COOLING LOADS ESTIMATIONS USING BUILDING INFORMATION MODELLING OF ROOM 103, ENGINEERING COMPLEX, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

BY

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MEng/SIPET/2018/8917

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN MECHANICAL ENGINEERING (THERMOFLUIDS AND POWER PLANT OPTION)

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ABSTRACT

This thesis presents the modelling and estimation of cooling load of a building. The case study (Room 103, Engineering complex, Federal University of Technology, Minna) was modelled using Autodesk Revit. Building components of the case study such as walls, window, doors, floor, lights and ceiling fan had pre-installed physical properties which were easily modified and applied. A dynamic database model was created which connected the geometry such that any modification on any of the views reflects automatically on others. Estimation of the cooling load of the case study was done by applying the Cooling Load Temperature Difference (CLTD)/Solar Cooling Load (SCL)/Cooling Load Factor (CLF) method. Manual calculation of the cooling load of the case study was considered. All assumptions, equations and tabulated data were applied in accordance to ASHRAE proposals on the (CLTD/SCL/CLF) method of cooling load calculation. The calculation was based on the atmospheric condition and parameters obtainable in the month of March at active period of the day, between the 8.00h and 18.00h of the day. The calculated maximum space cooling loads are 18293W sensible and 19746W latent. A computer application was developed in Java programming language and was also used to calculate the cooling load of the case study. Results from manual calculation and results from the computer application were compare and found to be the same.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of study

Human is born into a hostile environment with varying weather conditions. This is as a result of the rotation and revolution of the earth and the variation in solar intensity across the surface of the earth, hence the development of buildings. The priority of any building design is to provide a comfortable indoor environment for occupants all the time (Rabiatul *et al.*, 2013). Attempts such as planting of trees and flowers around buildings, spacing of buildings and creating of windows and doors had been in practice to provide a comfortable indoor environment. But change in seasons, indoor activities, increasing greenhouse gas emissions and environmental pollutants have made such attempts ineffective most times. During harmattan, infiltration of air into buildings could lead to drought because of fast moving dry air. Similar for high rise buildings that are prone to fast moving dry air all the time. During the dry season, sometimes, the weather becomes so hot that the natural ventilation in building is not enough to provide a tolerable indoor temperature and relative humidity for human comfort.

As a result of man's quest for a conducive environment, a system, which irrespective of the weather condition, height of building and human indoor activities will provide the required air condition for human comfort, was conceived. And that was the, mechanical intervention to provision of conditioned air through any or combination of the following processes; heating, cooling, humidification, dehumidification, ventilation, filtration, cleaning of air and air movement (McDowell, 2006). These systems are called Heating, Ventilation and Air Conditioning (HVAC) systems. HVAC systems, in addition to enabling human comfort, provides the right relative humidity to keep furniture and wall paints intact by preventing moulds from forming. In manufacturing firm, perishable raw materials are stored at certain relative humidity and temperature with the aid of HVAC systems. HVAC systems are also employed in oil and gas in monitory air quality and in animal homes, theatres, laboratory and hospitals especially in rooms where stringent air conditioning are to be maintained for operations and research purposes.

Air conditioning is the best way to maintain temperatures at comfortable level in hot weather. One of the places where air conditioning is highly needed is a school. In summer, classrooms can be overheated on hot days which hampers effective learning. It can reduce concentration, problem solving, social skills, just to mention a few. A comfortable classroom environment is absolutely necessary for learning (APEX, 2018). According to Matiak (2020), when teachers and students are hot, they loose concentration and their brains focus on the level of hotness of their bodies and not about the learning in the classroom. So, trying to achieve a comfortable body temperature devours bodily resources and mitigate brain function.

Some existing school buildings are deficient of climate control in the classrooms. According to Housh (2017), a lack of cooling in the classroom stems from various problems which include lack of fund for maintenance of the existing ones and installation of new ones where it has never existed. However, Housh (2017) reiterated that to improve students’ learning abilities, it is safe to say air conditioning in schools is needed.

The Federal University of Technology, Minna (FUTMinna) is not left out. Particularly, Room 103, Engineering complex, FUTMinna lacks an air conditioner. This has actually contributed to lack of concentration of many students in class during hot weather.

In Nigeria, energy consumption by ventilation and cooling systems account for 29% of energy usage (Arup, 2016). Set against inadequate supply of energy and energy generation in the country. Figure 1.1 depicts the estimated breakdown of energy use in high income and middle-income households in Nigeria.

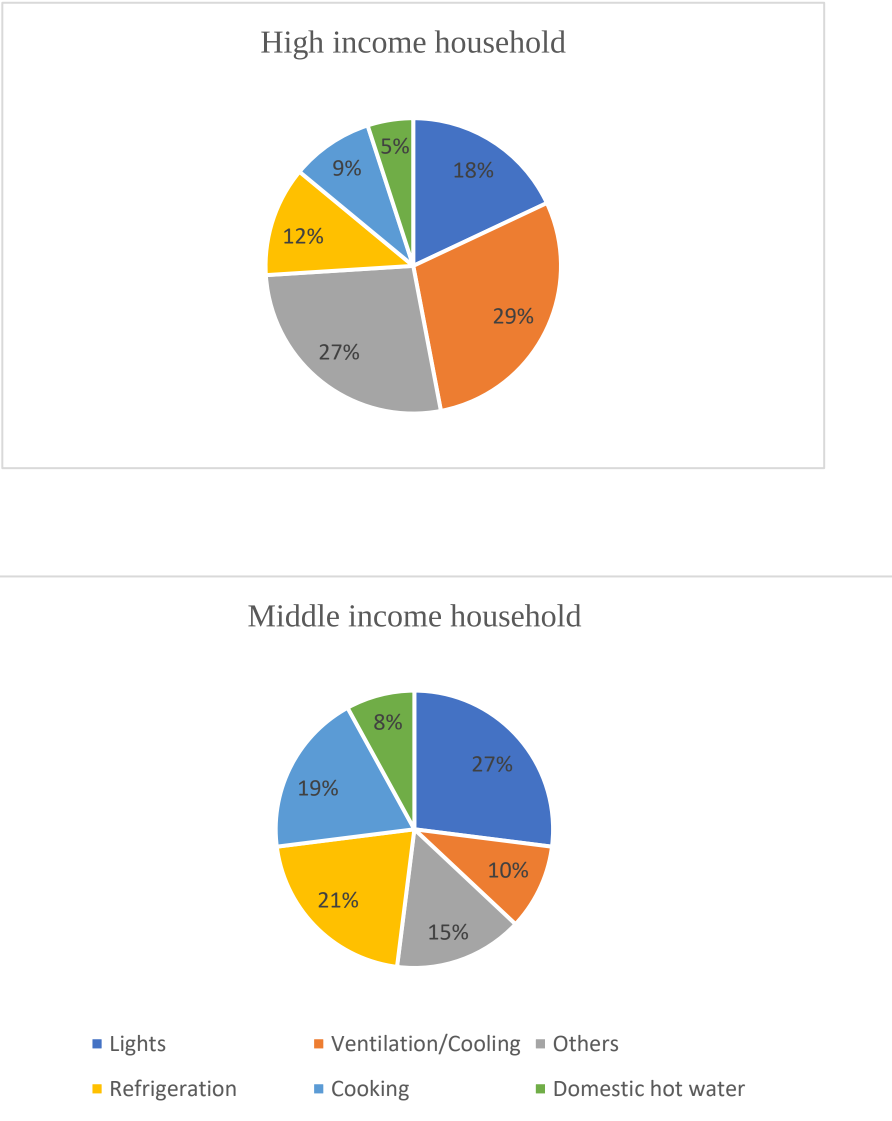

Figure 1.1: Estimated breakdown of energy use in high income and middle-income households in Nigeria (Adopted from Arup (2016)

Arup (2016) stated that energy efficiency measures represent the cheapest means to improving the state of energy supply in Nigeria. Hence, the need for energy efficient buildings through optimum ventilation and cooling systems design.

A way to prevent oversizing of ventilation and cooling systems is to begin with the calculation of cooling load, then its peak value determines the size of the air conditioner (Burdick, 2011). The load calculation is done with the consideration of all possible means through which a building gains or loses heat (ASHRAE, 2017).

Though the thumbs rule “1 ton per 500 square feet of floor area” has been widely employed in rough estimation of required air conditioner (Bhatia, 2004). The demerit of the thumbs rule is the assumption that the building design will not cause any change. Modern architectural building designs are paying more attention to attractive artistic outlook (Otuh, 2016), leading to very slim chances of having similar building design. For instance, a building whose envelop is curtain wall all round, could require twice the size of air conditioner of similar building of the same size whose envelop is made of just concrete blocks covered with plaster. Hence, it is needful to employ the calculation of cooling load in determination of the appropriate size of ventilation and cooling system in buildings in place of the thumbs rule.

Calculation of cooling load is a tedious task. But with the advent of computer, computer applications have been developed to ease the process. Formulation of the computer program is done in accordance to ASHRAE proposal on any of the cooling load methods. The CLTD/SCL/CLF method has been proven successful over the years by many experienced engineers in the design of HVAC systems of various building types (ASHRAE, 2017). Hence, the CLTD/SCL/CLF method has been adopted in this work.

This work, also covers the development of Windows application using Java programming language for estimation of cooling and heating loads.

1.2 Statement of the Problem

Among the recent computer applications that have been developed to ease cooling load calculations include Autodesk Revit, BLAST, Energyplus, HBfort, IBLAST and Hourly Analysis Program (HAP). The Autodesk Revit uses the Radiant Time Series method to calculate the cooling load and heating load of energy model generated from the building information model (BIM) (Ghedas & Benzarti, 2014). Due to its limited captured regions and sometimes, failure to automatically identify all the cooling or heating load contributing factors in the building information model, it is not suitable for load calculation in tropical regions like Minna, Nigeria. Energyplus, HBfort, IBLAST uses the Heat Balance Method for calculation of loads (Fantu, 2004). HAP employs the Transfer Function Method in determining heating and cooling load (Carrier, 2005). HAP does not capture every location, hence makes it inapplicable to buildings in areas like Minna, Nigeria.

1.3 Scope of Work

This work covered the modelling of the case study using Building Information Modelling (BIM) software, development of computer application for building cooling load calculation using Java programming language and manual calculation of cooling load of the case study. Results from the computer application and manual calculation would be compared.

1.4 Significance of Study

The study will enhance Engineers in achieving a more efficient design of ventilation and cooling systems for residential buildings and commercial buildings in any location. The software developed in the course of the study does not automatically link the internet for data, but will facilitate the determination of peak cooling load. Hence, the size of HVAC system.

1.5 Aim and objectives

The aim of this work is to model a lecture room (the case study) and develop a computer application that estimates the cooling load of the lecture room and any other building (residential or commercial). This will be accomplished through the following objectives:

i. Modelling of the case study using a Building Information Modelling (BIM) software.
ii. Development of a software for estimation of cooling load.
iii. Estimation of cooling load of the case study using manual calculation.
iv. Estimation of cooling load of the case study using the developed software.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Components of Cooling Load

Cooling load is the amount of heat energy needed to be removed from a space in order to attain a desired thermal comfort. Burdick (2011) stressed that the importance of accurate calculation of cooling and heating loads is that it has direct impact on occupant comfort, energy efficiency, building durability and indoor air quality. Cooling load calculation is done with the consideration of all possible means through which a building gains or loses heat (ASHRAE, 2017). Cooling loads emanate from many radiation, conduction and convection heat transfer processes through the building envelop (roofs, skylight, door, window, walls, floor, ceiling), through internal source (occupants, appliances, lights and equipment), from ventilation and infiltration (ASHRAE, 2013). The total cooling load comprises the latent load and sensible load component (Bhatia, 2004). The latent load affects the moisture content of the space, while the sensible load causes temperature change.

Bhatia (2004), in his work, classified building cooling loads into two. Namely: internally loaded and externally loaded. In internally loaded buildings, the cooling load is largely influenced by internally generating heat sources such as, people, lights, equipment and appliances. The cooling load from internally loaded buildings are generally assumed to be fairly constant. Externally loaded building has its cooling load largely affected by heat transfer between the surroundings and the conditioned space. Unlike the internally loaded building, the cooling load of externally loaded buildings varies on daily basis due to varying outdoor condition (Bhatia, 2004). Figure 2.1 illustrates a typical indoor environment with common cooling or heating load contributing components.

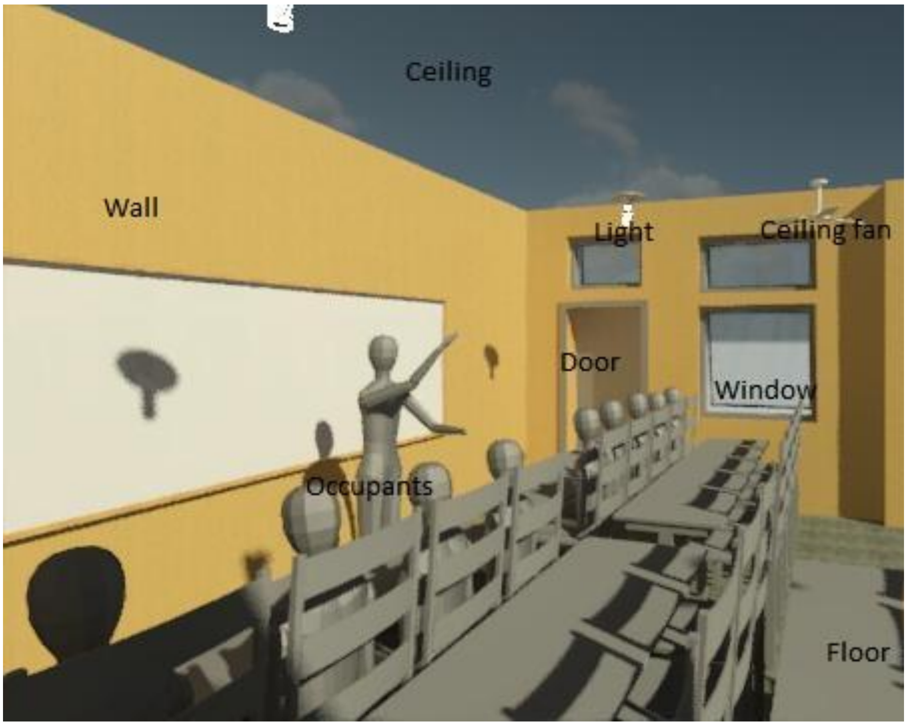

Figure 2.1: Various building components and human activities through which heat is transferred into a space

2.2 Cooling Load Calculation Methods

There has been increasing interest on the proper sizing of HVAC system even before the year 1945 till date (Mao, 2016). During the period prior to 1945, there were inconsistent cooling load calculation methods which, however laid the basis for modern load calculation methods (Obuka *et al.*, 2015). Most of the dynamic load calculation methods were proposed between 1942 and 1969.

The first thermal Resistor/Capacitor (R/C) network appeared in 1942. In 1958, a complete R/C thermal network for a house model was developed by Harry Buchberg using heat balance calculations in an analogue computer (Mao, 2016). With the aid of Mackey and Wright's earlier work, James P. Stewart was able to outline the Equivalent Temperature Differentials (ETD) in 1948. Stewart's ETD tables were generated under a certain condition: month of July, Latitude 40^{o}N, minimum and maximum outdoor temperature of 75°F and 95°F respectively and ambient temperature of 80°F. If the temperature difference between the ambient temperature and outdoor maximum design temperature were smaller (or larger) than 15°F, it was indicated to employ the published ETD tables and subtract (or add) the difference (Mao, 2016). In 1955, William McGuinness, a professor of architecture at Pratt Institute of Technology, published in his book, an improved data for calculating heat gains referencing Stewart's ETD tables. By 1950s, either the Total Equivalent Temperature Difference/ Time Averaging (TETD/TA) method or direct implementation of Mackey and Wright's sol air temperature Equation (Mitalas, 1972) were employed in load calculation. The idea of thermal Admittance was first introduced in United Kingdom by the Institute of Heating and Ventilating Engineers (IHVE) Guide in 1970 (Goulart, 2004). This led to the development of the admittance method by Loudon (Loudon, 1968). In 1972, the TFM was introduced by the ASHRAE Task Group on Energy Requirement (TGER) for peak cooling load analysis (Mao, 2016). TFM which was based on eairlier work by Mitalas and Stephenson (Obuka *et al.*, 2015) is reasoned as the first widespread, computer oriented method for evaluating dynamic heat transfer problems in buildings in the United State (Mitalas, 1972). In 1974, Rudoy and Duran developed the Cooling Load Temperature Difference/Cooling Load Factor (CLTD/CLF) method (Spitler *et al.*, 1993). The CLTD/CLF method was introduced as a hand calculation method. In 1988, Prof Edward Sowell modified the CLTD/CLF method by providing new tabulated values from series of simulations (Mao, 2016). In the same year, Harries and McQuiston proposed an additional Conduction Transfer Function (CTF) coefficients to cover more groups of wall and roof construction conditions (McQuiston *et al.*, 2000). In 1993, Spitler *et al.* (1993) modified the CLTD/CLF method to the CLTD/SCL/CLF method by introducing the term Solar Cooling Load (SCL) for an improved solar heat gain calculation through glass and fenestration. In 1997, Spitler *et al.*

(1997) introduced the Radiant Time Series (RTS) method which is an improvement over all previous methods. The correctness of the RTS method can be likened to that of TFM, if custom weighing factors and custom conduction transfer function coefficient were applied for all building components. In 1997, Pederson *et al.* (1997) developed the Heat Balance Method (HBM) including the mathematical description of the method (Pedersen *et al.*, 1997). Four years later (in 2001), Professor Pederson, with the use of FORTRAN programming language, developed the ASHRAE building load calculation toolkit (LOAD toolkits for ASHRAE members) to use (Pedersen *et al.*, 2003). In 2004, Charles Barnaby introduced the Residential Heat Balance (RHB) and the Residential Load Factor (RLF) method for residential load calculations (Barnaby *et al.*, 2005).

Recently, according to Mao (2016), the following five methods are still in use: the Heat Balance Method (HBM), Transfer Function Method (TFM), Total Eqivalent Temperature Difference Method (TETDM)/ Time Avaraging Method (TAM), Cooling Load Temperature Difference/ Solar Cooling Load/ Cooling Load Factor Method (CLTD/SCL/CLF) and the Radiant Time Series Method (RTSM).

2.2.1 Transfer function method (TFM)

The Transfer Function Method (TFM) is the most complex method recommended by ASHRAE (Bhatia, 2004). It requires several calculation steps. Hence, the need for computer program or advance spreadsheet. Its initial purpose was for energy analysis with emphasis on daily, monthly and yearly energy use (ASHRAE, 2013).

The Transfer Function Method (TFM) employs the concept of transfer function to relate cooling load to heat gain and rate of heat extraction to ambient temperature and cooling load (Mitalas, 1972). Transfer function as described by Mitalas (1972), involves set of coefficients that relates an output function at a specific time to one or more driving functions at that time and to previous values of the output and input functions. The TFM is a two-step simplified method that integrates the concepts of Room Transfer Functions (RTFs) also known as Weighting Factors and Conducion Transfer Functions (CTFs). Estimated values of solar intensities for each exterior surface are used to calculate the sol-air temperature. The CTFs and the sol-air temperature are used to calculate the conduction heat gains of roofs and walls. The absorbed and transmitted heat gain are calculated using the Absorbed Solar Heat Gain Factor (ASHGF) and Transmitted Solar Heat Gain Factor (TSGHF), respectively. The fenestration conduction heat gains can be gotten from the steady state conduction heat transfer process. TFM assumes that the heat gain due to infiltration directly influences the cooling load. The internal heat gains are calculated individually. Conduction heat gains are calculated by applying conduction weighting factor, solar heat gains are calculated from solar weighting factor and the internal heat gains from lights are calculated from lighting weighting factors, heat gain from occupant or equipment is calculated using weighting factor. The overall cooling load would be the summation of all the types of calculated cooling loads aforementioned (Mao, 2016).

2.2.2 Total equivalent temperature difference/time averaging method (TETD/TA)

The Total Equivalent Temperature Difference/Time Averaging Method (TETD/TA) was the preferred manual calculation or simple spreadsheet calculation method before CLTD/CLF was introduced. It uses the concept of sol-air temperature. Sol-air temperature is the temperature of the outdoor air that in the absence of all radiation changes gives the same rate of heat entry into the surface as would the combination of radiant energy exchange with the sky and other outdoor surroundings, incident solar radiation and convective heat exchange with the outdoor air (ASHRAE, 2001).

The Total Equivalent Temperature Difference (TETD) is calculated using the sol-air temperature (Gaadhe, 2019). Heat conduction through opaque surfaces such as walls, ceiling and roof is calculated using the Total Equivalent Temperature Difference (Mao, 2016). Heat gain through fenestration and glass is calculated using the Solar Heat Gain Factor (SHGF) and Shading Coefficient (SC). Heat from people is calculated applying the Allowance Factor (AF). Heat from electrical fixtures is calculated from Use Factor and Allowance Factor (AF).

