CHAPTER 1
INTRODUCTION

1.1 Background of Study

Recently, energy issues are being greatly discussed all over the world. Depletion of fossil fuel, discovery of renewable energy as well as global warming due to green house gas emission are mainly being the focus of discussion to find appropriate measures to solve those issues. Furthermore, the rapid increase of overall energy demand also further complicates energy related problem especially for increasing green house gas emission due to direct relation of those aspects. It is recorded that more than 50,000 power plants operating in the world are the most concentrated Carbon Dioxide (CO_2) sources worldwide. The amount of CO_2 emitted covers up to one fourth of the world CO_2 emission (Science Daily, 2007). This phenomenon is the result of rising global demand for energy. In Malaysia, it is reported by Energy Information Administration (EIA) in its official website that the country is also experiencing rapid increase of energy consumption for the last ten years. Table 1.1 compares the total energy consumption on 1997 and on 2006 for all energy resources such as petroleum, natural gas, coal and electricity.

Table 1.1: Comparison on Yearly Consumption of Various Energy Resources in Malaysia for 1997 and 2006 (EIA, 2009)

Resource Consumption	1997	2006	% Increase
Petroleum (Thousand Barrel Per day)	469	501	7
Natural Gas (Billion Cubic Feet)	589	1164	98
Coal (Million Short Tons)	3	13	403
Electricity (Billion Kilowatt-hours)	51	79	56

Generally, increasing world demand for energy is resulted from rapid growth of economic and industry sector which also lead to growing construction of big building for offices, air ports and so on (Eskin and Turkmen, 2006). The building sector is the largest energy consumer following the industrial sector. This is due to the fact that energy required for space heating and cooling in buildings has the highest share of all (Bakos, 2000). As for large scale building, heating and cooling are among the essential aspects of maintaining human comfort. For example in Turkey, it is reported that one third of the total electricity consumption is for building heating and cooling purposes (Eskin and Turkmen, 2006). It was estimated that heating, ventilation and air-conditioning (HVAC) accounted for some 65% of the energy consumption in the building sector (Yao, 2005). With such promising future growth of economy, it is expected that future energy demand will keep increasing. In order to alleviate the ever-growing demand for energy is to have more energy-efficient building designs and proper building energy conservation program. Therefore, one way of conserving energy is to reduce energy consumption on heating and cooling of a building which mainly by improving thermal performance of a building as well as implementing an efficient operational practices.

At the legislative level, Energy Policy, Heating and Air Conditioning policies establishment are among the measures taken by corporations and institutions for energy conservation. With the aim of cultivating energy conservation environment as well as reducing the operational, this method seems to be one of the most effective ways to increase efficiency and reduce energy consumption. In general, most countries in the world have established energy policy at the national level. As in Malaysia, the Ministry of Energy, Water and Communication has outlined three main principle of the country's energy policy which covers the energy supply, energy utilization and environmental objectives. On the other hands, at institutional level, energy policy such as air-conditioning and heating policy are being increasingly established in all over the world. Some of the educational institutions that have already established air-conditioning policy are Montana State University, University of Western Australia and University of Sydney. The policy generally outlines rule and regulation for usage, maintenance, design consideration, and operational parameter of the heating and air-conditioning system in compliance with the international standard such as American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) standards.

Universiti Teknologi PETRONAS Academic Complex is one of the high technology educational institutions in the world. With such large scale infrastructure, energy requirement for electricity and air-conditioning requirements are one of the essential components of the building which should be carefully analyzed. Electricity of UTP is supplied by an independent power, UTP Cogeneration/District Cooling (GDC) Plant. This facility produces electricity and chilled water for the new academic campus. The main new academic campus consists of a Chancellor complex which comprises Chancellor Hall, Library and Registry, sixteen academic blocks for various faculty, and two main lecture theaters, Pocket C and Pocket D. The air conditioning system of the whole academic is design to be a centralized system which can be divided into two separate systems, upstream and downstream. The upstream consists of chilled water pipelines loop from GDC to the main heat exchanger at the Chancellor Complex. The downstream system is the chilled water piping that circulates chilled water to the whole campus from the main heat exchanger. The chilled water is pumped to unit of Air Handling Units (AHU) in the new academic building. Figure 1.1 shows the aerial view of UTP new academic complex.

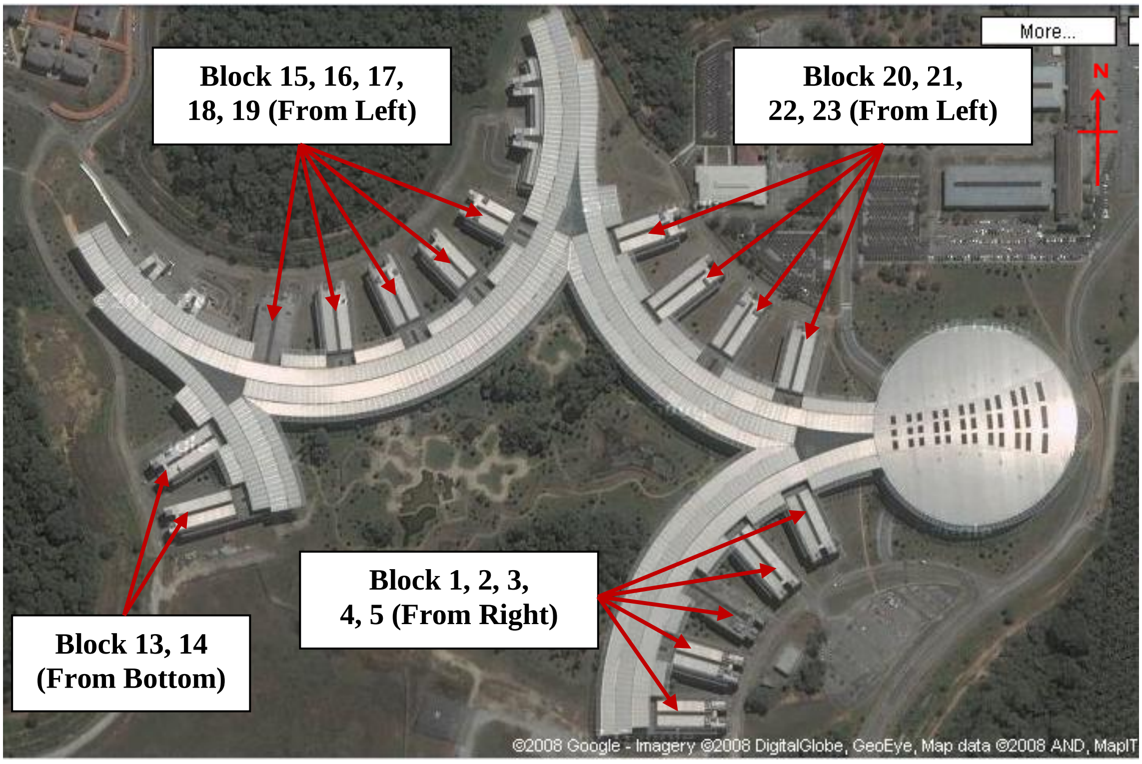


Figure 1.1: Aerial view of UTP new academic complex (Google earth, 2008)

Some of the unique features of the new academic complex lies in the envelope design especially for the faculty blocks. The walls are mainly covered by glass walls which can contribute high cooling load of the air conditioning equipments. In addition to that, a huge canopy roof which is design for pedestrian also acts as external shading to the 16 blocks which can reduce the cooling load of the buildings. With such unique architectural structure, it is necessary to carry out detailed investigation on the building's thermal performance to seek rooms for improvements especially for energy savings.

Since July 2003, there is no study yet to be done to assess the performance of the air conditioning system of the Academic Building. From a preliminary observation on the air conditioning system, it is found that there are plenty of rooms for improvement towards energy saving. For example, the system's air conditioning scheduling capability is not being fully utilized. As a result, most of the time when the labs are not being occupied, the rooms are constantly air-conditioned throughout the semester. Furthermore, there are also rooms that are not being used at all but still being air-conditioned which is obviously an energy wasteful practice. Obviously, it is an inefficient practice that the system is left to run in an energy wasting manner. Therefore, as part of the university commitment to inculcate energy conserving environment, this issue should be further discussed to plan for appropriate measures to conserve energy.

1.2 Problem Statement

The escalating phenomenon of global warming is becoming more serious day by day. This is mainly due to rapid increase of green house gasses emission to the atmosphere which is mainly from the industrial and the energy sector. The rising number of power plants and factories is mainly the effect of rapid growth of world population which also leads to increase in demand of energy resources to support country's economic and industrial growth. In addition to that, growing construction of mega project that involves large scale building also involves huge consideration in fulfilling the aspect of human comfort particularly in heating and air-conditioning aspects. As building heating and cooling requires lots of energy, efficient system is highly desirable to meet the aim for energy conservation and cost reduction.

Cooling system is the highest consumer of energy that has the greatest potential for energy saving (Perez, Capelluto (2008). In UTP, the centralized air conditioning system can be categorized as large scale application which the system average monthly consumption is up to 850000 refrigeration ton hour (RTh). With such huge amount of energy consumption, there are great potential to achieve energy and cost saving. Therefore, a detail study on the air-conditioning cooling load of UTP New Academic Complex should be conducted to identify possible energy saving measures to save energy as well as reducing operational cost.

1.2 Objectives and Scopes of Study

The research objective is to study potential energy saving measures within the air-conditioning system of the sixteen academic blocks of UTP. The objective shall be met by analyzing the cooling load and design of the installed system. A detail calculation as well as performing computer simulation of the building cooling load will be done to estimate the actual energy requirement by the air-conditioning system. Moreover, this study will be analyzing the buildings thermal performance and various factors towards energy saving. This research also will be looking into the building occupancy trend as well as the system's mode of operation to come out with a proposal for energy saving.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Previous Study

There are quite a numbers of studies on energy performance of a building especially in analyzing cooling and heating load with respect to various envelop design as well as with different local climates. Most of previous study in the hot and humid climate is done in Thailand, Hong Kong and India (Eskin, Turkmen (2006) For example, Yang, Lam and Tsang (2007) recorded a research on energy performance of building envelope in different climate zones in China. The study involves five different climate of China which is severe cold, cold, hot summer and cold winter, mild, and hot summer and warm winter. Building envelope that being investigated are based on data collected from building survey, local codes and ASHRAE standards. The analysis adopts the Overall Thermal Transfer Value (OTTV) and heating degree days method to determine energy performance of the building envelope. However, the authors stated that there are a few of limitations of their studies. One of them is that annual hourly energy simulation was not being done and they admitted that more work is required.

Perez and Capelluto (2008) reported a study on climatic consideration in school building in hot and humid climate for reducing energy consumption. The main purpose of the study is to propose design recommendation for school building as well as assessing the influence of different design variables towards minimizing energy consumption. Computer simulation ‘ENERGY’ was being used to conduct building thermal performance analysis. From this particular research, the main variables which have big influence on building thermal performance are types of shading, night ventilation, window area, and infiltration. The research also found that the proposed improved classroom design can reduce the energy consumption to about 50% which comply to the high thermal performance schools in Europe and US with annual energy saving ranges from 55% to 75%. However, even in the improved building performance, total energy consumed is still much higher compared to other systems. This is due to the hot and humid climate which high in sensible and latent heat gain.

