INTERNAL MICROCLIMATE: CUMMULATIVE EXERGY CONSUMPTION IN A SANDCRETE AND BRICK-WALLED STRUCTURE

By

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CERTIFICATION

This is to certify that this study was conducted by **IBRAHIM, Abdullahi Alabi (17/68GE007)** at the Department of Civil Engineering, University of Ilorin, Ilorin, Nigeria, and has been read and approved as meeting the requirements of the Department of Civil Engineering, University of Ilorin, Ilorin, Nigeria for the award of Master of Engineering (M. Eng.) in Civil Engineering.

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DEDICATION

This research work is dedicated to Almighty Allah to whom all thanks, gratitude and praises are due, for granting the will and knowledge required to successfully put this work together.

I also specially dedicate this project to my parents, Alh. & Mrs. Braimah Tijani for their relentless care, effort and support throughout the completion of my programme.

DECLARATION

I, Ibrahim Abdullahi hereby declare that this thesis entitled Internal Microclimate: Cumulative Exergy Analysis of a sandcrete-walled Structure is a record of my research work. It has neither been presented nor accepted in any previous application for a higher degree. All sources of information have been specifically acknowledged.

In addition, this research work has been ethically approved by the University Ethical Review Committee.

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Ibrahim A. Abdullahi. Date

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ABSTRACT

Current practices of planning and designing of buildings in Nigeria do not take into consideration the energy and exergy demand of the building, and thermal comfort which are very important from the occupants' perspective, thus, there is need for a better understanding of exergy analysis during the design, construction, and operation phase of buildings to improve the quality match between energy supply and energy demand in buildings. The aim of this study is to estimate the exergy consumption value for a sandcrete and a burnt brick-walled structure in a tropical sub region. The properties of the building were assessed and measured, eQuest was used to estimate the energy demand of the respective buildings and the exergy analysis was conducted using the exergetic factor of electricity. The annual energy consumption of the existing building per unit area was estimated to be 240 kWh/m^2/year, which was categorized as not a good practice for an air conditioned office, while the annual energy consumption of the various control buildings per unit area was 108 kWh/m^2/year which was categorized as best practice for an air conditioned office. The cumulative exergy consumptions of the existing, sandcrete and burnt brick-walled building were found to be 68,354 kWh/year, 35,735 kWh/year, and 35,721 kWh/year respectively. The sandcrete building, as well as the brick building were found to be 48 % more energy efficient than the existing building as a result of the reduction in the energy consumption of the electrical equipment. However, the exergy analysis suggested that the burnt brick-walled building perform better than the sandcrete-walled building.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The building sector accounts for the majority of electricity consumption in Nigeria and will inevitably increase significantly in absolute terms in the coming years driven by a rapidly increasing population, migration from low energy consuming rural dwellings to urban centres, and improvements in living standards (Arup & Genre, 2016). The energy consumed by residential buildings accounts for more than 50% of the total energy consumed in the country (Arup & Genre, 2016). By using bioclimatic design techniques with highly efficient active systems, it is possible to greatly reduce the energy required to cool and light a building, or even in some cases eliminate the need for cooling entirely (Arup & Genre, 2016).

Energy is defined as the ability to do work while exergy is the quality of energy. According to the second law of thermodynamics, exergy is the quantity that is consumed during processes. In contrast, energy is never destroyed during a process; it changes from one form to another (First Law of Thermodynamics). The second law of thermodynamics provides guiding principles to deduce whether certain processes can occur spontaneously, and also in which direction they are likely to take place. For example, we know that falling from a higher to a lower height is a spontaneous process (e.g. a waterfall), but that, rising from a lower to a higher height requires an input of work (e.g. water pump) (Boelman & Asada, 2003). Itard (2003) asserted that in a working system, exergy is consumed, entropy is generated, while energy is conserved. The exergy of an energy form or substance is a measure of its usefulness, quality or potential to cause change, as a result of not being completely in stable equilibrium with the reference environment. Unlike energy, exergy is not subject to a conservation law, except for ideal processes; rather, it is consumed or destroyed in any real process (Rosen & Dincer, 2001).

Itard (2005) explained that the energy demand of a building is based purely on physical balances between the building and its environment. The ways in which a building is used influence the internal heat load, the lighting and power demand considerably, hence, when defining the energy or exergy demand, it is important to consider both the physical aspects of a building and its uses.

Researchers have conducted studies on building exergy analysis ((Adedeji, Odeyemi, Bello, Adeyemi, & Kaigama, 2014); (Shukuya & Hammache, 2002); (Boelman & Asada, 2003); (Sakulpipatsin, Boelman, & Schmidt, 2005); (Itard, 2003); among others) in which several processes related to the building were analysed. The classical exergy analysis enables the designer to identify the location, understand the cause, and establish the true magnitude of waste and loss. The unit of exergy as well as energy is Joule.

1.2 Statement of the Problem

Current practices of planning and designing of buildings in Nigeria do not take into consideration the energy and exergy demand of the building, thermal comfort and overheating issues which seems to be very important from the occupants' point of view, hence, there is need for a better understanding of exergy analysis during the design, construction, and operation phase of buildings to improve the quality match between energy supply and energy demand in buildings.

1.3 Aim and Objectives

The aim of this study is to estimate the cumulative exergy consumption value for a hollow sandcrete and a hollow burnt brick walled structure in a tropical sub region.

The objectives of this project are to:

i. obtain the data necessary to perform the energy and exergy analysis of the existing building and the variants control building (buildings modelled with sandcrete block and that modelled with burnt bricks) with the aid of eQUEST software.

ii. estimate the exergy consumption of the existing building, and the various control buildings.

iii. determine the more sustainable building material to minimise energy consumption in the operation phase of the buildings.

1.4 Justification for the Study

The problem of quick exhaustion of hiked electricity tariff credit in Nigeria (Nigeria Current Affairs, 2016) leads to high building operational cost. It becomes imminent to carry out energy performance evaluation of systems associated to buildings and building services through exergy analysis as a means to help building designers meet functionality and comfort requirements while keeping the associated energy resource depletion to a minimum.

1.5 Research Methodology

1. The orientation, geometry, schedule as well as properties of the building will be assessed. The design factors will be obtained from the Building Energy and Efficiency Guideline for Nigeria and other international standards.

2. The building energy balances were determined using eQUEST software, version 3.64, build 7130 and the exergy balances will be adapted from Itard, (2005).

3. Recommendations will be made as to ways of improving the structure such that, it would be thermally comfortable and economical in terms of energy consumption

1.6 Scope of the Study

This study covers the exergy consumption of an examination hall using the first and second law of thermodynamics. A case study of Hall “E”, a computer-based test centre in University of Ilorin, Main campus, Ilorin, Nigeria, hereafter referred to as the existing building, has been embarked upon. The energy being supplied to the building is electrical energy and the cumulative exergy consumption of the appliances, lighting and air conditioning is considered in this study. The existing building, sandcrete and hollow burnt brick building will be modelled in the eQUEST software, after which the simulation of the respective buildings will be conducted and the energy consumption of the buildings will be determined. The cumulative exergy consumption of the respective buildings will be determined from the result of the energy simulation. The existing building is located on the longitude 8°28'57.4"N, latitude 4°40'36.6"E, time zone GMT +01:00 West Central Africa. The map of Nigeria indicating Kwara state, map of Kwara state indicating University of Ilorin, satellite view of University of Ilorin indicating the existing building are shown in Figures 1.1, 1.2 and 1.3 respectively.

Figure 1.1. Map of Nigeria, Representing Kwara State with Red Colour.
Source: Google-Map (2019).

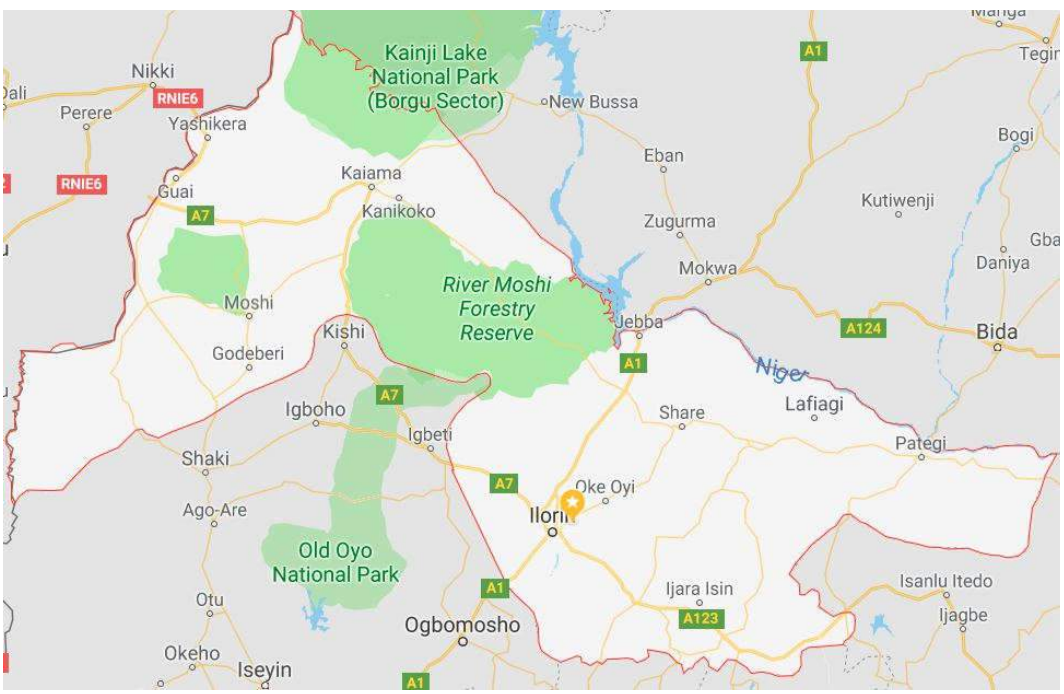


Figure 1.2. Map of Kwara State Showing Ilorin
Source: Google map (2019).

Reference Building- University of
Ilorin CBT Test centre, Hall ‘E’.

Figure 1.3. University of Ilorin Hall ‘E’ CBT Test Centre in Ilorin.

Source: Google-Map (2019).

CHAPTER TWO

LITERATURE REVIEW

2.1 Energy Consumption in the Nigerian Building Sector

In the Nigerian Building Sector, there is a shortage of reliable data on energy consumption in buildings, partly due to poor metering of mains electricity and also due to the fact that most buildings also generate electricity using petrol and diesel generators which complicates assessments. In 2015, Prof Chinedu Nebo estimated that 55% of Nigerian electricity users are not metered (The Guardian, 2015), this is recognised as a major barrier to energy efficiency. In 2013, GIZ commissioned a study on energy consumption in seven office buildings in Nigeria, the study suggested that office air-conditioning accounted for 40-68% of electrical consumption, with the other important uses being lighting (13-37%) and office equipment (12-25%). This is probably fairly typical for an air conditioned office in Nigeria, although office equipment consumption will depend heavily on the number and type of computers and other equipment in the building. The most common way of comparing building energy use is done by using the Energy Use Intensity (EUI) measured in $kWh/m^2/year$ (Arup & Genre, 2016).

2.2 Brief History of Exergy

Exergy first applications to the building sector were in the 1990s (Ilari, 2007). Sciubba and Wall (2007) presented a comprehensive history of exergy from early beginning till 2004. It was widely known that the exergy concept has originated from the early work of what would later become Classical Thermodynamic. An exact starting date was 1824, when Carnot stated that "the work that can be extracted of a heat engine is proportional to the temperature difference between the hot and the cold reservoir". This statement led, 30 years later to the position of the second law of thermodynamics by Clausius Clapeyron. However, Josiah Gibbs who had earlier defined the thermodynamic function “available energy”, was the first to explicitly introduce the notion of available work, including the diffusion term. He stated: “We will first observe that an expression of the form in equation 2.1 denotes the work obtainable by the formation (by a reversible process) of a body.

$$-\varepsilon + T\eta - Pv + M_1m_1 + M_2m_2... + M_nm_n \quad (2.1)$$

Where;

ε = Energy

η = Entropy

v = Volume

P = Pressure of the medium

T = Temperature of the medium

$m_1,m_2,...m_n$ = the quantities of the components,

$M_1,M_2,... M_n$ = the potentials of the medium

(The medium is taken to be so large that its properties are not sensibly altered in any part by the formation of the body.)” Equation 1 is in exact correspondence with the present definition of exergy. With no direct reference to Gibbs’ work, two researchers, (Louis Gouy and Aurel Stodola) independently derived an expression for “useful energy” (in French, énergie utilisable) as the difference between the enthalpy and the product of a reference temperature (which they specifically stated to be the ambient, or environment in modern terms, temperature) and the change in entropy, $H - T_o\Delta S$ (Sciubba & Wall, 2007). Where H, T_o and ΔS are respectively the enthalpy of the material stream, the ambient temperature and the change in entropy.

In an effort to reformulate the thermodynamic problem-solving procedures in terms of entropy or exergy, a number of authors engaged in a debate which continued in the 1960s', and led to the modern efficiency definitions we are using today. In the same years, other researchers were involved in a theoretical debate about the foundation, the formulation and the applicability of exergy. These works led not only to a more thorough understanding of the intrinsic loss mechanisms of engineering processes, but at times to quantum advances in cycle configurations, obtained by the more accurate analysis of the irreversibility allowed by the exergy approach.

The definitions of efficiency that emerged from the debate of the 1960s' converged to three fundamental ones:

a) the "exergy" efficiency (ε) = $\frac{useful\ exergy\ ouput}{used\ exergy\ input}$ (2.2)

b) the degree of reversibility (ψ) = $\frac{exergy\ of\ \text{"}products\text{"}}{\sum\ (energy\ inputs)}$ (2.3)

c) the coefficient of exergetic destruction (ξ) = $\frac{annihilated\ exergy}{total\ exergy\ input}$ (2.4)

$$\xi = \frac{T_0 \Delta S_{irr}}{\sum(energy\ inputs)} \quad (2.4a)$$

Where;

ξ = Exergetic destruction

T_0 = Ambient Temperature

ΔS_{irr} = Irreversible Change in Entropy

In general, the goal of these researchers is to show that the thermodynamic performance of any process in which energy is converted from one form into another cannot be measured properly by First Law considerations, and that the energy in- and outflows ought therefore to be expressed in exergy terms. (Sciubba & Wall, 2007).

2.3 The Concept of Exergy

The basic concept of exergy requires a comparison between exergy and enthalpy balances. As illustrated in Figure 2.1 representing material and enthalpy balances, material and energy are conserved in every device or process and cannot be destroyed. Material entering a system can be accounted for in the products and by-products and energy enter the system in the form of work, heat or raw material and can be found in the output as work, heat or waste, by-product and desired products material streams (Ghannadzadeh, 2013).

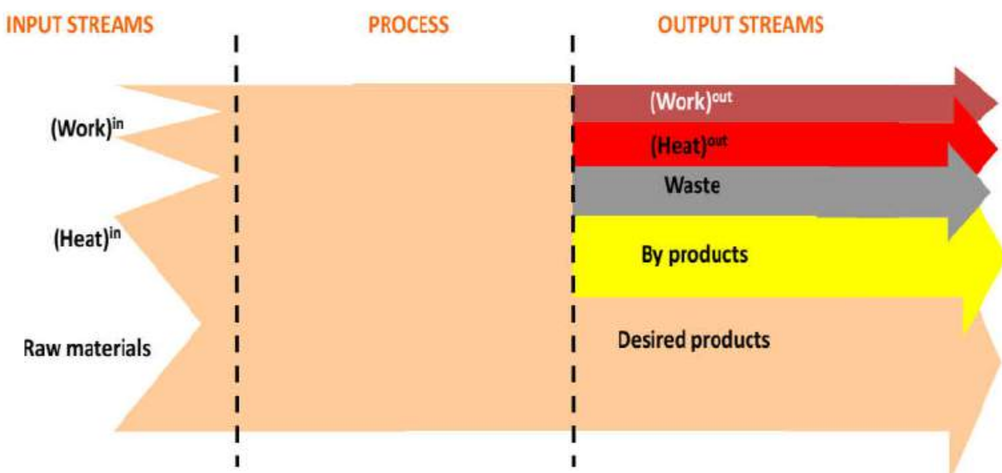


Figure 2.1. Energy Balance.
Source: (Ghannadzadeh, 2013).

This type of process analysis only shows the material or energy flows of the process and does not give insights on how the quality of the energy degrades through the process by dissipation; exergy notion contributes to fill this gap by measuring the quality of energy and then accounting for thermodynamic imperfection of real process. Decreasing the exergy losses of a process means a lower primary fuel consumption, thus, reducing the operating cost and increasing the process efficiency. When considering exergy balances, a Grassmann diagram (Kotas, 1985) such as illustration in Figure 2.2 should be used, as it highlights the degradation of the quality of energy.