2.2.3 Cooling load temperature difference/solar cooling load/cooling load factor method (CLTD/SCL/CLF)

The Cooling Load Temperature Difference/Solar Cooling Load/Cooling Load Factor Method (CLTD/SCL/CLF) is a one step method that depends on CLTD, SCL and CLF tables generated based on Transfer Function Method (ASHRAE, 1997). The CLTD, SCL and CLF for each month and latitude are required to calculate cooling load. If the actual indoor and outdoor conditions are different from that on which the CLTD tables were generated from, there will be need for adjustment. CLTD, SCL and CLF tables generated in ASHRAE handbook of fundamentals, 1997, were based on the following conditions:

i. Indoor temperature constant at 25.5℃.
ii. Outdoor mean temperature and maximum temperature of 29.5℃ and 35℃ respectively.
iii. Dark surfaces.
iv. Daily temperature range of 11.6℃.
v. Clear sky on 21st day of the month.
vi. No ceiling plenum air return system.

vii. Inside and outside surface film resistance of 0.121 m^2K/W and 0.059 m^2K/W respectively.

Cooling load due to conduction mode of heat transfer through exterior building components (wall, window, door, window and roof) are calculated using the cooling load temperature difference (CLTD). Solar radiation through exterior glasses (window and curtainwall) are calculated using shading coefficient (SC) and solar cooling load (SCL). The shading coefficient is a multiplying factor used in coverting the solar heat gain for a clear glass into a value for tinted. SC is defined as the ratio of the Solar Heat Gain Coefficient (SHGC) of a glazing system for a particular incidence angle and incident solar spectrum to that for clear, single-pane glass with the same angle and spectra distribution (ASHRAE, 1997). The CLTD/SCL/CLF method assumes that the total sensible heat gain from interior building components is not converted directly to cooling load. So that the radiant portion is first absorbed by the surrounding (furniture, floor, ceiling wall and partition), then convected to the space at a later time depending on the thermal property of the space (Bhatia, 2004). Hence, the Cooling Load Factor (CLF) term is introduced.

CLF is applied in determining the cooling load due to interior building components such as motor-driven equipment, appliances, people (occupants) and lights. In addition to CLF, the sensible heat gain (SHG) and latent heat gain (LHG) are also employed in calculating cooling load due to occcupants. While, the lighting use factor and special allowance factor are used in conjuction with the CLF for calculating cooling load due to lights. Lighting use factor represents the ratio of the wattage in use for a particular condition on which the load estimation is being made, to the total installed wattage. ASHRAE (1997) suggest that, for commercial applications, lighting use factor should be taken as unity and the term, special allowance factor or ballast factor is applicable to flouresents. Radiation factor which is a ratio of heat gain to appliance energy consumption, is also used as a multiplier for calculation of cooling load due to appliances.

2.2.3.1 General procedure for generating CLTD, SCL and CLF table data

Briefly, the conventional procedures to obtaining the CLTD, SCL and CLF tables involve; calculation of the cooling load of a given type of heat gain using the Transfer Function Method. Then the load is normalised to give CLTD, SCL or CLF (Spitler *et al.*, 1993). Cooling loads due to exterior surfaces are calculated using CLTD table data.

Spilter *et al.* (1993) outlined the conventional steps in generating table data for CLTD, SCL and CLF as follows.

1. The solar radiation is first determine. Then, its value is used to calculate the sol-air temperature for opaque surface or SHGF. According to Spilter *et al.* (1993), the sol-air temperature is written as:

$$t_{sa} = t_{ot} + \frac{\alpha I_{ir}}{h_o} + \frac{\varepsilon F}{h_o} \quad (2.1)$$

where:

t_{sa} is the sol-air temperature in K.

t_{ot} is outside air temperature in K.

α is surface absorptance.

I_{ir} is the total radiation incident on the surface in W/m^2.

h_o is outside convective and radiative heat transfer coefficient in $W/m^2\,K$.

ε is surface emmitance.

F is the difference between the long-wavelength radiation incident on the surface from the sky and the radiation emitted by black body at the outdoor air temperature in W/m^2.

2. The conduction transfer function coefficient is used in the conduction transfer function Equation to calculate the hourly heat gain through walls and roof. According to Iu and Fisher (2004) and Spilter *et al.* (1993), the conductive heat gain is given by:

$$q_{e,i} = A\left[\sum_{n=0} b_n\left(t_{e,i-n\delta}\right) - \sum_{n=1} d_n \left\{\frac{\left(q_{e,i-n\delta}\right)}{A}\right\} - t_{rc}\sum_{n=0} c_n\right] \qquad (2.2)$$

where:

$q_{e,i}$ is the heat gain via roof, partition, door, skylight and wall in W at calculation hour (h) i;

A is the area of indoor surface of the roof, wall, partition, door and skylight in m^2;

i is time in hour (h);

δ is time interval in hour (h);

n is the summation index;

$t_{e,i-n\delta}$ is the sol-air temperature at time $i - n\delta$ in K;

t_{rc} is the indoor room temperature in K;

b_n, c_n and d_n are conduction transfer function coefficients.

Equation 2.2 is solved iteratively since, the heat flux history terms on the righ-hand side are not known beforehand when analyzing a 24-hour period. Initially, the heat flux terms are assigned a value of zero and Equation 2.2 is solved successively for a period of 24 hours until convergence is attained. At this time, the results are independent of the initial values.

3. The heat gain through glass (fenestration) is divided into two parts, the radiation that passes (transmitted) through the glass (I_{tr}) and the fraction of the radiation absorbed by the glass that enters the zone, (I_{far}). According to Spilter *et al.* (1993), the transimitted radiation through the glass is given by:

$$I_{tr} = I_{dr} \sum_{j=0}^{5} t_j cosj\theta + I_{rr} \times 2 \sum_{j=0}^{5} \frac{t_j}{j+2} \quad (2.3)$$

where:

I_{dr} is the radiation striking the surface in W/m^2;

θ is angle of incidence;

I_{rr} is the diffused radiation reflected from the sky and ground in W/m^2;

t_j is the coefficient for radiation transmitted via the DSA glass.

And, the total radiation absorbed by the glass is written as:

$$I_{ar} = I_{dr} \sum_{j=0}^{5} t_j cosj\theta + I_{rr} \times 2 \sum_{j=0}^{5} \frac{a_j}{j+2} \quad (2.4)$$

where:

a_j is the coefficient for radiation absorption by DSA glass.

Only a fraction of I_{ar} enters the indoor environment. The rest are transferred to the outdoor environment through convection and radiation modes of heat transfer. The portion of the absorbed radiation that enters the zone is determined as follows:

$$I_{far} = R_i \times I_{ar} \quad (2.5)$$

where R_i is a fraction of inward flowing absorbed radiation.

$$R_i = \frac{h_i}{(h_i + h_o)} \quad (2.6)$$

Where h_i and h_o are the heat transfer coefficients for the indoor and outside air respectively.

4. Once the heat gain from any of the building components have been calculated, the heat gain is conververted to cooling load. Weighting factors are applied in determining the cooling load of a zone at any time based on past loads and current and past heat gains. According to Spilter *et al.* (1993), the cooling load at time θ, is written as:

   $$Q_\theta = x_0 q_\theta + x_1 q_{\theta-\delta} + x_2 q_{\theta-2\delta} - y_1 Q_{\theta-\delta} - y_2 Q_{\theta-2\delta} \quad (2.7)$$

   where:

   Q_θ is cooling load at time θ, Watt (W);

   $x_0, x_{1,}, x_2, y_1$ and y_2 are weighting factors;

   δ is the time interval;

   q_θ is heat gain at time θ.

   Previous heat gains and cooling loads are assigned initial value of zero and calculations are done in an iterative manner until results for a 24-hour cycle converge.

5. The next step is to calculate the CLTD, SCL and CLF from the cooling load. CLTD values for each wall type and roof group are calculated by dividing the hourly cooling load per unit area by the overall heat transfer coeficient of the surface. The hourly SCLvalues are the hourly cooling load values for the reference glazing system for the latitude and month listed and are calculated by adding the cooling load due to the transmitted portion of the solar energy to the inward-flowing fraction of the solar energy absorbed by the reference glazing system. CLF value is the cooling load due to a unit heat gain from appliances, people, lights or equipment.

2.3 Precision and Dependability of Various Load Calculation Methods

Mao (2016), in his work, distributed questionaires to some HVAC design engineers on the methods used for heating/cooling calculation. Found out, all five methods were still in use. Experienced engineers have succesfully adopted the various methods in so many building projects. ASHRAE (2017) hints that the precision of a particular cooling load method depends on the availability of accurate data and the judgment made by the engineer in assumptions made during interpretation of the available data. Thus, methods with less dependability on generated tables are more likely to yield best results. Not all appliances, type of light, activities by people, building materials and equipment are captured in the tables produced by ASHRAE. Hence, raising concerns on how to fairly assign parametals like usage factor, SCL and load factor without overestimating or underestimating the peak cooling load (Bhatia, 2004). This could generate uncertainties that far exceeds errors from using simple cooling load calculation methods. Thus, the added time/effort necessary for the more complex calculation methods would not be productive in terms of better precision of the results if uncertainties in the input data are high. Otherwise, simplified methods would, likely, have the same level of satisfactory accuracy (Bhatia, 2004).

The most commonly used calculation method is CLTD/SCL/CLF (Mao, 2016) and its calculation procedures are outlined in ASHRAE (1997). Similarly, the use of CLTD/SCL/CLF method requires engineering judgment. When the method is employed in conjunction with generated table data from steps or software described in Spilter *et al.* (1993) and for zones where external shading is not significant, it may be expected that the result produced, will be very close to that produced by the TFM. Some additional errors are introduced when using the printed tables. However, in many cases, the accuracy provided by implementing CLTD/SCL/CLF method should be enough (ASHRAE, 1997).

2.4 Computer Applications for Load Calculation

As mentioned before, calculation of cooling load is a tedious task. But with the advent of computer, applications have been developed to ease the process. Among the recent computer applications are Autodesk Revit, BLAST, Energyplus, HBfort, IBLAST, DOE-2 and Hourly Analysis Program (HAP). Among recent research works on development of computer application for building load calculation are:

Kadir (1998) developed a new computer-based tool for use by engineers when designing and selecting an air conditioning system. A computer model was constructed to carry out the calculations and to test the results. The CLTD/CLF method was used for the model by the researchers because of its flexibility. He used the dynamic behaviour of the model to compare results from different building designs obtained from his study. His results showed that the real load profiles were superior to the profile from using the static traditional method. It was remarked that results from the analysis of the new method can clearly demonstrate the use of the computer program and allow variations in cooling load, peak and minimum load to be observed.

In 2004, Fantu (2004) developed a user friendly MATLAB Graphical User Interface (GUI) program to estimate the cooling load of a single zone. Transient heat transfer through walls and roof were analysed using the Finite Difference Method (FDM). Cooling load due to window and glass were calculated using Solar Heat Gain Coefficient (SHGC) of the net glass area. He further classified building load components into radiant portion and convective portion. The radiant portions were multiplied by radiant time factor in order to convert to cooling load. While the convective portions were taken as cooling load directly.

In 2008, Kareem (2008) developed a computer program called Computer Aided Load Estimating for Air Conditioning using QBASIC programming language, for estimating cooling load. Cooling load due to door, wall, roof and ceiling were calculated using the Cooling Load Temperature Difference (CLTD). Cooling load from window and glass was calculated applying the Glass Load Factor (GLF). A constant cooling load by occupants of 67W per person was assumed. The computer program developed, was used to estimate the cooling load of Federal University of Technology, Akure (FUTA) library to be 806.26kW (Kareem, 2008).

Sahu (2014) established the results of cooling load calculation of different climate conditions by using CLTD method for a multi-story building which is a part of an institute. The researcher used MS-Excel programme to calculate cooling load items such as, people heat gain, lighting heat gain, infiltration and ventilation heat gain and cooling load due to walls and roofs. It was reported that the results were compared with the standard data given by ASHRAE and CARRIER Fundamental Hand Books and found to be satisfactory. It was also reported that the cooling requirement of summer is about 9% more as compared to Monsoon for climate condition of Rourkela.

In 2015, Obuka *et al*. (2015) developed a computer application for calculating the latent and sensible cooling load of a single zone in Visual Basic programing language. CLTD/SCL/CLF method was used in the calculation of cooling load. A case study of a lecture room at University of Nigeria, Nsuka, was considered. The software provided input for all load contributing components for a non-residential building except inputs for equipment and skylight.

2.5 Modelling of Building using BIM tool

Building Information Modelling (BIM) is a digital representation of physical and functional properties of a facility (Otuh, 2016). A BIM software is capable of representing both the intrinsic and physical properties of a building as an object-oriented model connected to a database (Bergin, 2012). Also, some BIM software now present an optimized feature of a specific classification, rendering engines and a programming environment to generate components of a model. The model can be viewed and interacted with in three-dimensional views, orthographic two-dimensional plan, sections, schedules and elevation views. As the model is modified, changes occur simultaneously on all other drawings within the project as indicated in the model. Constraints such as the height of a horizontal level can be assigned, which could be connected to the height of specified wall type and modified parametrically. Hence, a dynamic database model is created which is connected to the geometry. This development is of great importance to the architecture, engineering and construction (AEC) industries as it enables change of drawings at multiple scales and across fragmented drawing sheets easily. Resulting to the number of hours needed for the production of drawings to reduce drastically. BIM offers a greater advantage in terms of providing detailed model for energy and load analysis (Khan *et al.*, 2018). Each building component has pre-installed physical and chemical properties which can be easily modified and applied. Also, the accuracy of the relative space occupied by each building component in a model makes BIM suitable for Computational Fluid Dynamics (CFD) analysis (Cai, 2016).

The concept of BIM is dated as far back as 1962, when Douglas C. Englebart predicted the nature of future architect in his paper titled “Augmenting Human Intellect” (Englebart, 1962). He quotes:

The architect next begins to enter a series of specifications and data–a six-inch slab floor, twelve-inch concrete walls eight feet high within the excavation, and so on. When he has finished, the revised scene appears on the screen. A structure is taking shape. He examines it, adjusts it… These lists grow into an ever more-detailed, interlinked structure, which represents the maturing thought behind the actual design.

Englebart (1962) proposed an object-based design, parametric manipulation and relational database; dream that would become a reality in many years to come.

Today, there are several BIM software. Among the commonly used BIM software in the AEC industries are SKETCHUP, Autodesk REVIT and ArchiCAD (Ghedas & Benzarti, 2014).

The developed Windows application provides Engineers with opportunity to input metrological data peculiar to any location the cooling load design is meant for, instead of relying on data automatically generated by other existing software. The developed software also has more input parameters covering wider range of building components through which the cooling load maybe influenced.

CHAPTER THREE

3.0 METHODOLOGY

The CLTD/SCL/CLF Method of Cooling Load Calculation method is adopted in estimating the cooling load of the case study. The formulations involved in the cooling load calculation approach are first outlined. Layout, components and metrological data of the case study were obtained and used to estimate the cooling load.

3.1 CLTD/SCL/CLF Method of Cooling Load Calculation

The cooling load due to roof, exterior wall, window and door by conduction heat transfer according to Obuka *et al.*(2015), is written as:

$$q = \mathrm{U} \times \mathrm{A} \times (\mathrm{CLTD}) \tag{3.1}$$

where:

q is the cooling load in Watts (W);

U is the coefficient of heat transfer in $\frac{W}{m^2K}$ for wall, glass or roof;

A is the surface area of wall, glass or roof in m^2;

CLTD is the cooling load temperature difference across wall, glass or roof in Kelvin (K). For geographical location different from the location used to generate the ASHRAE tables, adjustments are made according to ASHRAE (1997) as:

$$CLTD_{corrected} = CLTD + (25.5 - t_{idt}) + (t_m - 29.4) \tag{3.2}$$

where:

$CLTD$ is cooling load temperature difference from ASHRAE (1997) table (K);

t_{idt} is the indoor design temperature (K);

$$t_m = maximum\ outdoor\ temperature - \frac{daily\ range}{2}$$

Solar cooling load due to glass (curtainwall) and window (made of glass) according to ASHRAE (1997), is written as:

$$q_{rad} = \text{A} \times (\text{SC}) \times (\text{SCL}) \quad (3.3)$$

where q_{rad} is cooling load due to solar radiation in W;

A is the net glass area of the window, m^2;

SC represents shading coefficient for combination of shading device and fenestration;

SCL is solar cooling load in, $\frac{W}{m^2}$;

Cooling load from fenestration and curtainwall includes heat gain by conduction and radiation.

Cooling load due to floor, partition or ceiling according to Mao (2016), is written as:

$$q = \text{U} \times \text{A}\left(t_{aj} - t_{idt}\right) \quad (3.4)$$

where:

U is the coefficient of heat transfer for floor, partition or ceiling, $\frac{W}{m^2K}$;

A is the surface area of floor, ceiling and partition given in building plans, m^2;

t_{aj} is the temperature of adjacent space, K;

t_{idt} is the inside design temperature, K;

The CLTD/SCL/CLF method assumes that the total sensible heat gain from occupants is not converted directly to cooling load. So that the radiant portion is first absorbed by the surrounding (furniture, floor, ceiling wall and partition) then convected to the space at a later time depending on the thermal property of the space. The instantaneous sensible cooling load caused by occupants, according to Bhatia (2004), is written as:

$$q_{os} = \mathrm{N} \times (SHG_p) \times (\mathrm{CLF}_p) \tag{3.5}$$

And the latent cooling load due to occupants according to Bhatia (2004), is written as:

$$q_{ol} = \mathrm{N} \times \left(\mathrm{LHG}_p\right) \tag{3.6}$$

where:

q_{os} is the sensible cooling load caused by occupants, W;

N is the number of occupants;

SHG_p is the sensible heat gain per person in W;

CLF_p is cooling load factor by hour of occupancy for people;

q_{ol} is the latent cooling load caused by occupants, W;

LHG_p is the latent heat gain per person, W;

The cooling load caused by electrical lighting fixtures, according to ASHRAE (1997), can be calculated as:

$$q_l = \mathrm{P}_l \times \mathrm{F}_{\mathrm{SA}} \times \mathrm{F}_{\mathrm{UT}} \times (\mathrm{CLF}_l) \tag{3.7}$$

where:

q_l is the cooling load caused by electrical lighting fixtures, W;

P_l is the power input for electrical lighting fixtures data or electrical plan, W;

F_{SA} is special allowance factor, as appropriate;

F_{UT} is lighting use factor, as appropriate;

CLF_l is the cooling load factor by hour of occupancy for lights;

The cooling load caused by motor-driven equipment, according to ASHRAE (1997), is written as:

$$q_e = \eta_e \times P_e \times (CLF) \quad (3.8)$$

where:

q_e is the cooling load caused by electrical equipment;

η_e is efficiency factors and arrangements to suit circumstances;

P_e is power rating from electrical plan or manufacturer's data and

CLF is cooling load factor by hour of occupancy.

Estimation of cooling load from appliances according to ASHRAE (1997), is written as:

$$q_{sensible} = q_{input} \times F_U \times F_R \times (CLF) \quad (3.9)$$

where: F_U and F_R are usage factor and radiation factor respectively;

q_{input} is the rated energy input from appliances, W;

CLF is the cooling load factor by schedule hours and hooded or not (ASHRAE, 1997);

Cooling load caused by infiltration and ventilation air from an individual according to ASHRAE (1997), can be calculated as follows:

$$q_{sensible} = 1.23 \times Q(t_o - t_i) \tag{3.10}$$

$$q_{lantent} = 3010 \times Q(W_o - W_i) \tag{3.11}$$

$$q_{total} = 1.20 \times Q(h_o - h_i) \tag{3.12}$$

where:

Q is ventilation from ASHRAE standard 62 in L/s;

t_o and t_i are outside and inside air temperatures, K;

W_o and W_i are outside and inside air humidity ratio, kg of water/ kg of air;

h_o and h_i are outside and inside air enthalpy (ASHRAE, 1997).

3.2 University lecture room (Room 103, Engineering Complex) profile

The case study is located at longitude 6.5463ºE and latitude 9.5836ºN. On the ground floor of two-storey Engineering Complex, Federal University of Technology, Minna, Nigeria. Figure 3.1 represents the layout of the lecture room. The case study (Room 103) was modelled using Autodesk Revit, 2019. Occupants and building components of the case study such as walls, desk, chairs window, doors, floor, lights and ceiling fan have pre-installed physical and chemical properties which were easily modified and applied. The case study has a floor area of $76m^2$ and height of $3.23m$. The lecture room is oriented such that its doors and windows face north or south. The wall facing east is shaded and the west wall is a partition wall having no wall opening. The lecture room was designed for maximum sitting capacity of 100 students. Components of the case study and their properties are tabulated below in Table 3.1.