Bojic, Yik and Leung (2000) did a study on the thermal insulation of cooled spaces in high rise residential building in Hong Kong. The study investigates the effect of including thermal insulation layer in the wall component at the middle, in door side and the outdoor side of fabric components on the heating and cooling of the building were evaluated and compared. The prediction of heating and cooling load is performed via energy simulation software HTB2. The simulation done also incorporates occupancy patterns, lighting and appliances operating patterns and well as room usage patterns. From the study, it is found that a maximum yearly cooling load reduction by 10.5% can be achieved when a 50 mm thick thermal insulation layer was placed at the indoor side of the wall that enclosed the cooling area. However, the load reduction is also highly dependent on the building orientation with respect to the sun.

Eskin and Turkmen (2006) reported another study on the analysis on annual heating and cooling energy requirements for office building in four different climates in Turkey. The paper's aim was to investigate the effect of different condition and control strategies with respect to energy demand of an office building. Energy Plus software is used in order to perform the annual simulation on the subject matter. This study involves in investigating a Turkish modelled 12 storey, four underground office building of 17,670 m^2 area. The effect of the parameters like the climatic conditions (location), insulation and thermal mass, building aspect ratio, color of external surfaces, shading, window systems including window area and glazing system, ventilation rates and different outdoor air control strategies on annual building energy requirement is examined and the results are presented for each city. From the analysis, it was found that providing thermal insulation in the walls can reduce cooling load ranges from 20 - 36% from the base case building. The simulation also illustrated that significant increase of cooling load with high number of glazing compared to much lower glazing building.

Another research done in Turkey on building energy performance was done by Aktacir, Buyukalaca, Bulut and Yilmaz (2007) which is on the effect of outdoor design condition on design cooling load and design cooling capacities of air conditioning equipments. The analysis is conducted by selecting a high school located in Andana, Turkey which gross area is about 1628m^2. The building is conditioned by a constant air volume system which consists of AHU, supply and return fans, ducts and control units. For cooling load calculation, Radiant Time Series (RTS) method is used. Occupancy pattern and all internal loads such as lightings and appliances are being considered in the load calculation. From the result obtained, it shows that half of the cooling load is weather dependent. As for the air-conditioning sizing in Turkey, it is considered as strictly adhere to the country's standard.

From the studies that are discussed in this section, accurate weather data and proper selection of outdoor design condition are the key factors of producing accurate building energy performance analysis. For energy saving purpose, building's air-conditioning cooling load should be thoroughly analyzed in order to identify possible area of improvement either improving the envelop design or improving the operational practices. From those studies, it is obvious that they are studies that are conducted outside Malaysia with different climate. Therefore, this research will outcome will be more related to this region building thermal performance analysis.

2.2 Theory of Cooling Load Calculation

Cooling load calculation is an essential stage of designing air-conditioning system especially in sizing the equipments. Careful and accurate peak load calculation will result in appropriate equipment sizing and avoid over sizing which is an energy wasting practice and would involve higher equipment cost. If the design is over sized, this would result in the system only operating in part load mode. As different equipment have different efficiency value in part load mode, this kind of practice may lead to inefficient performance of the equipments which should be avoided in the first place. Therefore, accurate calculation of cooling load will result in designing an efficient system by selecting efficient equipment based on the calculated cooling load requirements.

2.2.1 Concept of Cooling Load

Room or space cooling load is defined as the rate at which heat must be removed from a space to maintain it at the design temperature and humidity (ASHRAE, 2001). There are two different terms that should be properly defined in air conditioning load calculation which are heat gain and cooling load. Heat gain is basically instantaneous heat receive by a space at any time by conduction, radiation and convection. On the other hands, cooling load is a discounted heat gain due to heat storage by surfaces, furniture and equipments as well as time lag effect. The time lag effect is defined as energy absorbed by walls, roofs, furniture etc which contribute to space heat gain after a time lag (ASHRAE, 2001). There are various sources of heat gain that are taken into account in the load calculation stage which are heat gain via conduction, solar radiation, lightings and appliances, occupants, ventilation and infiltration, ducting heat gain as well as system equipments heat gain (from pumps, motors and etc). Figure 2.1 illustrates the interrelation between heat gain, heat storage and cooling load.

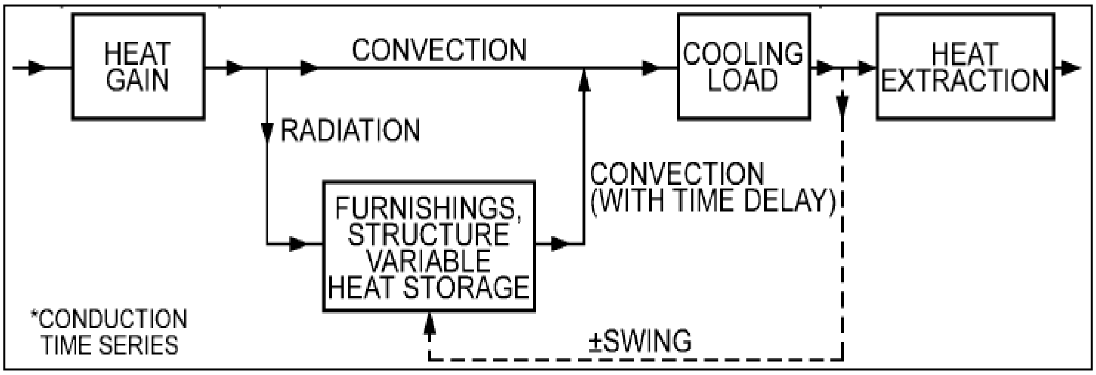


Figure 2.1: Heat flow diagram showing building heat gain, heat storage and cooling load (ASHRAE Handbook 2001, 2008)

2.2.2 Cooling Load Calculation

There are several methods for cooling load calculation available. This includes Heat Balance (HB) method, Radiant Time Series (RTS) method, Cooling Load Temperature Difference or Cooling Load Factor (CLTD/CLF) method and Transfer Function Method (TFM). Strand, Pederson and Crawley (2001) define HB methos as: “an attempt to capture the fundamental thermal physics of a building envelope by applying the First Law of Thermodynamics (conservation of energy) to important points within the building geometry,". HB method involves calculating a surface-by-surface conductive, convective, and radiative heat balance for each room surface and convective heat balance for the room air (ASHRAE, 2001). In this particular method, the air in the thermal zone is assumed to be weel mixed which signifies its uniform temperature throughout the space. Other assumptions that are made to the models are:

a. Uniform surface temperature.
b. Uniform long wave (LW) and short wave (SW) irradiation.
c. Diffuse radiating surfaces.
d. One dimensional heat conduction within.

Generally, heat balance model can be separated into four distinct processes which are **outside face heat balance, wall conduction process, inside face heat balance and inside zone air heat balance**. Figure 2.2 illustrates schematic processes of heat balance method for a single opaque surface.

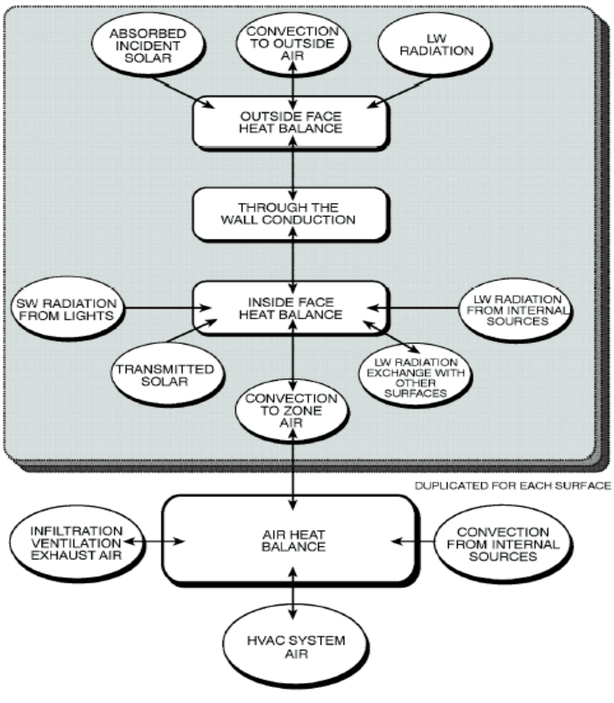


Figure 2.2: Schematic diagram of heat balance processes of a zone (ASHRAE Handbook 2001, 2008)

This is the most reliable means presented by ASHRAE of estimating cooling. All other methods are basically simplifications which are derived from this method. Using a complete heat balance would give better results than simplified methods as this method balances all energy flow in each zone (which is not guaranteed for the approximate methods). In addition to that, additional information about the component performance could be determined for example surface temperatures at various times). However, this method is considerably tedious due to needs of iterative procedure because all of the heat balance equations must be solved simultaneously, and therefore, a computer program should be used (Hassan, 2001).

CLTD/CLF method is a derivation from the Transfer Function method (TFM) in which TFM involves tedious and repetitive calculation and is identified by ASHRAE as the fundamental methodology of peak cooling load calculation (Hassan, 2003). Due to the complexity of TFM, ASHRAE developed CLTD/CLF method which highly depends on tabulated data to simplify its use for manual calculation. Upon constant revise of the method, ASHRAE has come to refine the method that is much simpler which then known as CLTD/SCL/CLF where SCL stands for solar cooling load factor. Three factors are used to deal with conduction heat gains, solar heat gains, and internal gains. Those factors are calculated using the transfer function method (TFM) which yields cooling loads for standard environmental conditions and zone types. This method also includes time–lag in conductive heat gain and heat storage effect in converting radiant heat gain to cooling load. The main drawback of this method would be the error would arouse from the inaccuracy of correcting the other months and latitude value than the given value from the tables.

2.3 Reviews on Heating, Ventilation and Air Conditioning (HVAC) Energy Conservation Opportunities (ECO)

Generally, it is well known that HVAC system accounts for most of building energy usage. As HVAC equipments over sizing practice is quite common nowadays, it is a strong indication that most systems if not being monitored, will operate inefficiently. Normally, the over sizing is done to compensate for energy inefficiency of building's design and construction or to balance design calculations errors.

Therefore, energy conservation opportunity has the biggest potential from the operation and maintenance side.

There are 5 Ts of energy conservation opportunity (Thumann and Younger, 2003) which are:

a. Turn it off
b. Turn it down
c. Tune it up
d. Turn it around
e. Tear it out

Those principles basically represent the operation and maintenance practices that should be implemented to the HVAC system. This includes proper scheduling of preventive maintenance especially for rotating equipments such as fans, motor as well as air filters, cooling coil, fire dampers and so on. Furthermore, unoccupied spaces should being air conditioned. These methods are basically meant to review what the system needs and what are the system capabilities to avoid disappointment if costly changes are to be implemented.

2.4 Energy Saving Features in Current Air Conditioning System

In realization of energy saving on the HVAC applications, there are several numbers methods being introduced especially for energy recovery. The principle is more or less similar with the concept of cogeneration plants which recover excess heat for other purpose such chilled water production by utilizing the heat to boil water to run the steam absorption chiller. In fact, in the air conditioning applications, there are several opportunities for heat recovery which can increase the system's efficiency.

One method for energy recovery is via the implementation of heat wheel. Heat wheel is a motor driven equipment which is packed with heat absorbing material like ceramic (Figure 2.3). One side of the wheel is ducted to the ventilation air while the other is ducted to either outdoor or to the intake air.

Plate type heat exchanger is one other method for heat recovery. It is basically a group of heat conducting plates which separates either cold supply air with warm return air or supplied chilled water with return warm water. The main advantage of implementing this method is that heat transfer is maximized due to large heat transfer surface is available. Percentage of heat recovered ranges from 40-60% (Pita, 2002). Figure 2.4 shows plate type heat exchanger working mechanism.