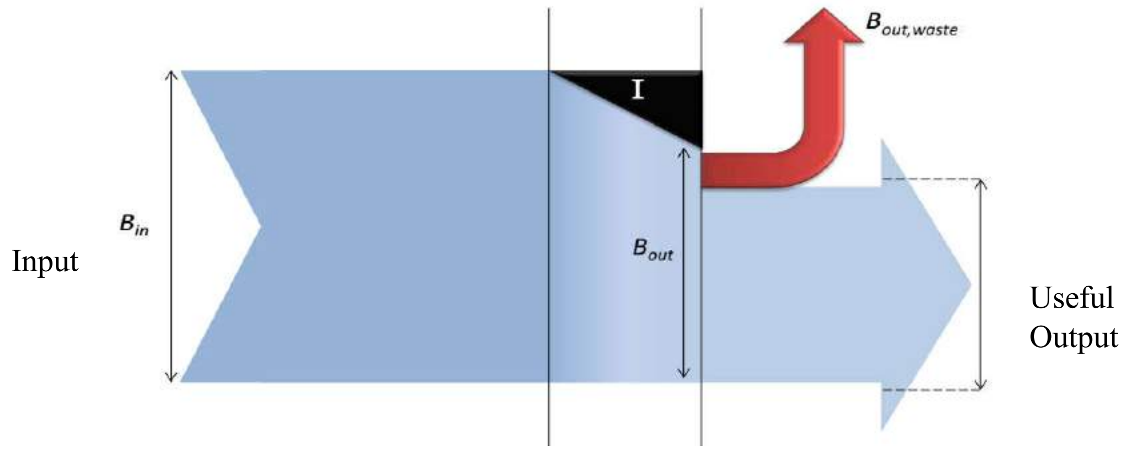
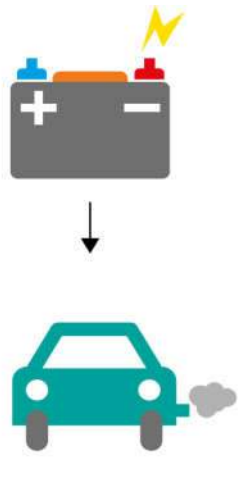


Figure 2.2. Grassman Diagram.
Source: (Kotas, 1985)

Ghannadzadeh (2013) further explained that, although 10kJ of low pressure (LP) steam and 10 kJ of electricity are equivalent in energy balance, 10 kJ of electric energy can be used to power your computer, television, radio, fan, etc. Hence, it is much more valuable than 10 kJ of thermal energy available at LP steam temperature (≈ 100°C). Electricity is useful whereas, energy of LP steam is valuable until its temperature is brought down to the plant environment temperature (e.g. 25°C).

In 2016, Brockway et al. (2016) explained that in a resource-constrained world, energy must also be appreciated from the point of view of quality, which is essentially a measure of its usefulness, or its ability to do work. In order to account for the quality and not just the quantity of energy, we need to measure exergy. As shown in Figure 2.3, the energy contained in the movement of air molecules in a $20m^3$ office at 20°c is more than the energy stored in three standard 12v car batteries. While you can only use the energy in the air to keep yourself warm, you could use the energy in the batteries to start your car, cook your lunch, and run your computer. The reason is that even if their quantities were the same, the quality or usefulness of the energy in the air and in the battery is different.



(a) (b)

Figure 2.3. Example of Exergy Showing (a) Battery Used to Start a Car Versus (b) Air Molecules in an Office Used to Heat the Occupant.
Source: (Brockway et al., 2016).

2.4 Definition of Exergy

The exergy analysis can give insight into the extent to which the quality levels of energy supply and energy demand are matched. Exergy factors are applied in numerical analysis for conversion of energy to exergy and exergy factors are listed for different energy sources in Table 2.1.

Table 2.1. Exergy Factors for Some Different Energy Sources

Fuel	Exergy factor
Natural gas	0.9
Fuel oil	0.9
Mineral coal	0.9
District heating at 100°C	0.21
Heat at 20°C	0.05
Electricity	1.0

Source: (Molinari, 2009)

Since electricity is an energy carrier of highest quality and all of the electric energy can be used for useful work, the exergy factor for electricity is 1 (Molinari, 2009). Electricity is not a primary energy source, but must be produced using some type of primary energy and then transform it to electricity through different types of processes. To receive a certain amount of electricity, a higher amount of primary energy is required as input. In the same way the exergy amount will diminish as energy conversion takes place. Lidholm, Odelbrink, and Sandwall (2012) reported that the amount of exergy depends on how the electricity is produced which could be through the use of coal, hydropower, wind, solar, etc. The primary energy required to generate electricity can be calculated with the following equation:

$$\text{Primary Energy} = \frac{Generated\ Energy}{Efficiency} \qquad (2.5)$$

Where η = efficiency

The reverse process, when observing how much energy that can be generated from a given amount of primary energy, a primary factor can be calculated as

$$\text{Primary factor} = \frac{1}{\eta} \qquad (2.6)$$

For example, if 100 kWh of electricity is needed for building operation, where the electricity is presumed to be derived from a coal condense plant with an efficiency of 40%, this means that 250 kWh of coal has been used (Lidholm et al., 2012).

2.5 Energy, Exergy, and Built Environment

The growing concern of environmental problems has amplified both the significance of all kinds of energy saving measures, and the inevitability for an increased efficiency in all forms of energy utilisation. Despite plenty of efforts made to improve energy efficiency in buildings, the issue of gaining an overall assessment and comparing different energy sources still exists (Schmidt, 2003). Exergy provides a common basis for comparing the energy performance of systems associated to buildings and to building services. For example, exergy analysis allows a designer to compare on the same basis between heat supplied by a fuel (e.g. through a boiler) and by solar heat (e.g. through a window). It also allows comparison between e.g. the electricity required by a mechanical ventilation system and the thermal energy savings resulting from the use of a heat recovery unit (Sakulpipatsin, Boelman, & Cauberg, 2007). This information can assist designers in integrating building and building services design, so as to meet user requirements with a minimum depletion of energy resources.

In the theory of thermodynamics, the concept of exergy is stated as the maximum work that can be obtained from an energy flow or produced by a system. The exergy content expresses the quality of an energy source or flow. This concept can be used to combine and compare all flows of energy according to their quantity and quality. Unlike energy, exergy is always destroyed because of the irreversible nature of energy conversion process. The exergy concept enables us to articulate what is consumed by all working systems (e.g. man-made systems like thermo-chemical engines and heat pumps, or biological systems including the human body) when energy and/or materials are transformed for human use (Sakulpipatsin, 2008).

Sakulpipatsin (2008) emphasised that exergy analysis can give insight into the extent to which the quality levels of energy supply (e.g. high-temperature combustion) and energy demand (e.g. low temperature heat) are matched. High-valued energy such as electricity and mechanical work consists of pure exergy. Energy which has a very limited convertibility potential, such as heat close to room air temperature, is low-valued energy. Low exergy heating and cooling systems allow the use of low-valued energy, which can be delivered by sustainable energy sources. Most of the energy needed for heating and cooling is used to maintain room air temperatures around 20°C. In this sense, because of the low temperature level, the exergy demand for applications in room conditioning is naturally low. In most cases, however, this demand is met with high quality sources, such as fossil fuels or using electricity. Exergy analysis provides us with additional information on where and when the losses occur. It helps us to see in which part of the energy chain the biggest savings can be achieved (Schmidt, 2003).

This also explains partly the resistance which is felt by engineers and consultants to use exergy as a tool. It clearly shows the sometimes extreme low exergy efficiencies of common systems like burning gas to heat at near environmental temperatures. In these cases exergy analysis is however at its strongest. It leads to the inevitable conclusion that certain processes or systems, however widely accepted and applied, are fundamentally wrong and should be replaced by more exergy efficient ways. This however contradicts the interests of huge industries and gas companies (Sakulpipatsin, 2008). The comparison between energy and exergy is shown in Table 2.2.

Table 2.2. Comparison of Energy and Exergy

Energy	Exergy
The energy change of a process is…	The exergy change of a process is…
its ability to produce motion	its ability to produce work
Conserved by the first law of thermodynamics	Only conserved for reversible processes and destroyed by irreversible processes
Different from zero ($E = mc^2$). Where E= Energy, m= mass, c= speed of light	Equal to zero when at equilibrium with the environment
Independent of Environment parameters	Dependent on environment parameters
A measure of quantity only	A measure of quality and efficiency of utilization.
Limited by the second law of thermodynamics	Unlimited for reversible processes due to the second law

Source: (Adedeji et al., 2014)

2.6 Internal Microclimate

A microclimate is the distinctive climate of a small area such as a neighbourhood or a park which may be slightly different from the regional climate. The combination of many different microclimate conditions is what builds up to the overall climate of the urban environment. Good master planning and building design can make improvements to the microclimate which in turn improve conditions inside the buildings, as well as improving the outside environment (Arup & Genre, 2016).

Microclimate condition surrounding a building has a direct impact on the comfort of the inhabitants (Mooney & Porter, 2010). One example of how buildings affect the local climate is the heat island effect in large cities where the average temperature is higher than the surrounding area. Buildings themselves create further microclimate by shading the ground, changing wind flow patterns. Also, solar energy absorbed and re-emitted from building surfaces, pavements road etc. create a large warming effect on the surrounding air. Also the quantities of building break up the wind flow, reducing wind speeds and causing the warm air to remain stagnant in the city. This also cause increased pollution as well as temperature. The presence of high rise buildings can degrade the local climate as wind speed at ground level can be significantly increased, while extensive shadows block access to sunlight for long periods, increasing heating in surrounding building.

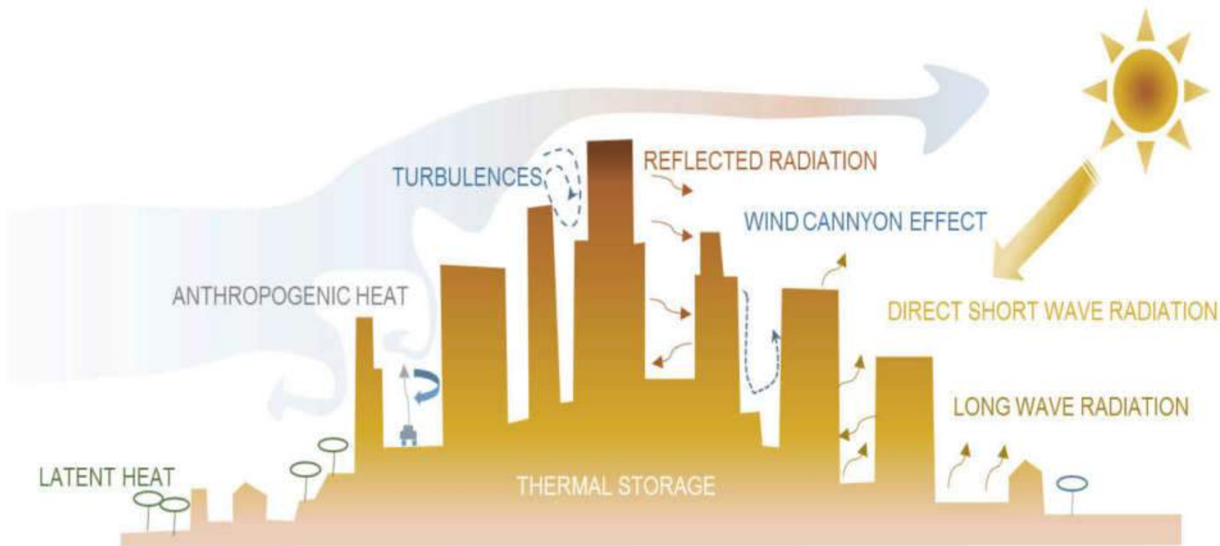


Figure 2.4 Urban Microclimate Factors (Arup & Genre, 2016).

The urban microclimate factors are shown in Figure 2.4. The concept of "city heat" too is well known, large expanse of concrete and stone absorb heat in the day and release it at night, making the average temperature in a city warmer than in adjacent areas. All these factors in combination with the area's patterns of topography and vegetation contribute to the formation of microclimates (Mooney & Porter, 2010). Higher urban temperatures have a very important impact not only on human comfort, but also on electricity demand for air conditioning (Santamouris, 2013). This is especially critical in hot climates where the warmer temperatures reduce potential for night cooling. Enhancing the microclimate is geared towards creating a more comfortable environment for those outdoors as well reducing the need for cooling systems inside buildings (Arup & Genre, 2016).

2.7 Building Materials

Material efficiency is one of the most important components of a sustainable building. Common materials such as sandcrete blocks and burnt bricks used for masonry works in housing delivery in

Nigeria, impact high energy and greenhouse gases on the environment due to the production processes involved. Intelligent choice of building materials capable of reducing energy used in buildings is imperative towards achieving materials efficiency and cost reduction (Adedeji & Fa, 2012). Correct selection of building materials can be performed by choosing products with the minimal environmental impacts and by taking into account their complete life cycle. González and Navarro (2006) estimated that the selection of building materials with low environmental impacts can reduce carbon dioxide (CO_2) emissions by up to 30%. The other factors that greatly affect the selection of building materials are their costs and social requirements such as thermal comfort, good mechanical properties (strength and durability), aesthetic characteristics and an ability to construct quickly. The process of housing development should be based on sustainability principles, which could be applied in the conception, construction and use of the buildings. The goals of the sustainability principles are to decrease the environmental costs incurred by inadequate constructive systems and solutions, minimizing the impacts on natural resources, and improving users' comfort (Amado, Pinto, Santos, & Cruz, 2007).

2.7.1 Hollow Sandcrete Blocks

Sandcrete blocks are composite material made up of cement, sand and water, moulded into different sizes. They are building units used in the construction of wall and partitions. They are of sizes and weights that can be easily handled by the bricklayer, with the facing surface layer than that of a brick but conveniently dimensioned (Abdullahi, 2005). Sandcrete blocks shown in Figure 2.5 are relatively cheap when compared to other construction materials and provide excellent resistance to damage without the added cost of protection devices. They do not rust, decay, or provide a home for damaging insects as other building materials can. They do not contain any material that is hazardous to the environment (Odeyemi, 2012).

Figure 2.5. Hollow Sandcrete Block.

Odeyemi (2012) experimented the Microclimate condition of a hollow sandcrete block building with two windows and a door and discovered that during the wet condition, the average ambient temperature became reduced from 28.3^{o}C to 21.8^{o}C when windows and doors were closed. Also, when the windows were opened and the door was closed the average ambient temperature of 28.3^{o}C was reduced to 18.7^{o}C. For the dry condition, when the windows and the door were closed the average ambient temperature of 35.6^{o}C was reduced to 22.4^{o}C. When the windows were opened and door closed the average ambient temperature of 35.6^{o}C was reduced to 20.4^{o}C. The author recommended that buildings be built with hollow Sandcrete block for thermal comfort. Hollow sandcrete block have a thermal conductance value (U-value) of 1.6 W/m^{2}K (Arup and Genre, 2016).

2.7.2 Hollow Burnt Bricks

Bricks are made out of clay-bearing subsoil. Hollow bricks are lighter and easier to handle, and have different thermal properties according to the model and the number of holes. Some models have very high thermal insulation properties, making them suitable for zero-energy building

(Shibib, Qatta, & Hamza, 2013) and a sample of hollow burnt brick is shown in Figure 2.6. Udawattha and Halwatura (2016) posited that thermal performance of walling materials can be measured by comparing outdoor ambient temperature and indoor ambient temperatures. Thermal performance can be simply compared with U value (thermal conductivity) of walling material. The thermal conductivity was measured by measuring the thermal transmittance (U-Value) of the walling material sample by using a thermal conductivity meter (Udawattha & Halwatura, 2016).

Figure 2.6 Hollow Burnt Bricks

In 2014, Sutcu, del Coz Díaz, Rabanal, Gencel, and Akkurt (2014) reported that different vertical perforation designs in brick lead to different thermal conductivities. These perforations act as barriers to heat flow by conduction through the walls of the brick. For the vertically perforated insulating clay brick, total wall thermal transmittance coefficient values are between 0.4 and 0.7 W/m^2K according to regional climate differences preferred for Turkey (TS825, 2008); (EN832, 1998). The thermal conductivities of the bricks show the difference as depending on their unit weights or densities. According to the TS 825 standard, for instance, the equivalent thermal conductivity values of the bricks with densities of 2400 kg/m^3 (solid brick) and 700 kg/m^3 (insulating brick) are about 1.40 W/m^2K and 0.24 W/m^2K, respectively (TS825, 2008). Thermal conductivity of the bricks depends on their firing temperatures, densities and therefore porosities (Sütc¸ü, 2010). A decrease of the material thermal conductivity implies a better thermal behaviour (Sutcu et al., 2014).

In a research conducted by Laaroussi, Cherki, Garoum, Khabbazi, and Feiz (2013) conclusion was drawn that the use of construction materials with more favourable thermal properties greatly reduces the heat gain. The average value of the thermal conductivity of the hollow brick was observed to be U = 0.346 W/m^2K and the author recommended that characteristic of the construction materials can be used and introduced by designers in the estimation of the thermal resistance of the walls construction in a building. Other thermal conductivity of hollow brick that have been reported by authors are 0.64 W/m^2K (Shibib et al., 2013), and 0.6 W/m^2K (Carl, 2017). All the thermal conductance value stated by the various authors are less than the thermal conductance value of hollow sandcrete block.

2.8 Energy Simulation Tool

Energy performance of a building depends on the subtle interactions of many building features and building services systems. Computer-based building-energy simulations are valuable design aid in giving a comprehensive picture of the building's energy-behaviour and the trade-off alternatives in detail (Lou, Tsang, Li, Lee, & Lam, 2017). Using the DOE-2 simulation engine, eQUEST was developed as a freeware tool designed to perform detailed energy analysis, even for critical decisions, including today's most sophisticated building energy use. The eQUEST software can conduct whole building performance simulation analysis throughout the entire design process. Simulations include equipment and energy consuming devices performance as well as several end uses. Graphic and tabulated results include energy cost estimation, daylight and energy system control, automatic implementation of common energy effciency measures, as well as energy consumption (Arup & Genre, 2016).

2.9 Area Lighting system

Lighting is one of the largest energy consumers in buildings (Nicol, Wilson, & Chiancarella, 2006) and accounts for 5–15% of the total electric energy consumption (Ryckaert, Lootens, Geldof, & Hanselaer, 2010). In order to reduce artificial lighting energy demands, daylighting strategies have been studied and proposed. Lighting controls in connection to daylighting can save lighting energy demands by 20–40% (Yun, Hwang, & Kim, 2010). As an alternative to artificial lighting, daylighting offers a lighting source that most closely matches human visual response and provides more pleasant and attractive indoor environment (Krarti, Erickson, & Hillman, 2005). Krarti et al. (2005) concluded that total building lighting savings is primarily a function of the perimeter office space area, the window area, and window transmittance.