3.3 Climatic Condition of Location of Case Study (Minna, Nigeria)

The climatic condition of the location of the case study (Minna) according to http://www.minna.climatemps.com (2020), is described as follows:

- The month of March is the hottest with average temperature of 30.2℃ and maximum temperature of 37.1℃.
- The month of September is the coolest with mean temperature of 24.9℃.
- Minna has a daily temperature range of 11.1℃.
- Mean temperature of 27℃.

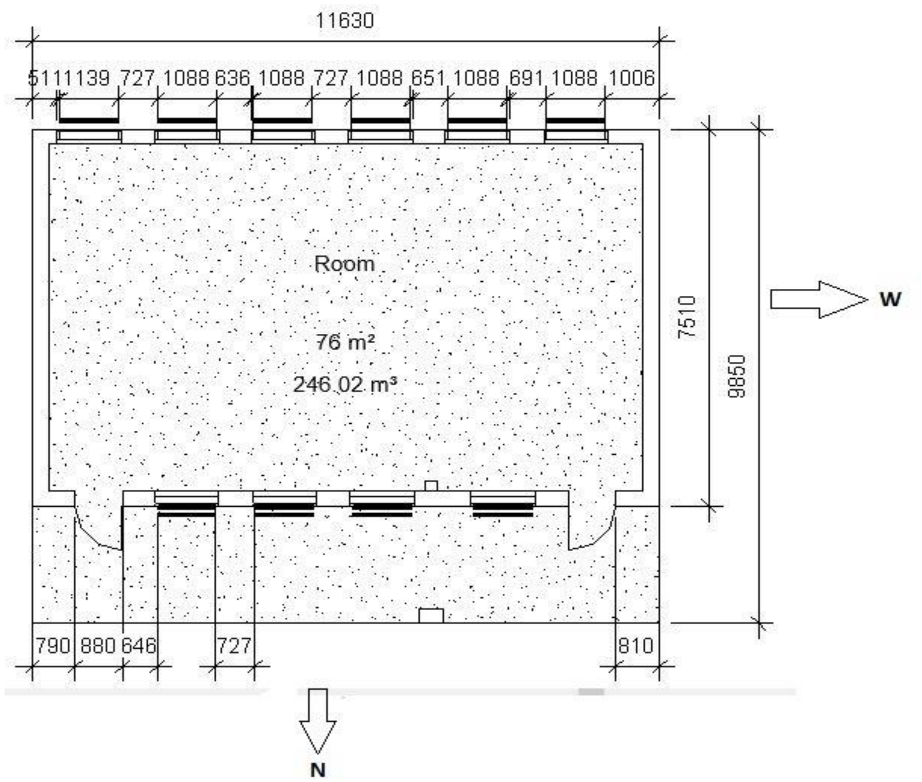

Figure 3.1: Layout of the lecture room

3.4 Design condition and assumptions

The cooling load of the case study was calculated based on the following design conditions:

i. Lights inside the classroom are turned on at 08:00 hour and remain on till 18:00 hour.
ii. Outdoor design dry-bulb temperature is 37.1℃.
iii. Indoor design dry-bulb temperature is 25℃.
iv. Daily temperature range is 11.1℃.
v. Relative humidity of 50%.
vi. Design outdoor humidity ratio 0.02kg of water/kg of air.
vii. Design indoor humidity ratio 0.01kg of water/kg of air.
viii. Occupancy period of lecture room is from 08:00 to 18:00.
ix. Maximum period of occupancy by students for a lecture is 3 hours. Occupancy period and hour after the entry of occupants is shown in Table 3.2.

The following assumptions were considered:

i. From (ASHRAE, 1997), thermal resistance, $R = 0.65 \frac{m^2K}{W}$ with core made of concrete block, corresponds to wall number 4. From the case study, wall facing west is a partition wall. Temperature of adjacent space to the west partition wall is the same as the indoor design temperature. Shaded walls have similar CLTD as walls facing North (ASHRAE, 1997). Since East exterior wall is shaded, hence its CLTD is the same as that of wall facing north.

Table 3.1: Given and measured parameter

S/N	Load Component	Parameter
1	Wall	Principal wall material: 230mm hollow concrete block covered with plaster; Wall thickness = 300mm; From Arup (2016), $U = 1.6 \frac{W}{m^2K}$ and Thermal Resistance, $R = 0.65 \frac{m^2K}{W}$.
2	Floor	Terrazzo of thickness = 25mm; Floor area = $76m^2$ Conductance, U = $71\frac{W}{m^2K}$. (ASHRAE, 1997).
3	Window	16 Projected Aluminium windows of sizes 1190mm by 1190mm (10 numbers), 1190mm by 600mm (4 numbers) and 880mm by 600mm (2 numbers). Glass thickness = 8mm; frame thickness = 25.4mm; $= 5.8 \frac{W}{m^2K}$.
4	People	101 people (100 seated students and one lecturer standing).
5	Light	6 × 26W fluorescent tubes, Ballast Factor, F_{SA} = 1.2.
6	Fan	4 × 70W Ceiling fans.

ii. Values of Cooling Load Temperature Difference (CLTD) for wall are taken from ASHRAE (1997).

iii. Values of Cooling Load Temperature Difference (CLTD) for glass are taken from ASHRAE (1997).

iv. Values of Shading Coefficient (SC) are taken from ASHRAE (1997).

v. Values of Solar Cooling Load (SCL) are taken from zone Type D, ASHRAE (1997).

vi. Rates of Sensible Heat Gain (SHG) and Latent Heat Gain (LHG) from people are obtained from ASHRAE (1997).

vii. Values of Cooling Load Factor (CLF) for people are taken from zone Type D, based on 10 hours from 8:00 hour to 18:00 hour in space, ASHRAE (1997).

viii. Walls, doors and windows are perfectly sealed to allow no infiltration of air. Therefore, cooling load due infiltration is negligible.

3.5 The computer application

A computer application was developed in JAVA programming language with the aid of Apache NetBeans Integrated Development Environment (IDE), version 11.1. The program comprises 9 Graphical User Interface (GUI). The first GUI is the starting window in Figure 3.2. It displays the purpose of the software. Below the title is the "NEXT" push button, it leads to the second GUI, when clicked.

The second GUI allows the user to input design parameters such as time of the day in hours, location, building type, floor area, ceiling area, roof area, skylight area, indoor design temperature, outdoor dry-bulb temperature, daily temperature range, outdoor humidity ratio, indoor humidity ratio, occupancy and rate of ventilation. The appearance of the second GUI is shown in Figure 3.3 below. The second GUI also contains the "PREVIOUS" and "NEXT" push buttons. The "PREVIOUS" button leads to the first GUI, when clicked. While the "NEXT" button leads to the third GUI, when clicked.

Table 3.2: Occupancy period and hour after entry of occupants**.**

Time of the Day (h)	Hours After Entry (h)
08:00	0
09:00	1
10:00	2
11:00	3
12:00	1
13:00	2
14:00	3
15:00	1
16:00	2
17:00	3
18:00	1

The third GUI allows the user to input total area of building components such as wall, glass (curtain wall), window and door on each face position. The face position includes North (N), North-East (NE), East (E), South-East (SE), South (S), South-West (SW), West (W) and North-West (NW). It also allows inputs for number and activity of occupants. As seen in Figure 3.4, the third GUI also contains the "PREVIOUS" and "NEXT" push buttons. The "PREVIOUS" button leads to the second GUI, when clicked. While the "NEXT" button leads to the fourth GUI, when clicked.

The fourth GUI allows the user to enter CLTD values for various building components such as wall, glass, window, door and roof corresponding to various faces such as N, NE, E, SE, S, SW, W and NW. As seen in Figure 3.5, the fourth GUI also contains the "PREVIOUS" and "NEXT" push buttons. The "PREVIOUS" button leads to the third GUI, when clicked. While the "NEXT" button leads to the fifth GUI, when clicked.

The fifth GUI allows inputs for Shading Coefficient (SC) and Solar Cooling Load (SCL) values for various building components such as glass and window corresponding to various faces such as N, NE, E, SE, S, SW, W and NW. It also takes in the Glass Load Factor (GLF) for skylights. As seen in Figure 3.6, the fifth GUI also contains the "PREVIOUS" and "NEXT" push buttons. The "PREVIOUS" button leads to the fourth GUI, when clicked. While the "NEXT" button leads to the sixth GUI, when clicked.

The sixth GUI allows inputs for surface area, U-factor and temperature of partition wall corresponding to various faces such as N, NE, E, SE, S, SW, W and NW. As seen in Figure 3.7, the sixth GUI also contains the "PREVIOUS" and "NEXT" push buttons. The "PREVIOUS" button leads to the fourth GUI, when clicked. While the "NEXT" button leads to the seventh GUI, when clicked.

The seventh GUI allows inputs for property of materials such as U-factor for curtain wall, wall, ceiling, door, window and roof and watt input, special allowance factor (ballast factor), lighting use factor and quantity of various types of lights. As seen in Figure 3.8, the seventh GUI also contains the "PREVIOUS" and "NEXT" push buttons.

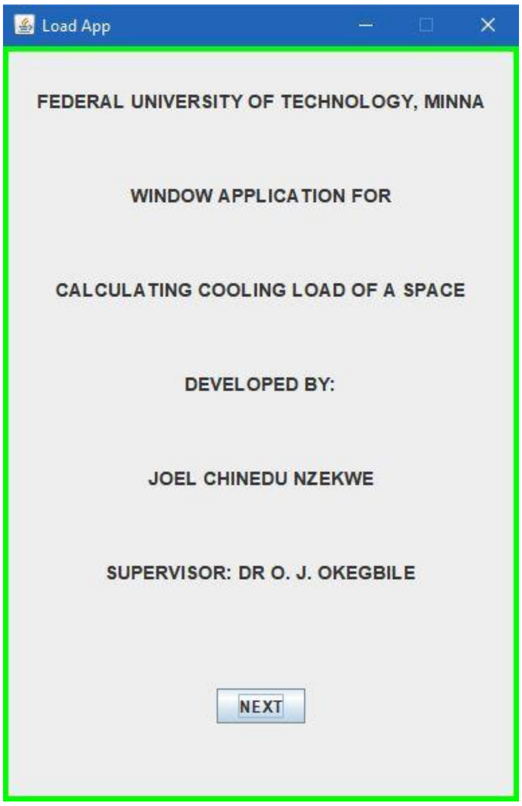

Figure 3.2: First Graphical User Interface (GUI)

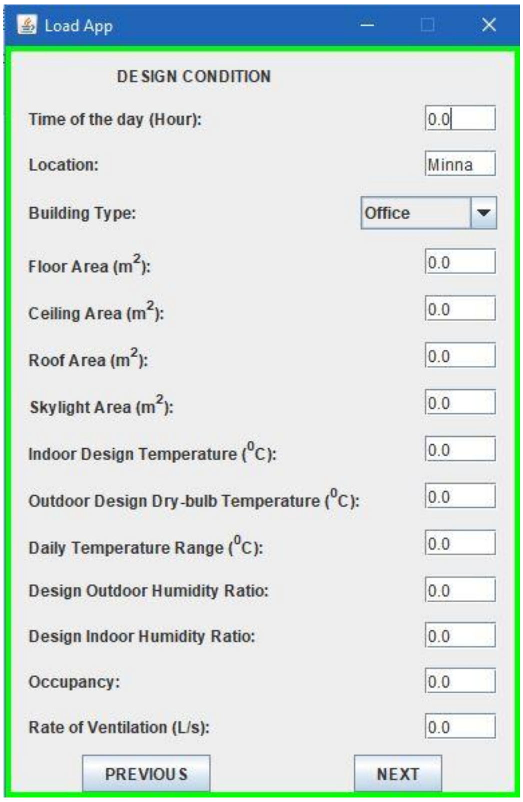

Figure 3.3: Second Graphical User Interface (GUI)

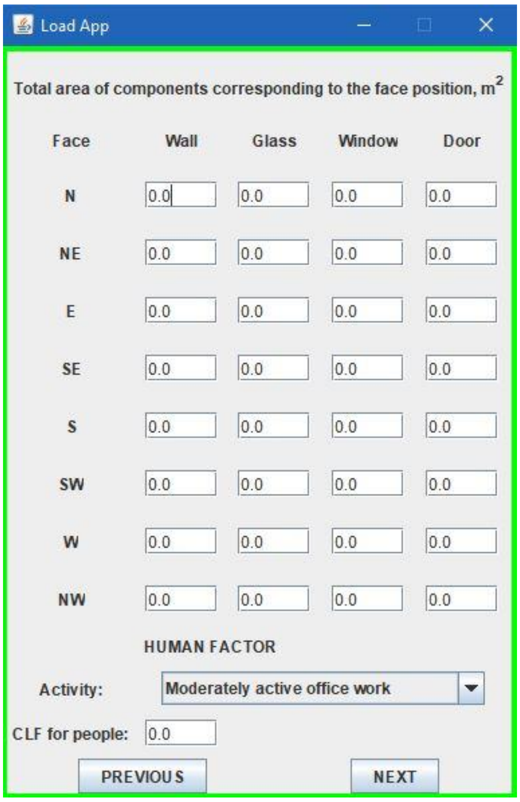

Figure 3.4: Third Graphical User Interface

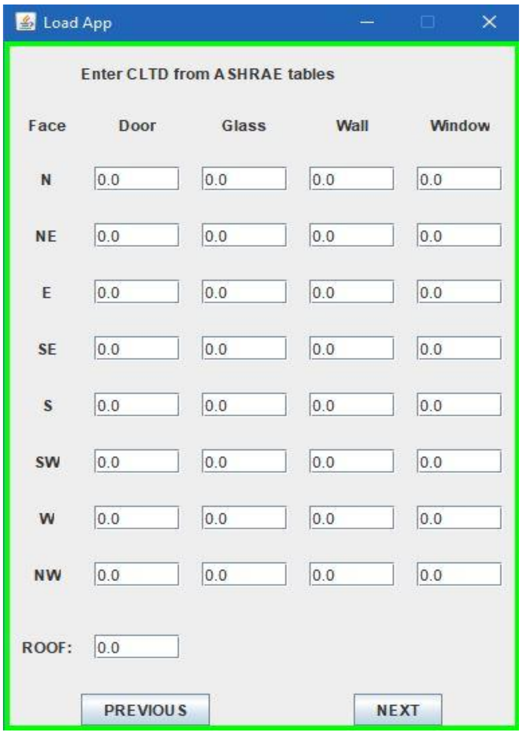

Figure 3.5: Fourth Graphical User Interface

The “PREVIOUS” button leads to the sixth GUI, when clicked. While the “NEXT” button leads to the eighth GUI, when clicked.

The eighth GUI allows the user to input efficiency, watt input, cooling load factor and quantity of various types of equipment; and energy input, usage factor, radiation factor, cooling load factor and quantity of various types of appliances. As seen in Figure 3.9, the eighth GUI also contains the “PREVIOUS” and “NEXT” push buttons. The “PREVIOUS” button leads to the seventh GUI, when clicked. While the “NEXT” button leads to the ninth GUI, when clicked.

The ninth GUI displays the results as text. As seen in figure 3.10, It also contains the “SAVE”, “CONTINUE” and “EXIT” push buttons. The “SAVE” push button provides the user with an option to save the displayed result in the computer memory. The “CONTINUE” push button leads to the second GUI. While the “EXIT” push button quits the program when clicked.

Flowchart on how the software functions is shown in Figure 3.11. The user starts by double-clicking the executable file. Input necessary parameters as displayed in the various Graphical User Interfaces. The cooling load of the building is being calculated automatically on hour basis. The “CONTINUE” button continues the loop from input of parameters. The “SAVE” button enables the computed results displayed on the screen to be save to desired computer memory. The program ends once the “END” button is clicked.

