixit, 2015; Wang et al., 2017)

4.4.4 Air-Conditioning Systems

A major source of household energy consumption are air-conditioners with high peak power demand, especially on hot summer days. In addition they are a key driver of growing greenhouse gases (GHG) emissions, because conventional air-conditioners uses refrigerants that have a significant climate impact, and their electricity consumption increases GHG emissions from fossil fuel power. For this very reason two of the three options considered for this thesis uses geothermal energy that is a renewable and environment friendly energy source. Table 4-5 shows the comparison between three different types of energy efficient air-conditioning systems.

Table 4-5: Comparison of different types of energy efficient air-conditioning systems

Options	Earth Pipes	Chilled Ceiling	Ground Source Heat Pumps(GSHP)
Energy Source	Geothermal	Electricity	Geothermal & Electricity
Energy Consumption (kWh/m2)	88.53	163.98	174.39
Installation Cost (PKR)	650,000	1,600,000	1,450,000
Advantages	• Used both for space heating and cooling • Use renewable energy source • Minimum or no impact on climate • Minimizes ventilation heat loses • Major reduction in the cooling and heating load of buildings • Low initial investment	• Used both for space heating and cooling • When compared with conventional air-conditioning devices can enhance indoor thermal comfort and indoor air quality while consuming less energy • Provides more effective ventilation	• Used both for space heating and cooling • reduces the emission of greenhouse gases
References	(Bansal et al., 2010; Niu et al., 2015; Peretti et al., 2013)	(Florides et al., 2002; Ge et al., 2011; Niu et al., 2002)	(Sarbu and Sebarchievici, 2014; Self et al., 2013)

4.5 Discussion

The simulation was run for total of 14 cases (simulation results for each case is attached in Appendix A), one for the base design using all the common construction practices and materials, and remaining 12 are the energy efficient options discussed earlier for each of the category shortlisted from the detailed literature review. The combination of energy efficient alternative used for each case is mentioned in Table 4-6 and the highlighted cell in in each row is the feature different from base design. Table 4-7 shows the simulation results (energy consumption) and other factors that are helpful for the selection of the options that are used in final design suggestion. Without considering the economic analysis, optimal energy efficient design combination cannot be selected. For this purpose, extra initial investments, savings in energy consumption and net present worth of those savings for the period of 40 years' service life of building for each of the scenario is calculated and used to perform cost benefit analysis for the selection of the options that are considered in the final design.

The first option in each of the category is taken from the base building design and then further compared with the three energy efficient alternatives. From cost benefit analysis, it is known that the highest value is most beneficial for the final design (Mishan, 2015).

The rows highlighted red shows that the options with high cost/benefit factor are considered for the final design. It is observed that options rat trap bond and earth pipes from category walls and air-conditioning system respectively are blank under benefit/cost heading, this is because the initial investment is already less than the base design, meaning these options are less costly and more energy efficient.

The last row of Table 10 shows energy consumption of the final energy efficient design. It is significant to notice that the final energy efficient design when compared to base design is more economical meaning the initial investment is already low from conventional building design techniques and is saving around 60% on electricity bills annually (simulation results attached in Appendix A).

Table 4-6: Energy efficient features combinations for simulations

FEATURE	WALLS	ROOF	WINDOWS	AIR-CONDITIONING SYSTEM
Case 1 (Base Design)	Brick Wall	6” Concrete	Single Glazing	Split AC systems
Case 2	Rat Trap Bond	6” Concrete	Single Glazing	Split AC systems
Case 3	Insulated Concrete Blocks	6” Concrete	Single Glazing	Split AC systems
Case 4	Gypsum Plastering	6” Concrete	Single Glazing	Split AC systems
Case 5	Brick Wall	Green Roof	Single Glazing	Split AC systems
Case 6	Brick Wall	Reflective Roof	Single Glazing	Split AC systems
Case 7	Brick Wall	Insulated Roof	Single Glazing	Split AC systems
Case 8	Brick Wall	6” Concrete	Double Glazing LowE Glass (Air)	Split AC systems
Case 9	Brick Wall	6” Concrete	Double Glazing LowE Glass (Argon)	Split AC systems
Case 10	Brick Wall	6” Concrete	Triple Glazing LowE Glass (Air)	Split AC systems
Case 11	Brick Wall	6” Concrete	Single Glazing	Earth Pipes
Case 12	Brick Wall	6” Concrete	Single Glazing	Chilled Ceilings
Case 13	Brick Wall	6” Concrete	Single Glazing	GSHP

Table 4-7: Cost/Benefit analysis of energy efficient options

Feature	Category	Installation Cost (PKR)	Energy Consumption (kWh/m2)	Energy Saving (kWh/m2)	Annual Saving (PKR)	Extra Initial Investment (PKR)	Recovery Period (years)	Benefit/Cost Analysis	Remarks
Brick Wall	**Walls**	**1,232,000**	**181.18**	-	-	-	-	-	**Base Design**
Rat Trap Bond		952,000	175.71	5.47	22,279	-280,000	-	-	***Already saving us money and energy**
Insulated Concrete Blocks		1,456,000	170.53	10.65	59,532	224,000	3.8	2.2	
Gypsum Plaster Brick Wall		1,456,000	170.61	10.57	58,848	224,000	3.8	2.2	
6"Concrete Roof	**Roofs**	**473,750**	**181.18**	-	-	-	-	-	**Base Design**
Green Roof		805,375	162.03	19.15	134,052	331,625	2.5	3.3	
Reflective Roof		1,155,950	160.88	20.3	143,100	682,200	4.8	1.7	
Insulated Roof		786,425	161.36	19.82	139,248	312,675	2.2	3.7	***Selected**
Aluminium + Glass	**Windows**	**250,000**	**181.18**	-	-	-	-	-	**Base Design**
Double LowE Glass (Air)		325,000	178.98	2.2	6,252	75,000	12.0	0.7	***Selected**
Double LowE Glass (Argon)		345,000	178.97	2.21	6,324	95,000	15.0	0.5	
Trpl LowE Glass (Air)		475,000	176.44	4.74	15,996	225,000	14.1	0.6	
Split AC	**Air-Conditioning System**	**825,000**	**181.18**	-	-	-	-	-	**Base Design**
Earth Pipes		650,000	88.53	92.65	317,870	-175,000	-	-	***Already saving us money and energy**
Chilled Ceiling		1,600,000	163.98	17.2	118,656	775,000	6.5	1.3	
GSHP		1,450,000	174.39	6.79	28,884	625,000	21.6	0.4	
Final Design	-	**2,713,425**	**71.24**	**109.94**	**377,188**	**-67,325**	-	-	***Final Design Savings us Initial Investment and on Energy Consumption**

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

As a summary, this thesis analyses the energy performance keeping in check the thermal comfort of a two-storey residential building by altering four different building features which are walls, roofs, types of windows and air-conditioning systems, as well as a base case as built specifications and investigate their applicability to Islamabad climate. DesignBuilder program was selected to perform a detailed energy analysis of building with utilizing different options. Selected option from each category are shown in Table 5-1.

Table 5-1: Selected options for final design

Feature	Option Selected
Walls	Rat Trap Bond
Roof	Insulated Roof
Windows	Double LowE Glass (Air)
Air-Conditioning System	Earth Pipes

For a country like Pakistan, it is best to use of simple and passive options that are affordable to a wide range of general income population rather than opting for new and active options that are being used and innovated in well-developed countries in west which are expensive. The design options suggested can be adopted easily in Pakistan and this will widely help curb the ever growing energy crisis in country and to some extent, the environmental degradtion too.

The following conclutions were drawn from the results:

- Green buildings will enhance efficiency of systems, allowing major reductions in energy usage, hence, contributing a significant role in bringing down global warming effects from building operations and construction industry.
- Application of these measures reduced the energy consumption of building from 181.18 kWh/m^2 to 71.24 kWh/m^2, which is almost 60% less energy usage annually.