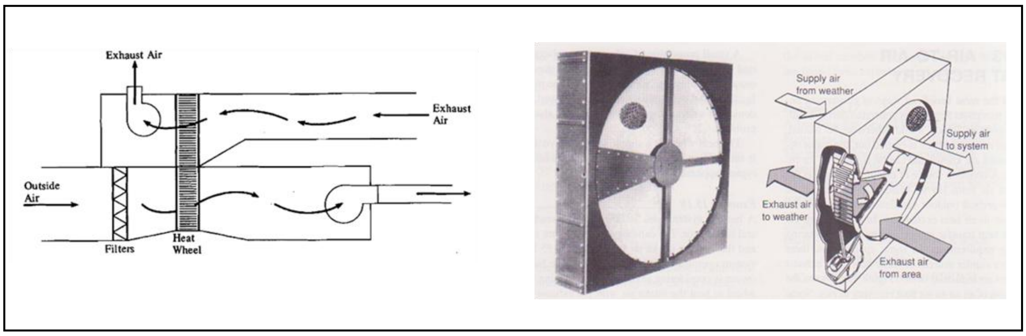


Figure 2.3: Heat wheel (Air Conditioning Principles and System, 2008, Handbook of Energy Audit, 2008)

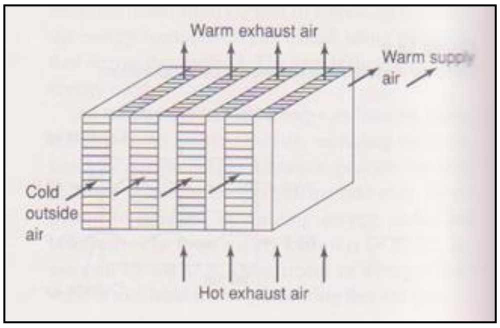


Figure 2.4: Plate heat exchanger working mechanism (Air Conditioning Principles and System, 2008)

Next option of HVAC heat recovery system is run around coil (Figure 2.5). The coil run-around cycle transfers energy from the exhaust stream to the make-up stream continuously. This is done by circulating a heat transfer medium, such as ethylene glycol fluid, between the two coils in the ducts. The fluid is circulated by a pump. The liquid absorb heat from the warm air stream and gives it up to the cold stream. The advantage of this system is that the two streams can be separated far from each other. The rated recovery efficiency is from 40-60%.

Heat pipe is the other option for heat recovery. It is installed through adjacent walls of inlet and outlet ducts; it consists of a short length of copper tubing sealed at both ends. Inside is a porous cylindrical wick and a charge of refrigerant. Its operation is based on a temperature difference between the ends of the pipe, which causes the liquid in the wick to migrate to the warmer end to evaporate and absorb heat. When the refrigerant vapor returns through the hollow center of the wick to the cooler end, it gives up heat, condenses, and the cycle is repeated.

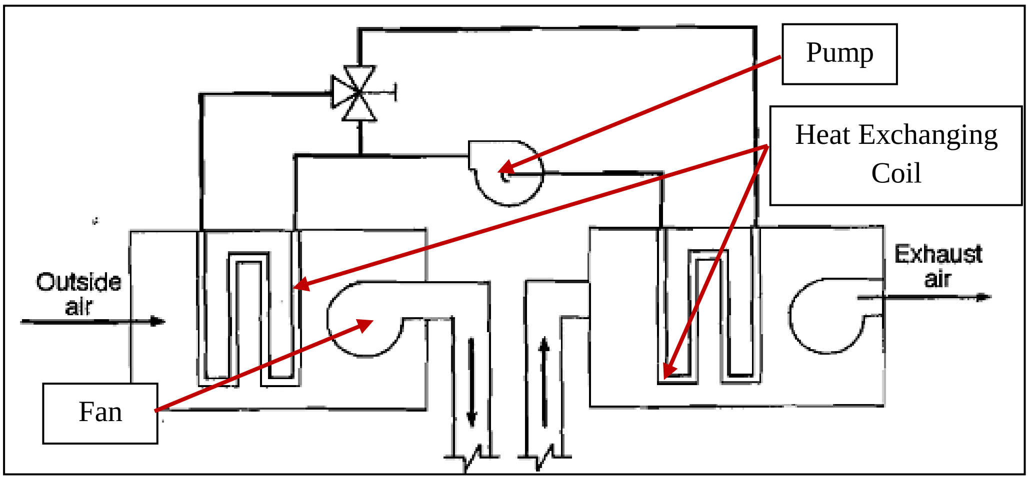


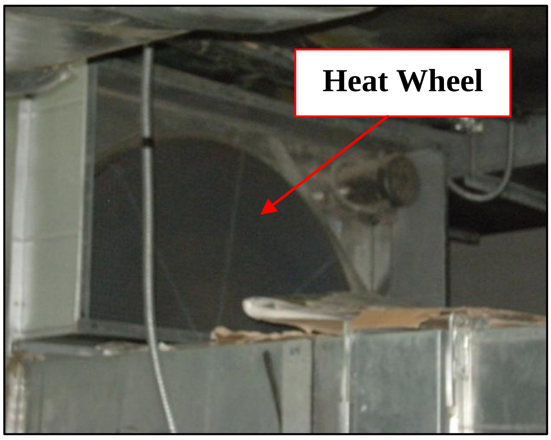
Figure 2.5: Run around coil (Handbook of Energy Audit, 2008)

In the control section of the air conditioning system, several types of sensors and transducers are being incorporated in the system to achieve higher system efficiency. One of the current technology is via installation of presence sensor to the control system. This particular feature is designed to overcome complexity of the users' occupancy pattern. The sensor will sense for movement of the occupants and signal the system whether switch of or switch on the air conditioning unit. This feature will avoid unnecessary wastage during the unoccupied hours of the room. Figure 2.6 shows the application of presence (movements sensor) for Fujitsu Genral Ltd. Air conditioning unit.

Figure 2.6: Presence (movement) sensor introduced by Fujitsu in the company latest air conditioning unit (Akasaka, 2009)

2.5 Energy Saving Features of UTP Air Conditioning System

UTP HVAC system is also well equipped with the energy saving. For instance, heat wheel. Figure 2.8 shows heat wheel which is installed for the AHU serving the Information Resource Centre (IRC). Besides that, there is also plate type heat exchanger (Figure 2.8) installed in the system. The central heat exchanger changes heat between the supplied chilled water from the GDC and the returning chilled water from all buildings.



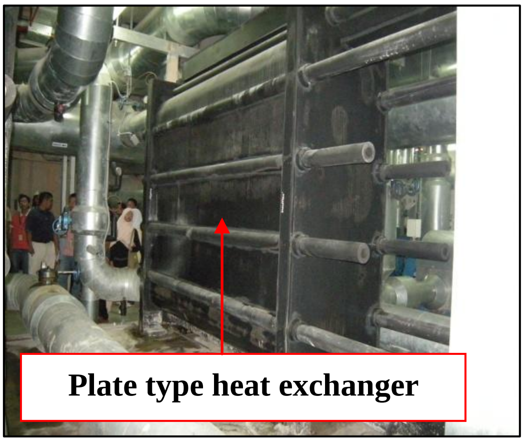


Figure 2.8 (a) and (b): (a) Heat Wheel (Left Figure) (b) Plate Heat Exchanger (Right Figure)

Furthermore, UTP HVAC system implements Variable Air Volume (VAV) system as well as variable speed drive for the fans' motors. The VAV systems are equipped with thermostats which monitor zones' indoor temperature. The opening of the fire dampers of the VAV boxes is based on the room set point temperature. On the other hands, the variable speed drive feature of the motors will correspond to duct static pressure. If any of the VAV boxes are fully closed, there will be pressure build up inside the ducting which is monitored by the pressure sensor. Then signal will be sent to the motor controller to reduce the motor speed and thus save in electricity.

The VAV mode of operation can be divided into two modes, pressure dependent and pressure independent. For pressure dependent mode, the VAV dampers opening will correspond to the minimum flow rate that is being specified by the manufacturers. This minimum flow rate is to fulfil occupants comfort level. However, this system may lead to over cooling if the VAV box still has not meet the minimum flow rate although the room temperature set point has been achieved. For pressure independent mode, VAV dampers will correspond to the VAV temperature set points and will remain on the user specified minimum damper opening. For this particular mode, the minimum opening of the damper can be manually adjusted according to the need of the user and thus overcooling can be prevented if the minimum opening is set to zero percent.

In the HVAC system point of view, UTP HVAC system is well equipped with energy saving feature. However, there are still plenty of rooms to improve the operations and maintenance system to achieve energy saving.

CHAPTER 3
METHODOLOGY

This particular chapter can be divided into three parts. First is the project management which covers project planning and flow charts. In the first part, detailed project planning and milestones are being identified and being constructed into a Gantt chart. Besides that, project flow chart is produced to illustrate the project flow from start till the end. Second part of this chapter describes all tools used in this project especially building energy simulation software, Energy Plus as well as the calculation involved. The last part of this section describes the experiment and data collection methodology for estimating envelope material thermal conductivity.

3.1 Project Flow

Project Gantt chart is shown in Appendix 1. Figure 3.1 shows the overall project flow diagram throughout the project period. This research can be divided into two sections, analysis of the academic building cooling load via software simulation and study on the operational part of the air conditioning system. Cooling load analysis is done via energy simulation software, Energy Plus. In performing cooling load simulation, all actual parameter of the building are being considered. For instance, glass area, building detailed structural dimension, building orientation with respect to sun, internal gains from lightings, occupant and some electrical appliances as well as the actual air conditioning time schedule. The simulation is also being done to investigate influence of various variables towards building cooling load. Variables that are being analyzed consist of effect of building orientation, effect of glazing shadings, effect of night ventilation, effect of infiltration load as well as effect of space overcooling.

The second part of the study is focusing on the operational side of the air conditioning system. For this particular section, it can be further divided into four main components; Occupancy pattern investigation, AHU scheduling, unoccupied rooms identification as well as VAV system mode of operation. Energy and cost saving are computed via the simulation software as well as from the real time data collection after implementing changes to the system.