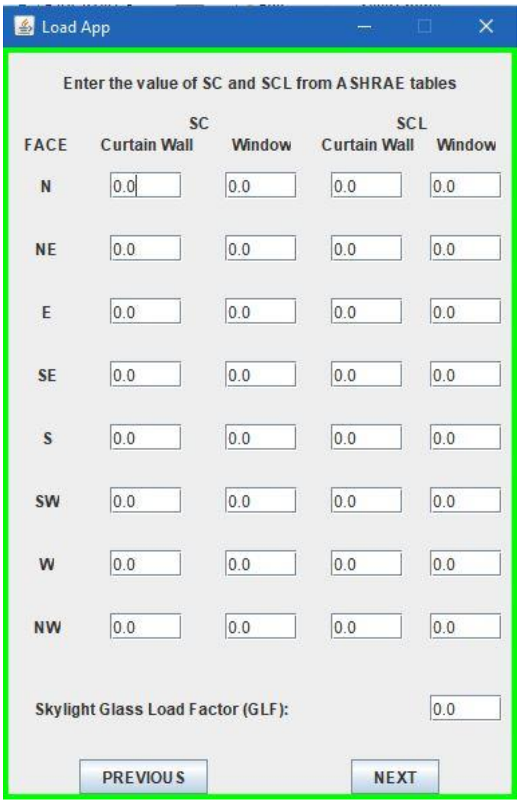

Figure 3.6: Fifth Graphical User Interface

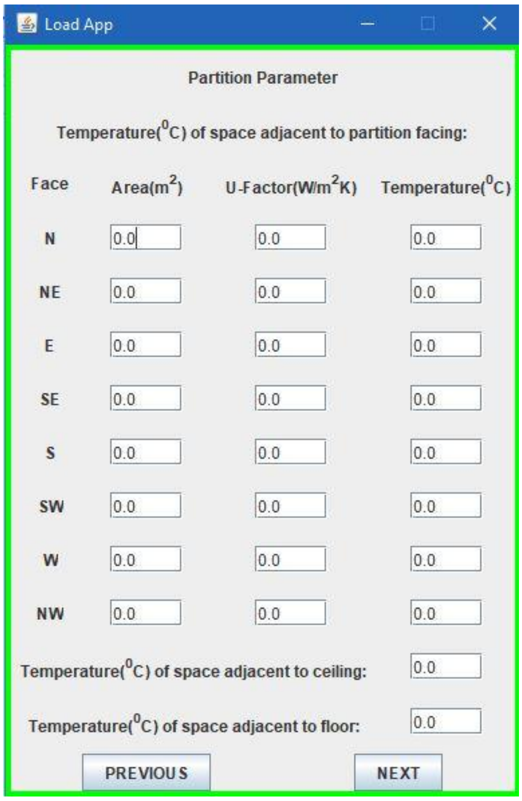

Figure 3.7: Sixth Graphical User Interface

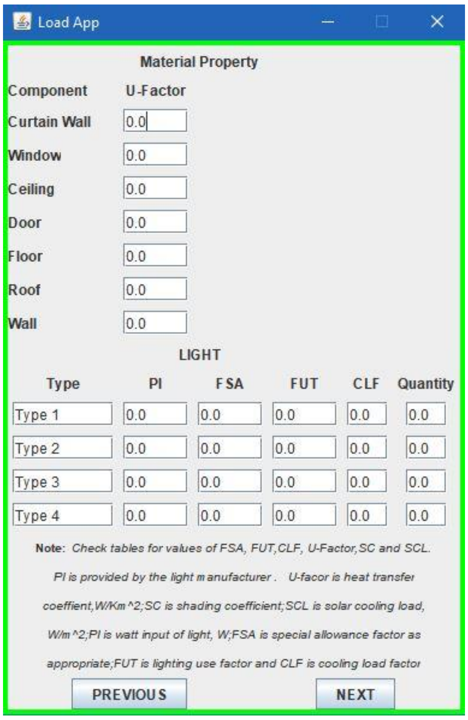

figure 3.7: Sixth Grapherical User Interface

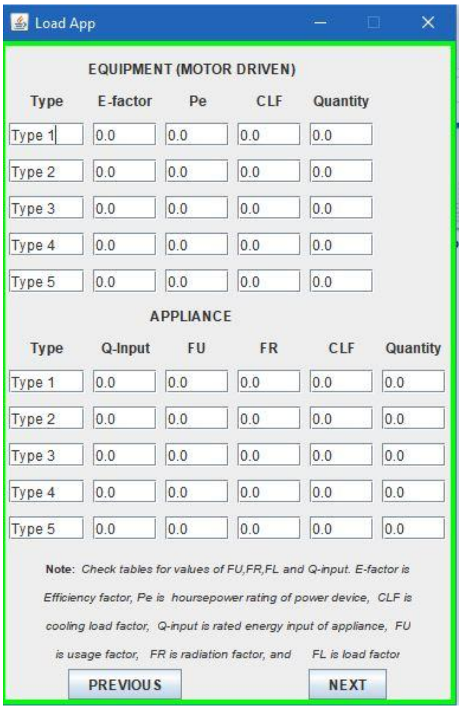

Figure 3.8: Seventh Graphical User Interface

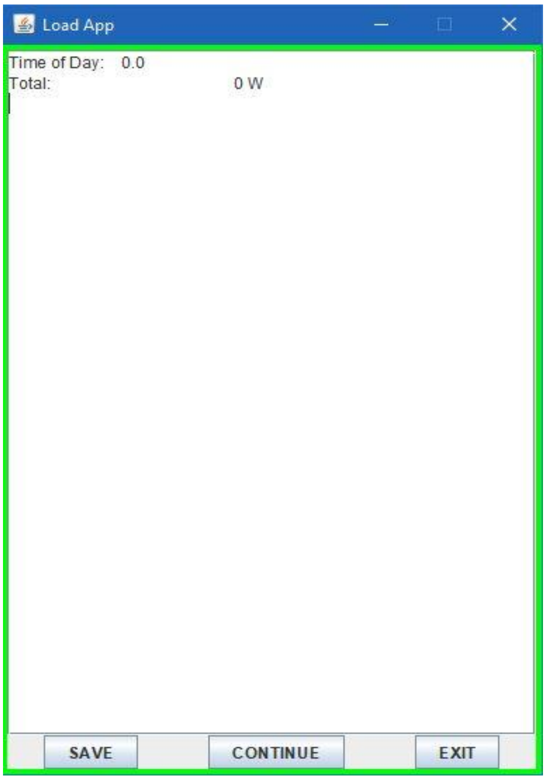

Figure 3.10: Ninth Graphical User interface

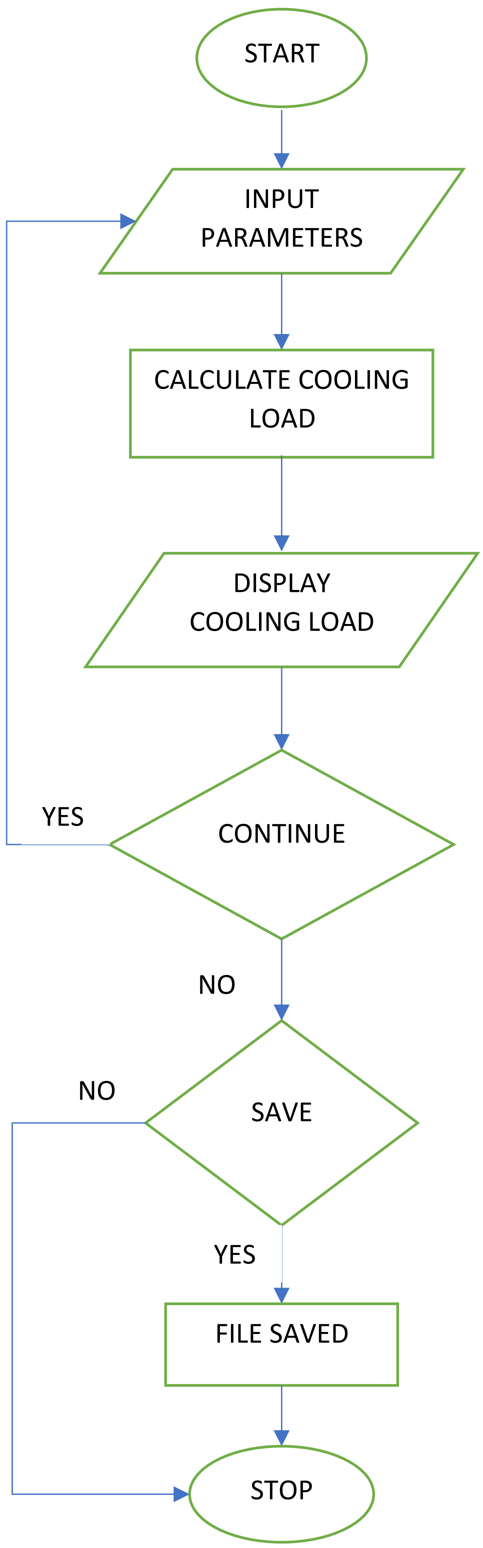

Figure 3.11 : Flowchart of how the software functions

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Modelled case study

All building components of the case study and occupants were modelled. As shown in Appendix B, the components comprise walls, windows, doors, lights, floor, ceiling, whiteboard and ceiling fan. 100 seated students and a standing lecturer represent the occupants of the case study as shown in Appendix B.

4.2 Manual calculation

4.2.1 Cooling load due to wall

Cooling load due to wall facing south at each hour of the day is shown in Table 4.1.

Table 4.1: Cooling load due to wall facing south

Time of the Day (h)	$\mathbf{U}\left(\frac{\boldsymbol{W}}{\boldsymbol{m^2K}}\right)$	$\mathbf{A}(\boldsymbol{m^2})$	CLTD (℃)	$CLTD_{corrected}$ (℃)	Hourly Cooling Load ($\boldsymbol{W}$)
08:00	1.6	28.099	1	3.65	164.0982
09:00	1.6	28.099	0	2.65	119.1398
10:00	1.6	28.099	1	3.65	164.0982
11:00	1.6	28.099	3	5.65	254.0150
12:00	1.6	28.099	7	9.65	433.8486
13:00	1.6	28.099	11	13.65	613.6822
14:00	1.6	28.099	16	18.65	838.4742
15:00	1.6	28.099	19	21.65	973.3494
16:00	1.6	28.099	23	25.65	1153.1830
17:00	1.6	28.099	24	26.65	1198.1410
18:00	1.6	28.099	23	25.65	1153.1830

It can be seen in Table 4.1 that the cooling load due to wall facing south at 08:00 hour is 164.0982W. Then increases from 119.1398W at 09:00h to a maximum value of 1198.141W at 17:00 hour and decreases to 1153.183W at 18:00h. This is due to the variation in cooling load temperature difference across the wall facing south during the day. Values of CLTD for wall number 4 facing south, from ASHRAE (1997), as seen in Table 4.1 above, continues to increase from 09:00 hour to 17:00h. Variation of cooling load with time of the day due to wall facing south is shown in Figure 4.1

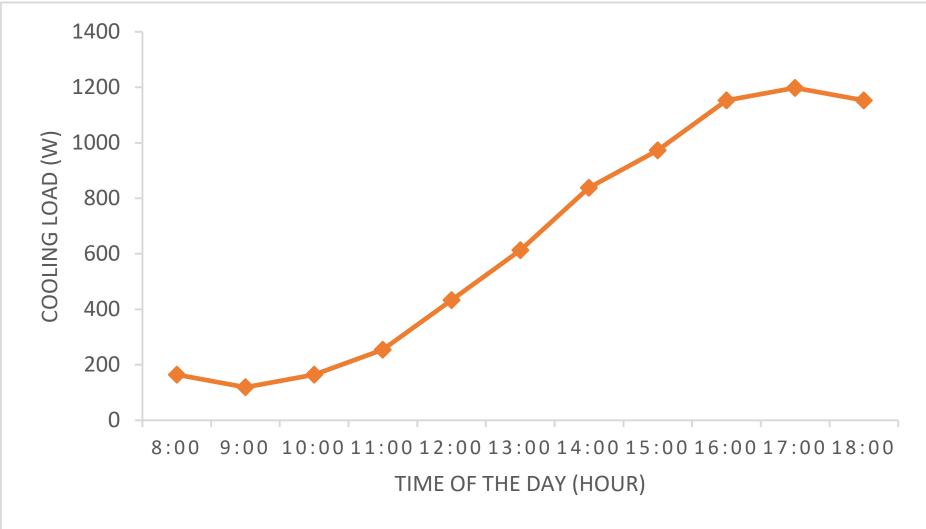

Figure 4.1: Variation of cooling load with time of the day due to wall facing south

It can be seen in Figure 4.1 that the cooling load due to wall facing the south continues to increase from 9:00h when there was sunrise to 17:00h and then drops as sunset approaches. The cooling load increases with increase in solar intensity.

Cooling load due to wall facing north at each hour of the day is shown in Table 4.2. It can be seen in Table 4.2, that the cooling load temperature difference (CLTD) from ASHRAE (1997) for wall facing north increases from 1℃ at 08:00h to 14℃ at 18:00h. Consequently, the cooling load temperature difference across the wall facing north ($CLTD_{corrected}$) and hourly cooling load increased relatively. The maximum cooling load and minimum cooling load due to heat gain from wall facing north, as shown in Table 4.2, are 719.8128W at 18:00h and 157.7968W at 08:00 hour respectively.

Table 4.2: Cooling load due to wall facing north

Time of the Day (h)	$\mathbf{U}\left(\frac{\boldsymbol{W}}{\boldsymbol{m^2K}}\right)$	$\mathbf{A}(\boldsymbol{m^2})$	CLTD (°C)	$CLTD_{corrected}$ (°C)	Hourly Cooling Load (W)
08:00	1.6	27.020	1	3.65	157.7968
09:00	1.6	27.020	2	4.65	201.0288
10:00	1.6	27.020	3	5.65	244.2608
11:00	1.6	27.020	4	6.65	287.4928
12:00	1.6	27.020	6	8.65	373.9568
13:00	1.6	27.020	7	9.65	417.1888
14:00	1.6	27.020	9	11.65	503.6528
15:00	1.6	27.020	11	13.65	590.1168
16:00	1.6	27.020	12	14.65	633.3488
17:00	1.6	27.020	13	15.65	676.5808
18:00	1.6	27.020	14	16.65	719.8128

Variation of cooling load with time of the day due to wall facing north is shown in Figure 4.2 below. It can be seen in Figure 4.2 that the cooling load due to wall facing the north continues to increase from 8:00h when there was sunrise in the morning to 18:00 hour during the day. The cooling load temperature difference due to the wall facing north is directly influenced by the solar intensity and tend to increase during the day when higher solar radiation is felt. Consequently, the cooling load is altered accordingly.

Cooling load due to wall facing east at each hour of the day is shown in Table 4.3 . Due to shade on the wall of the case study facing east, as seen in Table 4.3, values of CLTD are the same as CLTD for wall facing north. As shown in Table 4.3, the cooling load increases from 136.00192W at 08:00 hour in the morning to 620.39232W at 18:00 hour in the evening. Also, the trend in change of cooling load corresponds relatively to the change in CLTD values.

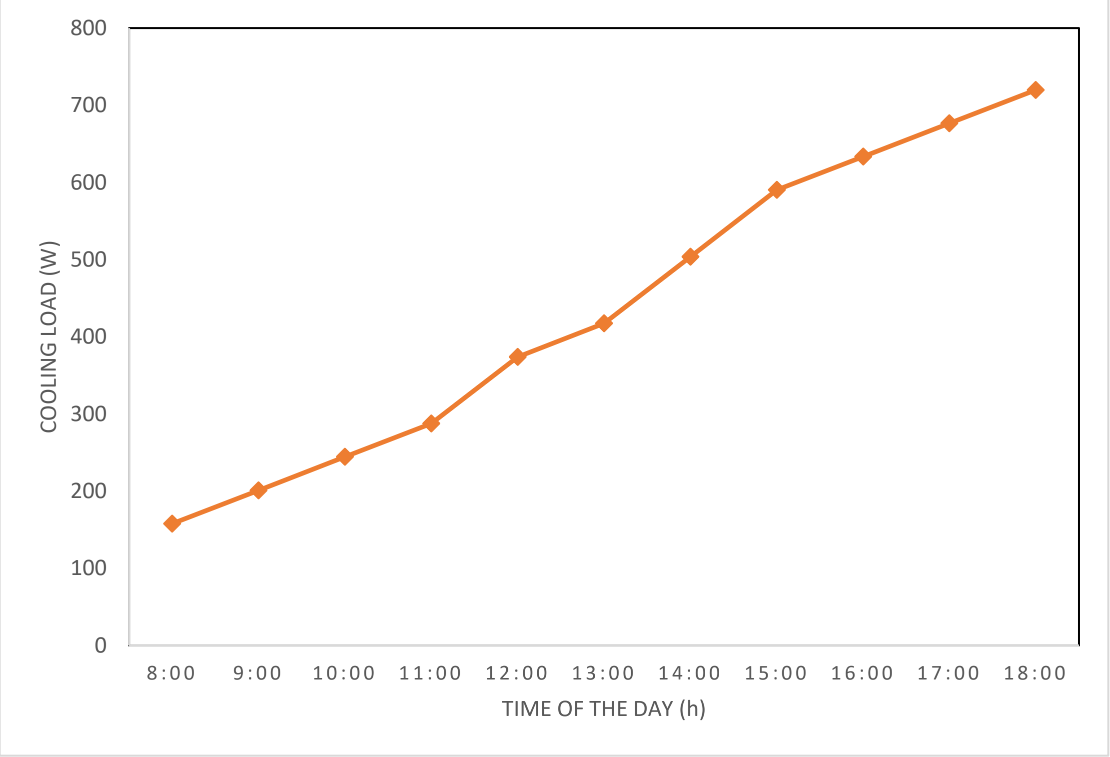

Figure 4.2: Variation of cooling load with time of the day due to wall facing north

Variation of cooling load with time of the day due to wall facing east is shown in Figure 4.3 below. It can be seen in Figure 4.3 that the cooling load due to wall facing the east continues to increase from 8:00h when there was sunrise in the morning to 18:00h during the day. The cooling load temperature difference due to the wall facing east is directly influenced by the solar intensity of the outdoor and tend to increase during the day when higher solar radiation is felt. Consequently, the cooling load is altered accordingly.

Total cooling load due to walls at each hour of the day is shown in Table 4.4. It can be seen in table 4.4 that the total cooling load due to heat gain from all the exterior walls of the case study increases from 458W at 8:0h to 2493W at 18:00h. Also, of all walls, cooling load due to heat gain from wall facing south is highest with maximum value of 1198W at 17:00h.

Table 4.3: Cooling load due to wall facing east

Time of the Day (h)	U $\left(\frac{W}{m^2K}\right)$	A(m^2)	CLTD (℃)	$LTD_{corrected}$ (℃)	Hourly Cooling Load (W)
08:00	1.6	23.288	1	3.65	136.00192
09:00	1.6	23.288	2	4.65	173.26272
10:00	1.6	23.288	3	5.65	210.52352
11:00	1.6	23.288	4	6.65	247.78432
12:00	1.6	23.288	6	8.65	322.30592
13:00	1.6	23.288	7	9.65	359.56672
14:00	1.6	23.288	9	11.67	434.83356
15:00	1.6	23.288	11	13.65	508.60992
16:00	1.6	23.288	12	14.65	545.87072
17:00	1.6	23.288	13	15.65	583.13152
18:00	1.6	23.288	14	16.65	620.39232

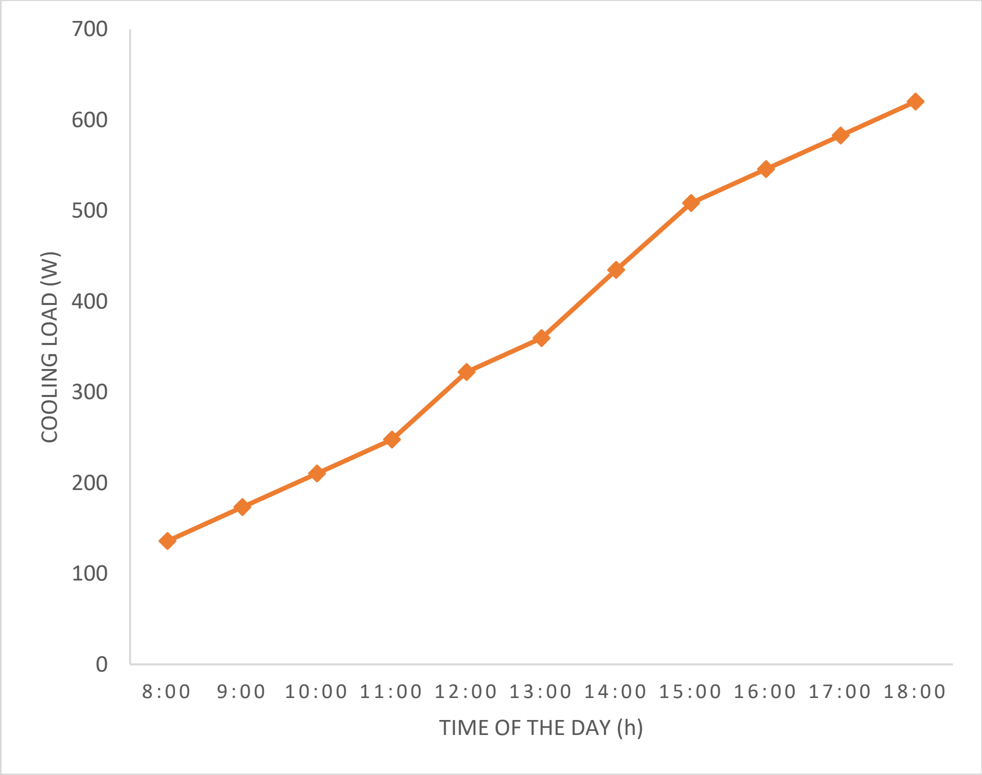

Figure 4.3: Variation of cooling load with time of the day due to wall facing east

Table 4.4: Total cooling load due to walls

Time of the day (h)	South Wall (W)	East wall (W)	North wall (W)	Total (W)
8:00	164	136	158	458
9:00	119	173	201	493
10:00	164	211	244	619
11:00	254	248	287	789
12:00	434	322	374	1130
13:00	614	360	417	1390
14:00	838	434	504	1776
15:00	973	509	590	2072
16:00	1153	546	633	2332
17:00	1198	583	677	2458
18:00	1153	620	720	2493

4.2.2 Cooling load due to window

4.2.2.1 *Cooling load due to conduction mode of heat transfer through windows*

Cooling load from conduction mode of heat transfer through windows facing north at each hour of the day is shown in Table 4.5. As shown in Table 4.5, the maximum cooling load due to conduction mode of heat transfer from all the windows facing north is 533.6928W at 15:00 hour and 16:00 hour. This corresponds to the maximum cooling load temperature difference (8^0C) across the windows facing north. furthermore, it can be seen in the Table 4.5 above that the least amount of cooling load due to conduction mode of heat transfer from all the windows facing north was recorded at 08:00 hour as 132.7968W, then increased to a maximum value of 533.6928W at 15:00 hour and 16:00h and later decreased to 483.5808W at 17:00 h.

Table 4.5: Cooling load from conduction mode of heat transfer through windows facing north

Time of the Day (h)	$\mathbf{U}\left(\frac{\boldsymbol{W}}{\boldsymbol{m^2K}}\right)$	$\mathbf{A}(\boldsymbol{m^2})$	CLTD (°C)	$CLTD_{corrected}$ (°C)	Hourly Cooling Load (W)
08:00	5.8	8.64	0	2.65	132.7968
09:00	5.8	8.64	1	3.65	182.9088
10:00	5.8	8.64	2	4.65	233.0208
11:00	5.8	8.64	4	6.65	333.2448
12:00	5.8	8.64	5	7.65	383.3568
13:00	5.8	8.64	7	9.65	483.5808
14:00	5.8	8.64	7	9.65	483.5808
15:00	5.8	8.64	8	10.65	533.6928
16:00	5.8	8.64	8	10.65	533.6928
17:00	5.8	8.64	7	9.65	483.5808
18:00	5.8	8.64	7	9.65	483.5808

Variation of cooling load with time of the day due to heat conduction via windows facing north is shown in Figure 4.4 below. It can be seen in Figure 4.4, that the cooling load from conduction mode of heat transfer through windows facing the north continues to increase from 8:00 hour when there was sunrise in the morning to 15:00 hour during the day and decreases from 17:00 hour during sun set. The cooling load temperature difference due to the window facing north is directly influenced by the solar intensity and tend to towards afternoon when higher solar intensity is experienced. Consequently, the cooling load is altered accordingly.