- Initial investment is less than the cost of the base design, meaning these design measures also reduces the initial construction cost.
- Except for rat trap bond, remaining three design considerations insulated roof, double lowE glass and earth pipes can be used as retrofitting techniques and installed at any stage of the building service life.
- Because of the low energy consumption, GHG emissions will be reduced after the implementation of these energy efficient features in building construction.
- The features used are durable and have low maintenance costs with their service life of minimum 40 years.

5.2 Recommendations

The scope of this thesis can be further improved by:

- Although many design parameters are evaluated in this research, other aspects are expected to have a considerable effect on the energy-efficient design of a building such as orientation, shading, lighting etc. More efforts are required to evaluate the impact of all the building systems on the energy-efficient design.
- Implementing advanced systems to utilize most of the renewable energy sources and reduce utility energy consumption.
- Include the plug-in loads and appliances energy consumption. This will assist in identifying the real case energy consumption and give more realistic approach towards energy efficiency.

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Appendix A

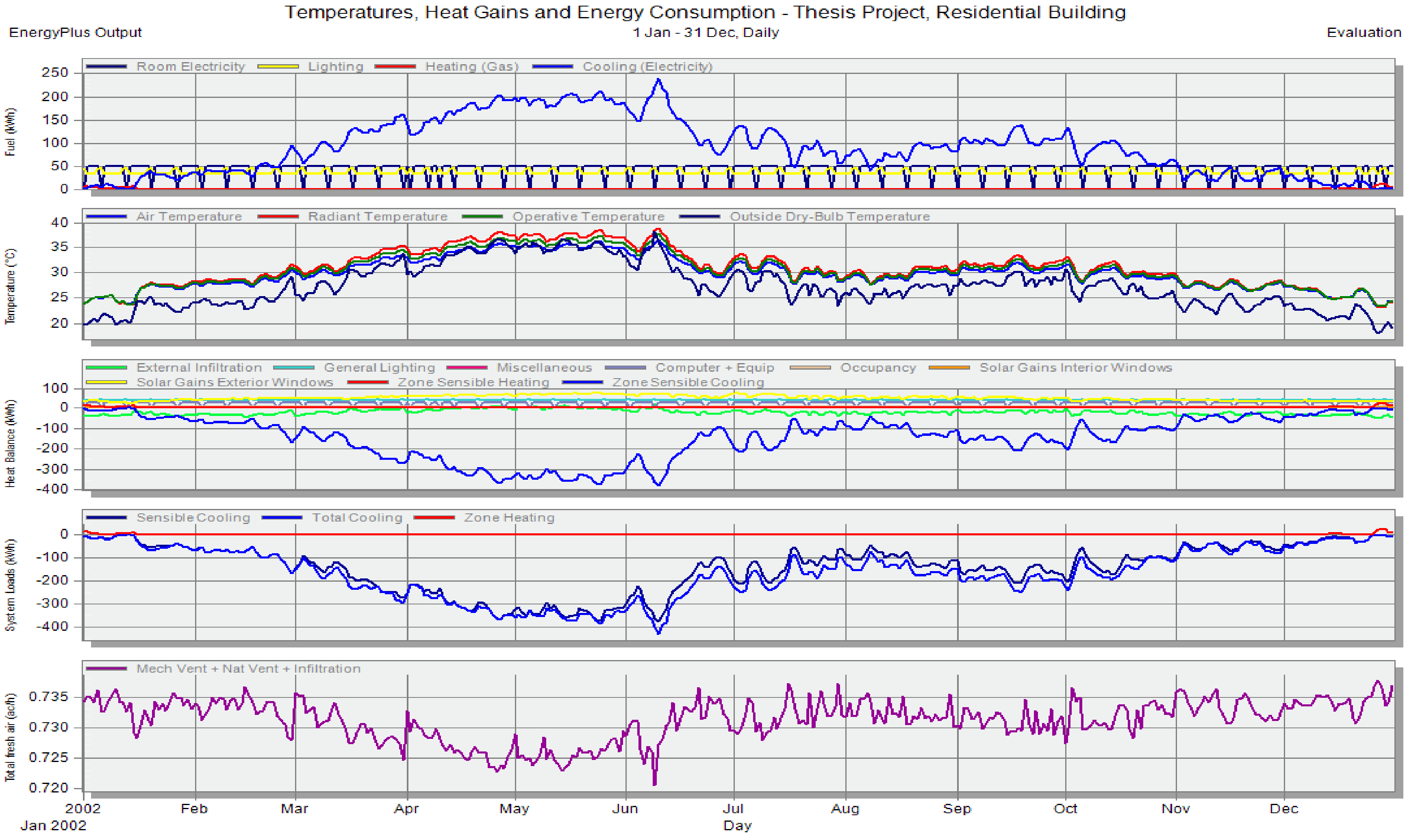

Figure 1: Base building simulation result

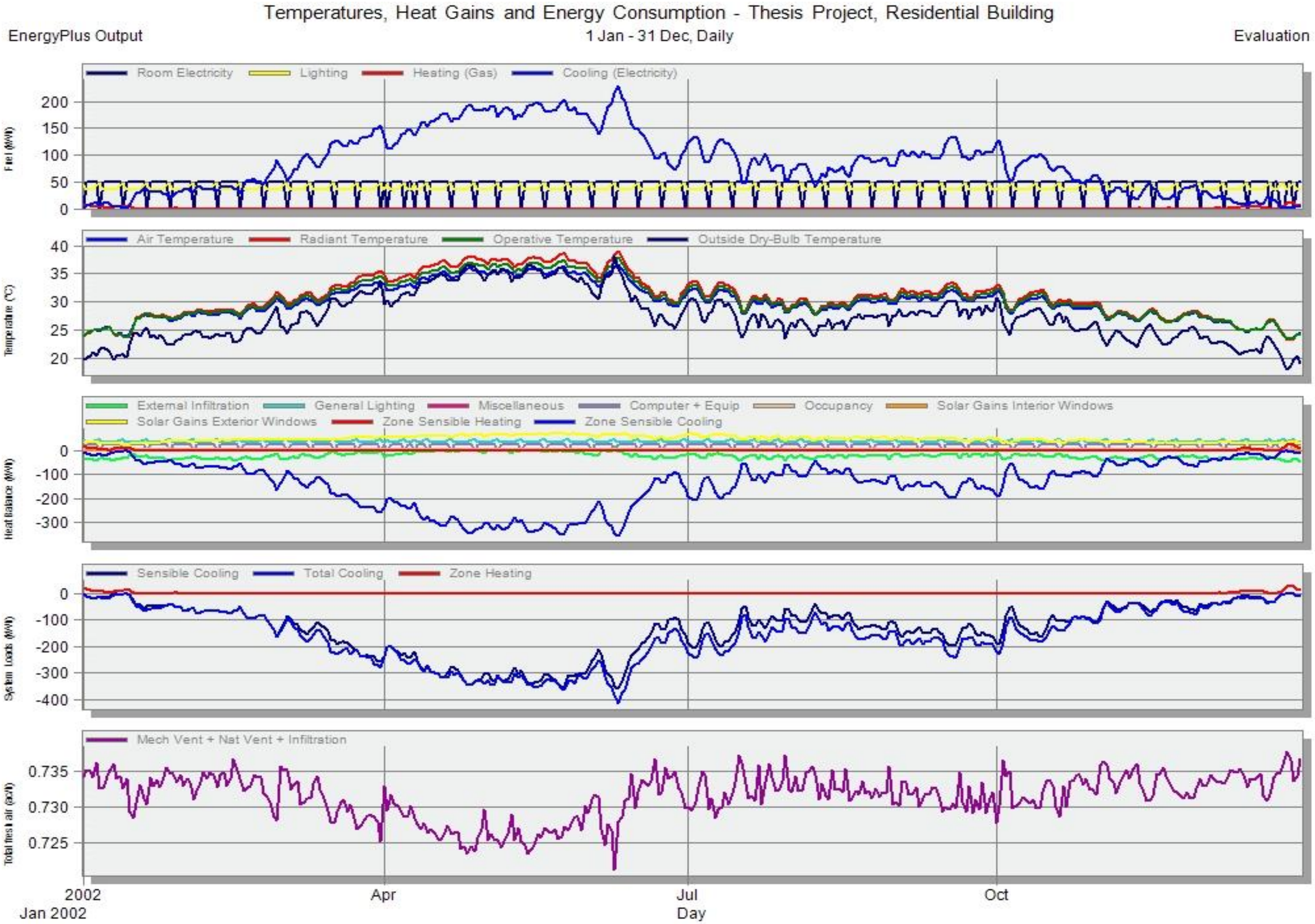