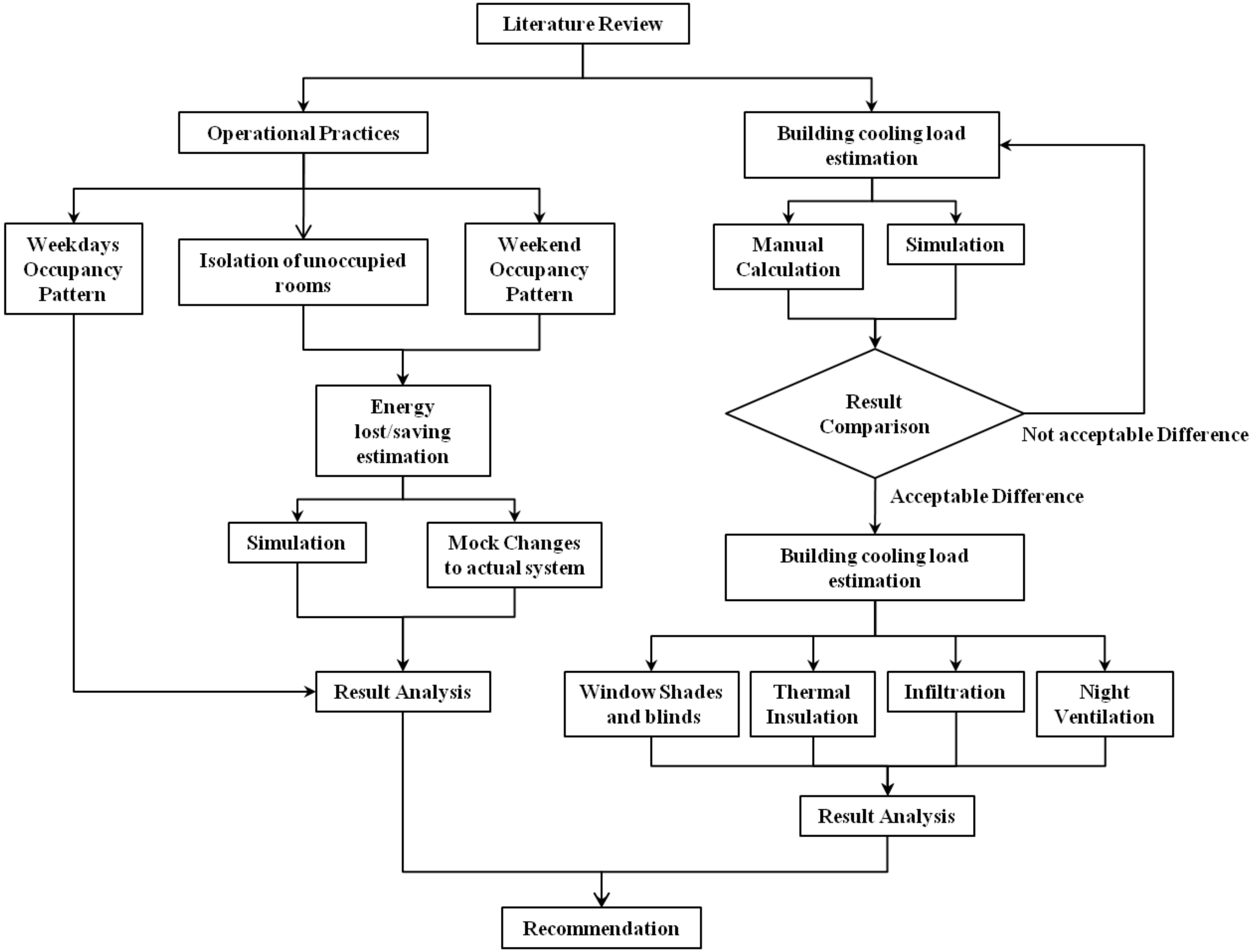


Figure 3.1: Project Flow Diagram

3.2 Cooling Load Simulation Tool: Energy Plus

Energy Plus is the official building simulation program by the United States Department of Energy. Energy plus is originally based on the previously popular energy simulation software BLAST (Building Loads Analysis and Systems Thermodynamics) and DOE-2. The software is created in order to model heating, cooling, lighting, ventilating and other energy related systems of a building. Based on a user's description of a building from the perspective of the building's physical make-up, associated mechanical systems, etc., Energy Plus will calculate the heating and cooling loads necessary to maintain thermal control set points, conditions throughout secondary HVAC system and coil loads, and the energy consumption of primary plant equipment as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would.

The simulation program is based on the heat balance method which allows for simultaneous calculation of radiant and convective effect at both interior and exterior surface during each time step. The heat balance method takes into account all heat balances on outdoor and indoor surfaces and transient heat conduction through building construction (Eskin and Turkmen, 2006). Figure 3.2 shows how the Energy Plus comes out with the final result of the energy simulation. Initially, user is required to provide all necessary building information such as envelop material properties.

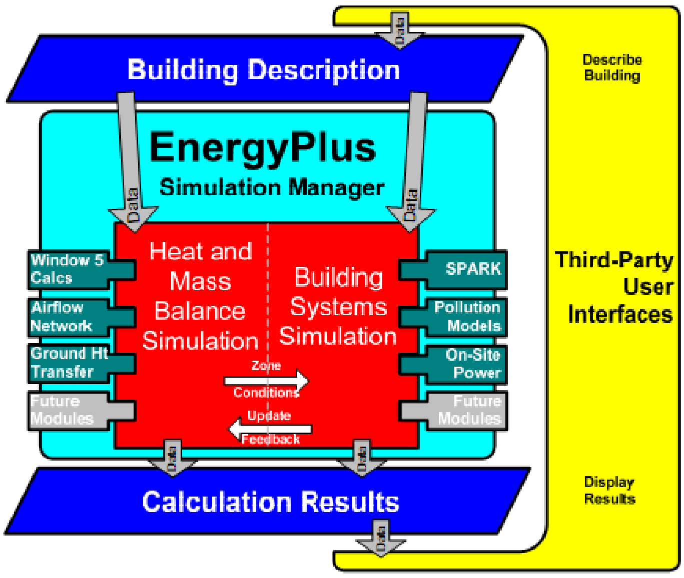


Figure 3.2: Energy Plus methodology schematic diagram (Energy Plus, 2008)

Next, user is to model the building in three dimensional drawing and defining those as either heat transfer surface or non heat transfer surfaces. Heat transfer surfaces consist of the wall, roof, floor, door and glazing. As for non heat transfer surfaces are the roof overhangs, external shading from adjacent building and etc. This is one of the unique features of the software which can accounts for the external shadings effect on the zone cooling load.

Next, data such as internal heat gain form lightings, ventilation, infiltration, electrical equipments as well as from the occupants are being defined in the software. One unique feature of the software is that scheduling can be applied to those internal heat gain such lightings schedule and so on. Finally, user should define the kind of output that is desired as the simulation report. The report comes in two ways whether in Microsoft Excel format of HTML format for ease of viewing. Besides that, user is also able to specify how detail the software should perform the simulation. A more detailed simulation would require slightly longer time but in return, a more accurate result.

3.3 Cooling Load Manual Calculation: CLTD Method

For manual cooling load calculation, CLTD method is used due to its relevancy and simplicity in estimating space peak cooling load to assist calculation.

3.3.1 Indoor and Outdoor Design Specification

The calculation is based on design data provided by ASHRAE for Kuala Lumpur as it is the closest town to Tronoh which available in the Energy Plus software which enable for calculation comparison of both methods. Reference location is taken at Kuala Lumpur with the latitude of 3.12 °N. Design dry bulb temperature and wet bulb temperature is 32.5°C and 26.9°C respectively. Daily temperature range of dry bulb (DB) temperature is 8.2°C. For indoor design condition, dry bulb temperature is 24°C with relative humidity of 50% (ASHRAE, 2001). From psychrometric chart, humidity ratio value is obtained for both outdoor and indoor design condition. For outdoor design condition, humidity ratio is at 0.014 kg of vapour/ kg of water while for indoor condition humidity ratio is 0.067 kg of vapour/ kg of water.

3.3.2 Building description

UTP new academic complex is modelled for both manual calculation and Energy Plus simulation for comparison purpose. Fully simulation by Energy Plus is being done to all 16 blocks of academic building. Most of the blocks are consist of four levels (including ground level). The top floor is the lecturers' offices which are made of glass walls. Table 3.1 summarizes dimensional details of the building. Figure 3.3 shows floor lay out for the lecturers' offices. Table 3.2 summarizes UTP building envelop material specifications.

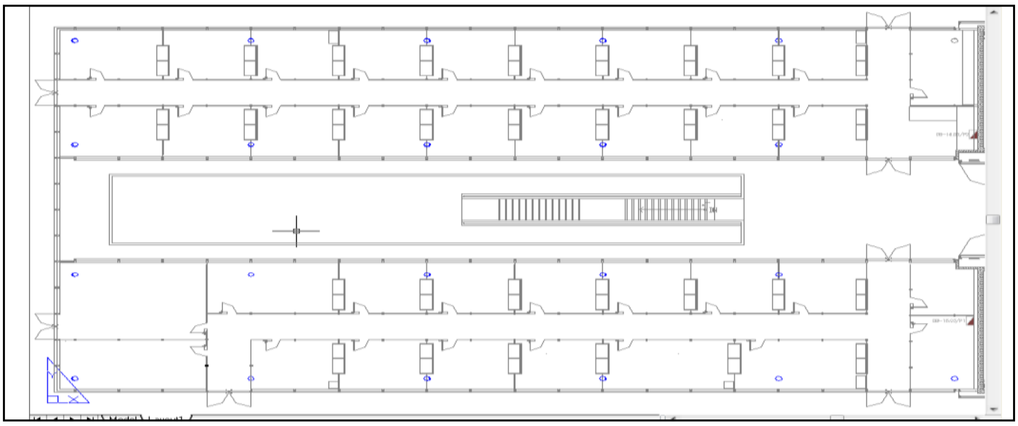


Figure 3.3: Floor layout for Block 17 level 3 (Maintenance Dept. UTP)

Table 3.1: Building 17 dimensional and envelop details (Maintenance Dept. UTP)

<table>
<tr><th>Level</th><th>Dimension (m)</th><th>Wall Area(m^2)</th><th>Wall Construction (from outer layer)</th><th>Window Area(m^2)</th><th>Window Construction</th><th>Roof & floor Construction</th></tr>
<tr><td>Ground</td><td>61.34 x 21.76 x 3.6</td><td>539.06</td><td>Tinted glass
MDF Board
Corian Ceramic
MDF Board</td><td>185.21</td><td>Single Glass</td><td>Heavyweight
Concrete</td></tr>
<tr><td>1</td><td>68.12 x 21.76 x 3.6</td><td>587.88</td><td>Tinted glass
MDF Board
Corian Ceramic
MDF Board</td><td>204.68</td><td>Single Glass</td><td>Roof
Heavyweight
Concrete</td></tr>
<tr><td rowspan="4">2</td><td colspan="2">Right Wing</td><td rowspan="4">Tinted glass
MDF Board
Corian Ceramic
MDF Board</td><td rowspan="4">169.4
237.51</td><td rowspan="4">Single glass</td><td rowspan="4">Heavyweight
Concrete</td></tr>
<tr><td>66.56 x 11.17 x 3.6</td><td>529.81</td></tr>
<tr><td colspan="2">Left Wing</td></tr>
<tr><td>66.56 x 11.17 x 3.6</td><td>529.67</td></tr>
<tr><td rowspan="4">3</td><td colspan="2">Right Wing</td><td rowspan="3">Single Glass</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4">Stucko embossed
Rock wool insulation
Aluminum sheet</td></tr>
<tr><td>35.25 x 7.5 x 2.75</td><td>235.13</td></tr>
<tr><td colspan="2">Left Wing</td></tr>
<tr><td>35.25 x 7.5 x 2.75</td><td>235.13</td><td>Single Glass</td></tr>
</table>

Table 3.2: Envelope material specification (Energy Plus material database from ASHRAE Handbook 2005)

Material	**Thickness (m)**	**k (W/m.K)**	**R value (m^2K/W)**
Glass	0.010	0.0139	0.0130
Tinted glass	0.010	0.0139	0.0130
1 ft Concrete	0.310	1.9500	0.1590
2ft Concrete	0.610	1.9500	0.3130
Aluminum sheet	0.010	250.0000	0.0004
Rock Wool Insulation	0.240	0.0300	8.0000
Stucco embossed sheet	0.010	0.7200	0.0140
Medium Density Fiber (MDF) Board	0.190	0.2000	1.0000

The building is in the 70° N orientation with respect to sun. In each floor, there are two plant rooms for the air handlers. For ground level, level 1 and level 3, there are roof overhangs which act as external shading to. However, the effects of the canopy roof as well as adjacent building are neglected for simplification of calculation.