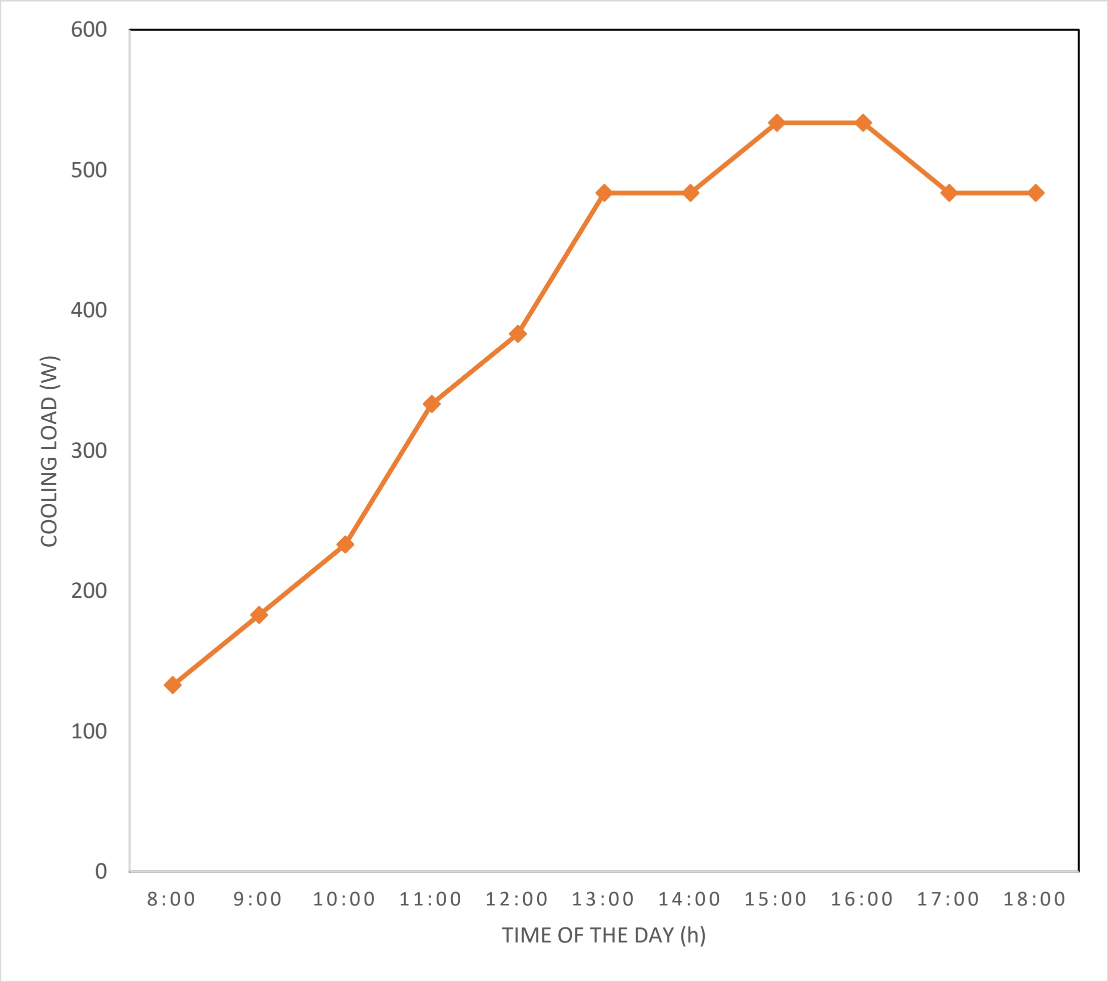

Figure 4.4: Variation of cooling load with time of the day due to conduction mode of heat transfer via window facing north

Cooling load from conduction mode of heat transfer through windows facing south at each hour of the day is shown in Table 4.6 below. It can be seen in Table 4.6 that the hourly cooling load due to conduction mode of heat transfer through windows facing south follows a similar trend as the windows facing north shown in Table 4.5. this is due to similar CLTD as indicated in ASHRAE (1997). However, due to different total window areas, the maximum cooling load from conduction mode of heat transfer through window facing south is 481.806W at 15:00 hour and 16:00h.

Variation of cooling load with time of the day due to heat conduction via windows facing south is shown in Figure 4.5

Table 4.6: Cooling load due to conduction mode of heat transfer through windows facing south

Time of the Day (h)	$\mathbf{U}\left(\frac{W}{m^2K}\right)$	$\mathbf{A}(m^2)$	CLTD (℃)	$CLTD_{corrected}$ (℃)	Hourly Cooling Load (W)
08:00	5.8	7.8	0	2.65	119.886
09:00	5.8	7.8	1	3.65	165.126
10:00	5.8	7.8	2	4.65	210.366
11:00	5.8	7.8	4	6.65	300.846
12:00	5.8	7.8	5	7.65	346.086
13:00	5.8	7.8	7	9.65	436.566
14:00	5.8	7.8	7	9.65	436.566
15:00	5.8	7.8	8	10.65	481.806
16:00	5.8	7.8	8	10.65	481.806
17:00	5.8	7.8	7	9.65	436.566
18:00	5.8	7.8	7	9.65	436.566

It can be seen in Figure 4.5, that the cooling load from conduction mode of heat transfer through windows facing the south continues to increase from 8:00 hour when there was sunrise in the morning to 15:00 hour during the day and decreases from 17:00 hour during sun set. The cooling load temperature difference due to the window facing south is directly influenced by the solar intensity and tend to increase towards afternoon when higher solar intensity occurs. Consequently, the cooling load is altered accordingly.

4.2.2.2 *Cooling load from solar radiation through windows*

Cooling load from solar radiation through windows facing north at each hour of the day is shown in Table 4.7 below. It can be seen in Table 4.7 that the maximum cooling load from solar radiation through windows facing north is 776.6496W at 13:00 hour and 18:00 hour.

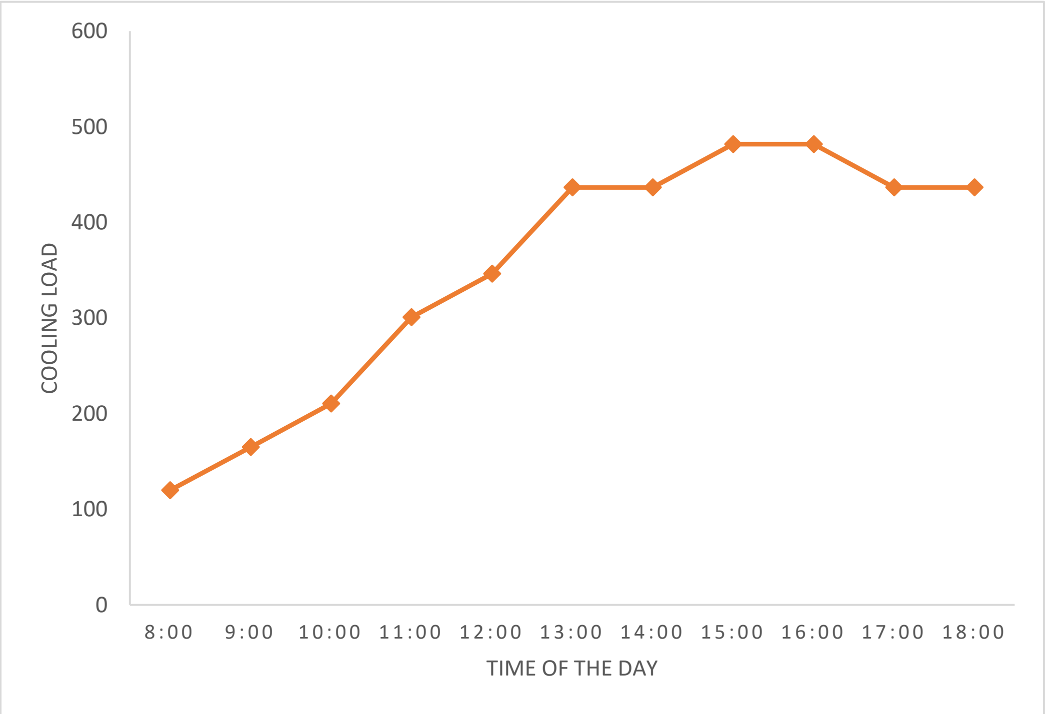

Figure 4.5: Variation of cooling load with time of the day due to conduction mode of heat transfer via window facing south

Table 4.7: Cooling load from solar radiation through windows facing north

Time of the Day (Hour)	$A(m^2)$	SCL (W/m^2)	SC	Hourly Cooling Load (W)
08:00	8.64	66	0.89	507.5136
09:00	8.64	76	0.89	584.4096
10:00	8.64	85	0.89	653.6160
11:00	8.64	91	0.89	699.7536
12:00	8.64	98	0.89	753.5808
13:00	8.64	101	0.89	776.6496
14:00	8.64	98	0.89	753.5808
15:00	8.64	95	0.89	730.5120
16:00	8.64	88	0.89	676.6848
17:00	8.64	91	0.89	699.7536
18:00	8.64	101	0.89	776.6496

Variation of cooling load with time of the day due to solar radiation via windows facing north is shown in Figure 4.6

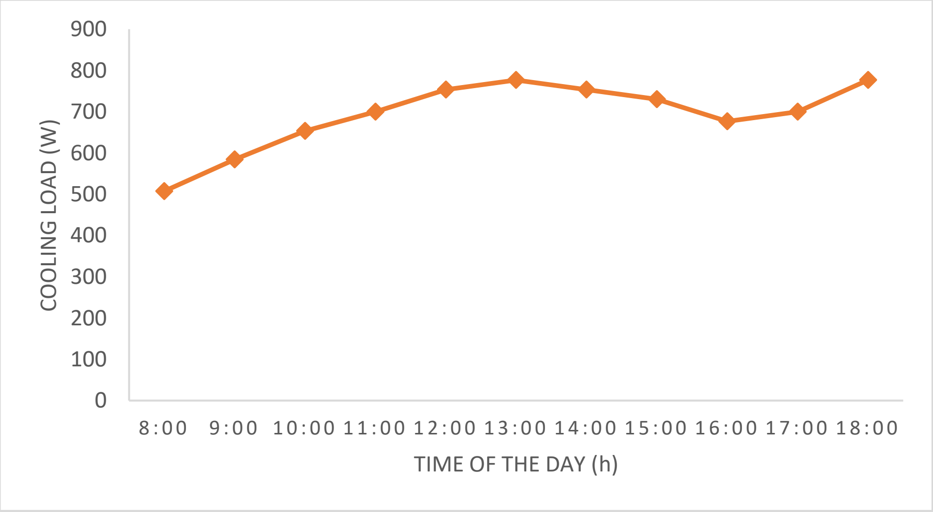

Figure 4.6: Variation of cooling load with time of the day due to solar radiation via facing north

As shown in Figure 4.6, the cooling load due to solar radiation is influenced by the solar intensity and tend to increase towards afternoon when higher solar intensity occurs.

Cooling load from solar radiation through windows facing south at each hour of the day is shown in Table 4.8 below. It can be seen in Table 4.8 cooling load due to solar radiation through windows facing south increases from a minimum value of 458.172W at 8:00h to a maximum value of 1506.414W at 13:00 hour, then decreases to 659.490W at 18:00h.

Variation of cooling load with time of the day due to solar radiation via windows facing south is shown in Figure 4.7 below. As shown in Figure 4.7, the cooling load due to solar radiation is influenced by the solar intensity and tend to increase towards afternoon when higher solar intensity occurs.

Table 4.8: Cooling load from solar radiation through windows facing south

Time of the Day (h)	A ($\boldsymbol{m^2}$)	SCL ($\boldsymbol{W/m^2}$)	SC	Hourly Cooling Load ($\boldsymbol{W}$)
08:00	7.8	66	0.89	458.172
09:00	7.8	101	0.89	701.142
10:00	7.8	145	0.89	1006.590
11:00	7.8	186	0.89	1291.212
12:00	7.8	211	0.89	1464.762
13:00	7.8	217	0.89	1506.414
14:00	7.8	198	0.89	1374.516
15:00	7.8	164	0.89	1138.488
16:00	7.8	129	0.89	895.518
17:00	7.8	113	0.89	784.446
18:00	7.8	95	0.89	659.490

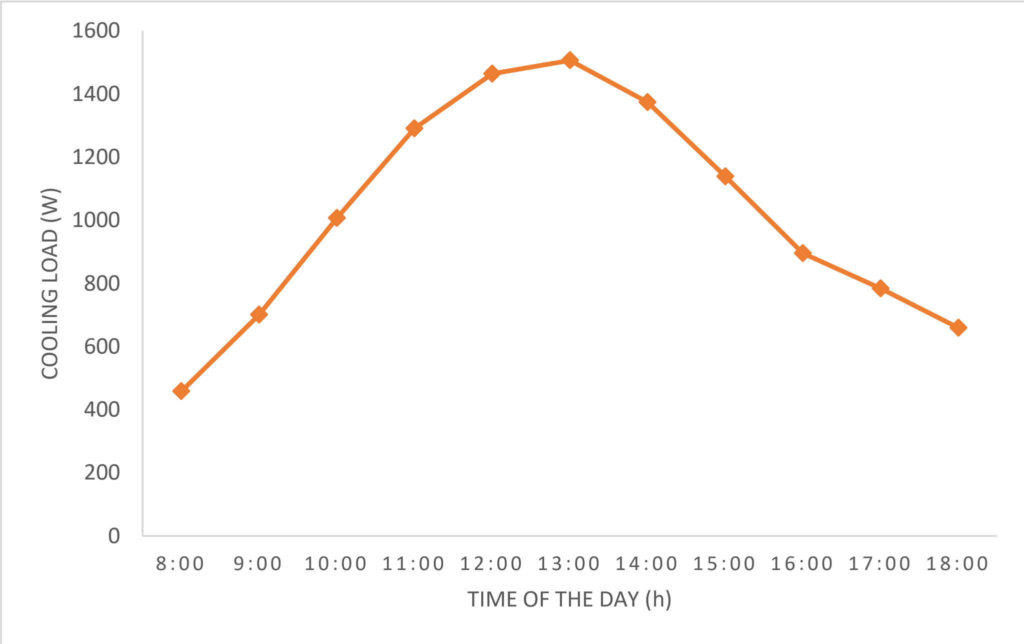

Figure 4.7: Variation of cooling load with time of the day due to solar radiation via window facing south

The total cooling load due to heat gain via windows of the lecture room considered is approximately 1218W at 08:00h as shown in Table 4.9. It can also be seen in the Table 4.9 that total cooling load due to windows continues to increase to a maximum value of 3203W at 13:00 in the afternoon and later decreased to 2356W at 18:00 hour in the evening. About 71% of sensible cooling load due to windows is from solar radiation This shows that the more the windows are exposed to sun, the more the heat transfer through solar radiation, the more the sensible load.

4.2.3 Cooling load due to occupants

Total cooling load due to window is the summation of both the cooling load from solar radiation and cooling load from conduction. Table 4.9 depicts the total cooling load due to heat gain from windows.

Cooling load due to heat gain into the lecture room from occupants (students and lecturer) is classified into sensible and latent. Table 4.10 shows the cooling load as a result sensible heat gain into the space from occupants for each hour of the day.

Table 4.9: Total cooling load due to heat gain from windows

Time of the Day (h)	North Window (Conduction, W)	North Window (Radiation, W)	South Window (Conduction, W)	South Window (Radiation, W)	Total (W)
08:00	133	508	120	458	1218
09:00	183	584	165	701	1634
10:00	233	654	210	1007	2104
11:00	333	700	301	1291	2625
12:00	383	754	346	1465	2948
13:00	484	777	437	1506	3203
14:00	484	754	437	1375	3048
15:00	534	731	482	1138	2884
16:00	534	677	482	896	2588
17:00	484	700	437	784	2404
18:00	484	777	437	659	2356

Table 4.10: Cooling load due to sensible heat gain from occupants

Time of the Day (h)	Number of People	Hours After Entry (h)	SHG_p (*W*)	CLF_p	Hourly Cooling Load (*W*)
08:00	101	0	70	0.00	0.0
09:00	101	1	70	0.62	4383.4
10:00	101	2	70	0.70	4949.0
11:00	101	3	70	0.75	5302.5
12:00	101	1	70	0.65	4595.5
13:00	101	2	70	0.71	5019.7
14:00	101	3	70	0.78	5514.6
15:00	101	1	70	0.67	4736.9
16:00	101	2	70	0.76	5373.2
17:00	101	3	70	0.80	5656.0
18:00	101	1	70	0.74	5231.8

Variation of cooling load due occupants with time of the day is shown in figure 4.8 below.

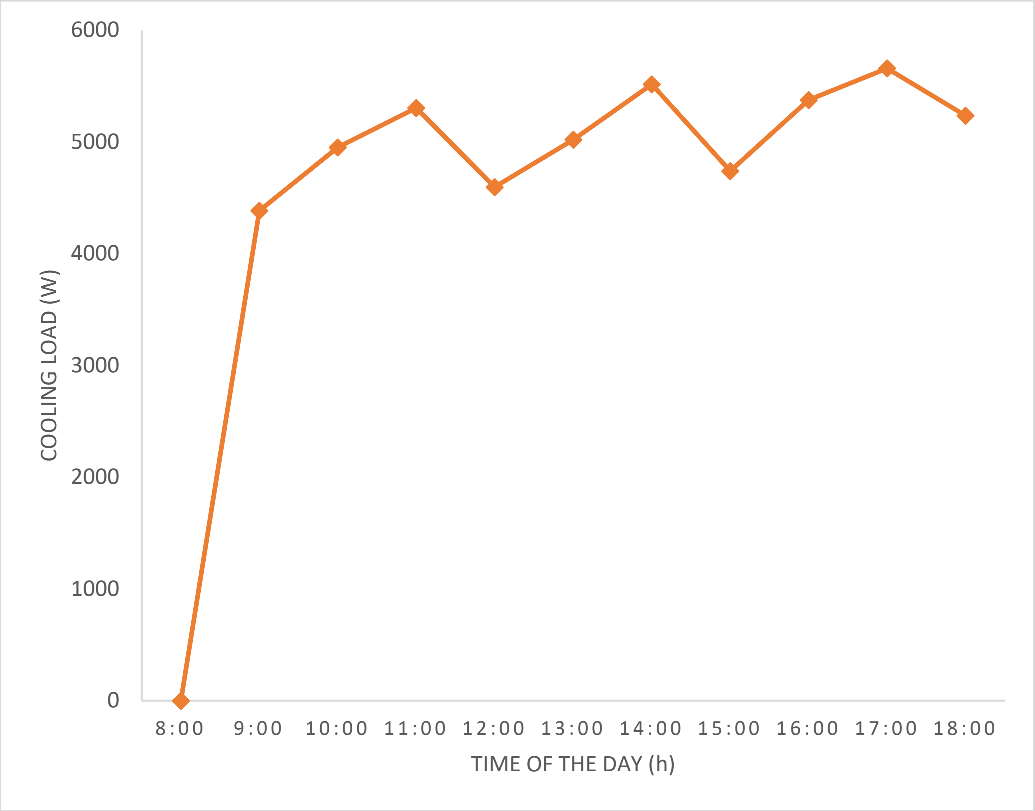

Figure 4.8: Variation of cooling load with time of the day due to occupants

It can be seen in Table 4.10 that the cooling load due to sensible heat gain is nil at 8:00 hour when the occupants just entered the lecture room. Then increases to 5302.5W at 11:00 due to the set of occupants for the first lecture assumed to last for maximum of 3 hours. As shown in Figure 4.8, it was observed that there was decrease in cooling load due to sensible heat gain on arrival of fresh set of occupants for the next lecture, and continues to rise as the hours after entry increases. This is because, the part of the heat gain responsible for temperature change is not directly affected on the arrival of occupants. As hours after entry increases for the same set of occupants, heat is conducted to the chairs and desk and later convected to the space. At the point, when heat is convected to the space, the temperature of the space is altered.

Cooling load as a result of latent heat gain into the space from occupants for each hour of the day is shown in Table 4.11 below.

Table 4.11: Latent heat gain from occupants

Time of the Day (h)	Number of People	LHG_p (*W*)	Hourly Cooling Load (*W*)
08:00	101	45	4545
09:00	101	45	4545
10:00	101	45	4545
11:00	101	45	4545
12:00	101	45	4545
13:00	101	45	4545
14:00	101	45	4545
15:00	101	45	4545
16:00	101	45	4545
17:00	101	45	4545
18:00	101	45	4545

The cooling load of the lecture room due to latent heat gain from occupants is constant from 08:00 hour to 18:00 hour with a value of 4545W as shown in table 4.11. The constant value is due to no change of activity assumed to be taking place in the lecture room.

4.2.4 Cooling load due to lights

Cooling load due to heat transfer from installed electric florescence bulbs into the lecture room is shown in figure 4.12 below.

Table 4.12: Cooling load due to lights

Time of the Day (h)	h After Turned On (h)	$\mathbf{P}_l$ (W)	F_{SA}	F_{UT}	$\mathbf{CLF}_l$	Quantity	Hourly Cooling Load (W)
08:00	0	26	1.2	1.0	0.00	6	0.000
09:00	1	26	1.2	1.0	0.66	6	123.552
10:00	2	26	1.2	1.0	0.74	6	138.528
11:00	3	26	1.2	1.0	0.77	6	144.144
12:00	4	26	1.2	1.0	0.81	6	151.632
13:00	5	26	1.2	1.0	0.83	6	155.376
14:00	6	26	1.2	1.0	0.86	6	160.992
15:00	7	26	1.2	1.0	0.88	6	164.736
16:00	8	26	1.2	1.0	0.90	6	168.480
17:00	9	26	1.2	1.0	0.91	6	170.352
18:00	10	26	1.2	1.0	0.92	6	172.224

It can be seen in Table 4.12 that the cooling load due to sensible heat gain from lights is nil at 8:00 h when the lights were turned on in the lecture room. Then continues to increase to a maximum value of 172.224W at 18:00 due to increase in the number of hours the lights were on. The recorded value of 0W at 8:00 hour indicates that the part of the heat gain responsible for temperature change is not directly affected immediately the lights were turned on. As hours after turned on increases, heat generated by the filaments are transferred to the light casings first and later convected to the space. At the point, when heat is convected to the space, the temperature of the space is altered.