The amount of lighting required in a room depends on the size of the room and the purpose of the room. Intricate tasks require more lighting and just moving around the room requires much less light. The amount of light required in an area is defined as "LUX" level that is equal to lumens/area (lm/m^2). The actual technical term for brightness is Lumens. The more the Lumens, the brighter the light is and the more energy is consumed (Jian, 2018). The amount of heat a lighting bulbs give off is equivalent to the amount of energy consumed by the bulb. Not only do CFL bulbs give off a significantly higher amount of heat than is emitted from LED lights, but they also contain highly toxic metals such as mercury. While a person can touch a CFL bulb that has been lit for some time without pulling back abruptly or being burned, they do become hot enough to cause discomfort.

LED lights will remain cool to the touch because the tiny amount of heat that is emitted during the production of light is so miniscule that it cannot affect the temperature of the casing (LEDlights.org, 2019).

It is important to meet the required brightness of a type of room as specified by standards. For example, if the required amount of brightness for a computer room is not met, it will result in the occupants straining their eyes to read from a computer system. To estimate the number of bulbs required in a room to meet the required lux level of that room the equation 2.7 is used

$$No\ of\ bulbs = \frac{Room\ square\ area\ X\ lux\ level}{Lumen\ rating\ of\ bulb} \tag{2.7}$$

2.10 Sizing Air Conditioner System for a Building

Air Conditioner is measured in BTU (British Thermal Units), and also measured in ton, this has nothing to do with weight, it is a measurement of heat, 1 ton = 12,000 Btu. In determining the ton of AC needed in a building, important factors such as the orientation of the building, the average high temperature of the building, the windows, shading, the insulative values of the windows, doors, walls, and roofing, internal loads, the solar gain are taken into cognisance (Bluejay, 2016). The internal loads will include the appliances in the room, people living in the space, and the lights in the room.

Bluejay (2016) asserted that the best way to size HVAC system is to have a “Manual J” calculation done on your building because it takes into account the above mentioned factors. The second method is to go by square metre and the basic formula for cooling is 1 ton of cooling for every 55.742 m^2 of house (Bluejay, 2016).

$$HVAC\ Size = Area\ of\ room\ (Sqm)\ X\ \frac{1\ ton}{55.74\ Sqm} \tag{2.8}$$

Energy efficiency ratio of an HVAC system (EER) is the ratio of the amount of cooling produced (BTU) to the amount of electricity (Watt) used. Mathematically expressed as

$$EER = \frac{Heat}{Power} \tag{2.9}$$

2.11 The Method of Exergy Analysis in Buildings.

Exergy analysis has been utilized in the optimization of thermal processes in power plants and in industry. However, energy systems in buildings are designed based solely on the energy conservation principle. This principle alone does not provide a full understanding of important aspects of energy use in buildings, e.g. matching the quality levels of energy supply and end-use; fully expressing the advantages of using passive (e.g. thermal insulation, window design) and ambient energy (e.g. heat pumps) in buildings. From this viewpoint, exergy analysis is an important link in understanding and designing energy flows in buildings (Sakulpipatsin et al., 2005). From a building designer's viewpoint, a building may be regarded as a shell allowing its occupants to interact with (or shelter from) the outdoor environment. Natural resources (e.g. sunshine, wind) may supply passive heat and cold (energy) to a building, as far as the building envelope can be designed for providing the desired indoor climate conditions. Additional energy needs may be met by building services, in the form of heat and electricity (see Figure 2.7) (Sakulpipatsin et al, 2005).

Quite often, building shape and function are more direct concerns of building designers than energy efficiency – although the resulting design decisions are likely to have a significant impact on building energy performance (Sakulpipatsin et al, 2005). A clear picture of where the potential for a further increase in an efficient energy use can be found by using a combined energy and exergy analysis. In buildings where people live, the most important thing is to have rational energy utilization patterns which enhance occupants' well-being within the built environment (Schmidt & Shukuya, 2005).

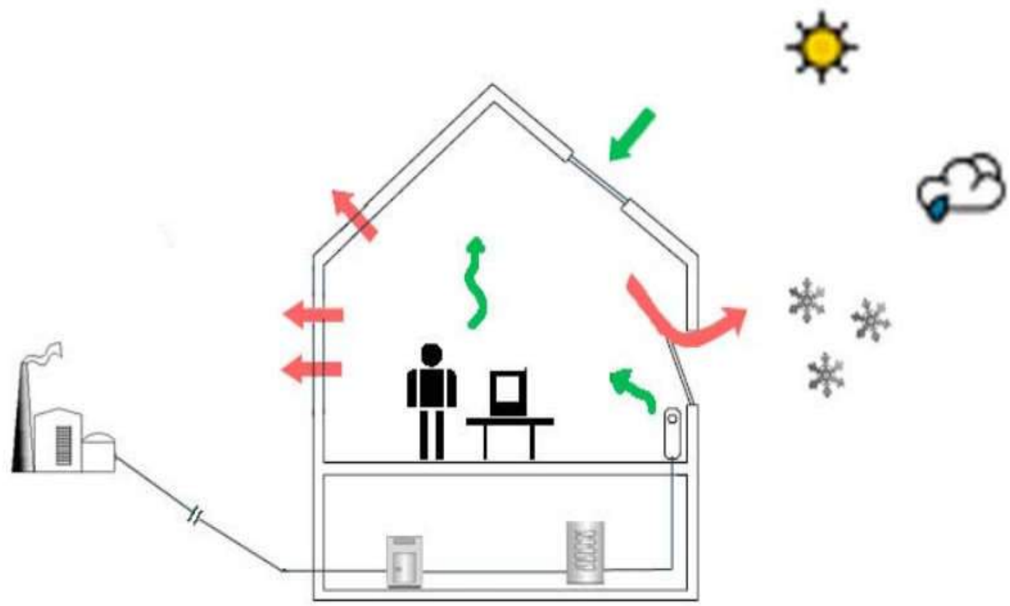


Figure 2.7. Building-Centred Energy Flow Model Underlying the Graphic Interface
Source: (Sakulpipatsin et al., 2005).

For the following study of building environmental control systems, such as heating or cooling, steady state conditions are assumed. Energy and matter are supplied into the system to make it work. Inputs and outputs are the same, according to the laws of energy and mass conservation. The energy flow through the building envelope is constant in time under steady state conditions. In the case of heating, heat transmission occurs from the warm interior to the cold ambient environment, across the building envelope. This is accompanied by an increasing flow of entropy, the entropy of a substance is a function of the temperature and pressure (Schmidt & Shukuya, 2005).

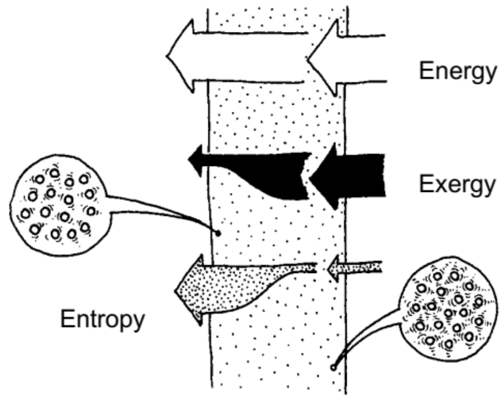


Figure 2.8. Energy, Entropy, and Exergy Flow through a Building Wall
Source: (Shukuya & Hammache, 2002).

Figure 2.8 shows the flow of energy, exergy and entropy through a building wall. Shukuya & Hammache (2002) reported that a certain amount of entropy is generated due to irreversible processes inside the building envelope. This generated entropy has to be discarded to the surroundings, i.e. the outdoor environment. It is important to recognize that the energy flowing out of the building envelope is not only accompanied by a destruction of exergy, but also by an increased flow of entropy. Disposition of generated entropy from a system allows room for feeding on exergy and consuming it again. This process, which underlies every working process, can be described in the four fundamental steps summarized below. Heating and cooling systems are no exception in this case (Shukuya, 1998):

1. Feed on Exergy
2. Consume exergy
3. Generate entropy
4. Dispose Entropy

All processes work according to these laws. The human body is no exception here and nor are the systems used in the built environment as shown in Figure 2.9 (Shukuya, 1998). It is important to note that our whole natural and man-made environment functions in the fundamental four steps of the exergy-entropy-process.

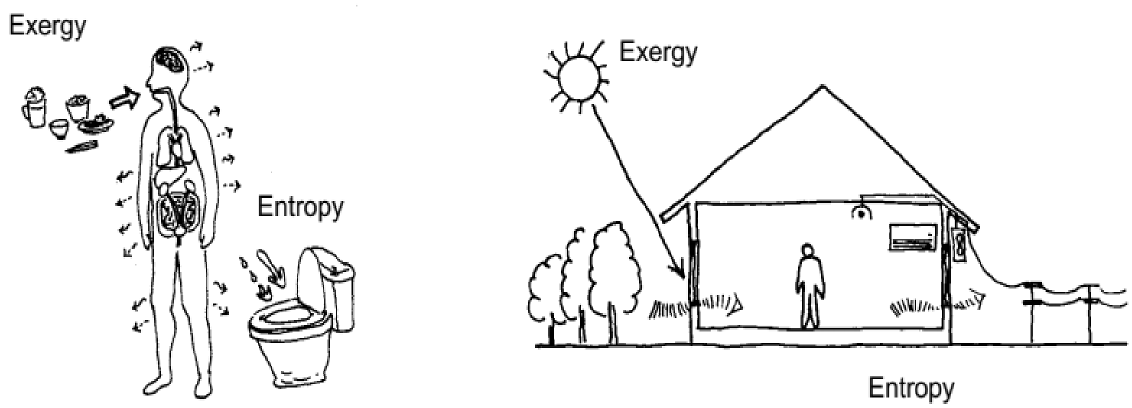


Figure 2.9. The Exergy-Entropy-Process on two Systems: The Human Body and a Building Source: (Shukuya, 1998).

Mahlia, Taufiq, Ong, and Saidur (2011) developed a methodology to calculate exergy consumption and applied it to a room space in a tropical climate. By using the derivations for the subsystems, the exergy analysis of the plane wall, window, fluorescent lamp, cooling system and floor for the room were conducted and the result is shown in figure 2.10. It was observed that day lighting system consumes about 28% of the total exergy, within the system, the wall destroys the majority of exergy, consuming about 78% of the total exergy in the day lighting system. The Electric lighting system consumes about 6% of exergy from the total exergy consumption of the room. Space cooling system is the system that consumes most exergy in the room.

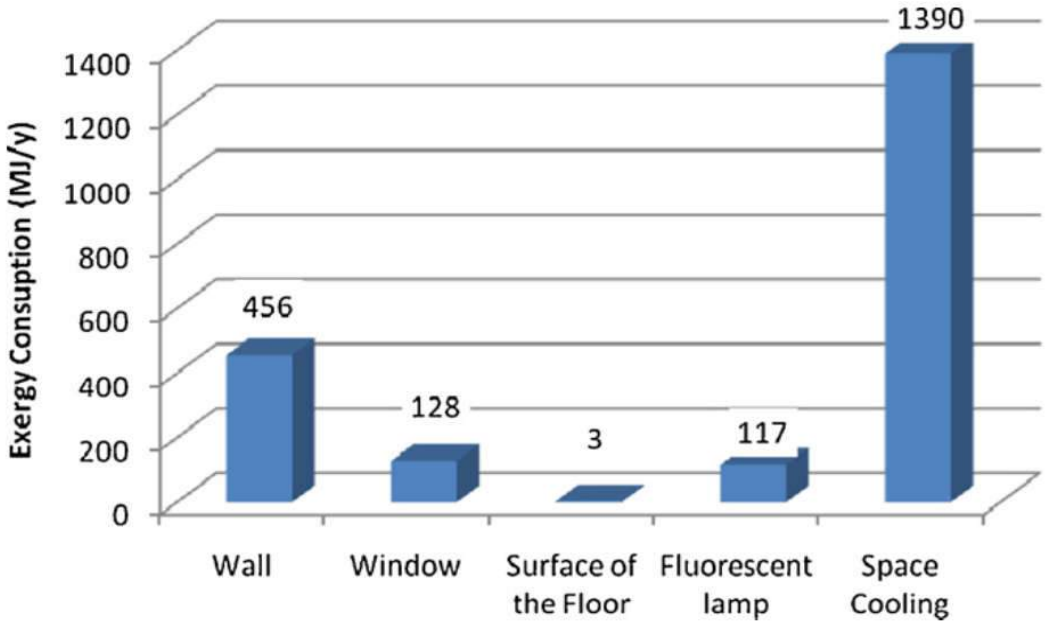


Figure 2.10. The Total Exergy Consumption for Each Subsystem in the Room Model for a Year in Malaysia. Source: (Mahlia et al., 2011).

Sakulpipatsin, Itard, Van der Kooi, Boelman, and Luscuere (2010) conducted an exploratory work to study the relevance of exergy analysis of buildings and Heating Ventilation Air Conditioning (HVAC) systems. It was discovered for the reference building, that reducing the thermal energy supplied by heating equipment remains a key concern in the cold day. In the warm day, while the internal thermal energy gains are crucial in the energy analysis, the exergy analysis shows that the solar exergy gain creates the main exergy losses when cooling is needed. These solar exergy gains should be minimized upon the situation, or better captured to be useful somewhere else (for instance, electricity generation).

Adedeji et al. (2014) used analytical approach to conduct exergy analysis for a residential building in ilorin, Nigeria. From the analysis for the model building, it was estimated that the heat demand in the building was 6181.54W. The building system was fed with primary exergy of 21.396KW which was consumed in each component as shown in Figure 2.11. When the flow of energy leaves the building through the building envelope (i.e. the sum of all building heat losses) all exergy has been consumed. The author noted that the greatest losses of exergy in the building occur in the Primary energy transformation and Heat generation.

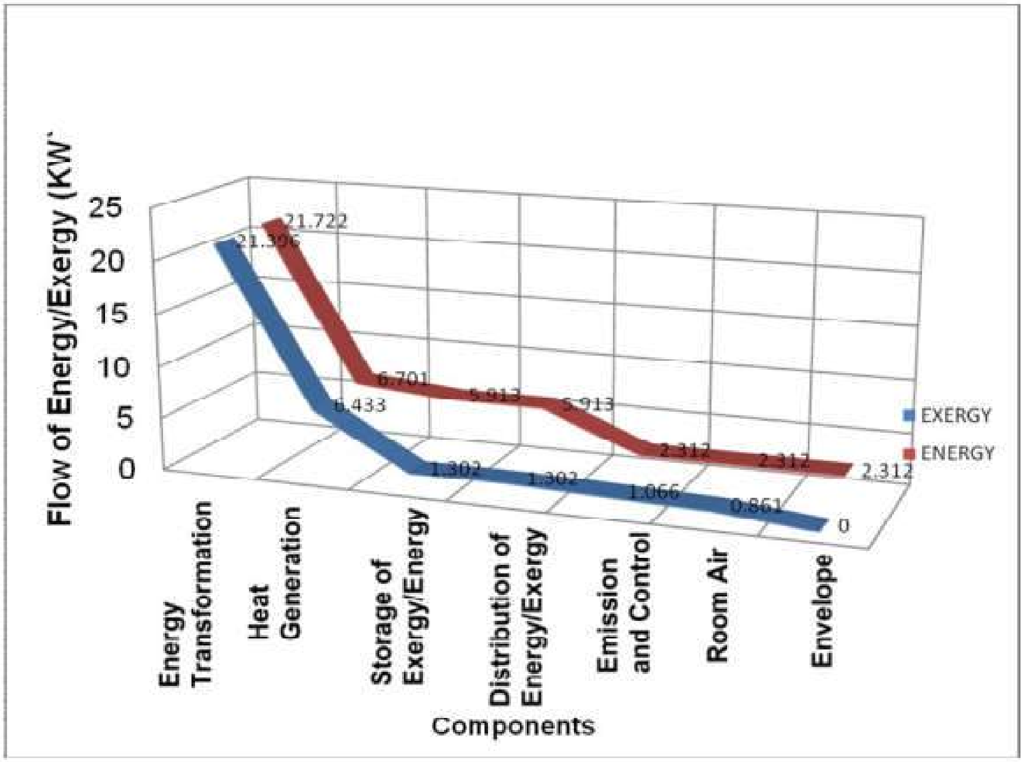


Figure 2.11. Absolute Values of Energy/Exergy Flows through all Components in the Building
Source: (Adedeji et al., 2014)

Itard (2005) proposed a comparison between traditional energy analysis of buildings and exergy analysis as shown in Figures 2.12 and 2.13. In both dwellings, most of the energy is consumed by room heating while the appliances consumed most of the quality of the energy.