3.3.3 Heat Gain Calculation (sample calculation for 3rd floor building 17):

Manual calculation is done via two versions of CLTD method which are for commercial building, ASHRAE CLTD method (ASHRAE 1989) and single family detached, residential ASHRAE CLTD method (ASHRAE 2001). The later method is used as the building 17 is modeled as per outlined criteria of single detached house. In this particular assumption, single detached house in this category usually has exposed walls in four directions, often more than one story, and a roof. The cooling system is a single-zone, unitary system with a single thermostat (ASHRAE 2001). Two methods of calculation are used due to the limitation of 1989 CLTD which the available envelop construction doesn’t match for all materials of the investigated building. On the other hands, 2001 CLTD has overcome that particular restriction. This also would allow the author to compare the cooling loads from both methods with heat balance approach by Energy Plus.

The whole wing is considered as single zone which is served by one unit of AHU. As being mentioned before, there are six groups of heat gain sources that must be considered in the load calculation. Firstly, heat gain via conduction is heat transferred from either exterior surface such as walls, roofs, floors and glass or interior partition of a space. Heat gain by conduction is calculated via the following formula:

$$Q = U \times A \times CLTD_c \tag{3.1}$$

where Q (in watt) is the cooling load value, U (in Btu/hr.Ft^2.°F) is the overall heat transfer coefficient of the exterior surface, A is the area of the surface while $CLTD_c$ (in °F) is the corrected value of CLTD. CLTD value which is found from table 6.1, 6.2 and 6.5 (Pita, 2002) need to be corrected by using the following formula:

$$CLTD_c = CLTD + LM + (78 - t_R) + (t_a - 85) \tag{3.2}$$

where LM (in °F) is found from table 6.4 (Pita, 2002) which is based on fenestration orientation as well as location latitude, t_R and t_a is taken from the indoor and outdoor design condition in table (ASHRAE, 2001). However for glass wall, LM correction not required. For conduction from partition (plan room), the room temperature is assumed 5°C lower than the design outdoor temperature which is 27.5°C (Pita, 2002). Table 3.3 lists all the value from CLTD, LM, and $CLTD_c$ for walls and roof:

Table 3.3: CLTD, LM and $CLTD_c$ values (Air Conditioning Principles and Systems, 2008)

Conduction	Wall Orientation	U	A,ft2	CLTD,F	LM, °F	CLTDc, °F
			Net	Table	Table	
Glass Single Pane	NW	0.25	222.01	13.00	0.00	13.75
	NE	0.25	1043.45	13.00	0.00	13.75
	SW	0.25	1043.45	13.00	0.00	13.75
	SE	0.25	222.01	13.00	0.00	13.75
Roof	Horizontal	0.02	5691.42	67.00	-5.00	62.75
Partition	N/A	1.10	222.01	14.50		

Secondly, heat gain via solar radiation is calculated by using the following formula:

$$Q = SHGF \times A \times SC \times CLF \tag{3.3}$$

where Q (in Btu/Hr , for convenient of calculation, this formula use British unit) is the solar cooling load value, max Solar Heat Gain Factor (SHGF, in Btu/hr.°F) is found in table 6.6 (Pita, 2002) for east facing glass wall, 20° N latitude (which is the nearest value with 4.22°N actual latitude) at the month of June , A (in Ft^2) is the glass area that is exposed directly to the sun light at that particular time. Based on table 6.8, for North East facing glass wall, the highest CLF value is at 8 am for heavy weight construction. Shading Coefficient is assumed 0.94 (table 6.7, Pita 2002) as no shading installed (this assumption is made to calculate maximum load of the zone).

Table 3.4: Table of SHGC, A, SC and CLF values (Air Conditioning Principles and Systems)

Solar Radiation	Fenestration Orientation	Shading	SHGF	A	SC	CLF
Glass	NW (right wing)	no.	189.00	945	0.94	0.79

Next, heat gain from the lightings. The load calculation is based on the following formulas:

$$Q = W \times BF \times CLF \tag{3.4}$$

where Q is the load in watt, W is the lamp wattage in watt, whereby Ballast Factor (BF) and CLF is normally taken to be unity (ASHRAE, 2001). The lighting used in the rooms is 30 W fluorescent lights. BF is taken 1.25 whereby CLF is assumed to be unity (Pita, 2002). As for heat gain from the appliances, ASHRAE standard heat gain is taken based on types of equipments. Table 3.4 summarizes the details on the equipments and appliances.

Table 3.5: Heat gain values for equipments and appliances (ASHRAE Handbook 2001)

Appliances	Watt	number
PC	55.00	10
Projector	250.00	1
Photocopy Machine	1100.00	1
Refrigerator	690.00	1
Toaster	1510.00	1
laser Printer	320.00	2

Next, heat gain via occupants. It is assumed that 10 peoples in each wing with level of activity taken as seated, very light work that account for 245 Btu/hr and 155 Btu/hr for sensible and latent heat gained from table 6.13 (Pita, 2002). For the ease of calculation, a spreadsheet is generated based on the CLTD/CLF. This calculation had imposed some rooms for errors; 1. CLTD value of roof from the table is approximated to the closest construction with the actual roof 2. LM correction is taken to latitude which closest to 3.12°N which is 0°.

Next, ASHRAE 2001 CLTD method is used to calculate cooling load of the building. Compared to the previous method, this approach is much simpler. The CLTD value provided in the table doesn't specify wall construction. The CLTD value is based on the outdoor design temperature as well as surface orientation. Table 3.6 shows heat gain by conduction formula. Furthermore, for glass surfaces, separate heat transfer by conduction calculation is not required. Total heat gain by glass surfaces are simplified by only one equation by introducing new factor, Glass Load Factor (GLF). Table 3.7 shows heat gain via fenestration formula.

Table 3.6: Heat gain values for equipments and appliances (ASHRAE Handbook 2001)

Surface Type	Wall Orientation	U W/m2K	A,m^2 Net	CLTD, K Table
Roof	Horizontal	0.12	528.75	21.00
Partition	N/A	6.25	20.63	8.00

Table 3.7: Glass load factor (GLF) values (ASHRAE Handbook 2001)

Conduction	Fenestration Orientation	A,m^2 Net	GLF Table
Windows	NW	96.94	205.00
	SW	96.94	255.00
	SE	20.63	255.00

Values for CLTD and GLF are taken from Table 1 and 3 of chapter 28 (ASHRAE 2001). Cooling load calculation for internal gain such as lightings and electrical equipments are the same as the previous method.

The final value of latent heat gain portion is obtained by multiplying the total sensible cooling load with a factor which is obtained from Figure 1 Chapter 28 (ASHRAE 2001). The factor is based on construction type whether loose, medium or tight construction as well as the difference of outdoor and indoor humidity ratio. In this study, the construction is assumed as air tight. Value obtained is 1.125.

3.3.4 Energy Plus Simulation

Similar condition in the manual calculation is also being implemented in the simulation stage. Yearly simulation is done in order to identify peak load of the whole year. For yearly simulation, a set of weather data is required for the software to perform the simulation. In this case a weather set of Kuala Lumpur provided by Energy Plus is used. The weather data comprises the essential information of the whole 24 hours for the use of the simulation, for instance, outdoor dry bulb temperature, wind speed, location geometrical details (latitude, longitude, elevation, ground temperature) and so on. One of the main settings that should be defined by user is solution algorithm either using Conduction Transfer Function (CTF) or Conduction Finite Difference (CFD). For this case, CTF algorithm is selected as per outlined by ASHRAE 2001 heat balance guideline. As for the building material, the simulation will be based on the experimental value of thermal resistance of the surfaces. This is due to unavailability of that particular data which means the simulation is performed in one dimensional steady state conduction.

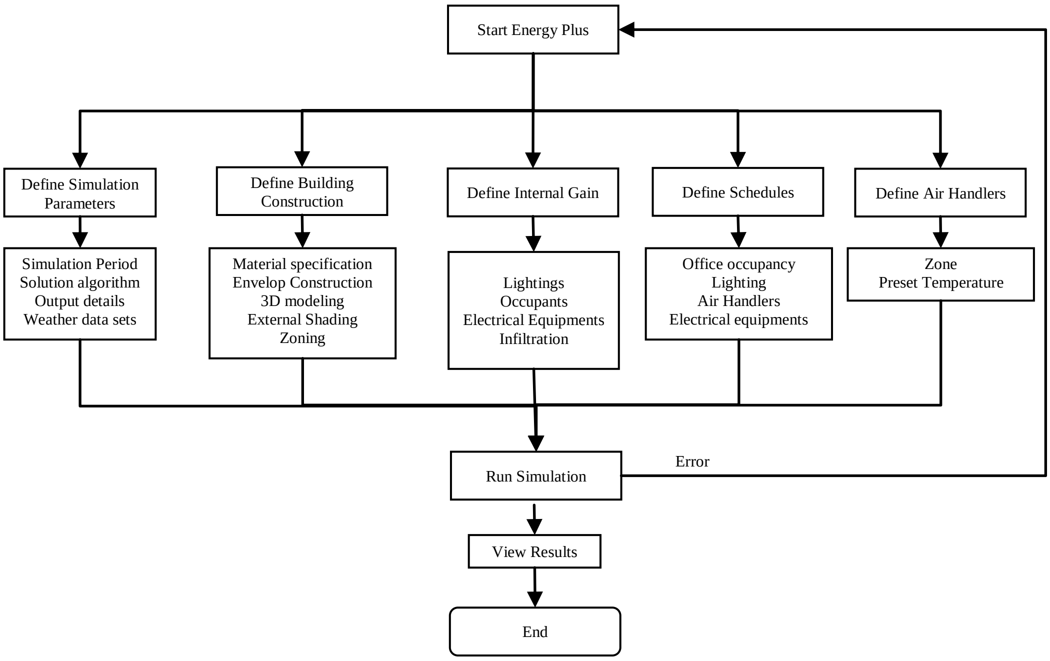


Figure 3.4: Methodology for Energy Plus simulation

Cooling load simulation will be done to all 16 blocks of the new academic complex. From the simulation, the resulting cooling load will be compared to the manual calculation to validate the simulation outcome. Cooling load simulations are also being done to investigate the effect of several design parameters such as thermal insulation, window shades and blinds, night ventilation, infiltration as well as the effect of space overcooling towards building annual cooling energy requirements.

3.4 Investigation on UTP Air Conditioning Operational Practice

This research also involved an investigation on the operational practice of the air conditioning system. The study was aimed to three main subjects, weekend and weekday occupancy pattern as well as analyzing energy saving by isolating the unoccupied rooms. These particular tasks were being performed with the assistance of UTP Property Management and Maintenance Department especially for data collections as well as on site system configuration.

3.4.1 Weekends Occupancy Patterns

Three weeks of observations was done to all sixteen UTP academic blocks to investigate weekends building occupancy. Among the things that had being done was personal interview with the users to gather information on the building occupancy pattern throughout the semester.

3.4.2 Weekday Occupancy Pattern

Weekday occupancy of UTP Mechanical Engineering Buildings was being performed. Interviews with the direct users of the rooms were being performed to get the information regarding rooms occupancy patterns. Class rooms timetable provided by Academic Central Services (ACS) were also being referred. Building occupancy pattern was then being compared to the AHU schedule to identify potential area for improvisation of the schedule.