Figure 2: Rat-Trap bond simulation results

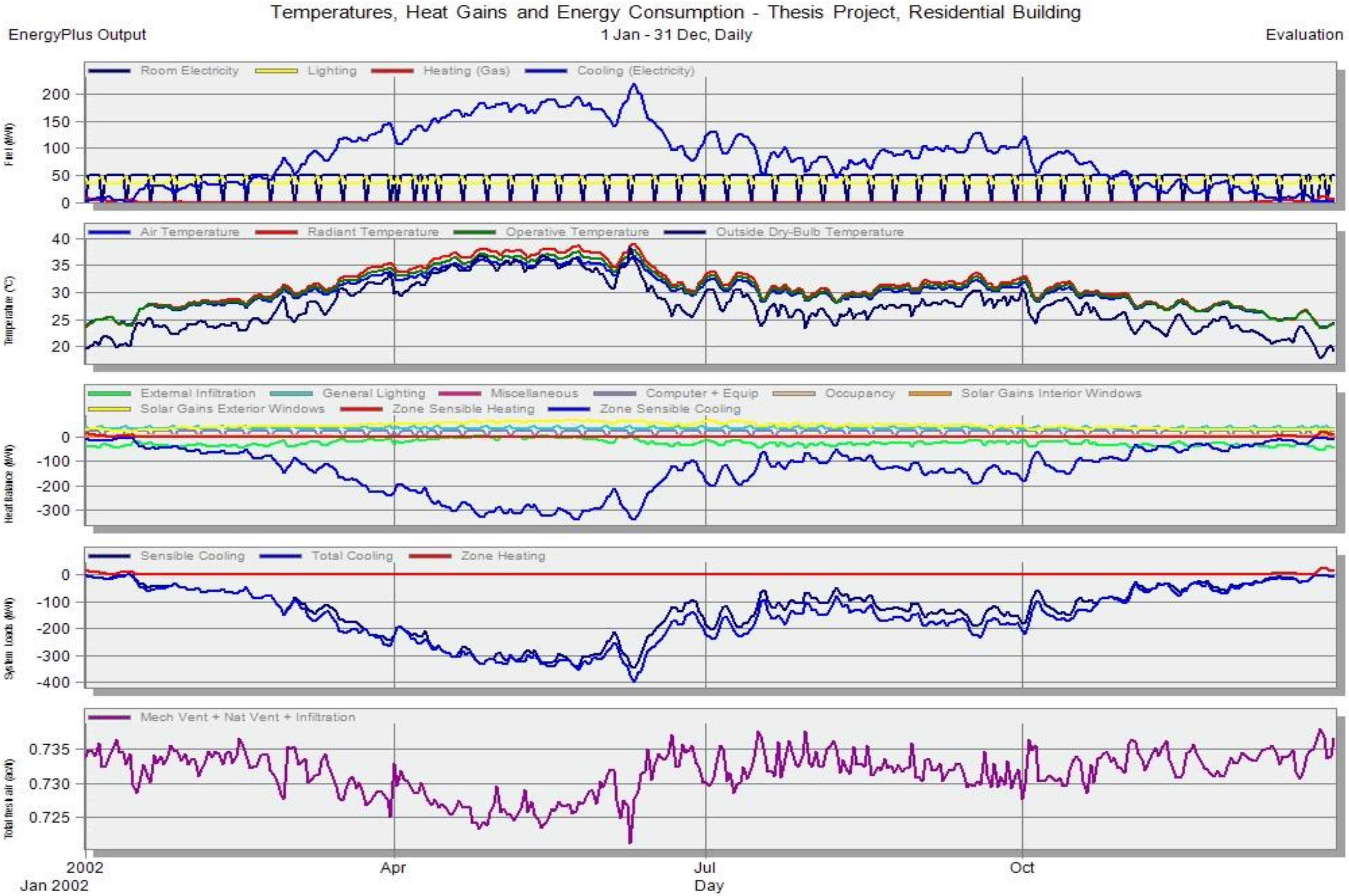

Figure 3: Insulated concrete Blocks simulation results

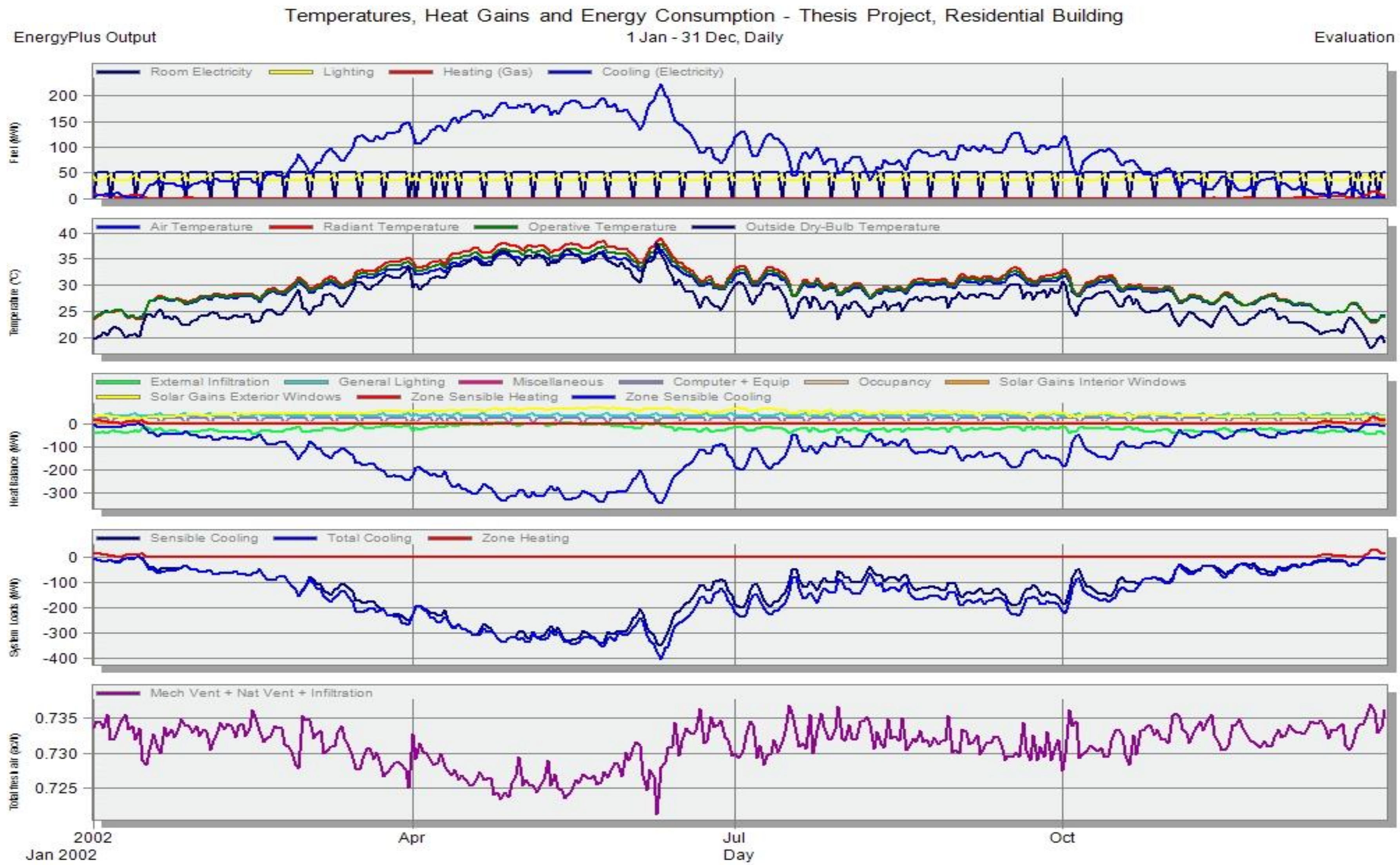

Figure 4: Gypsum plastering simulation results

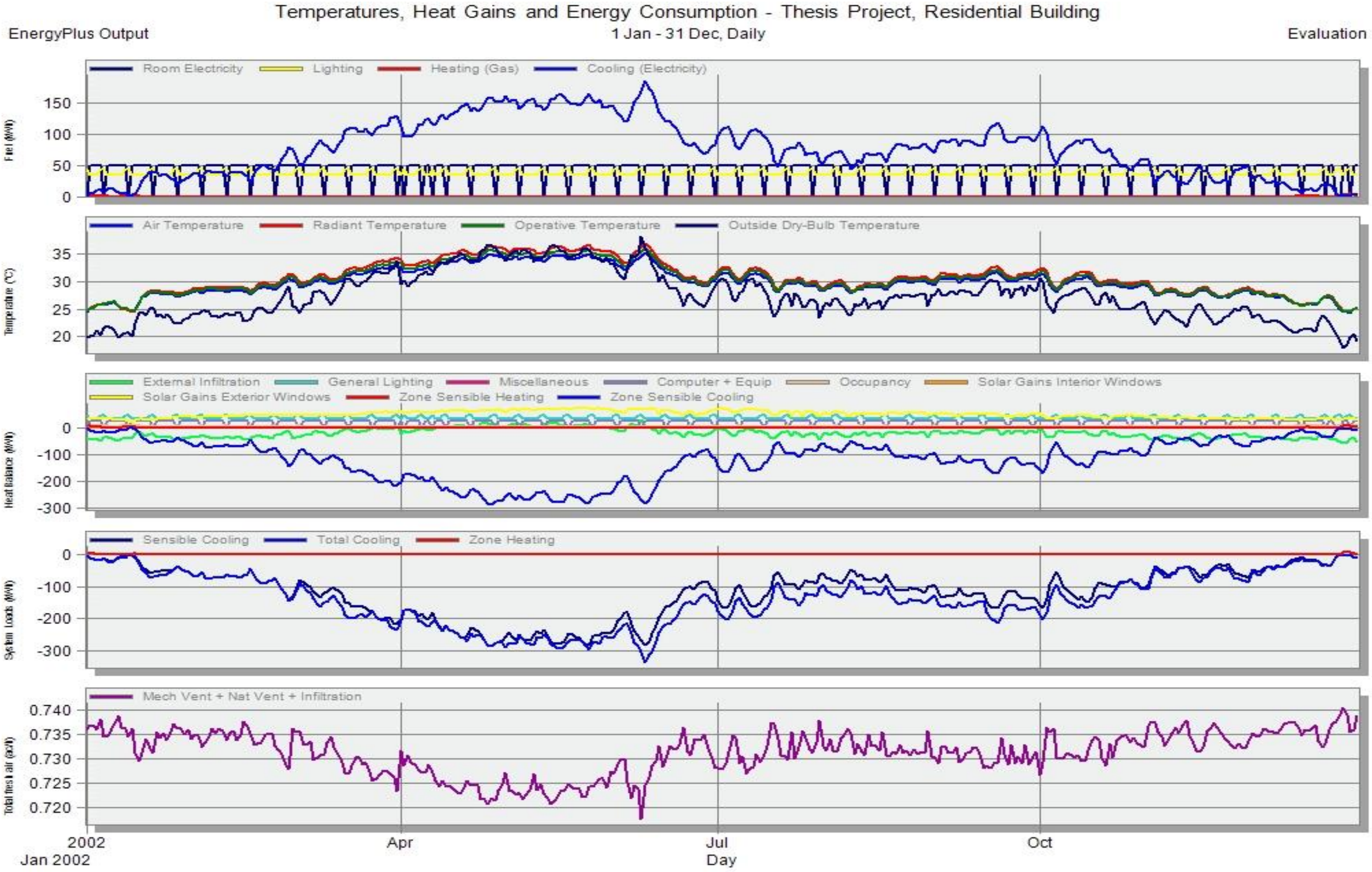

Figure 5: Green roof simulation results

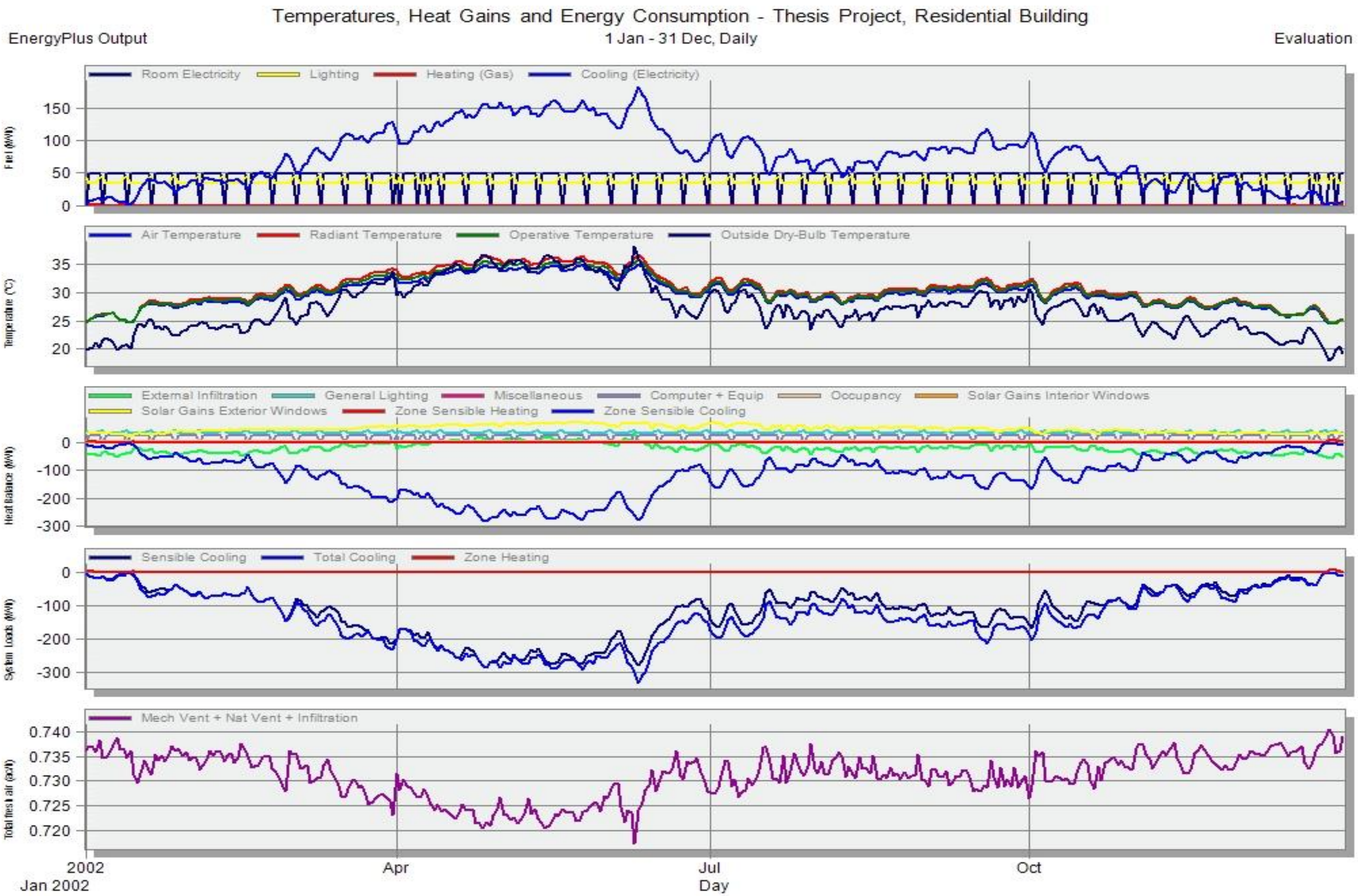

Figure 6: Reflective roof simulation results