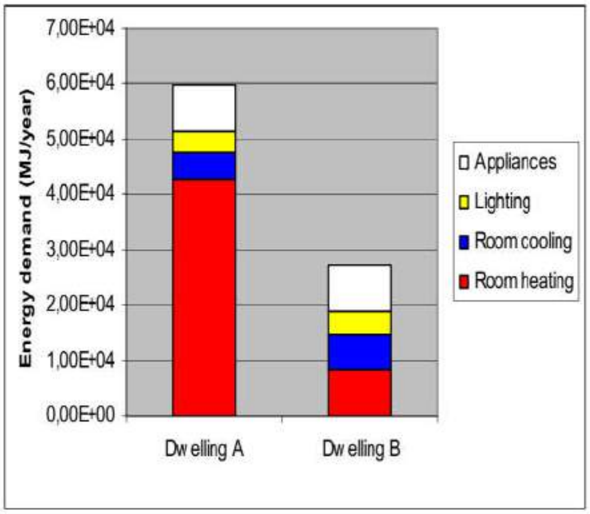


Figure 2.12. Average Annual Energy Demand (MJ/year) for a Prewar (A) and a Modern (B)
Source: (Itard, 2005)

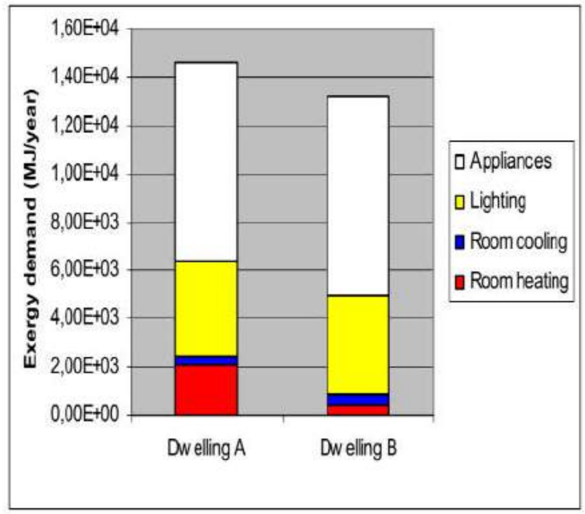


Figure 2.13. Average Annual Exergy Demand (MJ/year) for a Prewar (A) and a Modern (B)
Source: (Itard, 2005)

The author concluded that the exergy analysis suggest that long-term increases in the sustainability of buildings can be achieved only by reducing the energy demand for electrical appliances considerably and by either improving the efficiency of the electricity production process or applying sustainable electricity generation based on sun or wind. The reduction of the lighting demand is possible by designing buildings that make maximal use of day lighting and by developing efficient lighting. The energy demand for appliances, such as computers and televisions, should also be decreased considerably (Itard, 2005).

CHAPTER THREE

METHODOLOGY

3.1 Description of the Specimen Building

The existing building is Hall “E”, a Computer Based Test (CBT) centre in University of Ilorin, Nigeria, as shown in Figure 3.1. The existing building is not a storey building and has no room partition. It is a computer room with a rectangular geometry and has its shorter sides west oriented with two doors, and the longer sides north oriented with eight windows. The whole building is 22 meters long, and 15 meters wide, it is considered a one-zone model and all the walls are adjacent to the outdoor environment. As at the time of this analysis, there were 250 candidates writing their computer-based examination in the building. The typical layout plan and the interior of the existing building respectively are shown in Figures 3.2 and 3.3 respectively.

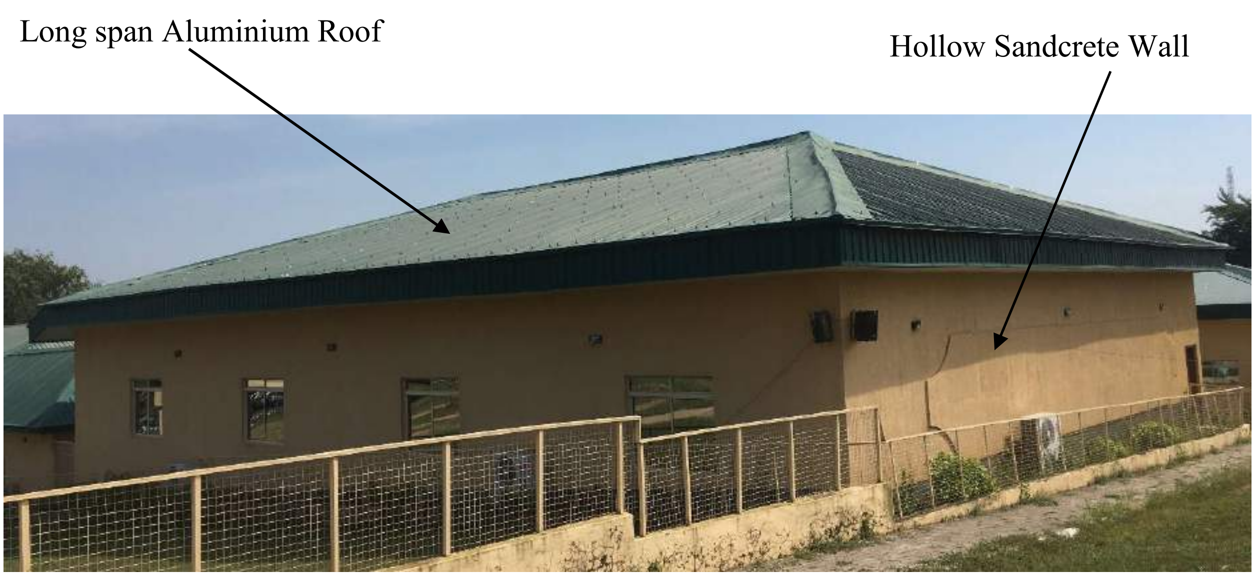


Figure 3.1. The Exterior of the Existing Building, Hall ‘E’ CBT Centre.

The reason for choice of a sandcrete-walled structure is because majority of the buildings in Nigeria are built with hollow sandcrete block (Arup & Genre, 2016) and the reason for choice of this building specimen is because the University computer-based test centre belongs to large public building in which the energy consumption is huge. Thus, it is worthy of doing research in this area.

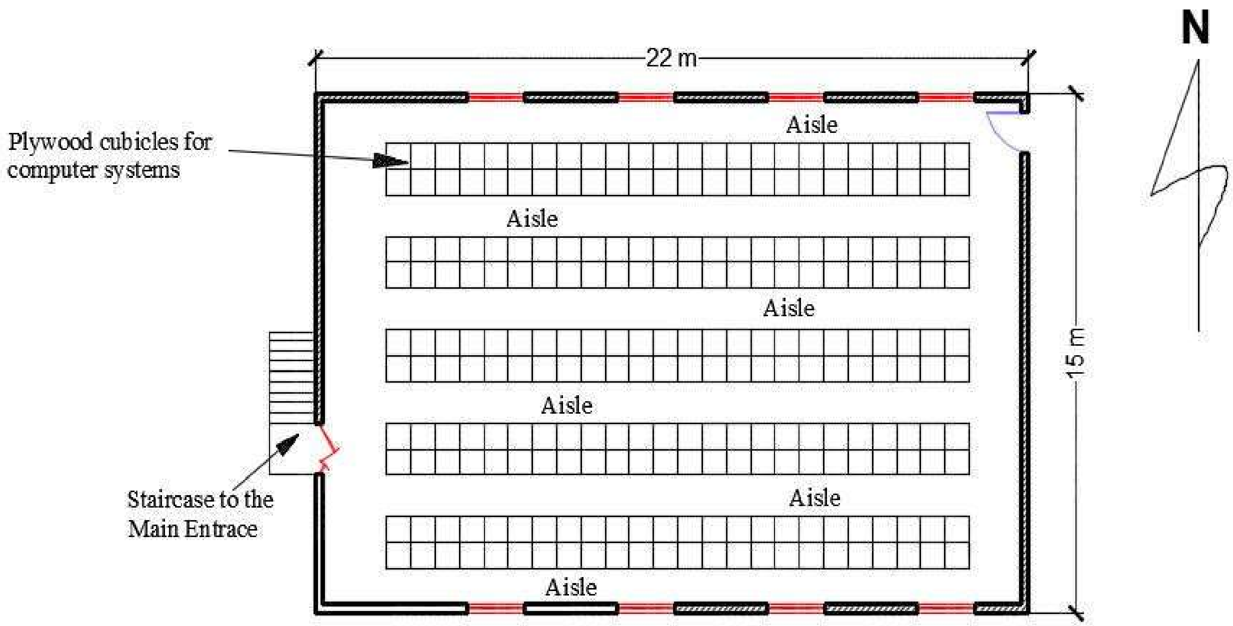


Figure 3.2. Typical Layout Plan of the Existing Building and Control Buildings

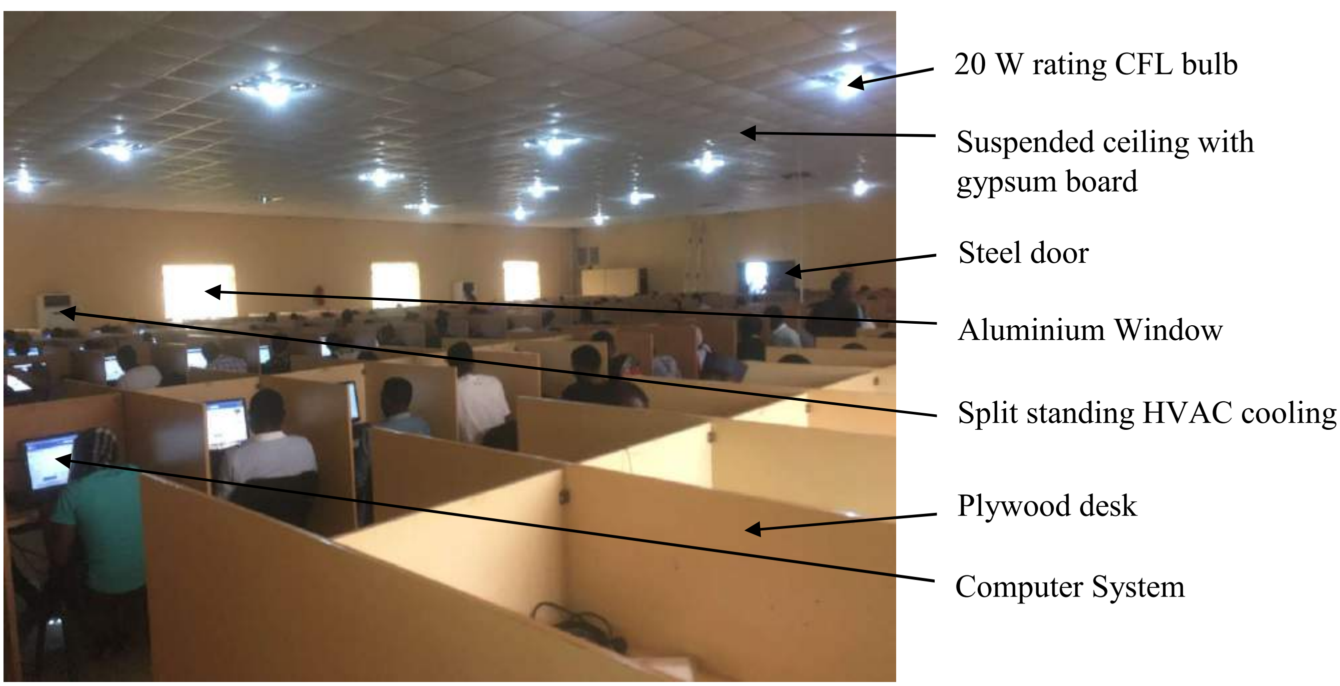


Figure 3.3. The Interior of the Existing Building

3.2 Sources of Data Used

The general project data, the net floor area, the headroom, the Air conditioning system thermostat value, Air conditioning system ratings, computer ratings, sandcrete wall finishing and coating, operative temperature, and lighting are obtained by visiting the building specimen, all parameters were measured as applicable and the data were recorded in fundamental units.

The power ratings of the appliances were known from the label attached to the appliances and the installed electrical load of appliances, in watts per square meter, were calculated. The net floor area, the headroom of the specimen building were measured using measuring tape and the internal temperature of the building was determined using laboratory thermometer. The heat load from people is calculated from occupancy profiles and from the sensible and latent heat of persons, depending on metabolism and indoor air temperature. The description of the existing building is shown in Table 3.1.

Table 3.1. Existing Building Envelope

Parameters	Description
Roof	Made up of Aluminium roof, void, and ceiling with U-value of 1.95 W/m^2K (Arup & Genre, 2016). The ceiling is a suspended ceiling.
Wall	Cream coloured hollow sandcrete block wall of 230 mm thickness with U-value of 1.6 W/m^2K (Arup & Genre, 2016).
Window	1.2m by 1.2m size with U-value of 5.8 W/m^2K (Arup & Genre, 2016) Single glazing glass with Aluminium frame
Door	1.5m by 2.1m (5ft x 7ft) steel door
Floor	Floor material of 150 mm Concrete slab thickness, Floor finishing with Ceramic tiles.

3.2.1 Area of building

Based on the measurements and calculations, the Gross floor area of the building is 330 m^2, ground-to-ceiling height of 3 m with space cooling. Occupancy of the building is 1.32 m^2/person, Equipment load of 83.3 W/m^2, light load of 1.2 W/m^2, and required fresh air of 54 m^3/h. The window-to-wall ratio (WWR) in north, east, south and west are 10.1%, 5.6%, 10.1% and 5.6%, respectively.

3.2.2 Description of HVAC system

The reference building contains four standing split Air Conditioner system each of the HVAC system have its outdoor unit. Each HVAC system has a coefficient of Performance (COP) 2.22, fan control at constant volume, zone set air temperature of the air conditioning system is 26 ^{o}C, Energy efficiency Ratio 7.58 Btu/h/W, dehumidification rate 3.0 l/h (See appendix B). The air conditioning system is the only source of ventilation for the building.

3.2.3 Description of lighting system

Twenty units of 20W Compact Fluorescent Light (CFL) bulb kept the brightness of the reference building lower than the standards (300 lux, (Arup & Genre, 2016)), with absence of daylight controls to reduce the lighting energy use.

3.2.4 Work schedule of the existing building

The existing building was assumed to be in use from January 1st, 2018 to mid of September 2018, Monday through to Friday, 8:00 am to 5:00 pm (peak period). The air conditioning system, computers and lighting are always powered on an hour before the opening time.

3.3 Control Building

The control building is a replicate of the existing building in terms of geometry, orientation, schedule and size. There are two variants of control building which are stated as follows

3.3.1 Hollow sandcrete walled building

This is the first variant of the control building, it was modelled to be built with hollow sandcrete block, the walls were insulated with one inch polystyrene, the window glazing were modelled to be double glazing, solar control with soft coating with U-value = 1.5 W/m^{2}K (see appendix B) in order to reduce the solar gains in the building. The roof was modelled as a naturally ventilated pitched metal sheeting roof with insulation. Multi-unit AC system was used in the building model, in which the indoor units are affixed to the wall and ceiling. It was sized in response to the actual demand of the building. In this control building, LED lights was used. The LED were used because it doesn't emit high levels of heat and they don't contain toxic chemicals (LEDlights.org, 2019). A double daylight and occupancy control sensor was placed in the centre along the length of the building. Continuous dimming was selected as the method of daylighting control. The standard brightness of a computer room (300 LUX (Arup & Genre, 2016)) was achieved with very minimal energy. The computers in the building were modelled to be laptop computers, Equipment Energy-Efficient software was installed which automatically and safely sleep computer when not in use or shuts down computers at night in case staff forget to do so before leaving.

3.3.2 Hollow burnt brick building

This is the second variant of the control building, it was modelled to be built with hollow burnt brick building, while other conditions were modelled like the first variant of the control building in terms of geometry, orientation, schedule, and electrical equipment.

3.4 Energy Analysis

The energy analysis of the existing building and the variants of control building was conducted using the schematic design wizard in the eQUEST software tool and the calculations for the data inputted in the schematic design wizard to perform the analysis can be found in Appendix D while the summary of the calculation is presented in Table 3.2.

Table 3.2. Model of Existing Building and Control Building

Building Envelope	Existing Building	Building Control
Wall	Hollow sandcrete wall, U = 1.5W/m^2K	Hollow sandcrete wall, U = 1.5W/m^2K, (Arup & Genre, 2016) (In comparison, Burnt Brick, U = 0.6 W/m2K (Carl, 2017))
Roof	Pitched metal sheeting roof without insulation	Naturally ventilated pitched metal sheeting roof with insulation
External shading to windows	Absent	Present
Equipment	27, 500 W	11, 750 W
HVAC - Cooling capacity - Power - Efficiency	4 split Air Conditioner 25000 x 4 = 100,000 Btu/h 3.3 kW x 4 = 13.2 kW 100,000 / 13.2 kW = 7.58	2 Multi-unit A / C 34100 x 2 = 68,200 Btu/h 2.9 kW x 2 = 5.8 kW 68,200 / 5.8 kW = 11.76
Lighting - Load - Brightness	CFL 1.20 W/m^2, 1210 X 20/330 = 73 LUX, which does not meet the required brightness for the building according to Arup and Genre (2016)	LED + Daylight Sensor 2.73 W/m^2 2780 X 36/330 = 300 LUX which meet the required brightness for the building according to Arup and Genre (2016).
Plug Load	83.3 W/ m^2	35.61 W/ m^2

3.5 Computer Simulation Approach

The simulation tool employed in the study is the eQUEST building energy program which builds on the well-validated DOE-2.2 simulation program and contributes to various worldwide green building crediting schemes such as LEED and BEAM Plus. The eQUEST package conducts hour-by-hour calculation, using 8,760 hourly records of measured weather data to analyse the heating and cooling loads, and calculates the energy consumptions. The typical meteorological year (TMY) of West Africa (specifically, Lagos, Nigeria) was adopted for the building energy performance analysis.