3.4.3 Unoccupied Rooms

From the investigation of rooms' occupancy patterns, the rooms which are unoccupied for the whole semester were being recorded. To estimate the energy saving by isolating the unoccupied rooms, Block 17 first floor was selected for analysis. For cooling load savings, Energy Plus simulation was performed for the assigned location. In addition to that, actual changes were also being applied to the system to isolate the unoccupied rooms to compute fan power saving. This involves configuring current VAV system from pressure independent to pressure dependent mode. This change would allow the VAV boxes correspond to room preset temperature. In addition to that, the minimum VAV box flow was also being configured to 0%. This implies that whenever the temperature set point is met, the VAV box will be fully closed. Rooms isolation were done by increasing room temperature set point from 24°C to 33°C. The variables that were being monitored consist of Variable Speed Drive, Duct Static Pressure, Supply and Return Air Temperature as well as Cooling Valve opening percentage.

3.5 Experiment for determining envelop thermal resistance

Due to unavailability of material specification of the building envelop, an experiment will be conducted to determine the thermal resistance value of the walls, windows, roof and floors. The experiment is conducted with the basic idea of thermal resistance circuit of composite wall. Figure 3.4 illustrates thermal circuit of wall. This comes with the system is assumed to be steady state one dimensional heat transfer without internal heat generation (Incropera and Witt, 2008). In this particular experiment, the outdoor air is treated as the warm fluid while the indoor as the cold fluid whereby heat is transferred from outside through the building composite wall. The thermal resistance equation is then further manipulated to yield the following equation for heat flux through the wall.

$$q_x = \frac{(T_{\infty,1} - T_{s,1})}{\frac{1}{h_1 A}} = \frac{(T_{s,1} - T_2)}{\frac{L}{k_A A}} = \frac{(T_2 - T_3)}{\frac{1}{h_2 A}} \qquad (3.5)$$

In this experiment, the intended variable is the thermal conductivity, k of the wall. To find the k, firstly, heat transfer coefficient, h of the outdoor air must be calculated. Assuming outside heat is transferred via natural convection, h of a vertical plate for constant surface temperature can be found by the following equation.

$$h = \frac{k}{L} Nu \qquad (3.6)$$

where Nusselt Number, Nu and Rayleigh's Number, Ra are as the following equations.

$$Nu = \left\{0.825 + \frac{0.387 Ra_L^{1/6}}{\left[1 + (0.492/Pr)^{9/16}\right]^{8/27}}\right\} \qquad (3.7)$$

$$Ra_L = \frac{g\beta(T_s - T_\infty)L^3}{v^2} Pr \qquad (3.8)$$

From the equation, the main information required is the wall outside surface temperature, T_s and outdoor surrounding temperature, T_∞. Value of gravitational acceleration, g is taken as 9.81 ms^{-2}, *L* is the surface vertical length, *k*, dynamic viscosity, *v* and β can be found from table A-15 (Heat Transfer: A practical Approach, Cengel, 2008) by finding the properties of air at film temperature. Hence, the experiment will be concentrating on collecting the surface temperature of walls, roofs and glazing of the building as well as the outdoor temperature. Measurement tools will be the k type thermo couple. Instrument used in this particular experiment if K type thermocouple. The model is Fluke 51that ranges from -200°C to 1370°C. The instrument accuracy is in the range of 0.1% + 0.7°C.

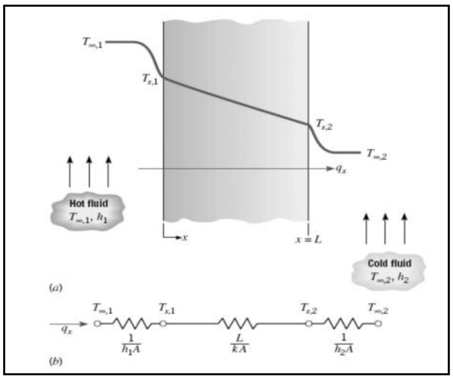


Figure 3.5: Thermal circuit schematic diagram (Introduction to Heat Transfer, 2008)

CHAPTER 4
COOLING LOAD ANALYSIS

In this section, all outcomes of the cooling load analysis are being discussed. Firstly, the result from the experiment of estimating the walls thermal resistance value is being discussed. Next, different methods of cooling load calculation are being compared to identify the validity of Energy Plus software cooling load results. In the next section, all result of the Energy Plus simulation results are being analyzed.

4.1 Building Envelope Thermal Resistance Experiment

Thermal resistance value for the building wall, single glass and double glass window are being experimented. For this purpose, room 18-01-06 envelope properties are being investigated. For each envelope, temperature is being taken at two points and the average temperature is calculated. Table 4.1 shows the obtained temperature for the wall.

Table 4.1: Thermal Resistance Experiment Results

Surface type: Wall

Reading		1	2	3	4	5	Average
$T_{surrounding}$		30.7	30.7	30.6	30.7	30.6	30.66
T_{sout}	Point 1	29.4	29.3	29.4	29.3	29.3	29.34
	Point 2	29.3	29.2	29.1	29.1	29.1	29.16
						Average T_{sout}	29.25
T_{sin}	Point 1	25.5	25.3	25.2	25.2	25.2	25.28
	Point 2	25.1	25.2	25	25	24.9	25.04
						Average T_{sin}	25.16

For single glass and double glass window results, please refer Appendix 2. From the temperature obtained, calculation is done to determine the wall's thermal resistance value. From equation 3.6 outdoor convection heat transfer coefficient, *h* is first being calculated by assuming heat transfer from outdoor air is via natural convection. Then thermal resistance, *R* value is calculated via equation 3.5. Table 4.2 summarizes the calculation result for *h* and *R* value for the wall, single glass and double glass window. The detailed calculation is shown in Appendix 3. From this experiment, the calculated R value for the building envelop will be used for cooling load calculation for both manual calculation as well as Energy Plus simulation.

Table 4.2: Result for *h* and *R* value calculation

	Wall	Single Glass	Double Glass
Convection Heat transfer coefficient, h (W/m^2K)	2.1105	2.0281	2.1001
Thermal Conductivity, k (W/mK)	0.1441	0.0143	0.0579
Thermal Resistance Value, R (m^2K/W)	1.3876	0.6993	1.3812
Overall Heat Transfer Coefficient, U (W/m^2K)	0.7207	1.4301	0.7240

4.2 Cooling Load Analysis

In this section, cooling load calculation is done via both manual calculation and software simulation. Then, the results will be compared to validate the software results. In analyzing the effect of several variables towards building annual cooling energy, computer simulation by Energy Plus is being performed.

4.2.1 CLTD Method and Heat Balance Method Comparison

This section will compare all results from the CLTD and heat balance method for determining the zone cooling load (block 17, level 3, right wing). From the calculation done to find peak load of the zone, Figure 4.2 summarizes the cooling load calculation via commercial building CLTD method to obtain the zone peak cooling load.

From this method, peak cooling load of the zone is 47.7 kW. Figure 4.1 illustrates the proportion of the calculated cooling load. From the figure, it is noted that solar radiation is the main source of the cooling load at about 66%. This is due to the fact that the walls are made of glass.

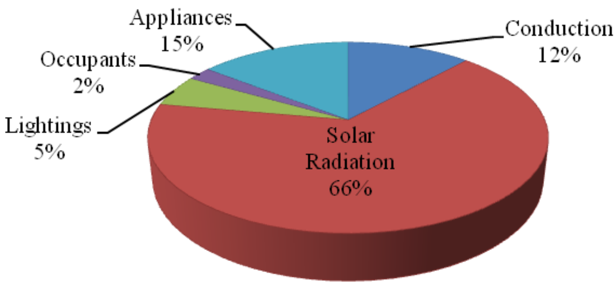


Figure 4.1: Cooling load distribution by Commercial Building CLTD Method

HEAT GAIN BY CONDUCTION & RADIATION

Conduction	Wall Orientation	Colour	U	A,ft² Net	CLTD,F Table	Total Load BTU/hr
Glass Single Pane	NW	clear	0.25	222.01	13.00	763.14
	NE	clear	0.25	1043.45	13.00	3391.22
	SW	clear	0.25	1043.45	13.00	3391.22
	SE	clear	0.25	222.01	13.00	721.53
Roof	Horizontal	N/A	0.02	5691.42	67.00	9203.02
Partition	N/A	N/A	1.10	222.01	14.5	3541.06
						21011.20

Solar Radiation	Dir.	Sh.	SHGF	A	SC & CLF	Load
Glass	NW (right wing)	no.	189.00	948.57	0.94, 093	115688.45
						115688.45

HEAT GAIN BY LIGHT, PEOPLE, APPLIANCES

Light	Watt	BF	CLF	number	Factor	Load
Fluorescent 900mm	30.00	1.25	1.00	60	3.41	7672
Fluorescent 450mm	30.00	1.25	1.00	14	3.41	1790
						9462

People	q_s/q_l	Number	CLF	Load
$Q_{sensible}$	245.00	10	1.00	2450
Q_{latent}	155.00	10	1.00	1550
				4000

Appliances	Rated Load	Conversion factor	number	Load
PC	55.00	3.41	10	1875
Projector	250.00	3.41	1	852
Photocopy Machine	1100.00	3.41	1	3751
Refrigerator	690.00	3.41	1	2352
Toaster	1510.00	3.41	1	5149
laser Printer	320.00	3.41	2	2182
				16163
				Total Sensible Load
				162643.00 Btu/hr
				47695.90 Watt

Figure 4.2: Cooling load calculation via Commercial Building CLTD Method

To validate the calculation result, second method for manual calculation is done which is via ASHRAE Residential CLTD method. Table 4.2 illustrates the cooling load calculation via this method.

HEAT GAIN BY CONDUCTION & RADIATION

Surface Type	Wall Orientation	U W/m²K	A,m² Net	CLTD, K Table	Cooling Load (W)
Roof	Horizontal	0.12	528.75	21.00	1332.45
Partition	N/A	6.25	20.63	2	257.88
				TD	1977.14

HEAT GAIN FROM FENESTRATION

Conduction	Fenestration Orientation	A,m² Net	GLF Table	Sensible Load
Windows	NW	96.94	205.00	19872.70
	SW	96.94	255.00	24719.70
	SE	20.63	255.00	5259.48
				49851.88

HEAT GAIN BY LIGHT, PEOPLE, APPLIANCES

Light	Watt	BF	CLF	number	Factor	Load
Fluorescent 900mm	30.00	1.25	1.00	60	3.41	2250.00
Fluorescent 450mm	30.00	1.25	1.00	14	3.41	525.00
						2775.00

People	qs/ql	Number	CLF	Load
Qs	65.00	10	1.00	650.00
QL	30.00	10	1.00	300.00
				950.00

Appliances	Watt	number	Load
PC	55.00	10	550.00
Projector	250.00	1	250.00
Photocopy Machine	1100.00	1	1100.00
Refrigerator	690.00	1	690.00
Toaster	1510.00	1	1510.00
laser Printer	320.00	2	640.00
			4740.00

	Sum of load
	60294.01
Total Cooling load (Watt)	67830.77

Figure 4.3: Cooling load calculation via Residential Building CLTD Method

The final method of cooling load calculation is via cooling load simulation by Energy Plus software. Maintaining the same parameter from the manual calculation, the yearly simulation is performed for block 17 level 3(lecturers' offices). Figure 4.3 illustrates the monthly maximum cooling load profile for block 17 level 3.