4.2.5 Cooling load due to ceiling fans

Cooling load due to heat gain from ceiling fans is shown in table 2.13 below.

Table 4.13: Cooling load due to ceiling fans

Time of the Day (h)	Hours After Turned On (h)	P_e (W)	η_e	CLF	Quantity	H Cooling Load (W)
08:00	0	70	0.35	0.00	4	0.00
09:00	1	70	0.35	0.66	4	64.68
10:00	2	70	0.35	0.74	4	72.52
11:00	3	70	0.35	0.77	4	75.46
12:00	4	70	0.35	0.81	4	79.38
13:00	5	70	0.35	0.83	4	81.34
14:00	6	70	0.35	0.86	4	84.28
15:00	7	70	0.35	0.88	4	86.24
16:00	8	70	0.35	0.90	4	88.20
17:00	9	70	0.35	0.91	4	89.18
18:00	10	70	0.35	0.92	4	90.16

It can be seen in Table 4.13 that the cooling load due to sensible heat gain from ceiling fans is nil at 8:00 hour when the ceiling fans were turned on in the lecture room. Then continues to increase to a maximum value of 90.16W at 18:00 due to increase in the number of hours the fans were on. The recorded value of 0W at 8:00 hour indicates that the part of the heat gain responsible for temperature change is not directly affected immediately when the fans were turned on. As hours after turned on increases, heat generated by the coil in the fans are transferred to casings first and later convected to the space. At the point, when heat is convected to the space, the temperature of the space is altered.

4.2.6 Cooling load due to ventilation

Sensible cooling load and latent cooling load due to ventilation are 7516W and 15201W respectively.

Total cooling load of the case study is shown in table 4.14 below. It can be seen from Table 4.14 that the minimum and maximum cooling load of the space due to sensible heat gain from the walls, windows, occupants, ventilation, lights and fans are 9192W at 8:00 hour and 18293W at 17:00 hour respectively. It is evident in Table 4.14 that the cooling load due to sensible heat gain from ventilation accounts for about 41% of the total hourly cooling loads. A recorded value of 0W at 8:00 hour for cooling load due to occupants, lights and fan is in conformity with the fact proposed by CLTD/SCL/CLF method of cooling load calculation that the sensible cooling load is not immediately affected by internal heat source such as people, equipment, appliances and lights (ASHRAE, 1997 and Bhatia, 2004).

A graph of cooling load against time of the day from various components of the building is shown in figure 4.9 below.

It is evident in Figure 4.9 that the cooling load due to sensible heat gain from ventilation is highest and cooling load due to ceiling fans is lowest.

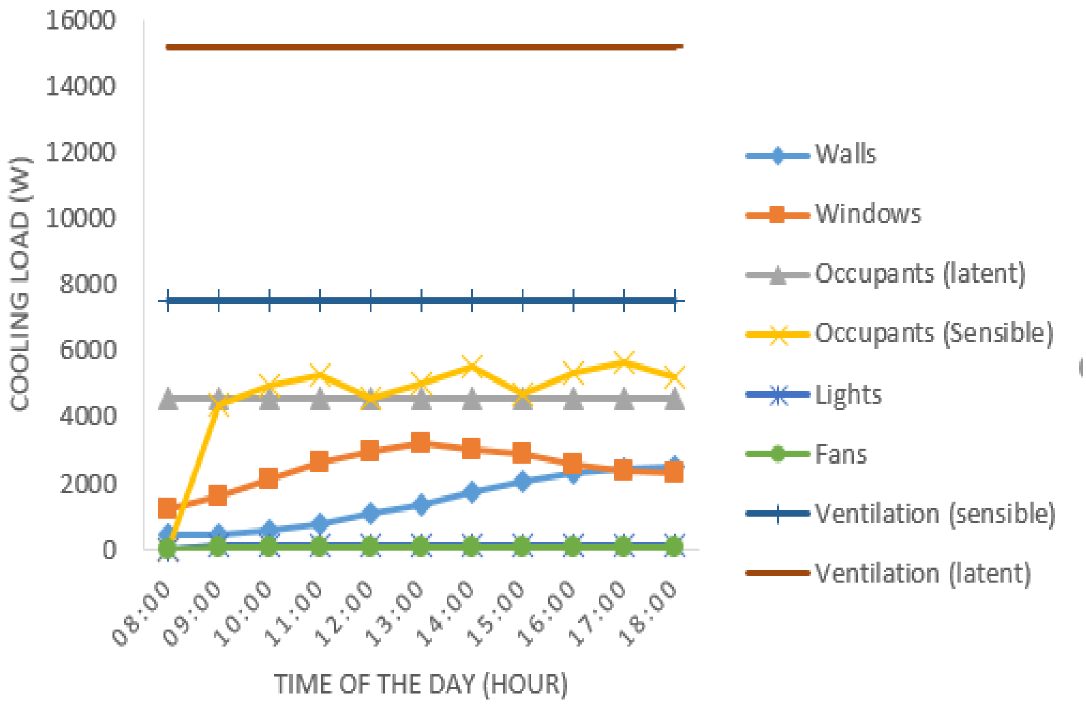

Figure 4.9: Variation of cooling load due to various building components with time of the day

Table 4.14: Total cooling load from heat gain through various building components

Time of the day (h)	Walls (W)	Windows (W)	People (Latent,W)	People (Sensible,W)	Light (W)	Fan (W)	Ventilation (Sensible, W)	Ventilation (Latent, W)	Total Sensible Cooling load (W)	Total Latent Cooling load (W)
08:00	458	1218	4545	0	0	0	7516	15201	9192	19746
09:00	493	1634	4545	4383	124	65	7516	15201	14215	19746
10:00	619	2104	4545	4949	139	73	7516	15201	15400	19746
11:00	789	2625	4545	5303	144	75	7516	15201	16452	19746
12:00	1130	2948	4545	4596	152	79	7516	15201	16421	19746
13:00	1390	3203	4545	5020	155	81	7516	15201	17365	19746
14:00	1776	3048	4545	5515	161	84	7516	15201	18100	19746
15:00	2072	2884	4545	4737	165	86	7516	15201	17460	19746
16:00	2332	2588	4545	5373	168	88	7516	15201	18065	19746
17:00	2458	2404	4545	5656	170	89	7516	15201	18293	19746
18:00	2493	2356	4545	5232	172	90	7516	15201	17859	19746

The variations of hourly total sensible cooling load and latent cooling load with time of the day are shown in figure 4.10.

It can be seen in figure 4.2 that the latent load is constant with the increase in the time of the day. This connotes that the latent heat gain from people within the space remains the same through out the classroom period. The total sensible load increased with the time of the day as evident in Figure 4.2. This shows that the more the exterior of the space is being heated by the sun, the more the heat that is conducted and transmitted to the space and the more the sensible load increase.

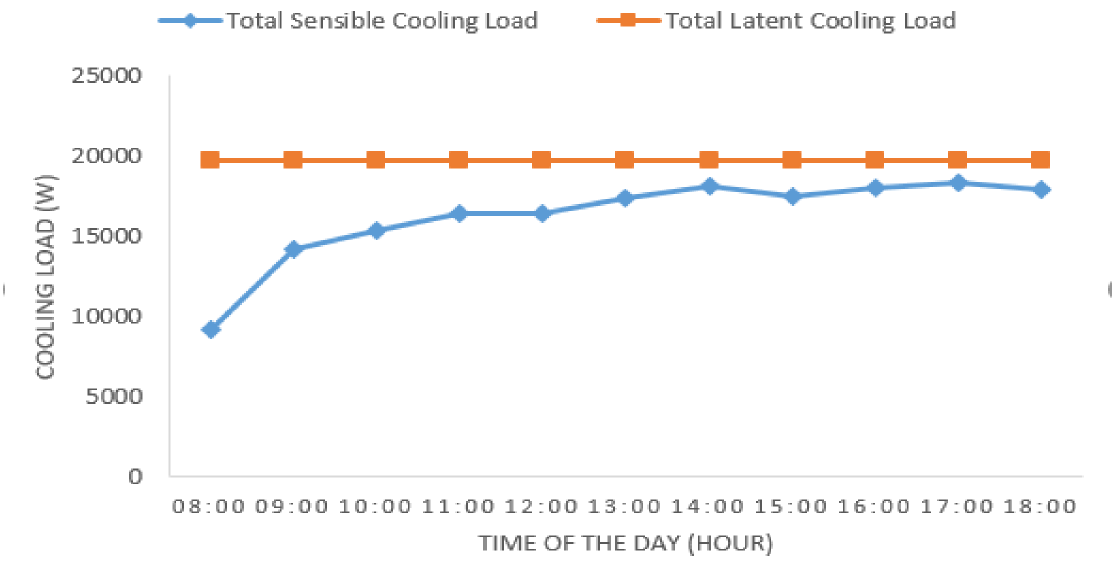

Figure 4.10: Variations of hourly total Sensible cooling load and latent cooling load with time of the day

The calculated maximum space cooling loads are 18293W sensible and 19746W latent. These values are comparable with 11432W sensible and 4120W latent obtained by Obuka *et al*. (2015) who used computer application to estimate the maximum space cooling load of a zone of 70 students and 5 laptops. The maximum cooling load sensible obtained in this research work is less than 20458.6W and 33541.3W obtained by Suziyana *et al*. (2013) for Computer Laboratory Room and in Excellent Centre Room respectively.

4.3 Cooling load calculation using computer application

The computer application developed was used to calculate the cooling load of the case study. First page of result from the computer application is shown in Figure 4.11 below.

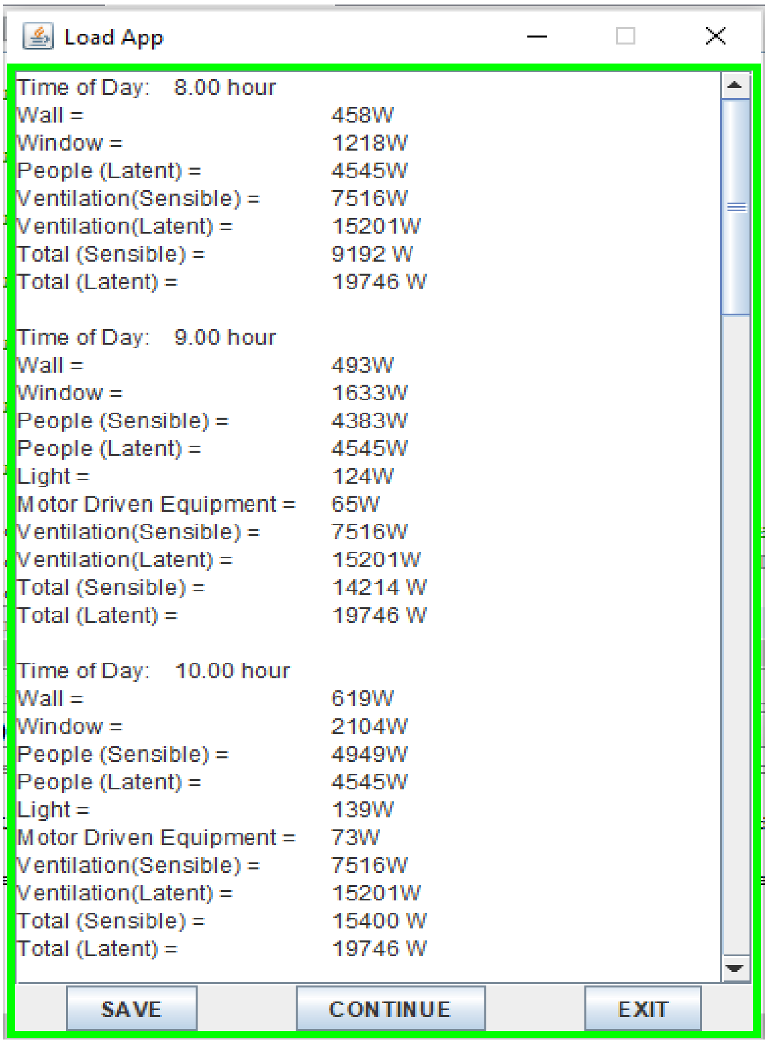

Figure 4.11: First page of result from computer application

As illustrated in Figure 4.11, values of cooling loads of various building components for 8:00 hour, 9:00 hour, 10:00 h and 11:00 hour correspond with values gotten from manual calculation in Table 4.14 above.

Second page, third page and fourth page of results from the computer application are shown in Figures 4.11, 4.12, 4.13 and 4.15 below respectively.

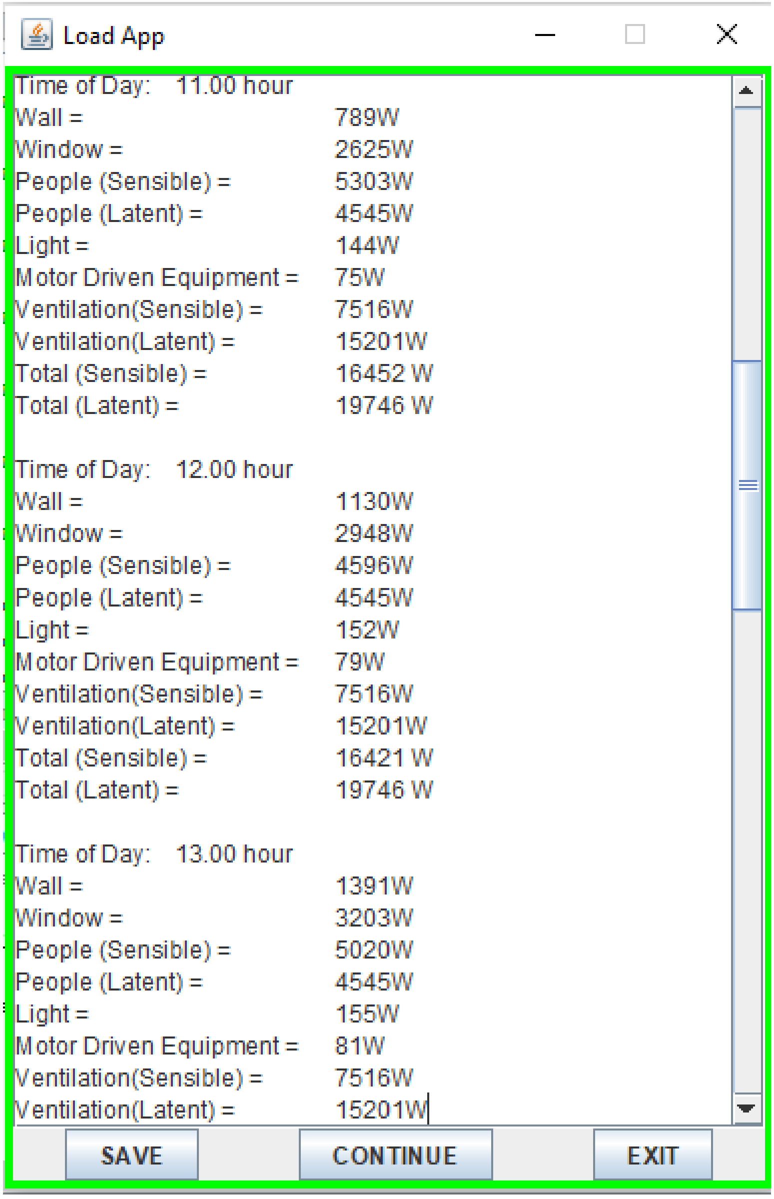

Figure 4.12: Second page of result from the computer application

As shown in Figure 4.12, values of cooling loads of various building components for 11:00 h, 12:00 h, 13:00 hour and 14:00 hour correspond with values gotten from manual calculation in Table 4.14 above.

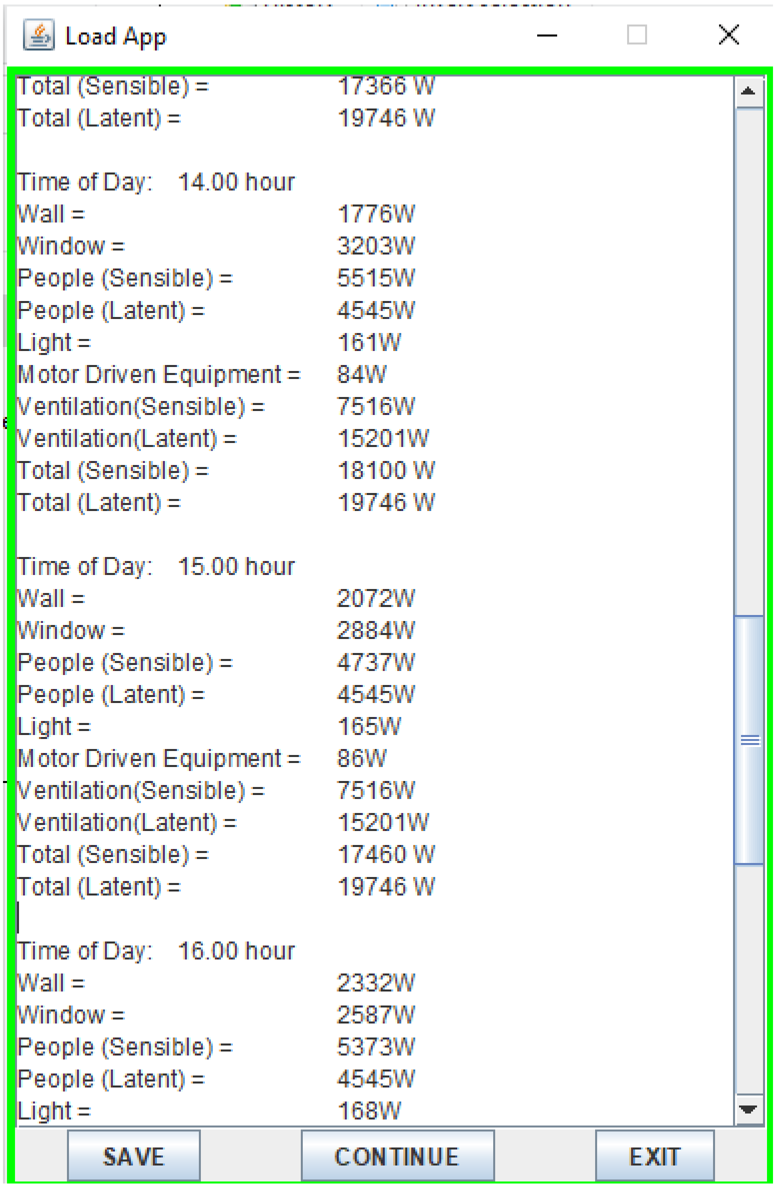

Figure 4.13: Third page of result from the computer application

Figure 4.13 depicts cooling loads due to various building components for the hours of 14:00, 15:00, 16:00 and 17:00. The values of the cooling loads for 14:00 h, 15:00 h, 16:00 h and 17:00h are the same as the values from manual calculation summarised in Table 4:14 above as shown in Figure 4.13.