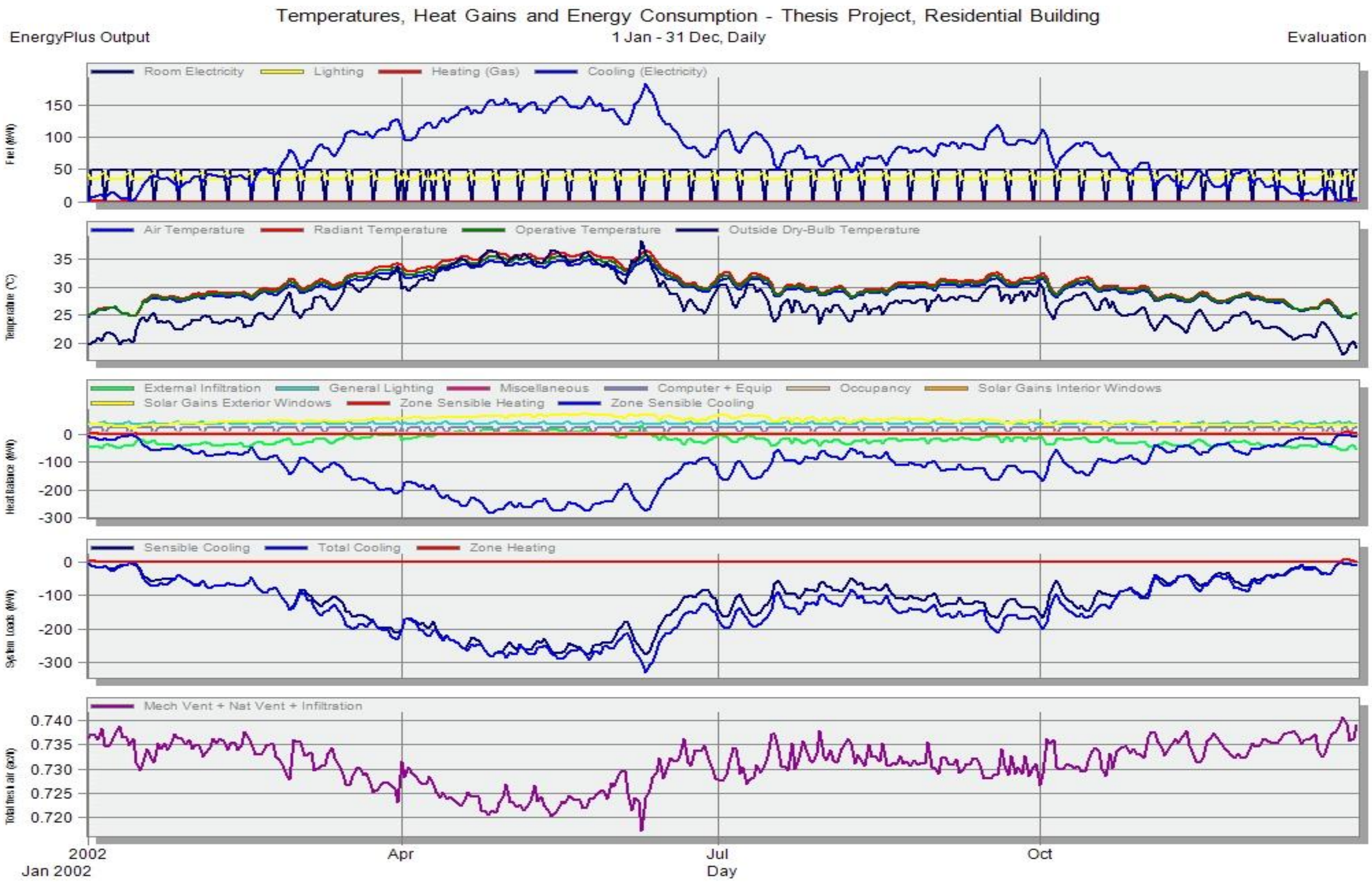

Figure 7: Insulated roof simulation results

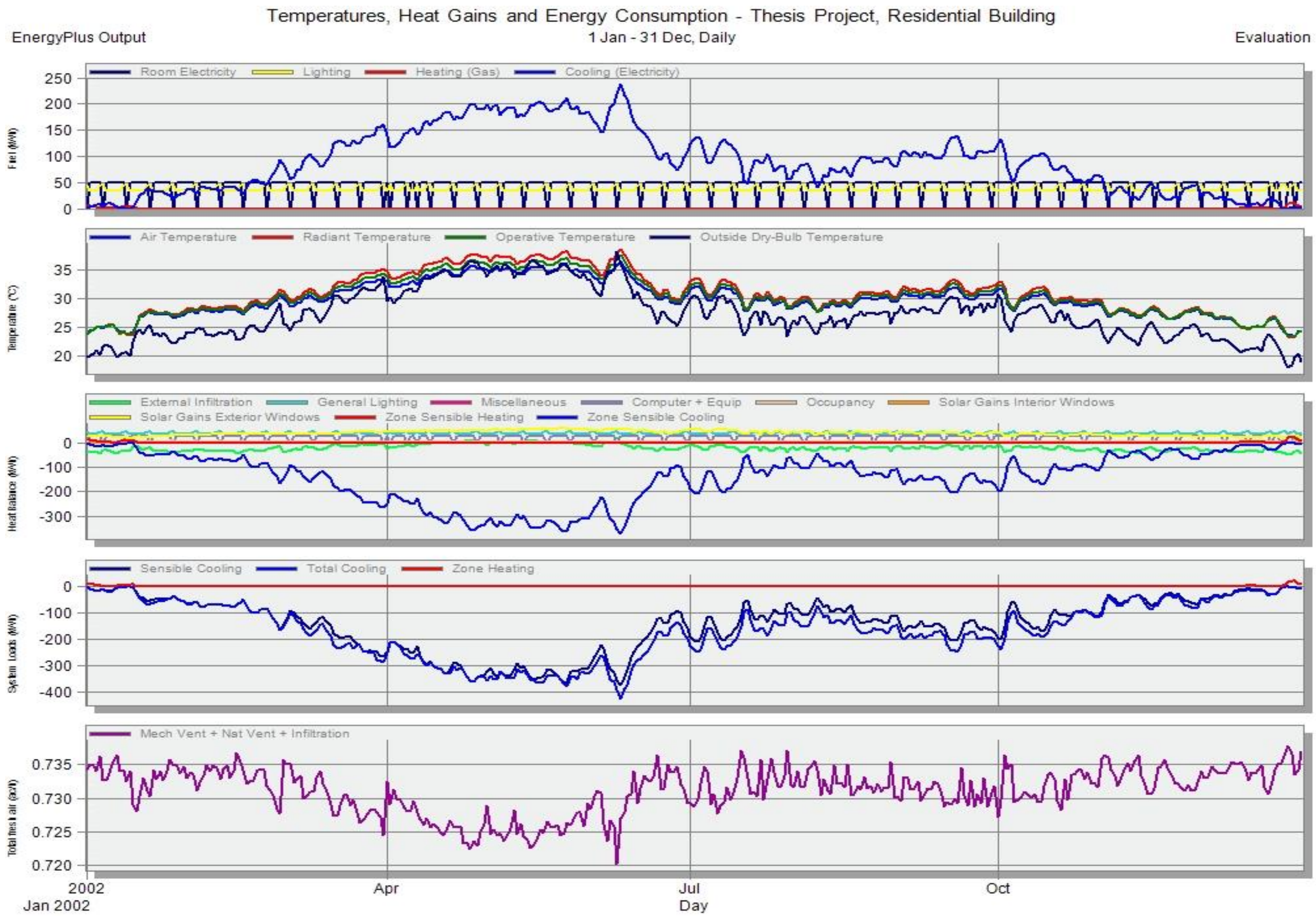

Figure 8: Double glazing lowE glass (Air) simulation results

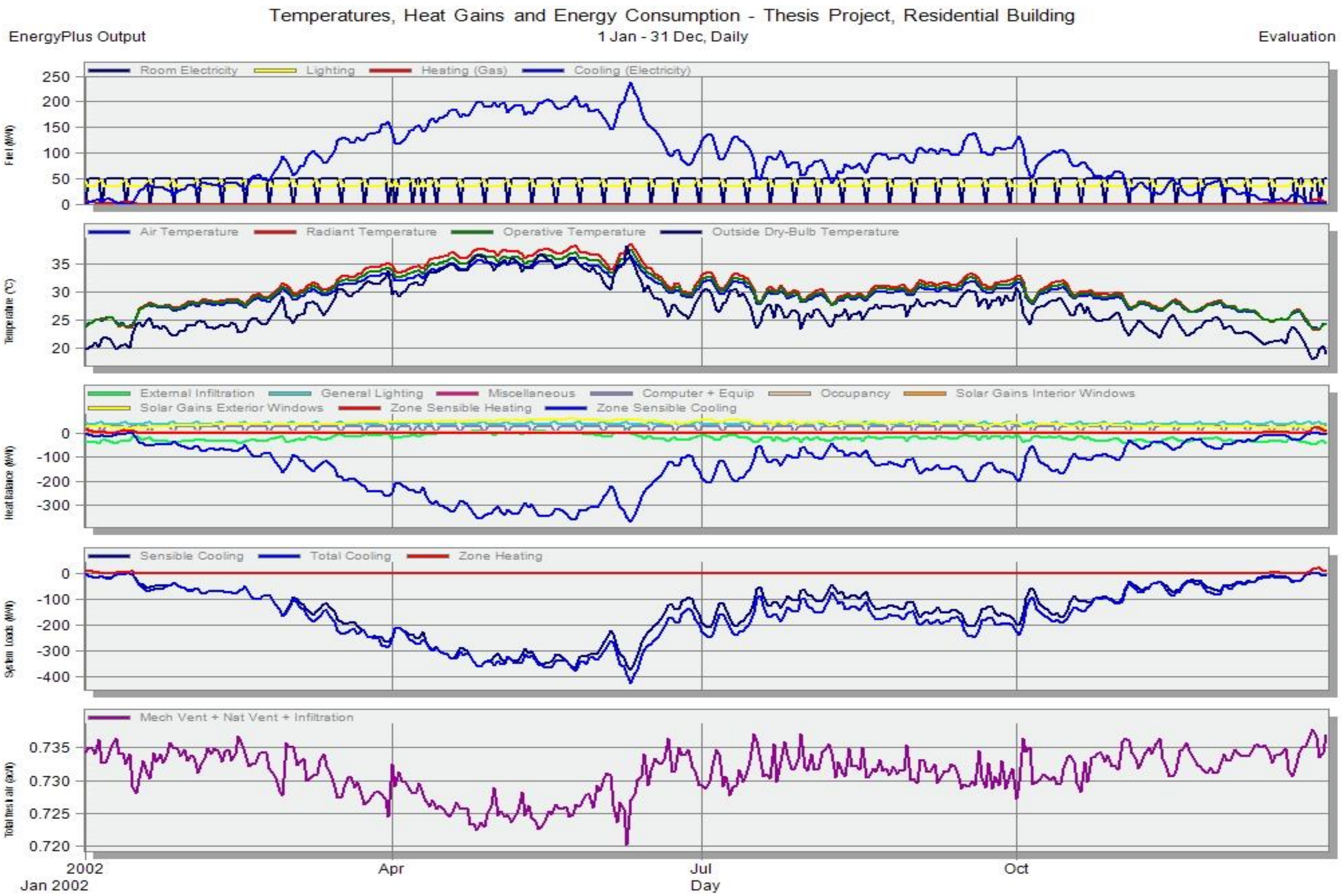

Figure 9: Double glazing lowE glass (Argon) simulation results

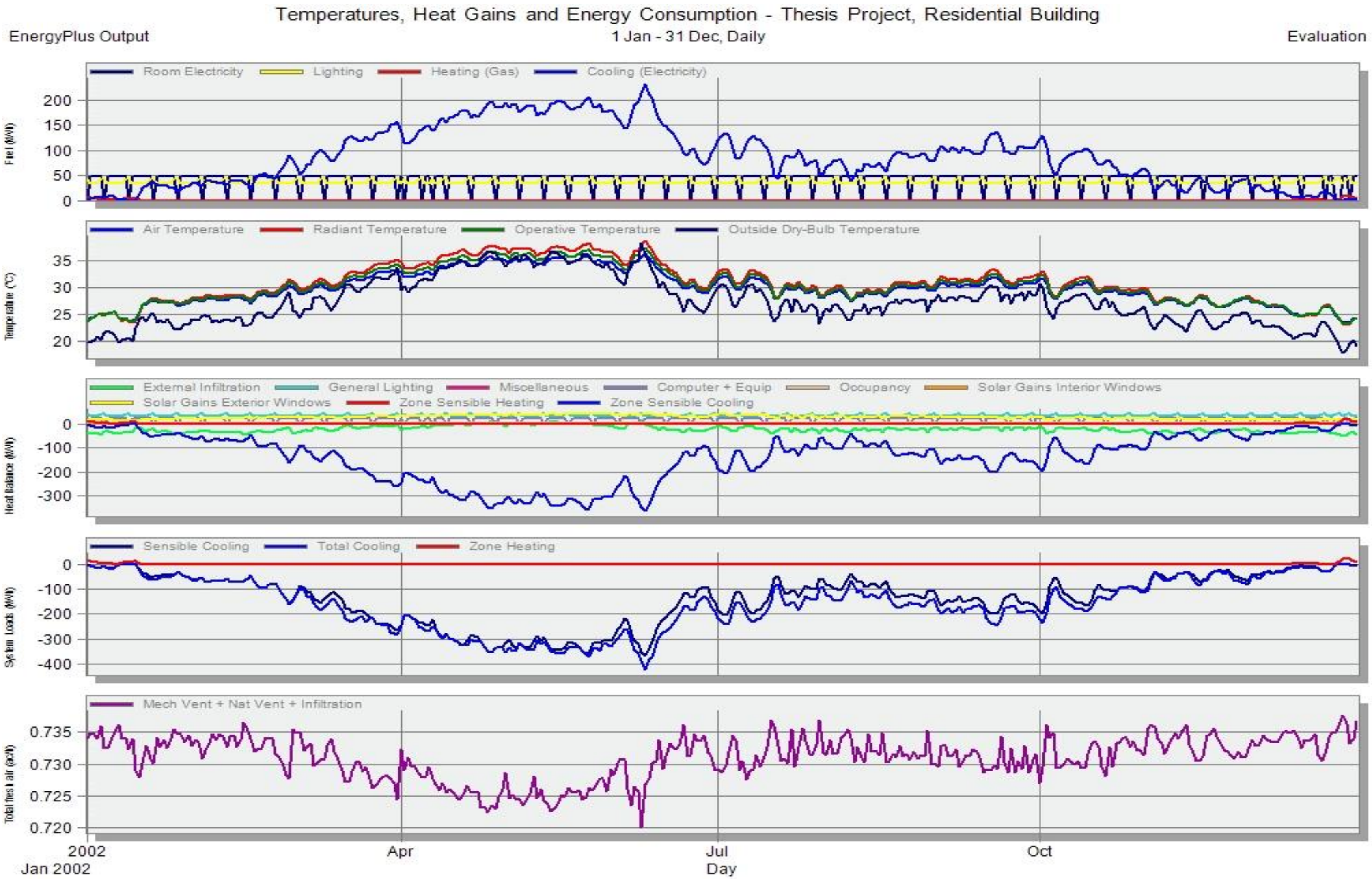

Figure 10: Triple glazing lowE glass (Air) simulation results