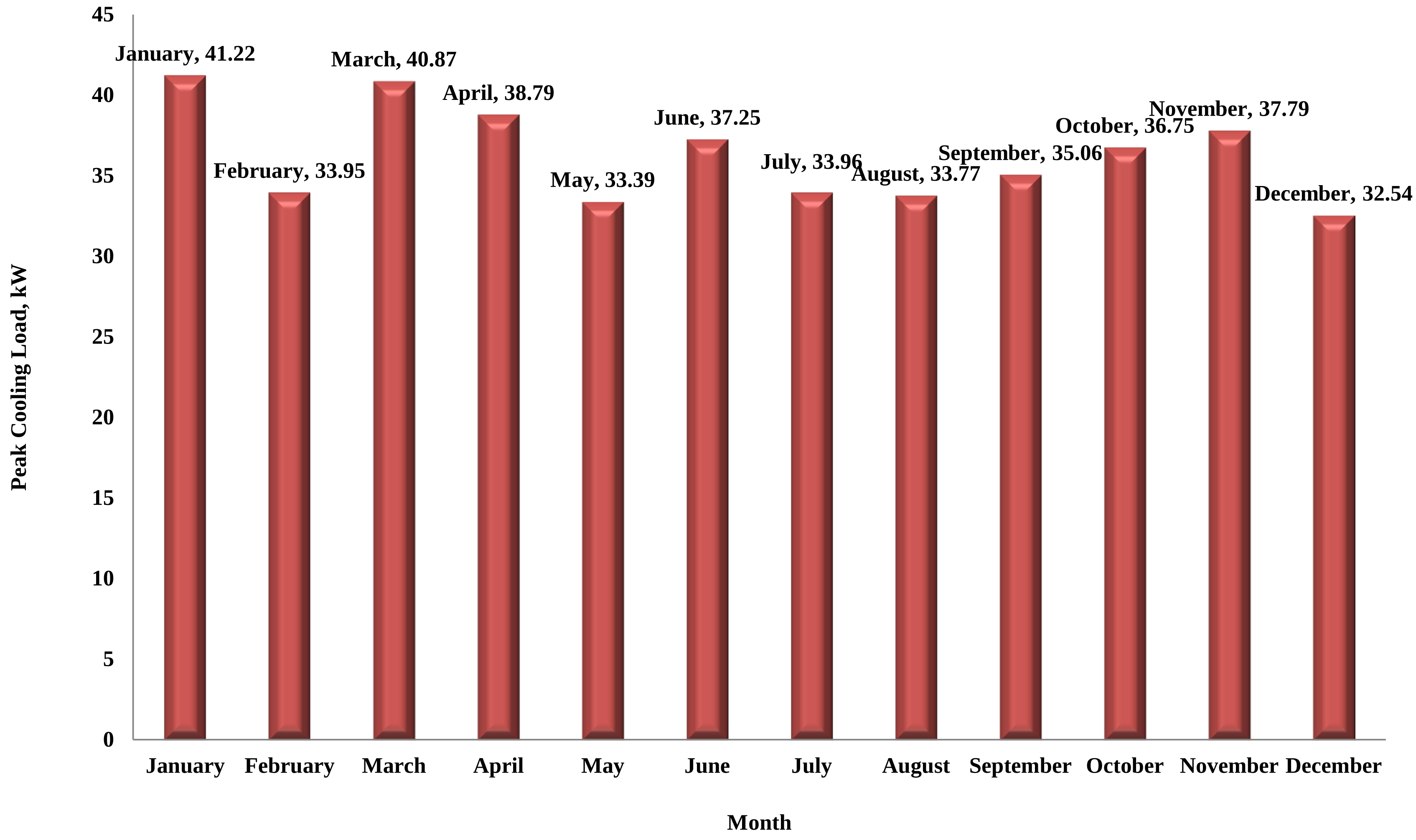


Figure 4.3: Annual simulation result of Energy Plus for block 17 level 3

Result of the three methods are compared to validate the Energy Plus simulation results. Table 4.3 summarizes the peak load comparison for both CLTD methods and Heat Balance (HB) method by Energy Plus. From the comparison, the result for HB method is very close to commercial building CLTD method while residential CLTD method deviates from HB method at about 65%. Besides that, HB method result is consistent with commercial CLTD Method with a difference at about 4%. The large difference showed by residential CLTD 2001 shows its unsuitability for use of cooling load calculation for commercial building. This is due to the fact that this method is much simplified based on the residential house criteria such as the air conditioning equipment and controls usually do not have refined provisions for humidity control and part load operation. Furthermore, homes are often conditioned 24 hours a day which lead to such simplification of load calculation (Pita, 2002).

Table 4.3: Comparison between CLTD and HB method

	HB Method	**CLTD 1989**	**CLTD 2001**
Peak Cooling Load (kW)	41.20	47.70	67.80
% differences with HB		16%	65 %

To further assess the validity of Energy Plus results, cooling load of level 3 for Block 5 and 23 are calculated via both method and the results are illustrated in Table 4.4. From the comparison, the result of both CLTD and HB method are consistent to each other.

Table 4.4: Cooling Load comparison between HB method and CLTD method

	B17	**B23**	**B5**
Building Orientation	160 °N	14 °N	90 °N
Cooling Load via Energy Plus Heat balance (kW)	41.20	69.84	42.87
Cooling Load via CLTD (kW)	47.70	63.94	45.98
Difference (%)	16	-9	7

It is believed that Energy Plus produces a more accurate result with its capabilities in incorporating other factors that contribute to the resulting cooling load. For instance, factor of external shading from roof overhangs or adjacent building of structure. In other publication for instance by Eskin and Turkmen (2006), result validation is done via comparison between the result form the software with the actual measured cooling load. The paper reported a consistent result for both actual measurement and Energy Plus simulation at about 5% difference for cooling load and 3% for heating load. However, due to instruments limitation on the UTP air conditioning system, actual measurement cannot be done. Therefore, with these two bases, it can be said that Energy Plus software is a valid tool to compute a building cooling load analysis.

4.2.2 Comparison between Equipment Design Cooling Capacity and Calculated Cooling Load

In analyzing the system's cooling load, it is necessary to see how the equipments manufacturer designs the size of the equipments especially the AHU. In table 4.5, equipments rated cooling capacity of Block 17, 23 and 5 level 3 Right Wing are being compared to the result obtained from HB method via Energy Plus.

Table 4.5: Cooling Load comparison Equipment Rated Cooling Capacity vs. HB method peak cooling load

	B17	B23	B5	B1	B21	B22
Building Orientation	160 °N	14 °N	90 °N	155 °N	52 °N	32 °N
Peak Sensible Cooling Load via HB method (kW)	41.20	69.84	42.87	40.22	69.40	69.70
Refrigeration Load by HB method = (Peak sensible x 1.26) kW	51.91	88.00	54.02	50.68	87.44	87.82
Equipments Rated Cooling Load (kW)	**80.80**	**111.00**	**70.00**	**96.00**	**112.00**	**112.00**
Overdesign Percentage, %	**36.00**	**21.00**	**23.00**	**47.00**	**22.00**	**22.00**

From figure 4.5, it is observed that the equipments are overdesigned by an average of 28%. In reality, sizing of air-conditioning equipments is normally being overdesign by 10% to 15% (Yu, Chow, 2000). This is due to some factors which are for future extension, to overcome uncertainty in assumptions during sizing calculation phase and also due to clients' request (Yu, Chow, 2000). However, overdesigning a system is not a good engineering practice. A system should be designed to be flexible. Over sizing has to pay the cost of running the plant at lower efficiency all the time. If there is a possibility of future extension or change of usage, the system should be designed so that it will be easy and inexpensive to add equipment or change equipment.

4.2.3 Cooling Load Simulation for UTP Academic Complex

In this particular section, building energy simulation is performed via Energy Plus to analyze UTP academic complex (all 16 academic building) cooling energy. Figure 4.3 shows the estimated yearly cooling energy for all sixteen blocks of UTP academic building. From yearly cooling load simulation, total cooling energy required by the whole 16 academic blocks are about 2,327,453 RTh (8,146,085kWh) which accounts for about RM 2,769,669 per year (RM0.34/kWh). From Figure 4.3, block 23 requires the highest annual cooling energy at about 195,630 RTh while block 3 requires the lowest cooling energy requirement at about 90,670 RTh/year. Average cooling annual cooling energy required for all 16 blocks is 145,465 RTH. Such variation in cooling energy requirement mainly due to each buildings different orientation with respect to sun, different window to wall ratio as well as different total hours of operations throughout a year. Furthermore, there are also differences in some of the buildings total building floor area. For instance, Block 3 and Block 15 were designed without third floor (lecturers' offices). Moreover, glazing systems of some of the buildings are different. Block 15, 18 as well as Block 21 are designed with double glazing window. The resulting annual cooling load can be categorized as high as compared to other countries in the world. This is mainly due to hot and humid climate which is high in latent and sensible heat (Perez, Capeluto (2008)). Therefore, in order to minimize the cooling load, several design variables will be further analyzed to find potential measures for cooling load reduction.

4.2.4 Effect of Building Orientation on Annual Building Cooling Energy Requirement

In order to investigate the factor that lead to high cooling load of block 23, the effect of building orientation with respect to the sun against cooling load is being investigated. Energy Plus simulation was done all 13 buildings third floor (lecturers' offices) to verify whether building orientation lead to high cooling load. The third floor was being selected due to its similarity in the design aspects (wall material, floor area, internal heat gain) except for building orientation. In Figure 4.4, yearly cooling energy for level 3 are being compared to analyze the effect of building orientation towards building cooling load.

From the figure, Block 23 (14°N) shows the highest annual cooling energy of all building at about 44,490 RTh while the lowest is Block 5 (90°N). From Figure 4.4, it is observed than the closer a building orientation to 0°N (orientation which 100% glass wall facing east or west), the higher the cooling energy. This is due to the fact that solar radiation intensity received by a surface is the highest at right angle (when the glass area is perpendicular to solar radiation) in which block 23 is the closest orientation to this angle. Compared to block 5 whereby the glass area totally facing south, the resulting annual cooling energy is the lowest. From this comparison, it can be concluded building orientation with respect to the sun is one of the factor that results in the variation of each building annual cooling energy requirements. Figure 4.5 shows orientation of all 16 academic block of UTP.