The Schematic Design Wizard was used to create building description in eQUEST. The wizard includes screens covering the following:

- General project information including building type, size and principal Air conditioning system type which is shown in Figure 3.4

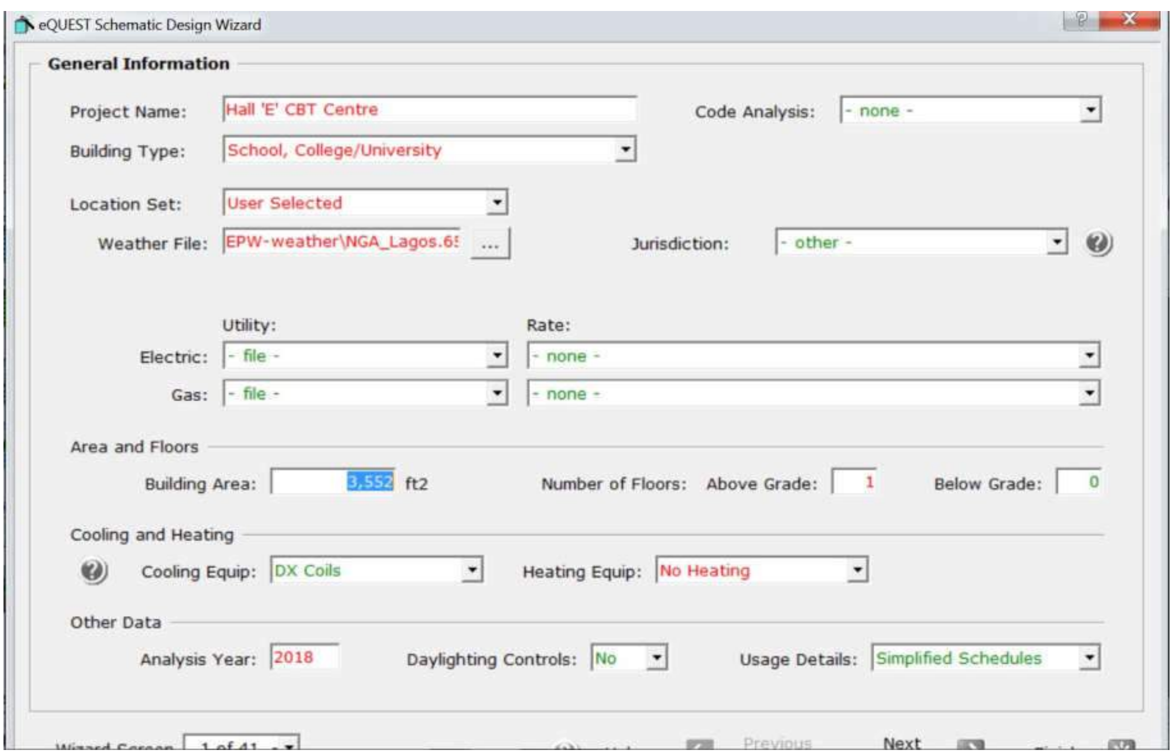


Figure 3.4. General Information of Existing Building in eQUEST

- Overall building geometry including footprint, floor-to-ceiling distance and zoning pattern which is shown in Figure 3.5

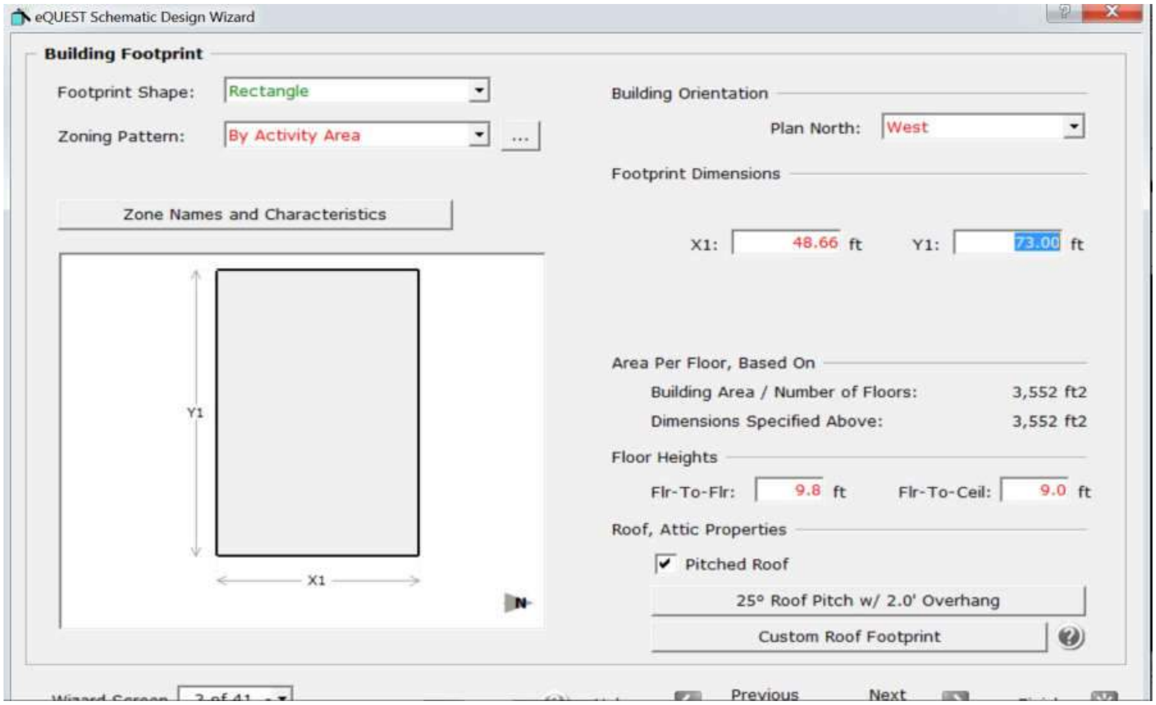


Figure 3.5. Existing Building Footprint in eQUEST.

- Building constructions types for walls, floors, roofs, etc. as shown in Figures 3.6 and 3.7

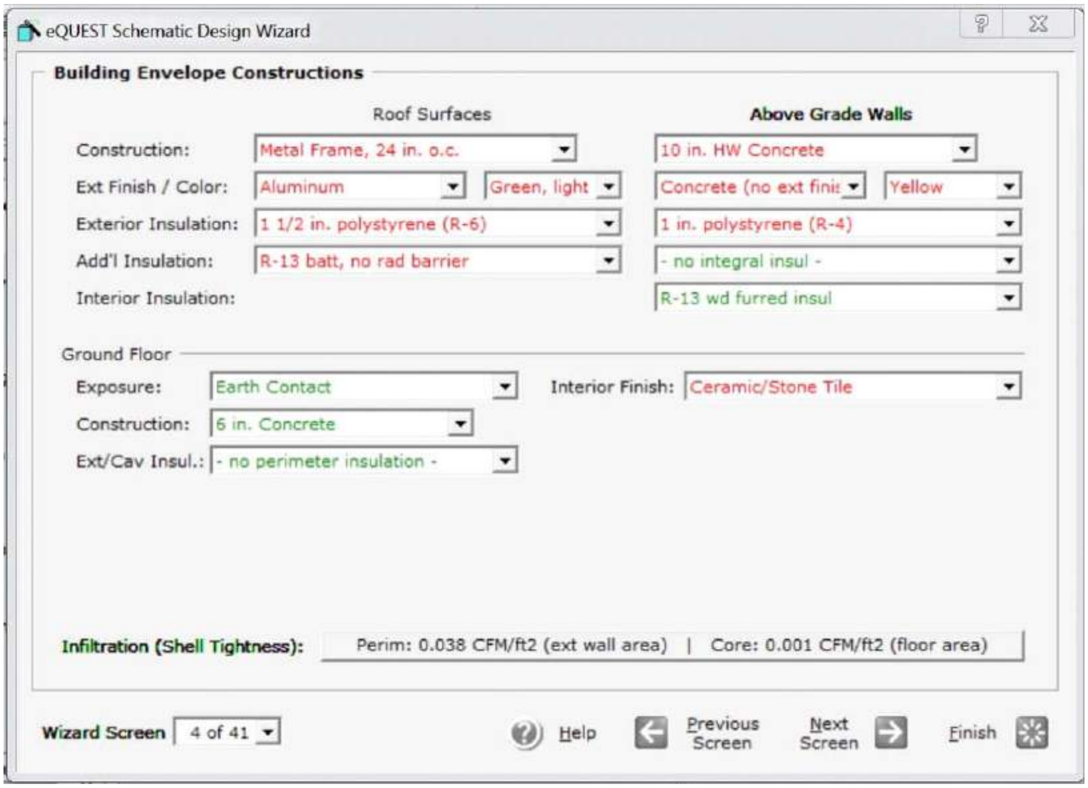


Figure 3.6. Hollow Sandcrete Building Envelope Constructions

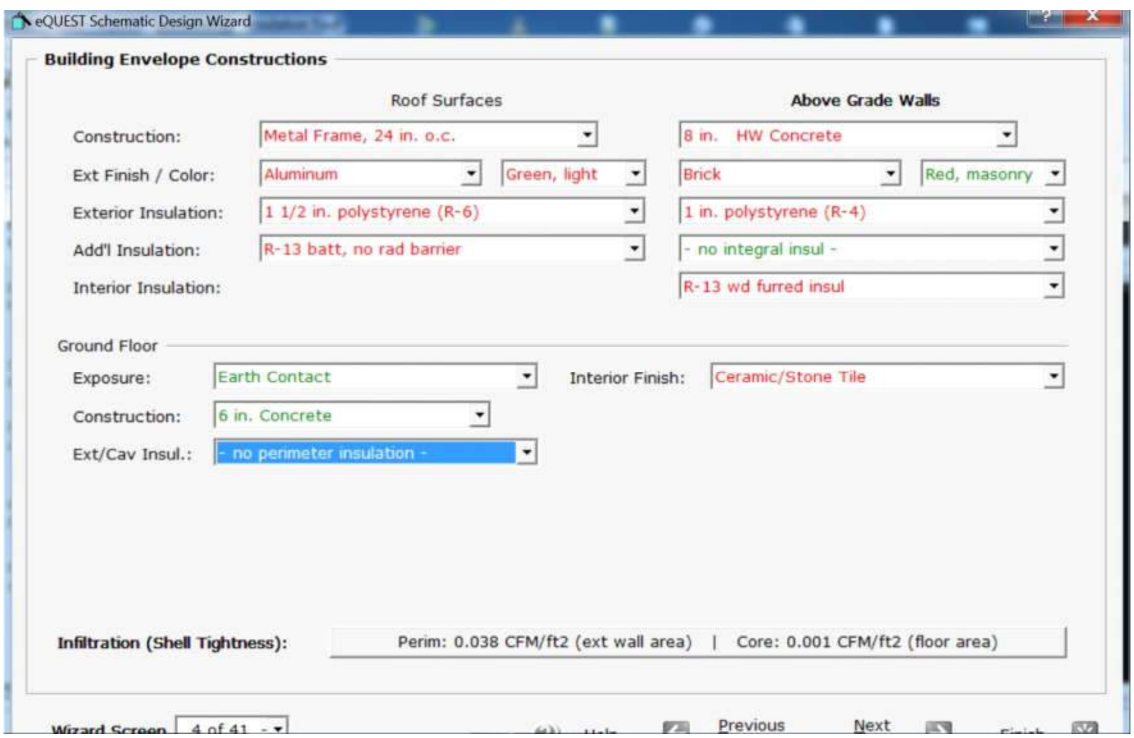


Figure 3.7. Hollow Burnt Brick Building Envelope Constructions

- Window and door sizes, distribution by orientation and glass type
- "activity areas" by fraction of total building area and distribution
- Building operations schedules for occupancy, lights and equipment which is shown in Figure 3.6

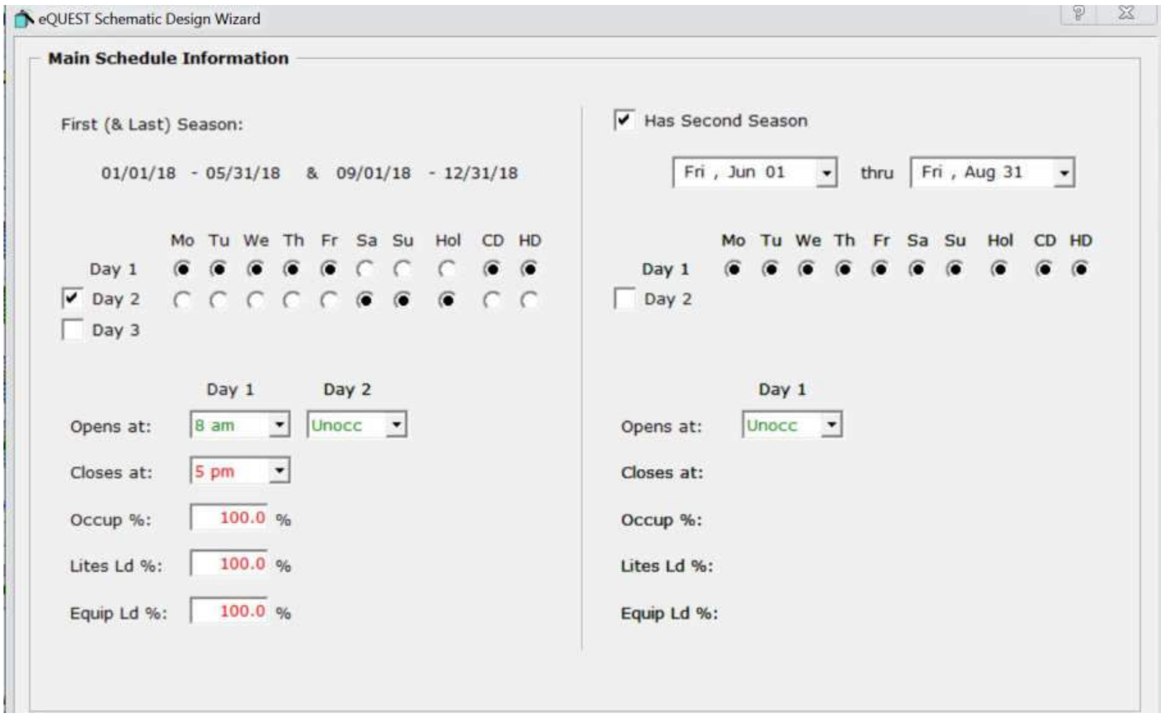


Figure 3.8. Existing Building Main Schedule Information

- Type and area assignment for Air conditioning system types which is shown in Figure 3.7
- Air-side and water-side equipment design capacities, power and efficiencies, setpoints and control options.

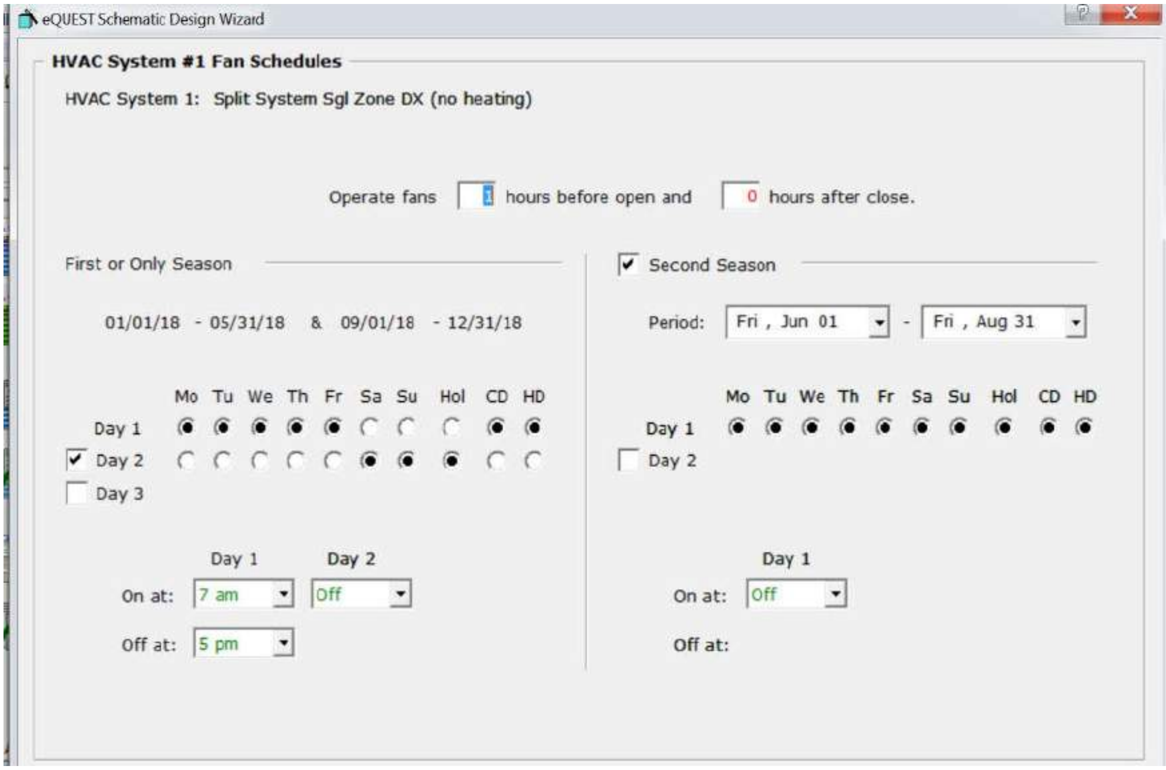


Figure 3.9. Existing Building HVAC System Schedule.

- Domestic water heating type, demands, capacity and efficiency (Hirsch, 2010).

After inputting all these details, simulation was performed and the result was presented

3.5 Exergy Analysis

To simplify the calculations including exergy in energy transformation there is a method for converting energy to exergy (Lidholm et al, 2012). The exergy factor is defined as the ratio of Exergy to Energy, expressed as

$$\text{Exergy Factor } = \frac{Exergy\ E}{Energy\ Q} \tag{3.1}$$

From equation (3.1), Exergy $=$ Exergy factor x Energy (3.2)

When the temperature of the energy is constant but differs from the surroundings, the exergy factor can be defined as $\frac{E}{Q} = \frac{T-T_o}{T}$ (Lidholm et al., 2012) (3.3)

Where T is absolute temperature in the object and T_o is the surrounding absolute temperature.

3.6 Energy and Exergy Demand for Electrical Appliances

The energy demand of all electrical appliances (Lighting, Ventilators and Appliances) is calculated using the net surface area and the specific needed capacity per square meter, which is known from the program of requirements or from experience. Lighting, appliances and ventilators are electrical equipment. For all electrical equipment, an exergetic efficiency of one is applied (Itard, 2005), and therefore:

$$E_{light,\ ventil,\ appl} = Q_{light,\ ventil,\ appl} \quad (3.4)$$

Where

E_{appl} = Exergy of appliances

E_{ventil} = Exergy of Air conditioning system

E_{light} = Exergy of lighting

Q_{appl} = Energy of appliances

Q_{ventil} = Energy of Air conditioning system

Q_{light} = Energy of lighting

Their respective unit is Joule.