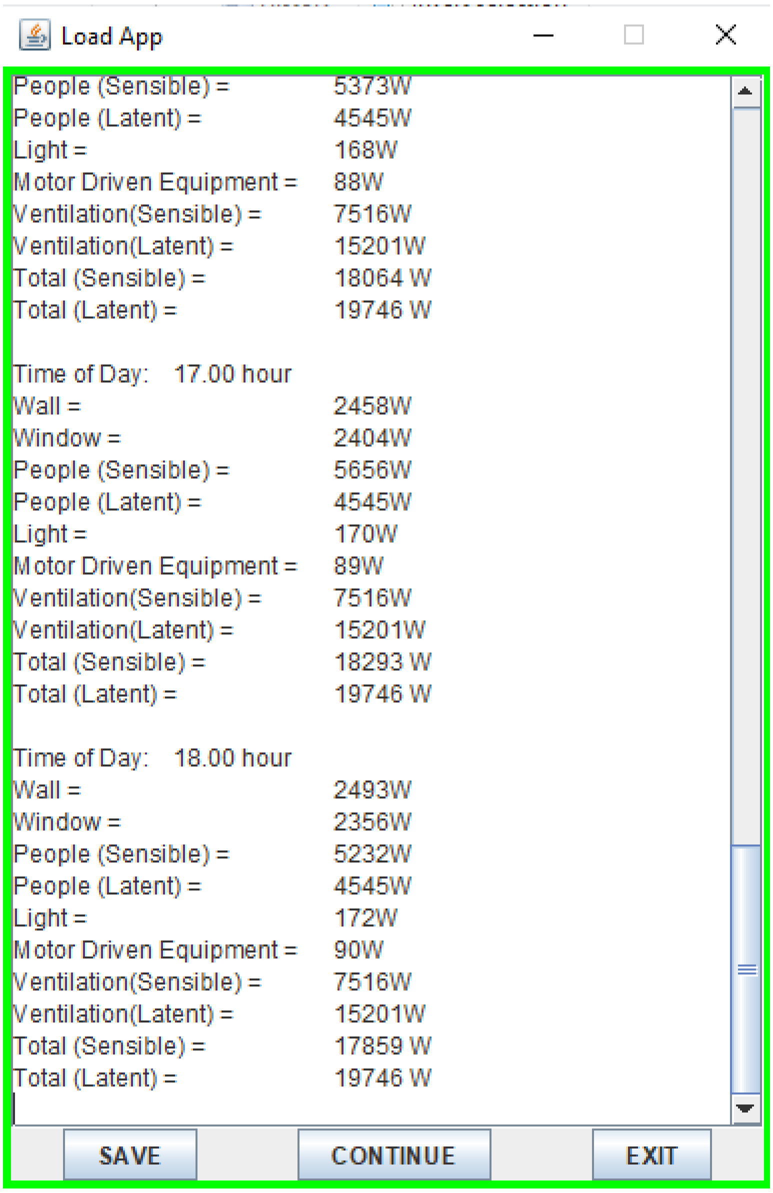

Figure 4.14: Fourth page of result from the computer application

It can be seen in Figure 4.14 that the peak sensible cooling load is 18293W at 17:00 h which corresponds with the peak value from manual calculation summarised in Table 4.14 above. Values of cooling loads of various building components for 16:00h 17:00 h and 18:00 h are the same with values gotten from manual calculation summarised in Table 4.14 above.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

With the aid of Building Information Modelling software, the case study was easily modelled and all the building components well visualised as shown in Appendix A.

The computer software developed can be applied in estimation of cooling loads of residential buildings and commercial buildings provided the inputs are well determined. Results from the software and manual calculations shows that the maximum cooling loads of Room 103, are 18923W sensible and 19746W latent.

Hence, the cooling system of Room 103, must have a maximum capacity enough to extract a sensible heat energy of 18293W and latent heat energy of 19746W from the indoor, in order to bring the indoor temperature to a range from 21℃ to 26℃ and relative humidity to range from 55% to 60% respectively.

5.2 Recommendations

Results from the CLTD/SCL/CLF method depends on tabulated data from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). An efficient use of the software created in this work would require a proper use of the table. Extraction of data from the ASHRAE tables may be quite stressful to novice. Hence, I will recommend further research on how the computer application can be linked to the internet for automatic extraction of data from any geographical location and applying them in calculating cooling load when needed.

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APPENDIX A

CALCULATIONS

Cooling loads from various components of Room 103, occupants and ventilation are calculated. The geographical location of the case study is different from that which was used to generate the CLTD tables. Hence, applying equation 3.2, the correct CLTD is calculated as:

$$t_m = 37.1 - \frac{11.1}{2} = 31.55℃$$

$$CLTD_{corrected} = CLTD + (25.5 - 25) + (31.55 - 29.4)$$

$$CLTD_{corrected} = CLTD + 2.65 \quad (3.13)$$

Cooling loads due to walls

Cooling loads due to heat conduction through the walls are calculated using Equation 3.1 for each time of the day from 8.00hr to 18.00hr. From Equation 3.1, cooling load due to walls is written as:

$$q = \mathrm{U} \times \mathrm{A} \times (\mathrm{CLTD}) \quad (3.1)$$

Geographical location of the case study is different from that which was used to generate the CLTD table. Hence, substituting $CLTD_{corrected}$ for CLTD into Equation 3.1,

$$q = \mathrm{U} \times \mathrm{A} \times CLTD_{corrected}$$

$$q = \mathrm{U} \times \mathrm{A} \times (CLTD + 2.65) \quad (3.14)$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South $CLTD$ at 8:00hr = 1℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 8:00hr,

$$q = 1.6 \times 28.099 \times (1 + 2.65) = 164.0982W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$, and South *CLTD* at 9:00hr = 0℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 9:00hr,

$$q = 1.6 \times 28.099 \times (0 + 2.65) = 119.1398W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 10:00hr = 1℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 10:00hr,

$$q = 1.6 \times 28.099 \times (1 + 2.65) = 164.0982W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 11:00hr = 3℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 11:00hr,

$$q = 1.6 \times 28.099 \times (3 + 2.65) = 254.0150W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 12:00hr = 7℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 12:00hr,

$$q = 1.6 \times 28.099 \times (7 + 2.65) = 433.8486W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 13:00hr = 11℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 13:00hr,

$$q = 1.6 \times 28.099 \times (11 + 2.65) = 613.6822W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 14:00hr = 16℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 14:00hr,

$$q = 1.6 \times 28.099 \times (16 + 2.65) = 838.4742W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 15:00hr = 19℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 15:00hr,

$$q = 1.6 \times 28.099 \times (19 + 2.65) = 973.3494W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 16:00hr = 23℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 16:00hr,

$$q = 1.6 \times 28.099 \times (23 + 2.65) = 1153.1830W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 17:00hr = 24℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 17:00hr,

$$q = 1.6 \times 28.099 \times (24 + 2.65) = 1198.1414W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 28.099m^2$ and South *CLTD* at 18:00hr = 23℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing south at 18:00hr,

$$q = 1.6 \times 28.099 \times (23 + 2.65) = 1153.1830W$$

Cooling loads due to wall facing south at each hour of the day are tabulated in Table 4.1.

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 8:00hr = 1℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 8:00hr,

$$q = 1.6 \times 27.020 \times (1 + 2.65) = 157.7968W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$, and North *CLTD* at 9:00hr = 2℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 9:00hr,

$$q = 1.6 \times 27.020 \times (2 + 2.65) = 201.0288W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 10:00hr = 3℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 10:00hr,

$$q = 1.6 \times 27.020 \times (3 + 2.65) = 244.2608W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 11:00hr = 4℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 11:00hr,

$$q = 1.6 \times 27.020 \times (4 + 2.65) = 287.4928W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 12:00hr = 6℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 12:00hr,

$$q = 1.6 \times 27.020 \times (6 + 2.65) = 373.9568W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 13:00hr = 7℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 13:00hr,

$$q = 1.6 \times 27.020 \times (7 + 2.65) = 417.1888W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 14:00hr = 9℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 14:00hr,

$$q = 1.6 \times 27.020 \times (9 + 2.65) = 503.6528W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 15:00hr = 11℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 15:00hr,

$$q = 1.6 \times 27.020 \times (11 + 2.65) = 590.1168W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 16:00hr = 12℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 16:00hr,

$$q = 1.6 \times 27.020 \times (12 + 2.65) = 633.3488W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 17:00hr = 13℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 17:00hr,

$$q = 1.6 \times 27.020 \times (13 + 2.65) = 676.5808W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 27.020m^2$ and North *CLTD* at 18:00hr = 14℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing north at 18:00hr,

$$q = 1.6 \times 27.020 \times (14 + 2.65) = 719.8128W$$

Cooling loads due to wall facing north at each hour of the day are tabulated in Table 4.2.

The wall facing East is shaded, hence, the *CLTD* values will be the same as that of the wall facing North (ASHRAE, 1997).

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 8:00hr = 1℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 8:00hr,

$$q = 1.6 \times 23.288 \times (1 + 2.65) = 136.00192W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 23.288m^2$, and North *CLTD* at 9:00hr = 2℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 9:00hr,

$$q = 1.6 \times 23.288 \times (2 + 2.65) = 173.26272W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 10:00hr = 3℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 10:00hr,

$$q = 1.6 \times 23.288 \times (3 + 2.65) = 210.52352W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 11:00hr = 4℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 11:00hr,

$$q = 1.6 \times 23.288 \times (4 + 2.65) = 247.78432W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 12:00hr = 6℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 12:00hr,

$$q = 1.6 \times 23.288 \times (6 + 2.65) = 322.30592W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 13:00hr = 7℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 13:00hr,

$$q = 1.6 \times 23.288 \times (7 + 2.65) = 359.56672W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 14:00hr = 9℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 14:00hr,

$$q = 1.6 \times 23.288 \times (9 + 2.65) = 434.08832W$$

Putting, $U = 1.6 \frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 15:00hr = 11℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 15:00hr,

$$q = 1.6 \times 23.288 \times (11 + 2.65) = 508.60992W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 16:00hr = 12℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 16:00hr,

$$q = 1.6 \times 23.288 \times (12 + 2.65) = 545.87072W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 17:00hr = 13℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 17:00hr,

$$q = 1.6 \times 23.288 \times (13 + 2.65) = 583.13152W$$

Putting, $U = 1.6\frac{W}{m^2K}$, $A = 23.288m^2$ and North *CLTD* at 18:00hr = 14℃ (ASHRAE, 1997) into Equation 3.14.

Cooling loads due to wall facing east at 18:00hr,

$$q = 1.6 \times 23.288 \times (14 + 2.65) = 620.39232W$$

Cooling loads due to wall facing east at each hour of the day are tabulated in Table 4.3.

Cooling load due to windows

Cooling loads due to windows are in two categories. Namely, cooling load caused by conduction mode of heat transfer through the windows and cooling load as a result of solar radiation through the windows. Equations 3.14 and 3.3 are used in calculation of cooling loads due to conduction and solar radiation respectively.

$$q = \mathrm{U} \times \mathrm{A} \times (CLTD + 2.65) \quad (3.14)$$

$$q_{rad} = \mathrm{A} \times (\mathrm{SC}) \times (\mathrm{SCL}) \quad (3.3)$$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North $CLTD$ at 8:00hr = 0℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 8:00hr,

$$q = 5.8 \times 8.64 \times (0 + 2.65) = 132.7968W$$

Putting, $A = 8.64m^2$, $\mathrm{SC} = 0.89$ (ASHRAE, 1997) and North SCL at 8:00hr = 66W/m^2 (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 8:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 66 = 507.5136\mathrm{W}$$

Cooling load due to windows facing North at 8:00hr $= 132.7968 + 507.5136 = 640.3104W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North $CLTD$ at 9:00hr = 1℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 9:00hr,

$$q = 5.8 \times 8.64 \times (1 + 2.65) = 182.9088W$$

Putting, $A = 8.64m^2$, $\mathrm{SC} = 0.89$ (ASHRAE, 1997) and North SCL at 9:00hr = 76W/m^2 (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 9:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 76 = 584.4096\mathrm{W}$$

Cooling load due to windows facing North at 9:00hr $= 182.9088 + 584.4096 = 767.3184W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North $CLTD$ at 10:00hr = 2℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 10:00hr,

$$q = 5.8 \times 8.64 \times (2 + 2.65) = 233.0208W$$

Putting, $A = 8.64m^2$, SC $= 0.89$ (ASHRAE, 1997) and North SCL at 10:00hr = 85W/m^2 (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 10:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 85 = 653.616\text{W}$$

Cooling load due to windows facing North at 10:00hr $= 233.0208 + 653.616 = 886.6368W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North $CLTD$ at 11:00hr = 4℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 11:00hr,

$$q = 5.8 \times 8.64 \times (4 + 2.65) = 333.2448W$$

Putting, $A = 8.64m^2$, SC $= 0.89$ (ASHRAE, 1997) and North SCL at 11:00hr = 91W/m^2 (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 11:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 91 = 699.7536\text{W}$$

Cooling load due to windows facing North at 11:00hr $= 333.245 + 699.754 = 1032.999W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North *CLTD* at 12:00hr = 5℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 12:00hr,

$$q = 5.8 \times 8.64 \times (5 + 2.65) = 383.3568W$$

Putting, $A = 8.64m^2$, SC $= 0.89$ (ASHRAE, 1997) and North SCL at 12:00hr = $98W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 12:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 98 = 753.5808\text{W}$$

Cooling load due to windows facing North at 12:00hr $= 383.357 + 753.581 = 1136.938W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North *CLTD* at 13:00hr = 7℃ (ASHRAE, 1997) into Eequation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 13:00hr,

$$q = 5.8 \times 8.64 \times (7 + 2.65) = 483.5808W$$

Putting, $A = 8.64m^2$, SC $= 0.89$ (ASHRAE, 1997) and North SCL at 13:00hr = $101W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 13:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 101 = 776.6496\text{W}$$

Cooling load due to windows facing North at 13:00hr $= 483.581 + 776.650 = 1260.231W$

Putting, $U = 5.8 \frac{W}{m^2K}$, $A = 8.64m^2$ and North $CLTD$ at 14:00hr = 7°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 14:00hr,

$$q = 5.8 \times 8.64 \times (7 + 2.65) = 483.5808W$$

Putting, $A = 8.64m^2$, SC $= 0.89$ (ASHRAE, 1997) and North SCL at 14:00hr = $98W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 14:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 98 = 753.5808\text{W}$$

Cooling load due to windows facing North at 14:00hr $= 483.581 + 753.581 = 1237.162W$

Putting, $U = 5.8 \frac{W}{m^2K}$, $A = 8.64m^2$ and North $CLTD$ at 15:00hr = 8°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 15:00hr,

$$q = 5.8 \times 8.64 \times (8 + 2.65) = 533.6928W$$

Putting, $A = 8.64m^2$, SC $= 0.89$ (ASHRAE, 1997) and North SCL at 15:00hr = $95W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 15:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 95 = 730.512\text{W}$$

Cooling load due to windows facing North at 15:00hr $= 533.693 + 730.512 = 1264.205W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North *CLTD* at 16:00hr = 8℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 16:00hr,

$$q = 5.8 \times 8.64 \times (8 + 2.65) = 533.6928W$$

Putting, $A = 8.64m^2$, $\text{SC} = 0.89$ (ASHRAE, 1997) and North SCL at 16:00hr = $88W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 16:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 88 = 676.6848\text{W}$$

Cooling load due to windows facing North at 16:00hr $= 533.693 + 676.685 = 1210.378W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North *CLTD* at 17:00hr = 7℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 17:00hr,

$$q = 5.8 \times 8.64 \times (7 + 2.65) = 483.5808W$$

Putting, $A = 8.64m^2$, SC $= 0.89$ (ASHRAE, 1997) and North SCL at 17:00hr = $91W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 17:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 91 = 699.7536\text{W}$$

Cooling load due to windows facing North at 17:00hr $= 483.581 + 699.754 = 1183.335W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 8.64m^2$ and North $CLTD$ at 18:00hr = 7°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing north at 18:00hr,

$$q = 5.8 \times 8.64 \times (7 + 2.65) = 483.5808W$$

Putting, $A = 8.64m^2$, SC $= 0.89$ (ASHRAE, 1997) and North SCL at 18:00hr = $101W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing north at 18:00hr,

$$q_{rad} = 8.64 \times 0.89 \times 101 = 776.6496\text{W}$$

Cooling load due to windows facing North at 18:00hr $= 483.581 + 776.650 = 1260.231W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South $CLTD$ at 8:00hr = 0°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 8:00hr,

$$q = 5.8 \times 7.8 \times (0 + 2.65) = 119.886W$$

Putting, $A = 7.8m^2$, SC $= 0.89$ (ASHRAE, 1997) and South SCL at 8:00hr = $66W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 8:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 66 = 458.172\text{W}$$

Cooling load due to windows facing South at 8:00hr $= 119.886 + 458.172 = 578.058W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South *CLTD* at 9:00hr = 1℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 9:00hr,

$$q = 5.8 \times 7.8 \times (1 + 2.65) = 165.126W$$

Putting, $A = 7.8m^2$, SC $= 0.89$ (ASHRAE, 1997) and South SCL at 9:00hr = $101W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 9:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 101 = 701.142\text{W}$$

Cooling load due to windows facing South at 9:00hr $= 165.126 + 701.142 = 866.268W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South *CLTD* at 10:00hr = 2℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 10:00hr,

$$q = 5.8 \times 7.8 \times (2 + 2.65) = 210.366W$$

Putting, $A = 7.8m^2$, SC $= 0.89$ (ASHRAE, 1997) and South SCL at 10:00hr = 145W/m^2 (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 10:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 145 = 1006.59\text{W}$$

Cooling load due to windows facing South at 10:00hr $= 210.366 + 1006.59 = 1216.956W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South $CLTD$ at 11:00hr = 4°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 11:00hr,

$$q = 5.8 \times 7.8 \times (4 + 2.65) = 300.846W$$

Putting, $A = 7.8m^2$, SC $= 0.89$ (ASHRAE, 1997) and South SCL at 11:00hr = 186W/m^2 (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 11:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 186 = 1291.212\text{W}$$

Cooling load due to windows facing South at 11:00hr $= 300.846 + 1291.212 = 1592.058W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South $CLTD$ at 12:00hr = 5°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 12:00hr,

$$q = 5.8 \times 7.8 \times (5 + 2.65) = 346.086W$$

Putting, $A = 7.8m^2$, $\mathrm{SC} = 0.89$ (ASHRAE, 1997) and South SCL at 12:00hr = $211W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 12:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 211 = 1464.762\mathrm{W}$$

Cooling load due to windows facing South at 12:00hr $= 346.086 + 1464.762 = 1810.848W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South *CLTD* at 13:00hr = 7℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 13:00hr,

$$q = 5.8 \times 7.8 \times (7 + 2.65) = 436.566W$$

Putting, $A = 7.8m^2$, $\mathrm{SC} = 0.89$ (ASHRAE, 1997) and South SCL at 13:00hr = $217W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 13:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 217 = 1506.414\mathrm{W}$$

Cooling load due to windows facing South at 13:00hr $= 436.566 + 1506.414 = 1942.98W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South *CLTD* at 14:00hr = 7℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 14:00hr,

$$q = 5.8 \times 7.8 \times (7 + 2.65) = 436.566W$$

Putting, $A = 7.8m^2$, $\text{SC} = 0.89$ (ASHRAE, 1997) and South SCL at 14:00hr = $198W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 14:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 198 = 1374.516\text{W}$$

Cooling load due to windows facing South at 14:00hr $= 436.566 + 1374.516 = 1811.082W$

Putting, $U = 5.8 \frac{W}{m^2K}$, $A = 7.8m^2$ and South $CLTD$ at 15:00hr = 8°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 15:00hr,

$$q = 5.8 \times 7.8 \times (8 + 2.65) = 481.806W$$

Putting, $A = 7.8m^2$, $\text{SC} = 0.89$ (ASHRAE, 1997) and South SCL at 15:00hr = $164W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 15:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 164 = 1138.488\text{W}$$

Cooling load due to windows facing South at 15:00hr $= 481.806 + 1138.488 = 1620.294W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South $CLTD$ at 16:00hr = 8°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 16:00hr,

$$q = 5.8 \times 7.8 \times (8 + 2.65) = 481.806W$$

Putting, $A = 7.8m^2$, $\mathrm{SC} = 0.89$ (ASHRAE, 1997) and South SCL at 16:00hr = $129W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 16:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 129 = 895.518\mathrm{W}$$

Cooling load due to windows facing south at 16:00hr $= 481.806 + 895.518 = 1377.324W$

Putting, $U = 5.8\frac{W}{m^2K}$, $A = 7.8m^2$ and South $CLTD$ at 17:00hr = 7°C (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 17:00hr,

$$q = 5.8 \times 7.8 \times (7 + 2.65) = 436.566W$$

Putting, $A = 7.8m^2$, $\mathrm{SC} = 0.89$ (ASHRAE, 1997) and South SCL at 17:00hr = $113W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 17:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 113 = 784.446\mathrm{W}$$

Cooling load due to windows facing south at 17:00hr $= 436.566 + 784.446 = 1221.012W$

Putting, $U = 5.8 \frac{W}{m^2K}$, $A = 7.8m^2$ and South $CLTD$ at 18:00hr = 7℃ (ASHRAE, 1997) into Equation 3.14.

Cooling load due to conduction mode of heat transfer via windows facing south at 18:00hr,

$$q = 5.8 \times 7.8 \times (7 + 2.65) = 436.566W$$

Putting, $A = 7.8m^2$, $\text{SC} = 0.89$ (ASHRAE, 1997) and South SCL at 18:00hr = $95W/m^2$ (ASHRAE, 1997) into Equation 3.3.

Cooling load from solar radiation through windows facing south at 18:00hr,

$$q_{rad} = 7.8 \times 0.89 \times 95 = 659.49\text{W}$$

Cooling load due to windows facing south at 18:00hr $= 436.566 + 659.49 = 1096.056W$

Total cooling loads due to windows at each hour of the day are tabulated in Table 4.9 below.