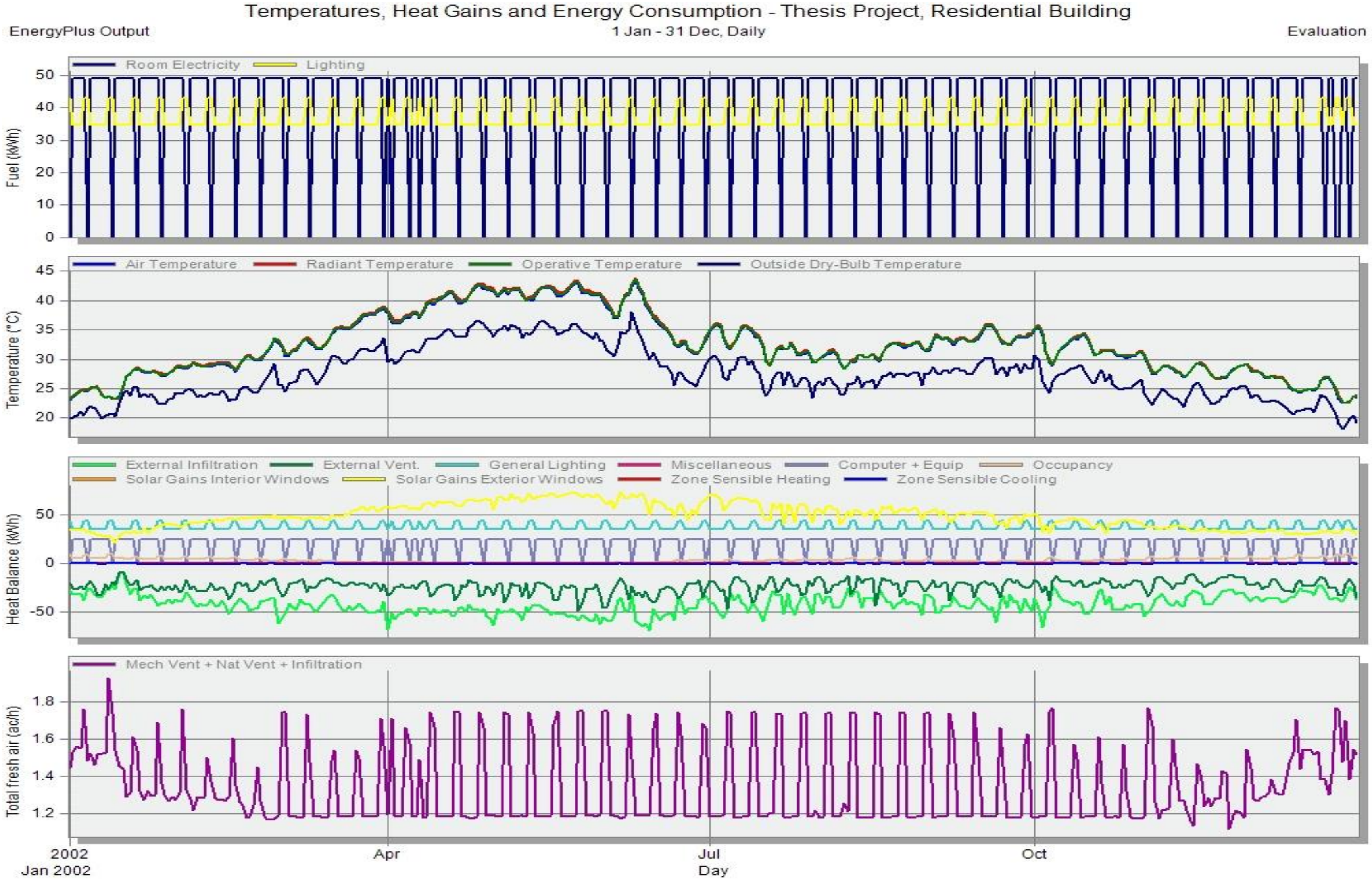

Figure 11: Earth pipes simulation results

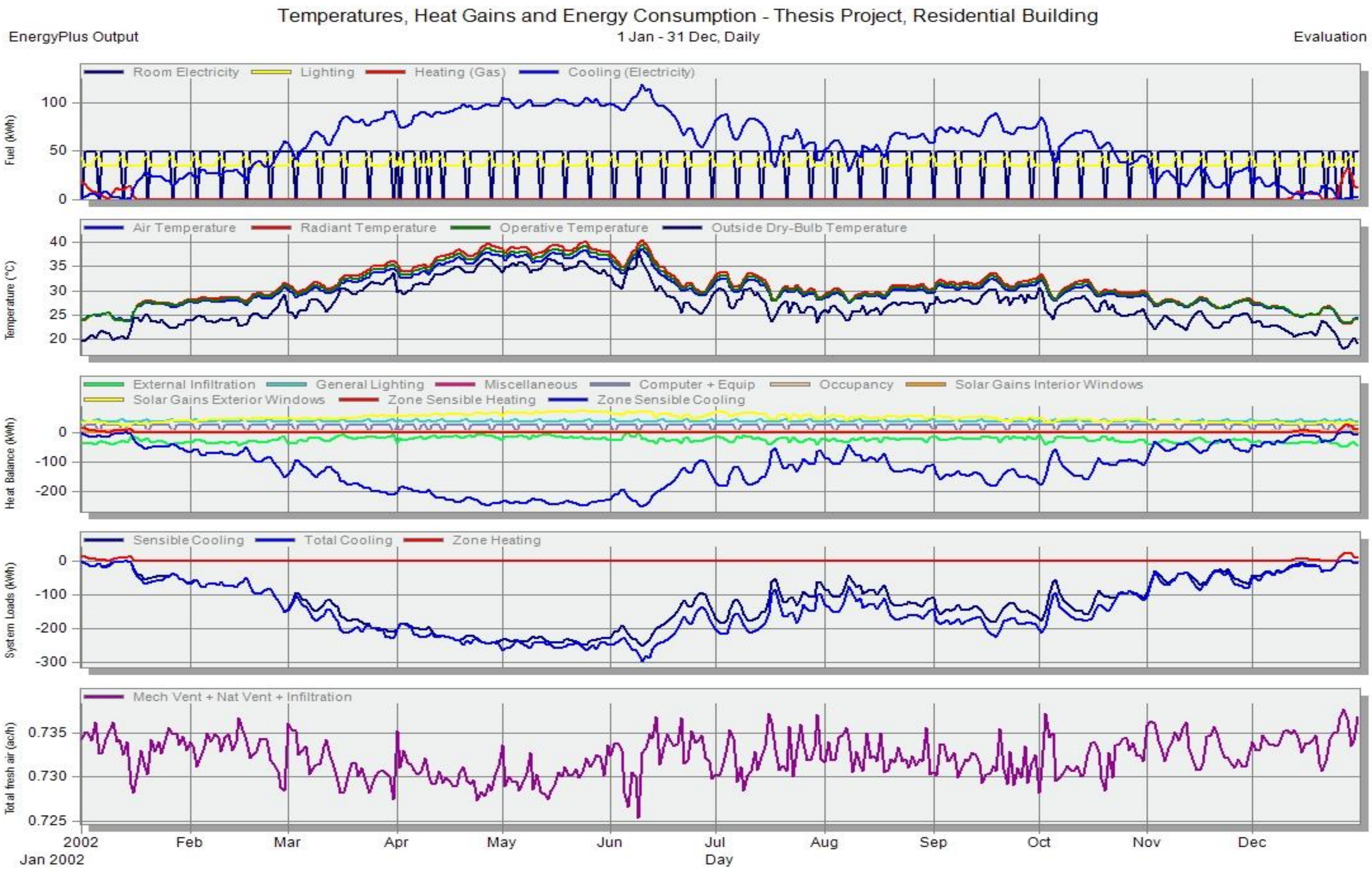

Figure 12: Chilled ceiling simulation results

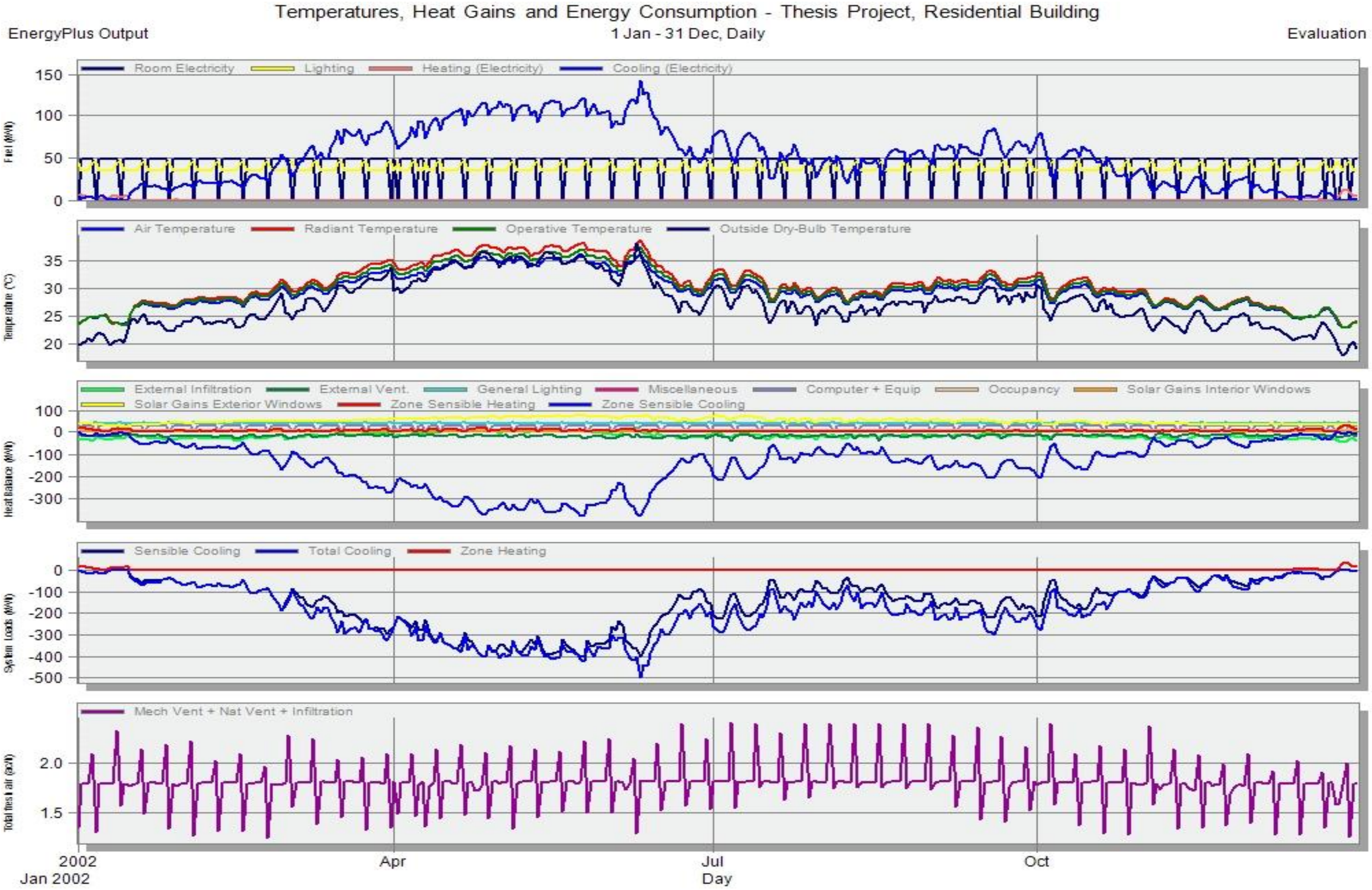

Figure 13: Ground source heat pump simulation results

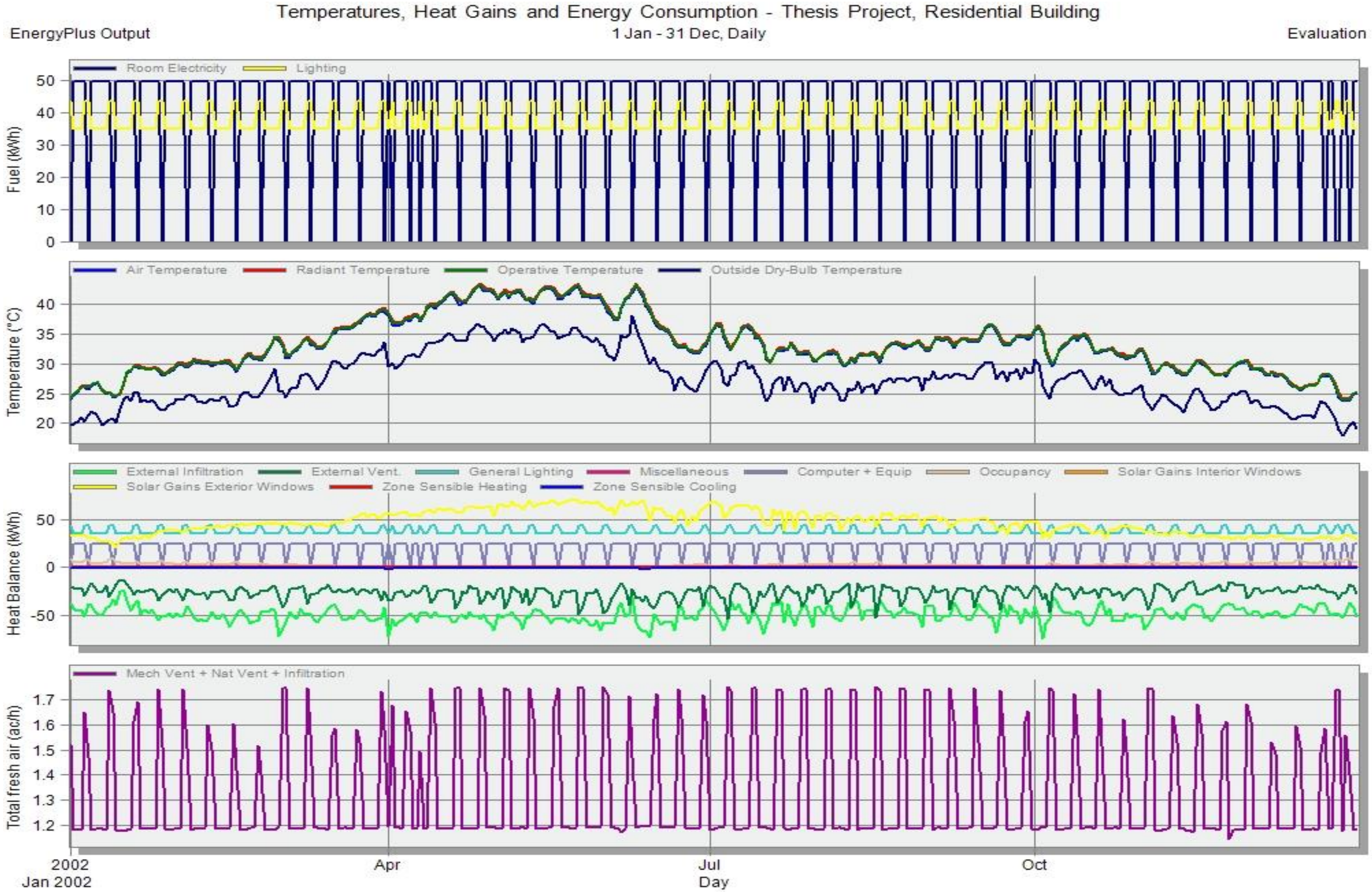

Figure 14: Final Design simulation result