As stated in Table 2.1, the exergetic factor of electricity is one, when substituted into equation (3.2), it is expressed as

$$\text{Exergy} = 1 \text{ x Energy} \quad (3.5)$$

Which is consistent with equation (3.4) by Itard (2005).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Energy Analysis

The result of the energy analysis is discussed from the results obtained after conducting simulation of the buildings in eQUEST software.

4.1.1 Existing building

Table 4.1. Monthly Electric Consumption of the Existing Building

	Electric Consumption (kWh x1000)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	2.22	2.06	2.39	2.29	2.35	2.11	2.00	2.26	1.22	-	-	-	18.9
Vent Fans	0.30	0.27	0.31	0.30	0.31	0.30	0.30	0.33	0.19	-	-	-	2.61
Equip ment	5.22	4.72	5.47	5.22	5.22	5.22	5.22	5.72	3.23	-	-	-	45.47
Area Light	0.13	0.12	0.14	0.13	0.14	0.13	0.13	0.14	0.11	0.07	0.07	0.07	1.37
Total	7.87	7.18	8.30	7.93	8.27	7.76	7.65	8.44	4.74	0.07	0.07	0.07	68.35

The simulation result of the monthly electric consumption of the existing building is shown in Table 4.1 with the Equipment (Computer system), air conditioning systems and area lights consuming 45,470 kWh, 21,510 kWh, and 1,370 kWh respectively, annually. Figure 4.1 shows the bar chart representation of the monthly electric consumption of the existing building (in Table 4.1). The bar chart shows that the largest electric consumption is up to 8440 kWh in the month of August, However, the minimum power consumption is only 70 kWh in October which is as a result of inactivity of the building during this period except in the night when the security lights are powered on.

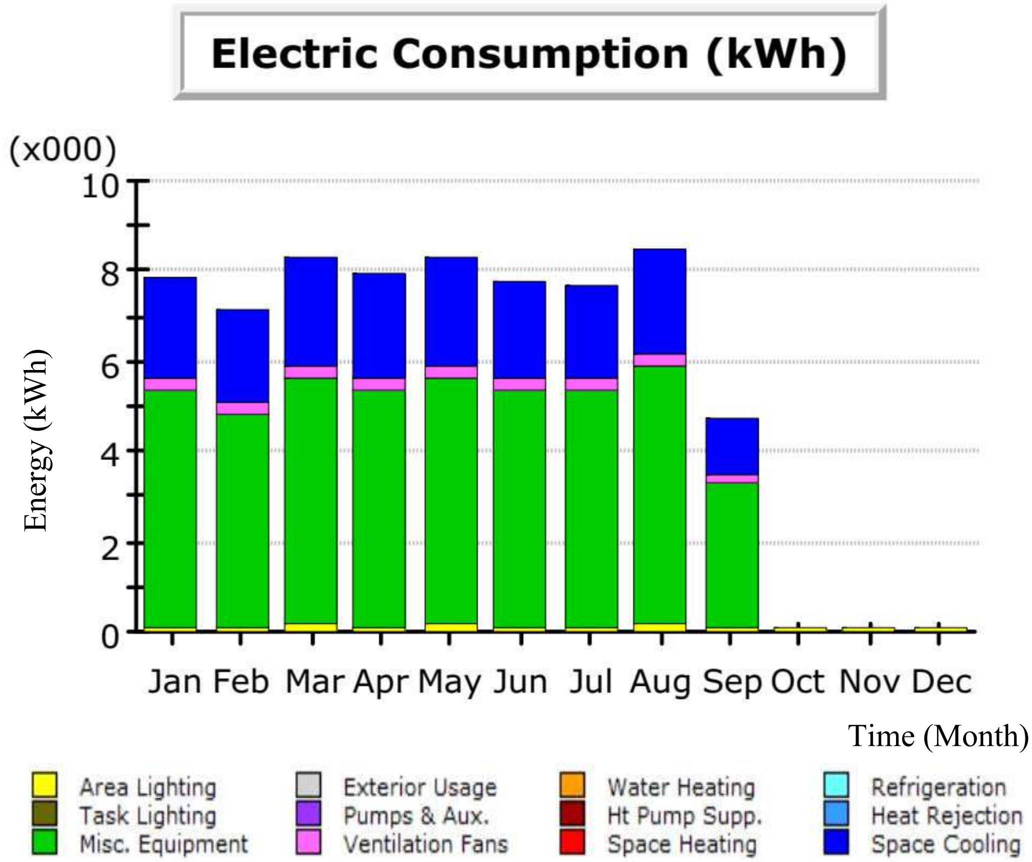


Figure 4.1. Monthly Electric Consumption of the Existing Building

During the holidays, the building was not open for examination purpose, so the energy consumption from October to December is minimal. In the month of August, the building energy consumption reached the maximum. Calculated by the whole building area of 330 m^2, the annual energy consumption of the specimen building per unit area was 240 kWh/m^2, which falls within 210 - 320 kWh/m^2/year (Arup & Genre, 2016) and thus, cannot be categorized as a good practice air conditioned office. Based the above results, it can be concluded that the annual energy consumption was consistent with the actual operation of the Hall ‘E’ CBT Test Centre.

The total annual energy for the year 2018 consumed by the building was 68,354 kWh, and it was represented in a pie chart in Figure 4.2. Based on the pie chart representation, it can be depicted that 67%, 32% and 2% of the energy were consumed by the equipment (Computer systems), space cooling & Ventilation fans and Area lighting respectively. Which depicts that largest percentage of energy is consumed by the Computer systems in the building while the least electric energy is consumed by lighting.

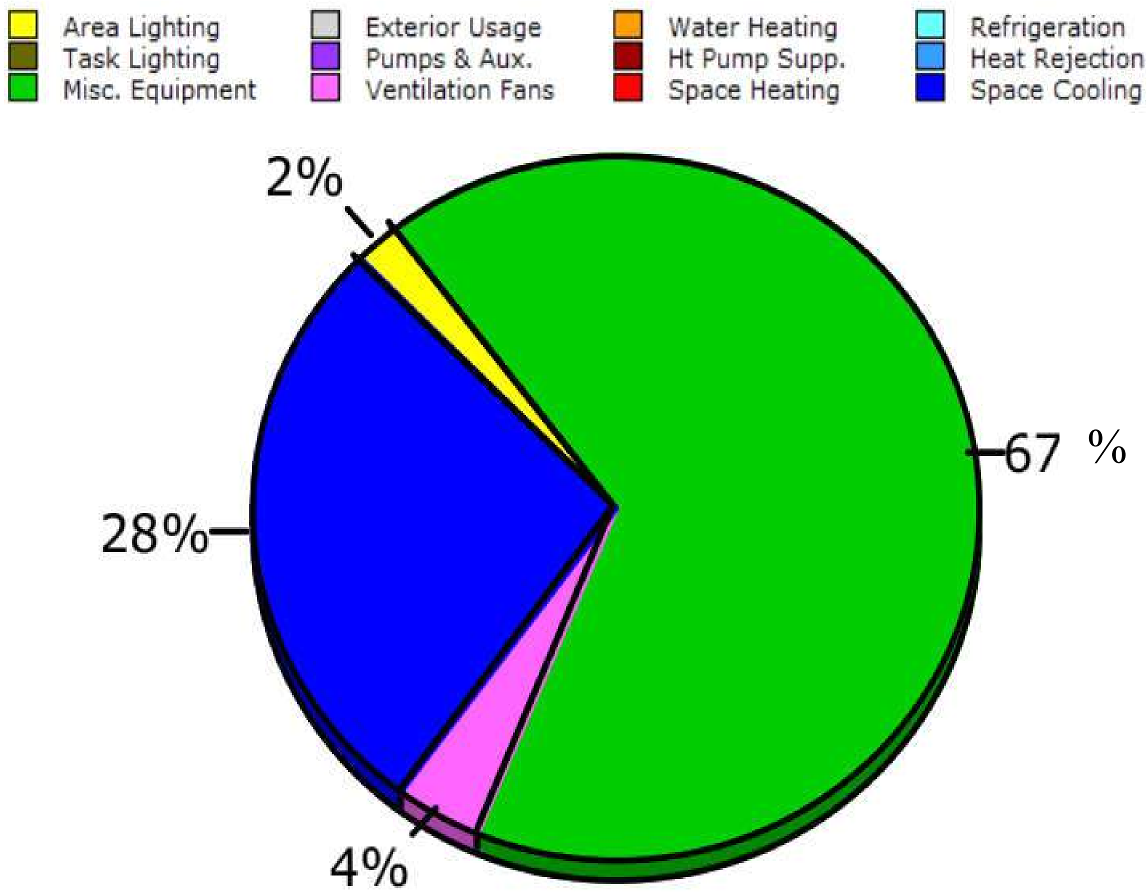


Figure 4.2: Annual Electric Consumption of the Existing Building

4.1.2 Control building

1. **Hollow Sandcrete Walled Building**

Table 4.2. Simulation Result of the Monthly Electric Consumption of the Sandcrete Building

	Electric Consumption (kWh x1000)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	1.75	1.64	1.92	1.82	1.79	1.53	1.40	1.51	0.60	-	-	-	13.97
Vent Fans	0.27	0.25	0.29	0.27	0.28	0.29	0.28	0.29	0.12	-	-	-	2.35
Equip ment	2.06	1.89	2.22	2.06	2.14	2.14	2.06	2.22	0.9	-	-	-	17.68
Area Light	0.19	0.18	0.20	0.19	0.20	0.20	0.19	0.20	0.10	0.03	0.03	0.03	1.74
Total	4.27	3.96	4.64	4.34	4.41	4.15	3.92	4.23	1.72	0.03	0.03	0.03	35.74

The simulation result of the monthly electric consumption of the hollow sandcrete walled building is shown in Table 4.2 with the Equipment (Computer system), Air conditioning systems and area lights consuming 17,684 kWh, 16,314 kWh, and 1,737 kWh respectively, annually. Figure 4.3 shows the bar chart representation of the monthly electric consumption of the hollow sandcrete building (Table 4.2). The bar chart shows that the largest power consumption was up to 4,640 kWh in March. However, the minimum power consumption is only 30 kWh in October as well as November and December, which is only 0.65 % of electric consumption in March.

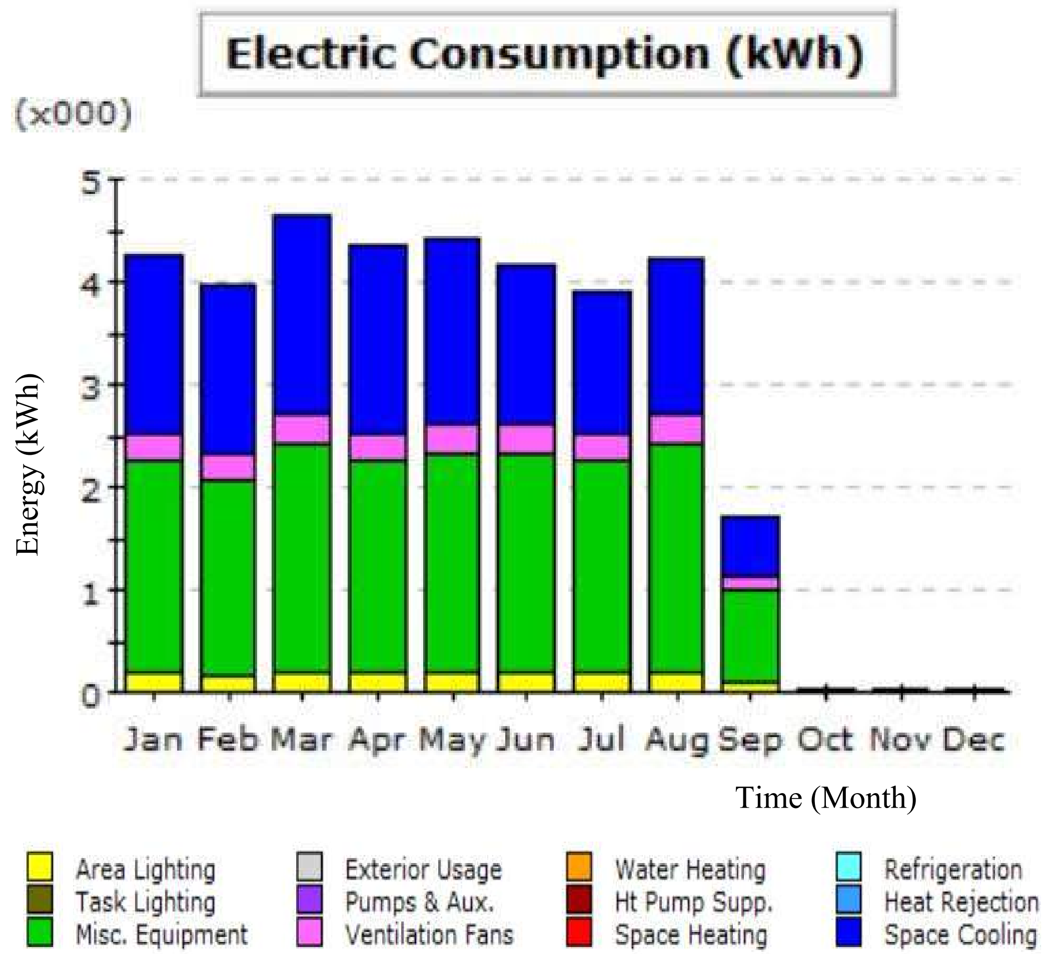


Figure 4.3. Monthly Electrical Consumption of the Hollow Sandcrete Building

During the holidays, the building was not open for examination purpose, so the energy consumption from October to December was minimal. Calculated by the whole building area of 330 m^2, the annual energy consumption of the hollow sandcrete building per unit area was 108 $kWh/m^2/year$ which falls under 130 $kWh/m^2/year$ (Arup & Genre, 2016) and thus can be categorized as a best practice air conditioned office. Based on the above results, it can be concluded that the annual energy consumption is consistent with the actual operation of the hollow sandcrete building.

The total annual energy consumed by the building was 35, 735 kWh, and it was represented on a pie chart in Figure 4.4. Based on the pie chart representation, it can be depicted that 49%, 46% and 5% of the energy are consumed by the equipment (Laptop computer), space cooling & Ventilation fans and Area lighting respectively, which depicts that largest percentage of energy is consumed by the computer systems in the building while the least energy is consumed by the area lighting.

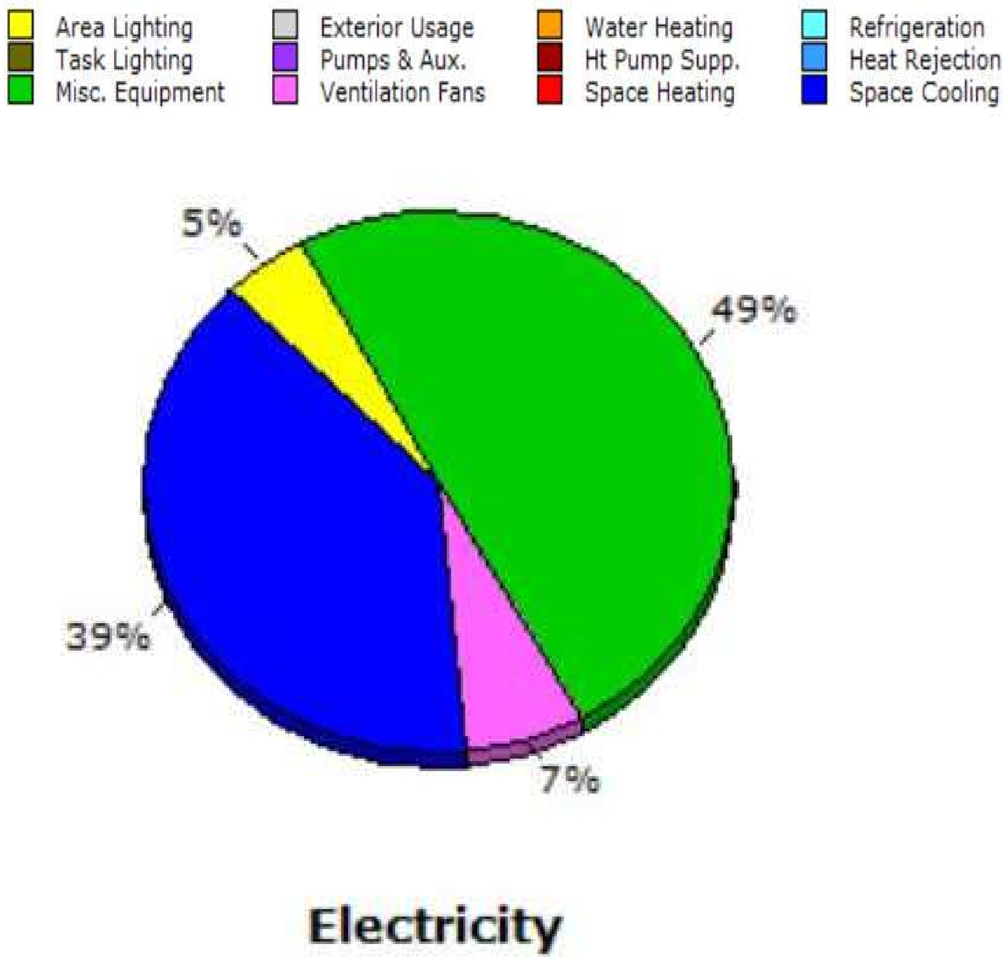


Figure 4.4. Annual Energy Consumption by End-use in the Hollow Sandcrete Walled Building.