Cooling load due to occupants

Cooling load due heat gain into the lecture room from occupants (students and lecturer) is classified into sensible cooling load and latent cooling load. Equations 3.5 and 3.6 are used to determine the sensible cooling load and latent cooling load due to occupants respectively.

$$q_{os} = \text{N} \times (\text{SHG}_p) \times (\text{CLF}_p) \tag{3.5}$$

$$q_{ol} = \text{N} \times (\text{LHG}_p) \tag{3.6}$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 0hr of occupancy at 8:00hr = 0.0 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 8:00hr,

$$q_{os} = 101 \times 70 \times 0 = 0W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 1hr of occupancy at 9:00hr = 0.62 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 9:00hr,

$$q_{os} = 101 \times 70 \times 0.62 = 4383.4W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 2hr of occupancy at 10:00hr = 0.7 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 10:00hr,

$$q_{os} = 101 \times 70 \times 0.7 = 4949W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 3hr of occupancy at 11:00hr = 0.75 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 11:00hr,

$$q_{os} = 101 \times 70 \times 0.75 = 5302.5W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 1hr of occupancy at 12:00hr = 0.65 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 12:00hr,

$$q_{os} = 101 \times 70 \times 0.65 = 4595.5W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 2hr of occupancy at 13:00hr = 0.71 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 13:00hr,

$$q_{os} = 101 \times 70 \times 0.71 = 5019.7W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 3hr of occupancy at 14:00hr = 0.78 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 14:00hr,

$$q_{os} = 101 \times 70 \times 0.78 = 5514.6W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 1hr of occupancy at 15:00hr = 0.78 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 15:00hr,

$$q_{os} = 101 \times 70 \times 0.67 = 4736.9W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 2hr of occupancy at 16:00hr = 0.78 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 16:00hr,

$$q_{os} = 101 \times 70 \times 0.76 = 5373.2W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 3hr of occupancy at 17:00hr = 0.8 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 17:00hr,

$$q_{os} = 101 \times 70 \times 0.8 = 5656W$$

Putting $\mathrm{N} = 101$ persons, SHG_p for activity "seated, very light work" $= 70W$ (ASHRAE, 2017) and CLF_p for 1hr of occupancy at 18:00hr = 0.74 (ASHRAE, 1997) into Equation 3.5.

Sensible cooling load due to occupants at 18:00hr,

$$q_{os} = 101 \times 70 \times 0.74 = 5231.8W$$

Putting $\mathrm{N} = 101$ persons and LHG_p for activity "seated, very light work" $= 45W$ (ASHRAE, 2017) into equation 3.6.

Latent cooling load due to occupants,

$$q_{ol} = 101 \times 45 = 4545W$$

Cooling load due to lights

Cooling load due to lights are calculated using Equation 3.7.

$$q_l = \mathrm{P}_l \times \mathrm{F}_{\mathrm{SA}} \times \mathrm{F}_{\mathrm{UT}} \times (\mathrm{CLF}_l) \qquad (3.7)$$

Putting $\mathrm{P}_l = 156W$ (6 florescence bulbs of 26W each), $\mathrm{F}_{\mathrm{SA}} = 1.2$ (from manufacturer's data), $\mathrm{F}_{\mathrm{UT}} = 1$ (ASHRAE, 1997) and CLF_l for 0hr after turned on $= 0$ into Equation 3.7.

Cooling load due to lights at 8:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0 = 0W$$

Putting $\mathrm{P}_l = 156W$ (6 florescence bulbs of 26W each), $\mathrm{F}_{\mathrm{SA}} = 1.2$ (from manufacturer's data), $\mathrm{F}_{\mathrm{UT}} = 1$ (ASHRAE, 1997) and CLF_l for 1hr after turned on $= 0.66$ into Equation 3.7.

Cooling load due to lights at 9:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.66 = 123.552W$$

Putting $\mathrm{P}_l = 156W$ (6 florescence bulbs of 26W each), $\mathrm{F}_{\mathrm{SA}} = 1.2$ (from manufacturer's data), $\mathrm{F}_{\mathrm{UT}} = 1$ (ASHRAE, 1997) and CLF_l for 2hr after turned on $= 0.74$ into Equation 3.7.

Cooling load due to lights at 10:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.74 = 138.528W$$

Putting $\mathrm{P}_l = 156W$ (6 florescence bulbs of 26W each), $\mathrm{F}_{\mathrm{SA}} = 1.2$ (from manufacturer's data), $\mathrm{F}_{\mathrm{UT}} = 1$ (ASHRAE, 1997) and CLF_l for 3hr after turned on $= 0.77$ into Equation 3.7.

Cooling load due to lights at 11:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.77 = 144.144W$$

Putting $P_l = 156W$ (6 florescence bulbs of 26W each), $F_{SA} = 1.2$ (from manufacturer's data), $F_{UT} = 1$ (ASHRAE, 1997) and CLF_l for 4hr after turned on = 0.81 into Equation 3.7.

Cooling load due to lights at 12:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.81 = 151.632W$$

Putting $P_l = 156W$ (6 florescence bulbs of 26W each), $F_{SA} = 1.2$ (from manufacturer's data), $F_{UT} = 1$ (ASHRAE, 1997) and CLF_l for 5hr after turned on = 0.83 into Equation 3.7.

Cooling load due to lights at 13:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.83 = 155.376W$$

Putting $P_l = 156W$ (6 florescence bulbs of 26W each), $F_{SA} = 1.2$ (from manufacturer's data), $F_{UT} = 1$ (ASHRAE, 1997) and CLF_l for 6hr after turned on = 0.86 into Equation 3.7.

Cooling load due to lights at 14:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.86 = 160.992W$$

Putting $P_l = 156W$ (6 florescence bulbs of 26W each), $F_{SA} = 1.2$ (from manufacturer's data), $F_{UT} = 1$ (ASHRAE, 1997) and CLF_l for 7hr after turned on = 0.88 into Equation 3.7.

Cooling load due to lights at 15:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.88 = 164.736W$$

Putting $\mathrm{P}_l = 156W$ (6 florescence bulbs of 26W each), $\mathrm{F_{SA}} = 1.2$ (from manufacturer's data), $\mathrm{F_{UT}} = 1$ (ASHRAE, 1997) and CLF_l for 8hr after turned on $= 0.90$ into Equation 3.7.

Cooling load due to lights at 16:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.90 = 168.48W$$

Putting $\mathrm{P}_l = 156W$ (6 florescence bulbs of 26W each), $\mathrm{F_{SA}} = 1.2$ (from manufacturer's data), $\mathrm{F_{UT}} = 1$ (ASHRAE, 1997) and CLF_l for 9hr after turned on $= 0.91$ into Equation 3.7.

Cooling load due to lights at 17:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.91 = 170.352W$$

Putting $\mathrm{P}_l = 156W$ (6 florescence bulbs of 26W each), $\mathrm{F_{SA}} = 1.2$ (from manufacturer's data), $\mathrm{F_{UT}} = 1$ (ASHRAE, 1997) and CLF_l for 10hr after turned on $= 0.92$ into Equation 3.7.

Cooling load due to lights at 18:00 hr,

$$q_l = 156 \times 1.2 \times 1 \times 0.92 = 172.224W$$

Cooling load due to ceiling fans

Cooling load due to ceiling fans are calculated using equation 3.8.

$$q_e = \eta_e \times \mathrm{P}_e \times (\mathrm{CLF}) \quad (3.8)$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 0hr after turned on $=$ 0 (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 8:00hr,

$$q_e = 0.35 \times 280 \times 0 = 0W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 1hr after turned on $= 0.66$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 9:00hr,

$$q_e = 0.35 \times 280 \times 0.66 = 64.68W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 2hr after turned on $= 0.74$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 10:00hr,

$$q_e = 0.35 \times 280 \times 0.74 = 72.52W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 3hr after turned on $= 0.77$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 11:00hr,

$$q_e = 0.35 \times 280 \times 0.77 = 75.46W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 4hr after turned on $= 0.81$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 12:00hr,

$$q_e = 0.35 \times 280 \times 0.81 = 79.38W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 5hr after turned on $= 0.83$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 13:00hr,

$$q_e = 0.35 \times 280 \times 0.83 = 81.34W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 6hr after turned on $= 0.86$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 14:00hr,

$$q_e = 0.35 \times 280 \times 0.86 = 84.28W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 7hr after turned on $= 0.88$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 15:00hr,

$$q_e = 0.35 \times 280 \times 0.88 = 86.24W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 8hr after turned on $= 0.90$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 16:00hr,

$$q_e = 0.35 \times 280 \times 0.90 = 88.2W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 9hr after turned on $= 0.91$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 17:00hr,

$$q_e = 0.35 \times 280 \times 0.91 = 89.18W$$

Putting $\eta_e = 0.35$, $\mathrm{P}_e = 280W$ ($4 \times 70W$ ceiling fans) and CLF for 9hr after turned on $= 0.92$ (ASHRAE, 1997) into Equation 3.8.

Cooling load due to ceiling fan at 18:00hr,

$$q_e = 0.35 \times 280 \times 0.92 = 90.16W$$

Cooling load due to ventilation

Sensible cooling load and latent cooling load due to ventilation are calculated using Equation 3.10 and 3.11 respectively.

$$q_{sensible} = 1.23 \times Q(t_o - t_i) \quad (3.10)$$

$$q_{lantent} = 3010 \times Q(W_o - W_i) \quad (3.11)$$

Putting $Q = 5L/s \times 101 = 505L/s$ (ventilation rate is given as $5L/s$ per person for a lecture room according to ASHRAE Standard 62.1 (2019)), $t_o = 37.1℃$ and $t_i = 25℃$ into Equation 3.10.

Sensible cooling load due to ventilation,

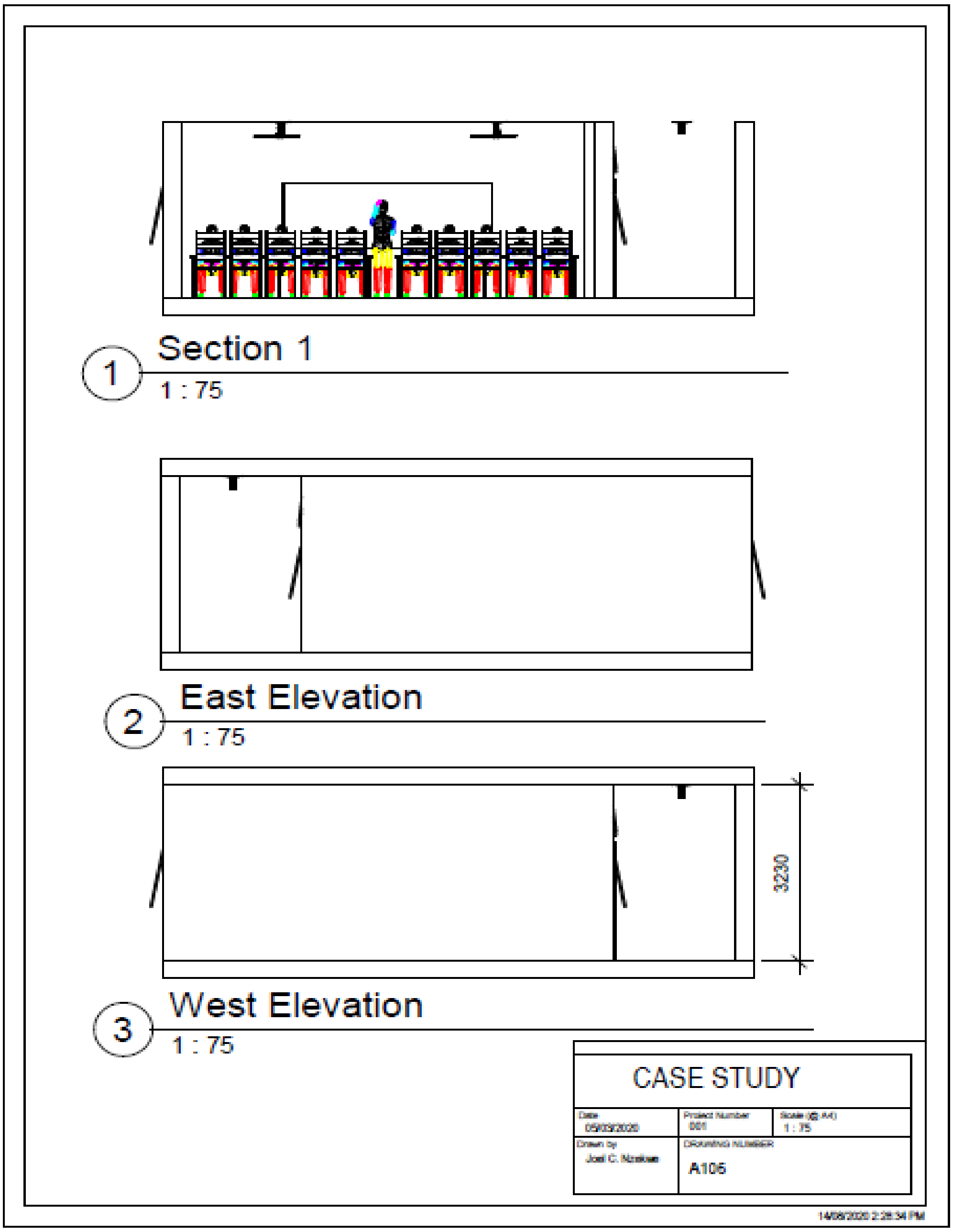
$$q_{sensible} = 1.23 \times 505(37.1 - 25) = 7515.915W$$

Putting $Q = 505L/s$, $W_o = 0.02\text{kg of water/kg of air}$ and $W_i = 0.01\text{kg of water/kg of air}$ into Equation 3.11.

Latent cooling load due to ventilation,

$$q_{lantent} = 3010 \times 505(0.02 - 0.01) = 15200.5W$$

APPENDIX B



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Drawn by
DRAWING NUMBER
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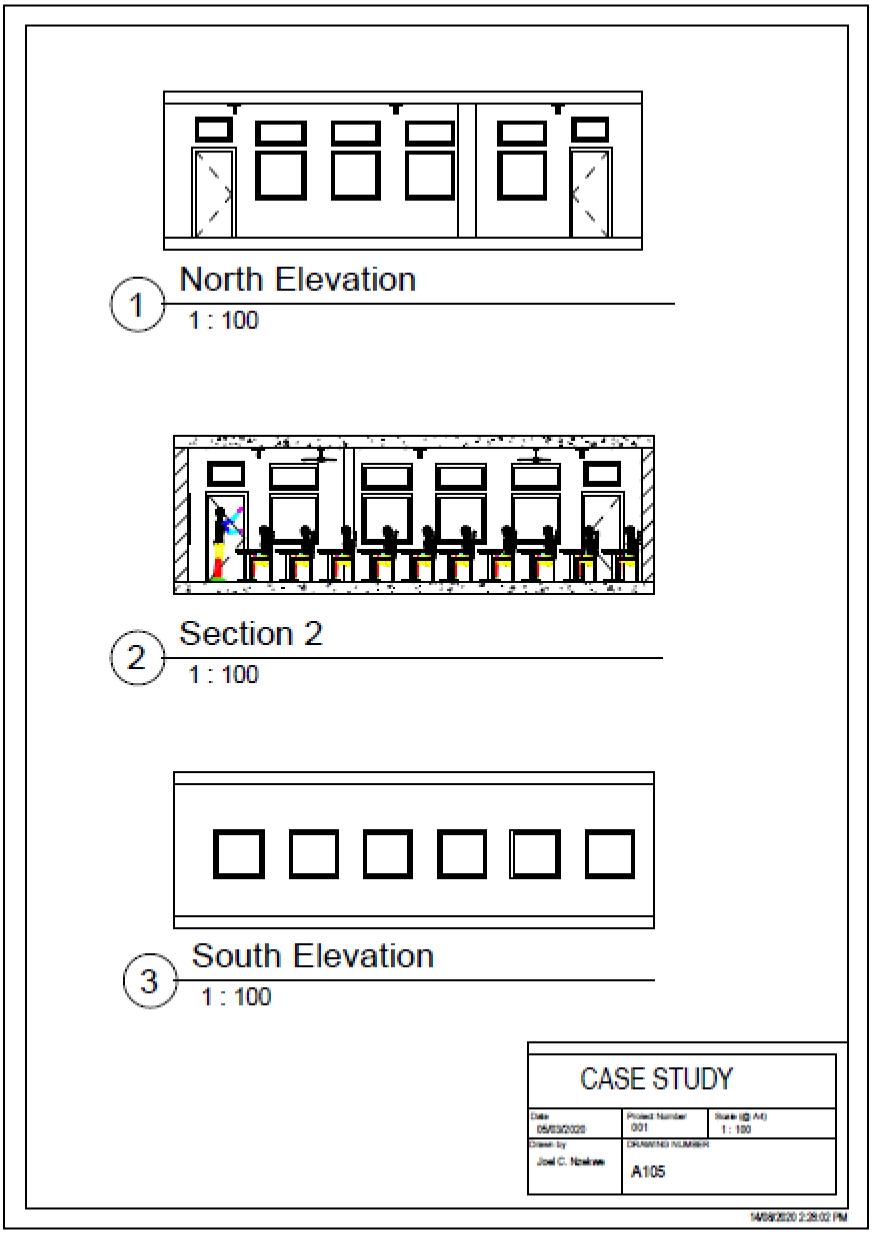
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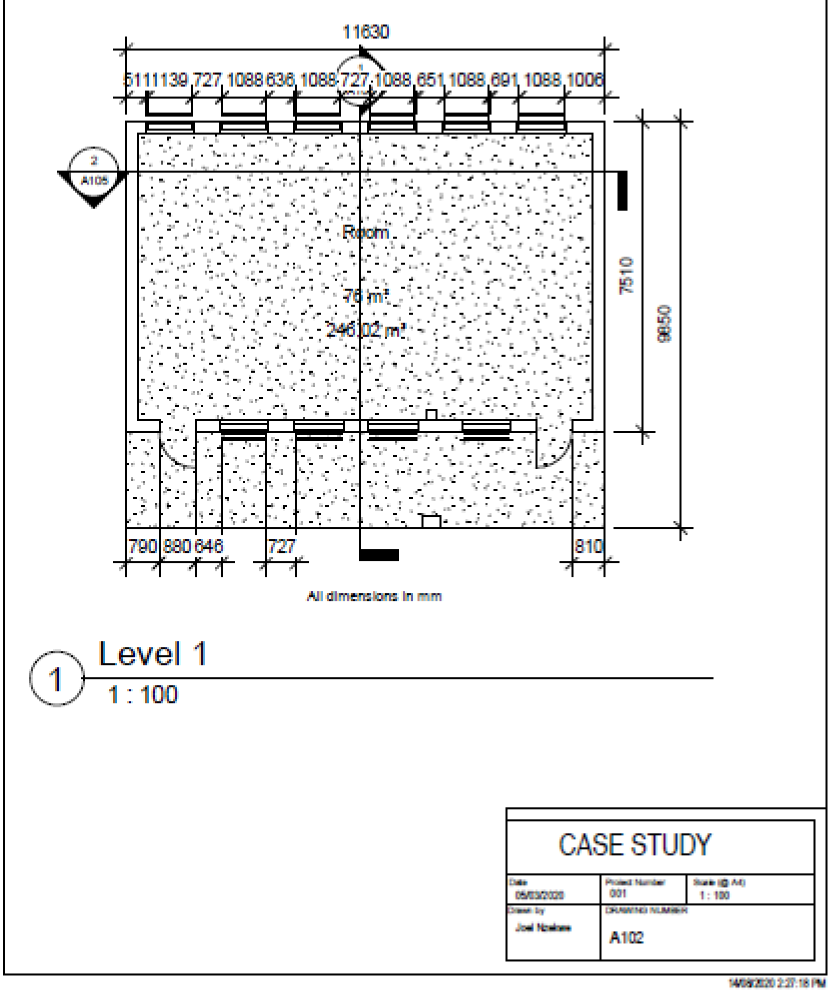
2
Section 2
1 : 100
3
South Elevation
1 : 100
CASE STUDY
001
1 : 100
A105

APPENDIX B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9850
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727
810
All dimensions in mm
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Level 1
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CASE STUDY
001
1 : 100
A102

APPENDIX C

JAVA CODE OF DEVELOPED WINDOWS APPLICATION

Class: MasterApp

```
package masterapp;
import javax.swing.SwingUtilities;
//author JOEL C.N
public class MasterApp {
public static void main(String[] args) {
SwingUtilities.invokeLater(new Runnable(){
public void run(){
new CORE(); }
});}}
```

Class: CORE

```
package masterapp;
// @author JOEL C.NZEKWE
import java.awt.CardLayout;
import java.awt.Color;
import java.awt.Container;
import java.awt.Toolkit;
import java.awt.event.ActionListener;
import javax.swing.BorderFactory;
import javax.swing.JButton;
import javax.swing.JFrame;
```