2. **Hollow Burnt Brick Walled Building**

The results of the hollow burnt brick building simulation is shown in Figures 4.5 and 4.6

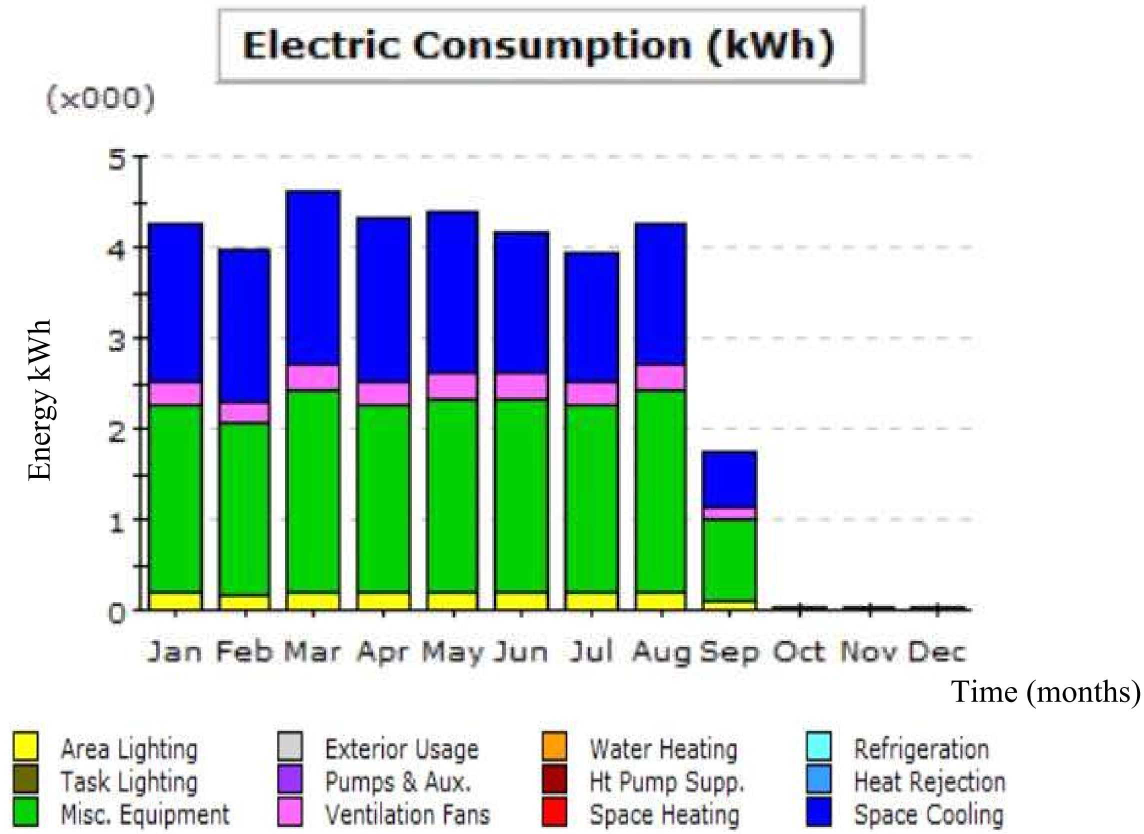


Figure 4.5. Monthly Electrical consumption by End use in the Burnt Brick Building

In Figure 4.5, the bar chart representation of the monthly electrical consumption by end use in the brick building is shown. The result shows that the largest electric consumption was up to 4630 kWh in March while the minimum was only 30 kwh in October, as well as November and December.

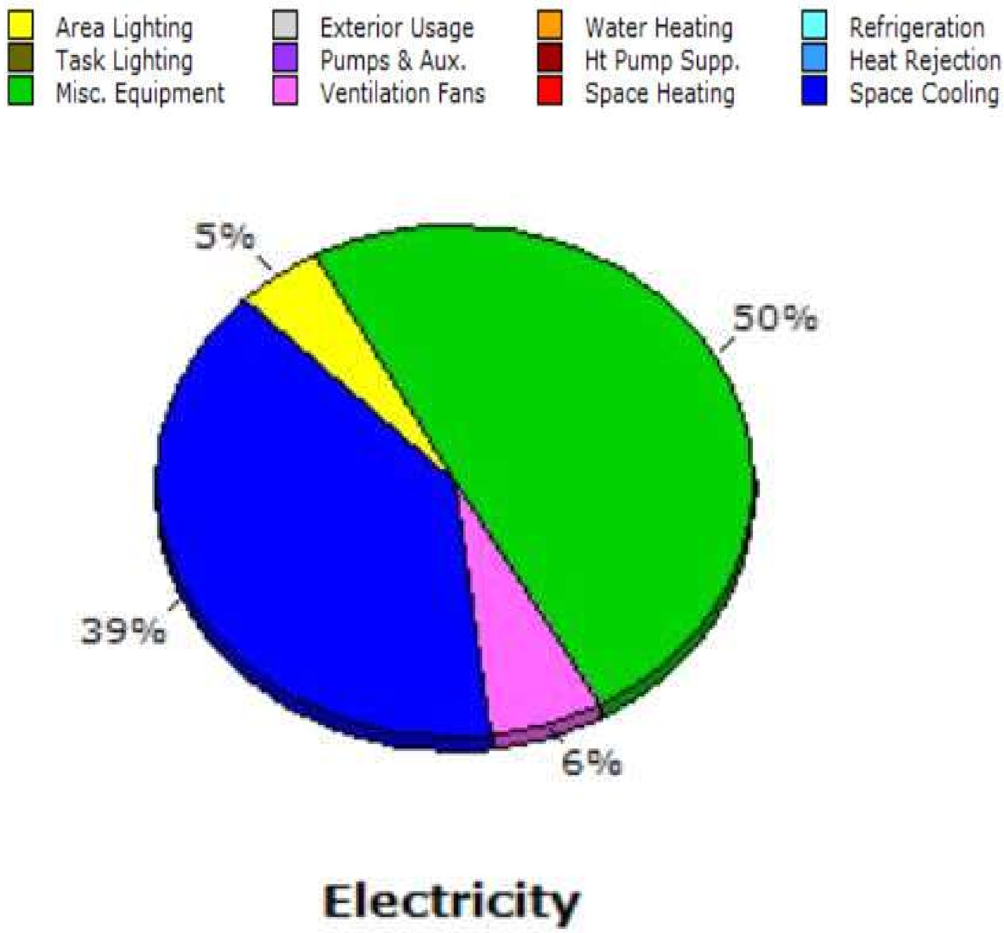


Figure 4.6. Annual Electrical Consumption by End use in the Burnt Brick Building

The total annual energy consumed by the brick building is 35, 721 kWh, and it is represented on a pie chart in Figure 4.6. Based on the pie chart representation, it can be depicted that the amount of energy consumed by the laptops, air conditioner and area lighting systems were 17,684 kWh, 16300 kWh, and 1,737 kWh respectively. Which depicts that the largest percentage of energy is consumed by the computer systems in the building while the least energy is consumed by the area lighting. The annual energy consumption of the brick building per unit area is 108 kWh/m^2/year which falls under 130 $kWh/m^2/year$ (Arup & Genre, 2016) and thus can be categorized as a best practice air conditioned office

4.2 Exergy Analysis

Exergy is expressed as shown in equation (3.2). The exergy demand of the computer systems, HVAC system and lighting are calculated using equation (3.4). Hence,

Exergy of Lighting ($E_{lighting}$) = Energy of lighting x 1

Exergy of Appliances ($E_{Appliances}$) = Energy of Appliances x 1

Exergy of Air Conditioning System (E_{AC}) = Energy of Air Conditioning Sytem x 1

The result of the exergy analysis for the specimen, control and brick building is shown in Figure 4.7.

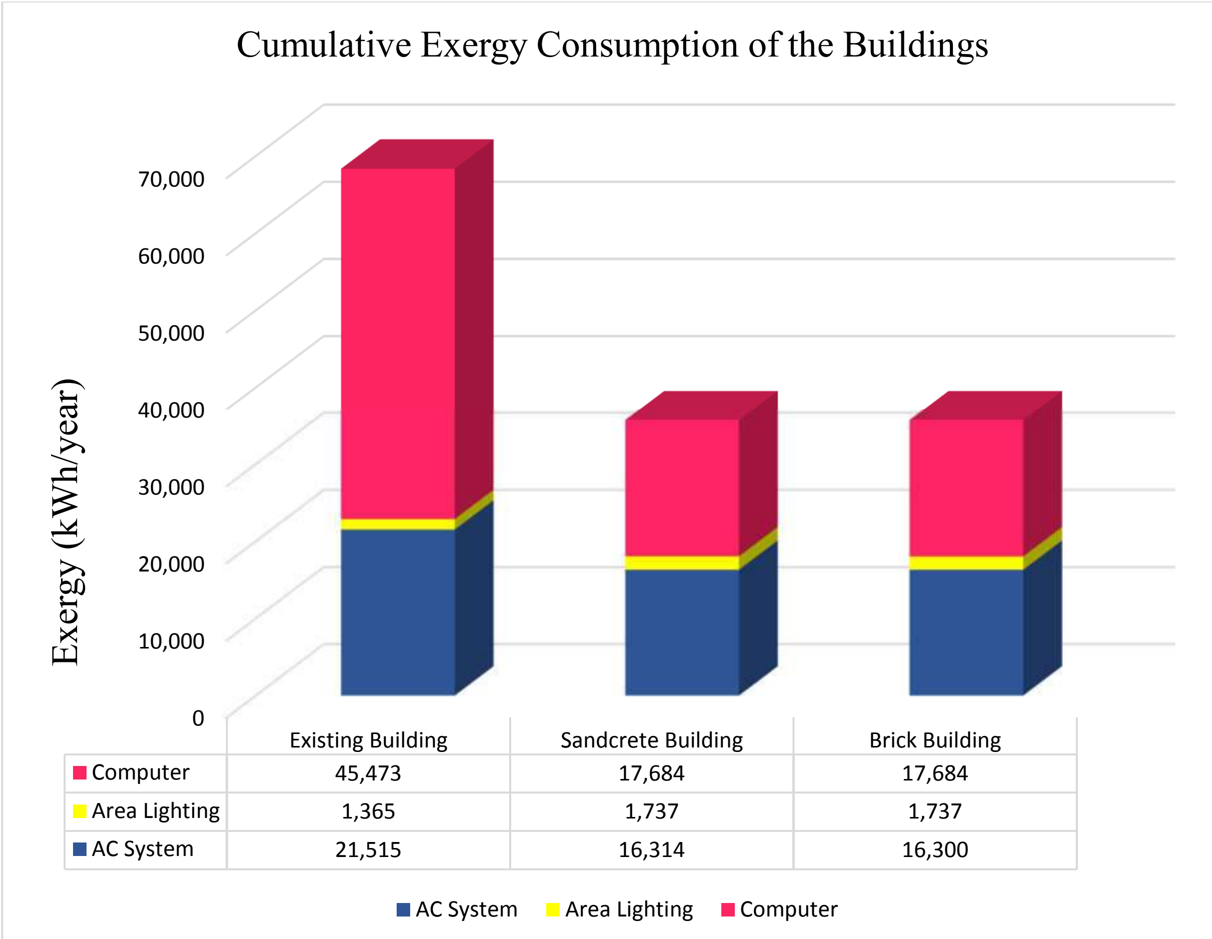


Figure 4.7. Cumulative Annual Exergy Consumption of the Existing, Control and Brick Building.

From Figure 4.7, it was observed that the annual exergy consumption of lighting in the variants of control building is greater than that in the existing building because the lighting in the sandcrete building as well as the brick building were designed to meet the required brightness for a computer room and the higher the brightness, the more exergy is consumed. On the other hand, the existing building did not meet the required brightness for the room (according to Arup and Genre (2016)). The total exergy consumed by the existing building, the hollow sandcrete walled building and the burnt brick walled building were 68,354 kWh/year, 35,735 kWh/year, and 35, 721 kWh/year respectively. Thus, the sandcrete building, and the brick building were 47.72 % and 47.74 %

respectively more energy efficient than the specimen building. The burnt brick walled building performed better than the sandcrete walled building as it was able to save extra 14 kWh/year exergy in the air conditioner system as a result of its low thermal conductivity when compared to the thermal conductivity of a sandcrete walled building.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Exergy consumption analysis for the University Hall 'E' CBT Test centre, and various control buildings (sandcrete walled building and a burnt brick walled building) has been carried out in this research and the following conclusion can be drawn:

1. The data necessary for conducting the exergy analysis were acquired by visiting the existing building and using standard measuring equipment to determine their respective measurements. The annual energy consumption of the existing building per unit area was estimated to be 240 kWh/m^2/year, which was categorized as not a good practice for an air conditioned office, while the annual energy consumption of the variants of control building per unit area was 108 kWh/m^2/year which was categorized as best practice for an air conditioned office.

2. The cumulative exergy consumptions of the existing, hollow sandcrete and burnt brick walled building were found to be 68,354 kWh/year, 35,735 kWh/year, and 35,721 kWh/year respectively. The sandcrete building, as well as the burnt brick building were found to be 48 % more energy efficient than the specimen building as a result of the reduction in the energy consumption of the electrical equipment.

3. The exergy analysis suggested that the burnt brick building performed better, and is more sustainable than the hollow sandcrete walled building, as it was able to save extra 14 kWh in the electricity demand for air conditioning. This is as a result of the low thermal conductance value of the burnt bricks which greatly reduces the heat gain in the building.

5.2 Recommendations

1. For a long term sustainability, structures built with burnt bricks are more appropriate than hollow sandcrete walled structures.
2. In the design phase of a building, the operational cost, energy efficiency and thermal comfort of the occupants should be highly considered by the design engineers.
3. Since the case study is located in a tropical sub region a more sustainable source of generating electricity based on solar and/or wind should be adopted.

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APPENDIX A

DESCRIPTION OF LIGHTING

Table A1: Guideline for comparison of bulbs

Incandescent (Watts)	**CFL (Watts)**	**LED (Watts)**	**Lumens (Brightness)**
40	8 - 12	4 – 5	450
60	13 - 18	6 – 8	890
75 - 100	18 - 22	9 – 13	1210
100	23 - 30	16 - 20	1750
150	30 - 55	25 - 28	2780

Source: (Seaman, 2011)

Table A2: LUX level for various tasks

Activity	**Illumination (lux, Lumen/m^2)**
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 – 100
Work areas where visual tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes	250
Normal Office work, PC work, Study Library	500

Source: (Engineering ToolBox, 2018)

APPENDIX B

PARAMETERS OF REFERENCE BUILDING ENVELOPE

Table B1: Typical Envelope R and U values for the construction system analysed

Construction System	Typical R value (m^2K/W)	Typical U value (W/m^2K)
Metal roof, void, ceiling	0.51	1.95
Metal roof, void, 100mm mineral wool, ceiling	3.22	0.31
Concrete roof with 50mm polystyrene on top	2.69	0.37
150mm hollow sandcrete block wall (rendered)	0.53	1.9
230mm hollow sandcrete block wall (rendered)	0.65	1.6
150mm hollow sandcrete, 25mm polystyrene, 25mm cavity, 100mm brick wall	1.28	0.8

Source: (Arup & Genre, 2016)

APPENDIX C

DESCRIPTION OF HVAC SYSTEM

Table C1: Specifications of the Single Unit Air Conditioning System

TP-C306SLV0 | Where to Buy

PRODUCT INFORMATION

Product Type	Floor Standing
Power Cooling	Yes
Indoor Unit Noise Level (H/M/L)	50 / 48 / 46 dB(A)
Refrigerant Type	R22

GENERAL SPECIFICATIONS

Power Supply (ø / V / Hz)	3/380~415/50
Cooling Capacity	25000 Btu/h
Power Input (Set)	3300 W
EER	7.58 Btu/h/W
COP	2.22 W/W

Source: (LG Electronics, 2018)

Table C2: Showing the Specifications of the Multi-unit Air Conditioning System

FJM , 5 ROOM, HEAT PUMP

Power

MCA [A]	26.2
MFA [A]	28.8

Energy Efficiency

EER (Nominal Cooling)	3.45
COP (Nominal Heating)	4.10
Energy Grade (Cooling)	A++
Energy Grade (Heating)	A+

Source: (Samsung HVAC, 2018)

Table C3: Showing the Specifications of the Multi-unit HVAC system

FJM , 5 ROOM, HEAT PUMP

Heating [kW]

12

Heating [Btu/h]

40900

Power Input (Nominal)

Cooling 1)

2.9 kW

Heating 2)

2.93 kW

Current Input (Nominal)

Cooling 1)

13.3 A

Heating 2)

13.4 A

Source: (Samsung HVAC, 2018)

APPENDIX D

ENERGY ANALYSIS

1. Specimen Building

(A) Lighting

20 Watt CFL bulb is been used in the building. 500 lux is the required brightness to adequately brighten the building (see Table A2 in appendix A).

$$20\ Watts\ X\ 20\ units = 400\ Watts$$

400 Watts / 330 m^2 = 1.21 W / m^2

Required Brightness to light up a room = illumination of bulb X square area of building (4)

20 W CFL bulb will produce 1210 Lumens (see Table A1 in appendix A)

$$1210\ Lumens\ /\ Bulb\ X\ 20\ bulbs = 24{,}200\ Lumens$$

$$300\ Lux\ X\ 330\ m^2 = 99{,}000\ Lumens$$

24, 200 Lumens is the amount of brightness in the room where 99,000 Lumens is required. Hence, it is less than the requirement to brighten the building.

If the required brightness of the room were to be met using 20 W CFL bulb, then

$$\frac{99{,}000\ Lumens}{1210\ Lumens} = 82\ CFL\ bulbs$$

$$82\ bulbs\ X\ 20\ W = 1640\ W$$

(B) HVAC System

According to Bluejay, 2016, since we are considering only cooling, the rule of thumb is enough to size our HVAC equipment, it goes thus: 1 ton of cooling is for every 600 SqFt of a building. Hence,

$HVAC\ Size = Area\ of\ room\ (SqFt)\ X\ \frac{1\ ton}{600\ SqFt}$ (4.2)

$$330\ m^2\ X\ \frac{1\ ton}{55.74\ m^2} = 5.92\ tons\ HVAC$$

It is safe to approximate it to 6 tons considering solar gains, internal loads etc.

Since 1 ton = 12, 000 Btu, then 6 $tons = 12{,}000\ X\ 6 = 72{,}000\ Btu/h$

There are 4 active split standing air conditioner systems in the building rated 25,000 Btu/h and power input of 3300 W (see Table C1 in appendix C)

$$Cooling\ capacity\ of\ 4\ Air\ conditioners = 4\ X\ 25000\ Btu/h\ = 100{,}000\ Btu/h$$

100,000 Btu/h is greater than required cooling capacity for 300 m^2 building (72,000 Btu/h). Hence, there is wastage.

(C) Equipment

The power rating on the flat screen monitor is 55W and the one on the CPU is 55 W which is summed up to be 110W.

Summation of power consumed by the computers = $110\ W\ X\ 250\ computers = 27500\ W$

(D) Plug Load

Plug load which is made up of the computer systems within the building is calculated as follow

Sum of power consumed by the equipment = $110\ W\ X\ 250 = 27{,}500\ W$

Plug load = $\frac{27500\ W}{330\ Sqm} = 83.33\ W/m^2$

2. **Control building**

(A) Lighting

LED lighting was used to meet the brightness required for the control building. For a LED bulb of 25 - 28 Watts, it will produce a brightness of 2780 Lumens (see Table A1 in appendix A).

$$\text{Required Brightness to light up a room} = \text{illumination of bulb X square area of building (4)}$$

$$\text{300 lux X 330 sqm} = \text{99,000 Lumens}$$

$$\frac{99{,}000\ Lumens}{2780\ Lumens} = 36\ LED\ bulbs$$

$$Lighting\ load = \frac{\sum Power\ rating\ of\ bulb}{Square\ area\ of\ building} \tag{4.1}$$

$\sum$ Power rating of bulb = 36 units X 25 Watts = 900 Watts

$$Lighting\ load = \frac{900\ Watt}{330\ m^2} = 2.73\ W/m^2$$

(B) HVAC System

Sizing of HVAC equipment

One multi-unit Air conditioner is rated 34100 Btu/h, 2.9 kW power

$$\frac{72{,}000\ Btu/h}{34100\ Btu/h} = 2.1$$

Hence, two multi-unit Air conditioner is enough to ventilate the building.

(C) Efficient Equipment

Laptop computer is being considered in this control building because it has its monitor being powered by the CPU, hence it is more energy efficient than a desktop. The power rating for the desktop being considered is 20 V and 3.25 A.

Power = Current x Voltage

Power = 20 x 3.25 = 65W

Laptop computers also come with backup batteries which are being designed to last up to 4 hours but for the sake of this study the batteries are assumed to last 1 hour.

Students are matched into the test centre in two batches, Close to half (say 100) of the computer systems in the building are left powered on and idle for close to 30 minutes before next batch of students are matched into the building to occupy the computer systems. Installation of Equipment Energy-Efficient Software will cut the energy consumption of the equipment by a significant percentage (BEEG, 2016). When a laptop computer is on energy saving mode it consumes an average 20 Watt or less

Sum of power consumed by the equipment = (65 x 150 units) + (20 x 100 units) = 11, 750 Watt

(D) Plug load = $\frac{11750\ W}{330\ Sqm} = 35.61\ W/sqm$

APPENDIX E

3D MODEL OF SPECIMEN AND CONTROL BUILDING FROM eQUEST

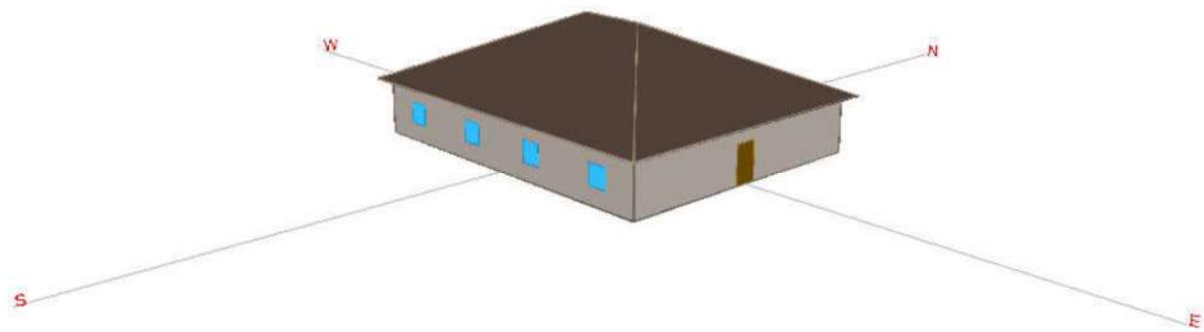

Figure E1: 3D model of the specimen building

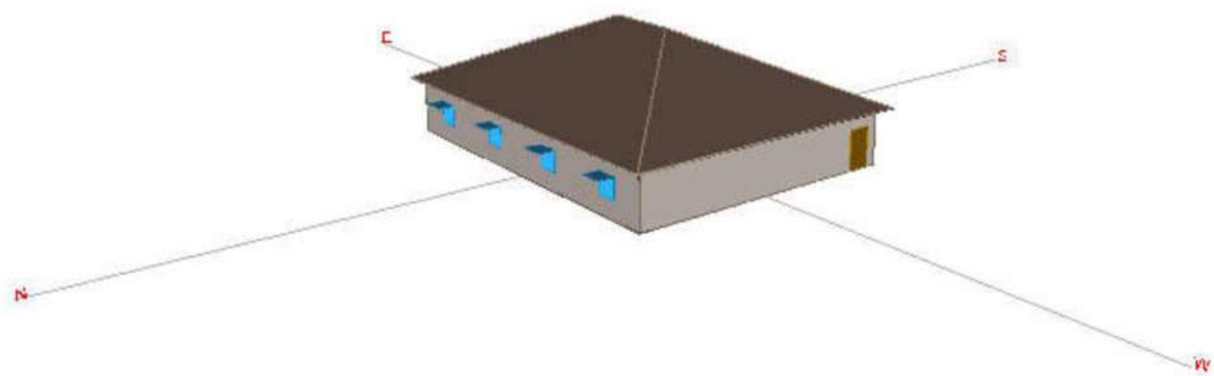

Figure E2: 3D model of the control building

APPENDIX F

ENERGY ANALYSIS RESULT FROM eQUEST.

Table F1. Monthly Electric Consumption of the Specimen Building

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	2.22	2.06	2.39	2.29	2.35	2.11	2.00	2.26	1.22	-	-	-	18.90
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.30	0.27	0.31	0.30	0.31	0.30	0.30	0.33	0.19	-	-	-	2.61
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.22	4.72	5.47	5.22	5.47	5.22	5.22	5.72	3.23	-	-	-	45.47
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.13	0.12	0.14	0.13	0.14	0.13	0.13	0.14	0.11	0.07	0.07	0.07	1.37
Total	7.87	7.18	8.30	7.93	8.27	7.76	7.65	8.44	4.74	0.07	0.07	0.07	68.35

Table F2. Annual Energy Consumption by End-use in the Specimen Building

	Electricity kWh	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	18,902	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	-	-	-	-
Vent. Fans	2,613	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	45,473	-	-	-
Task Lights	-	-	-	-
Area Lights	1,365	-	-	-
Total	68,354	-	-	-

Table F1. Monthly Electric Consumption of the Control Building

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	1.75	1.65	1.92	1.82	1.79	1.53	1.40	1.51	0.60	-	-	-	13.97
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.27	0.25	0.29	0.27	0.28	0.28	0.27	0.29	0.12	-	-	-	2.35
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	2.06	1.89	2.22	2.06	2.14	2.14	2.06	2.22	0.90	-	-	-	17.68
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.19	0.18	0.20	0.19	0.20	0.20	0.19	0.20	0.10	0.03	0.03	0.03	1.74
Total	4.27	3.96	4.64	4.34	4.41	4.15	3.92	4.23	1.72	0.03	0.03	0.03	35.74

Table F4. Annual Energy consumption by End-use in the Control Building

Annual Energy Consumption by Enduse

	Electricity kWh	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	13,969	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	-	-	-	-
Vent. Fans	2,345	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	17,684	-	-	-
Task Lights	-	-	-	-
Area Lights	1,737	-	-	-
Total	35,735	-	-	-

APPENDIX G

WEATHER DATA UTILIZED IN eQUEST SOFTWARE

Table G1. Weatherdata of Lagos, Nigeria

LOCATION		LAGOS/IKEJA		NGA	SWERA	654720	5.6	-0.17	0	69		
DESIGN CONDITIONS												
TYPICAL/EXTREME PERIODS		3	No Dry Se:	Typical	12-Oct	16-Dec	No Dry S:	Extreme	19-Mar	25-Mar	No Dry Se:	Extreme
GROUND TEMPERATURES		3	0.5				28.62	28.29	27.64	27.04	25.9	25.31
HOLIDAYS/DAYLIGHT SAVINGS		No	0	0	0							
COMMENTS 1		Solar and Wind Energy Resource Assessment (SWERA) project funded by the United Nations Environment Program.; NR										
COMMENTS 2		-- Ground temps produced with a standard soil diffusivity of 2.3225760E-03 {m**2/day}										
DATA PERIODS		1	1	Data	Sunday	1/ 1	31-Dec					
	1991	1	1	1	60	B8B8E8B8	24	14.2	54	100300	0	0
	1991	1	1	2	60	B8B8E8B8	23.5	13	52	100300	0	0
	1991	1	1	3	60	B8B8E8B8	23	11.8	49	100300	0	0
	1991	1	1	4	60	B8B8E8B8	22.5	10.6	47	100300	0	0
	1991	1	1	5	60	B8B8E8B8	22	9.5	45	100300	0	0
	1991	1	1	6	60	A7A7E8A7	21.5	8.3	43	100300	0	0
	1991	1	1	7	60	A7A7E8A7	21	14	64	100400	104	1095
	1991	1	1	8	60	A7A7E8A7	22	16	69	100400	422	1414
	1991	1	1	9	60	B8B8E8B8	24	10	41	100400	717	1414
	1991	1	1	10	60	A7A7E8A7	26	4	24	100500	960	1414
	1991	1	1	11	60	B8B8E8B8	27	4.4	23	100400	1134	1414
	1991	1	1	12	60	A7A7E8A7	28	4.8	23	100400	1227	1414
	1991	1	1	13	60	B8B8E8B8	29	5.4	22	100300	1233	1414
	1991	1	1	14	60	A7A7E8A7	30	6	22	100200	1151	1414
	1991	1	1	15	60	A7A7E8A7	29.8	8.5	26	100200	988	1414
	1991	1	1	16	60	A7A7E8A7	29	9	29	100200	754	1414
	1991	1	1	17	60	A7A7E8A7	28	12	37	100200	464	1414
	1991	1	1	18	60	B8B8E8B8	27	15	48	100200	143	1288
	1991	1	1	19	60	B8B8E8B8	26.4	14.8	49	100200	0	0
	1991	1	1	20	60	B8B8E8B8	25.8	14.7	50	100200	0	0
	1991	1	1	21	60	B8B8E8B8	25.2	14.5	51	100200	0	0
	1991	1	1	22	60	B8B8E8B8	24.7	14.3	52	100300	0	0
	1991	1	1	23	60	B8B8E8B8	24.1	14.2	54	100300	0	0
	1991	1	1	24	60	B8B8E8B8	23.5	14	55	100300	0	0
	1991	1	2	1	60	B8B8E8B8	22.9	13.8	56	100300	0	0
	1991	1	2	2	60	B8B8E8B8	22.3	13.7	58	100300	0	0

1999	5	11	1	60 B8B8E8B8	25.5	23	86	100300	0	0
1999	5	11	2	60 B8B8E8B8	25.2	23	88	100300	0	0
1999	5	11	3	60 A7A7E8A7	25	23	89	100300	0	0
1999	5	11	4	60 B8B8E8B8	24.9	23	89	100300	0	0
1999	5	11	5	60 B8B8E8B8	24.8	23	90	100300	0	0
1999	5	11	6	60 A7A7E8A7	24.7	23	90	100300	6	227
1999	5	11	7	60 B8B8E8B8	26.3	23.5	85	100400	224	1340
1999	5	11	8	60 B8B8E8B8	27.9	24	79	100400	542	1340
1999	5	11	9	60 A7A7E8A7	29.5	24.5	75	100400	826	1340
1999	5	11	10	60 B8B8E8B8	30.2	24.7	72	100400	1058	1340
1999	5	11	11	60 B8B8E8B8	30.8	25	71	100400	1219	1340
1999	5	11	12	60 A7A7E8A7	31.5	25.2	69	100400	1301	1340
1999	5	11	13	60 B8B8E8B8	29.5	24.8	76	100400	1297	1340
1999	5	11	14	60 B8B8E8B8	27.5	24.4	83	100400	1207	1340
1999	5	11	15	60 A7A7E8A7	25.5	24	91	100300	1037	1340
1999	5	11	16	60 B8B8E8B8	26	23.5	86	100300	800	1340
1999	5	11	17	60 B8B8E8B8	26.5	22.9	81	100300	511	1340
1999	5	11	18	60 A7A7E8A7	27	22.4	76	100300	192	1340
1999	5	11	19	60 B8B8E8B8	27.5	21.9	72	100200	2	96
1999	5	11	20	60 B8B8E8B8	27.4	22	72	100200	0	0
1999	5	11	21	60 B8B8E8B8	27.4	22.1	73	100200	0	0
1999	5	11	22	60 B8B8E8B8	27.3	22.2	74	100300	0	0
1999	5	11	23	60 B8B8E8B8	27.3	22.4	75	100300	0	0
1999	5	11	24	60 B8B8E8B8	27.2	22.5	76	100300	0	0
1999	5	12	1	60 B8B8E8B8	27.2	22.6	76	100300	0	0
1999	5	12	2	60 B8B8E8B8	27.1	22.7	77	100300	0	0
1999	5	12	3	60 B8B8E8B8	27.1	22.9	78	100300	0	0
1999	5	12	4	60 A7A7E8B8	27	23	79	100400	0	0
1999	5	12	5	60 B8B8E8B8	27.1	23.2	79	100400	0	0
1999	5	12	6	60 B8B8E8B8	27.2	23.5	80	100400	6	230
1999	5	12	7	60 B8B8E8B8	27.3	23.7	81	100400	224	1340
1999	5	12	8	60 B8B8E8B8	27.4	24	82	100500	542	1340
1999	5	12	9	60 A7A7E8A7	27.5	24.2	82	100500	826	1340
1999	5	12	10	60 B8B8E8B8	28.6	23.7	75	100500	1056	1340

2001	7	5	7	60 B8B8E8B8	25.4	24	92	100600	183	1322
2001	7	5	8	60 B8B8E8B8	25.5	24	91	100700	490	1322
2001	7	5	9	60 B8B8E8B8	25.6	24	91	100700	767	1322
2001	7	5	10	60 B8B8E8B8	25.7	24	90	100700	996	1322
2001	7	5	11	60 B8B8E8B8	25.9	24	89	100700	1160	1322
2001	7	5	12	60 A7A7E8A7	26	24	89	100800	1249	1322
2001	7	5	13	60 B8B8E8B8	25.8	23.8	89	100800	1257	1322
2001	7	5	14	60 B8B8E8B8	25.6	23.6	89	100800	1182	1322
2001	7	5	15	60 B8B8E8B8	25.3	23.3	89	100800	1030	1322
2001	7	5	16	60 B8B8E8B8	25.1	23.1	89	100800	811	1322
2001	7	5	17	60 B8B8E8B8	24.9	22.9	89	100800	541	1322
2001	7	5	18	60 B8B8E8B8	24.7	22.7	89	100800	238	1322
2001	7	5	19	60 B8B8E8B8	24.4	22.4	89	100800	11	324
2001	7	5	20	60 B8B8E8B8	24.2	22.2	89	100800	0	0
2001	7	5	21	60 A7A7E8A7	24	22	89	100800	0	0
2001	7	5	22	60 B8B8E8B8	24	22.2	90	100700	0	0
2001	7	5	23	60 B8B8E8B8	24	22.3	90	100700	0	0
2001	7	5	24	60 B8B8E8B8	24	22.5	91	100700	0	0
2001	7	6	1	60 E9E9E9E9'	24.1	22.7	92	100700	0	0
2001	7	6	2	60 E9E9E9E9'	24.1	22.9	93	100700	0	0
2001	7	6	3	60 E9E9E9E9'	24.2	23	93	100600	0	0
2001	7	6	4	60 E9E9E9E9'	24.2	23.2	94	100600	0	0
2001	7	6	5	60 E9E9E9E9'	24.1	23.2	95	100600	0	0
2001	7	6	6	60 E9E9E9E9'	24	23.3	96	100600	1	88
2001	7	6	7	60 E9E9E9E9'	24	23.1	95	100700	182	1322
2001	7	6	8	60 E9E9E9E9'	24	23	94	100800	489	1322
2001	7	6	9	60 E9E9E9E9'	25	23	89	100800	767	1322
2001	7	6	10	60 E9E9E9E9'	26	23	84	100800	996	1322
2001	7	6	11	60 E9E9E9E9'	26.3	23.3	84	100700	1161	1322
2001	7	6	12	60 E9E9E9E9'	26.7	23.7	84	100600	1250	1322
2001	7	6	13	60 E9E9E9E9'	27	24	84	100600	1257	1322
2001	7	6	14	60 E9E9E9E9'	26.7	23.8	84	100500	1183	1322
2001	7	6	15	60 E9E9E9E9'	26.5	23.6	84	100500	1031	1322
2001	7	6	16	60 E9E9E9E9'	26	23	84	100500	812	1322