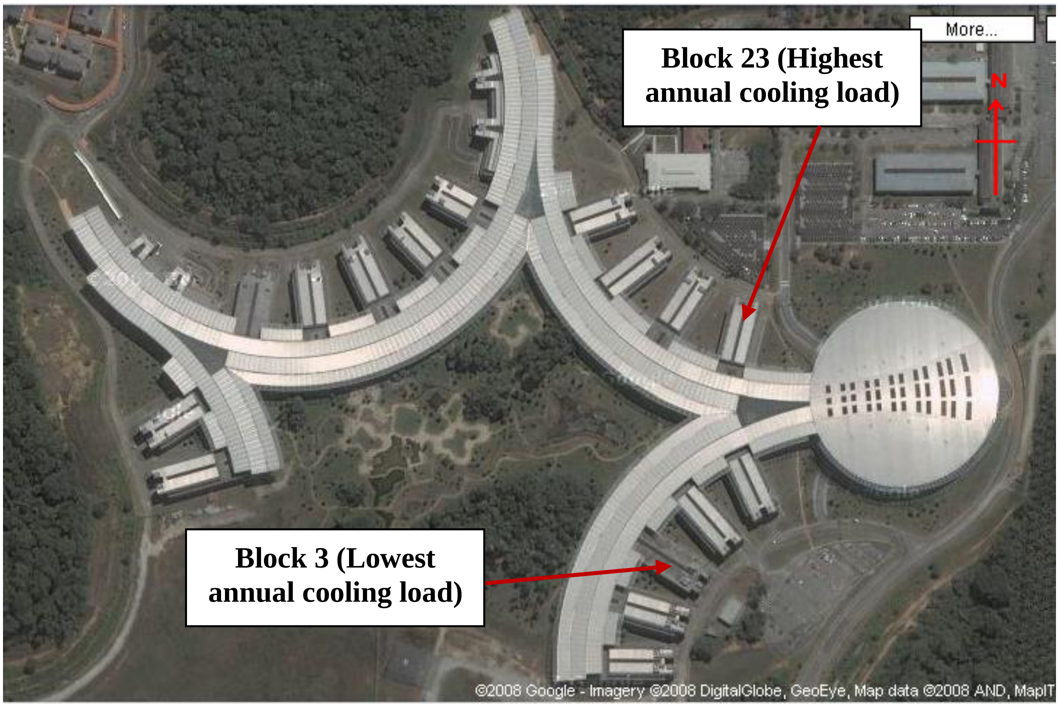


Figure 4.5: UTP Academic building annual cooling energy

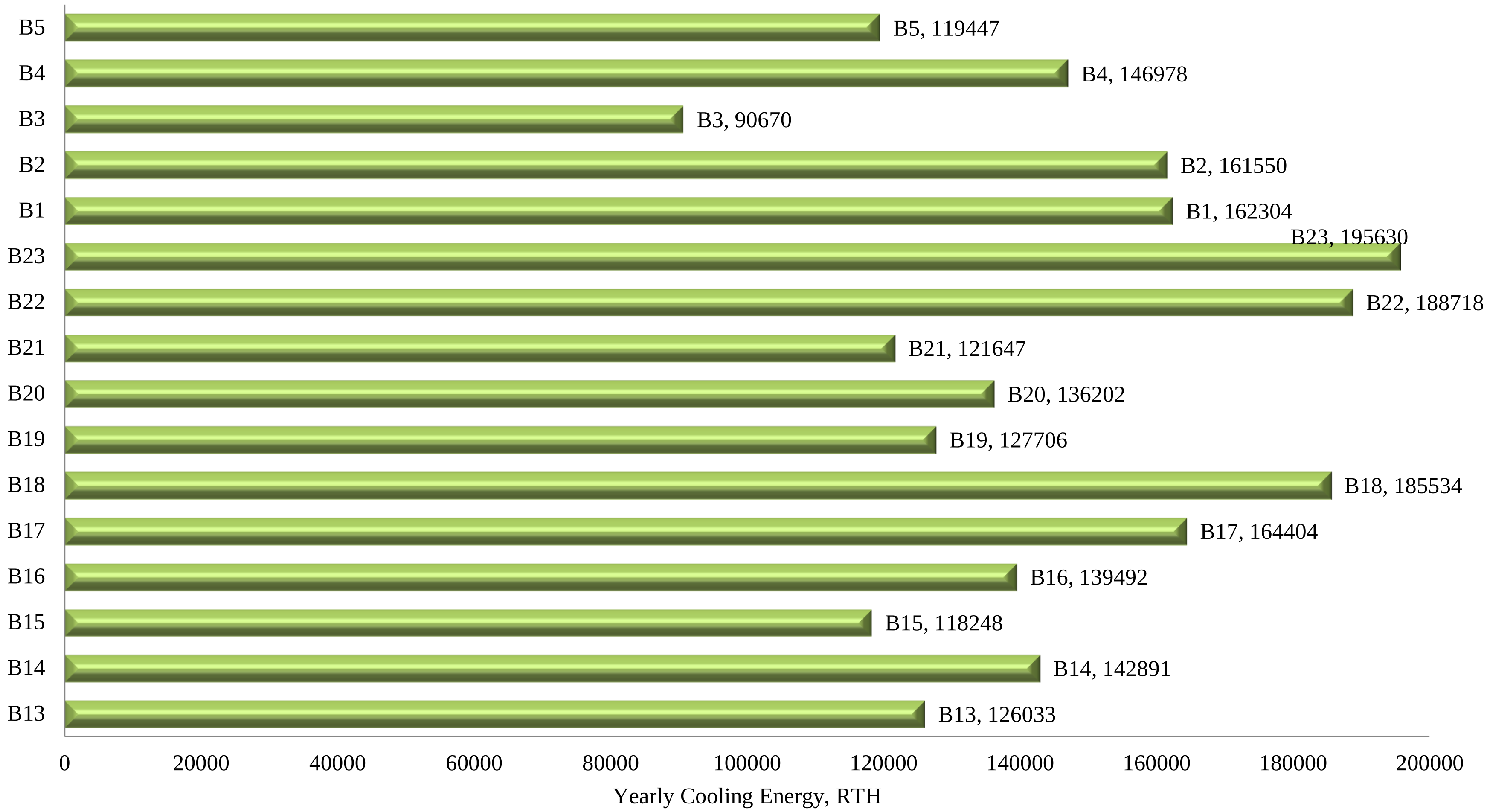


Figure 4.3: UTP Academic building annual cooling energy

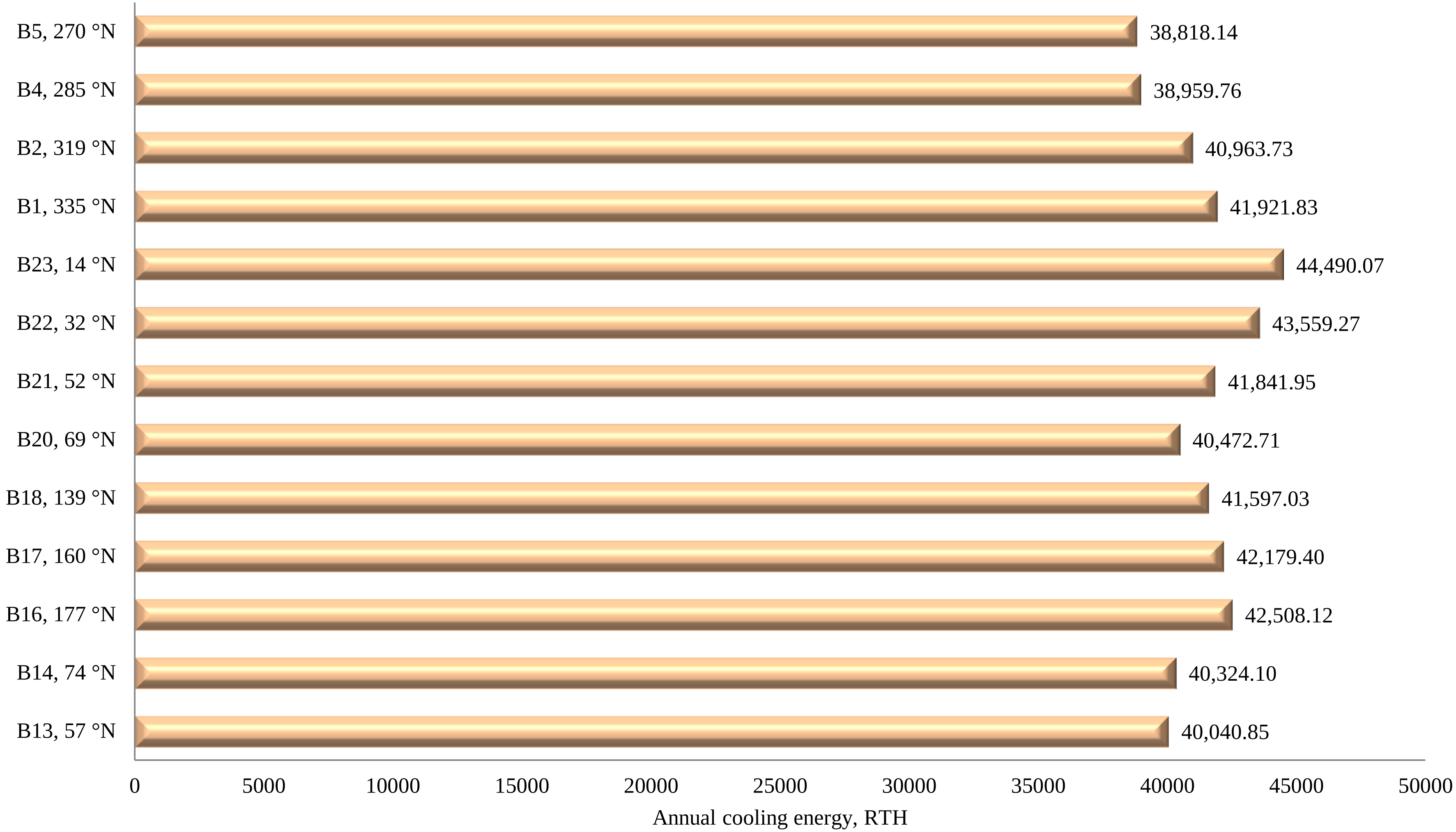


Figure 4.4: Effect building orientation on annual cooling energy

4.2.5 Effect Window Blind and Shading on Building Cooling Load

Various types of windows blind and shading devices can be used either internally or externally in a building. In this study, effect of internal shading was being analyzed since it is the common application for typical building in Malaysia. Six types of window blinds and shading devices are being investigated to determine which will result is the greatest energy saving. Three types of blinds being studied are High Reflectivity (HIREF) Slats, Medium Reflectivity (MIDREF) Slats and Low Reflectivity (LOWREF) slats. As for shading devices, High Reflectivity Low Transmittance (HRLT) shade, Medium Reflectivity Low Transmittance (MRLT) shade and Low Reflectivity Low Transmittance (LRLT) shade are being analyzed. Energy Plus simulation is done for Block 23 base case model from ground level 1 to level 3. Simulation results indicate that blinds and shades with high reflectivity material give the highest reduction of base case cooling load. The percentage of annual cooling load reduction for all types of blinds and shades is shown in Table 4.6.

Table 4.6: Effect of windows blinds and shadings on annual cooling energy requirement for Block 23

	Annual Cooling Load Reduction, %					
	Blinds			**Shades**		
Floor Level	**HIREF**	**MEDREF**	**LOWREF**	**HRLT**	**MRLT**	**LRLT**
3	16.63	-9.45	2.40	34.62	18.48	-2.44
2	20.02	2.56	10.52	33.02	19.86	7.23
1	18.88	1.22	9.21	32.54	18.62	5.91
Ground	3.61	-4.93	-1.11	9.82	3.19	-2.74
Total Load Reduction (Block 23)	14.19	4.95	-2.71	26.53	14.38	1.78

From table 4.6, the highest annual cooling load saving can be achieved by installing HRLT shades at about 26.53% which accounts for 51,687.08 RTH (RM 17,573.61) saved per year for block 23. For window blinds, 14.19% annual cooling load reduction can be achieved by installing HIREF blinds which yield 27,638.17 RTH (RM 9,396.98) of cooling energy saving per year. Both types of shadings yields the highest energy saving due to its high reflectivity and low transmittance property that reflects most of the solar radiation and minimize heat being transmitted into the space.

4.2.6 Effect of Thermal Insulation

In analyzing building thermal performance, most study includes the effect of providing thermal insulation to the building envelope. Bojic, Yik and Leung (2000) found that providing insulation at the indoor side would give the maximum cooling load reduction. Hence simulation done for this particular study analyzes the effect of providing thermal insulation at the indoor side of the building envelope. In this study, thickness of insulation layer is increased in steps from 25 mm to 89 mm thickness. Insulation material used is the batt insulation with thermal conductivity of 0.03 W/m.k and specific heat of 1,210 J/kg.K. Table 4.7 summarizes the resulting cooling energy reduction for Block 23 by introducing thermal insulation layer at the indoor side of the walls.

Table 4.7: Effect of thermal insulation on annual cooling energy requirement for Block 23

	Reduction of cooling energy requirement		
Insulation Thickness, mm	**Ground Level, %**	**Level 1, %**	**Level 2, %**
25	0.59	0.3	0.38
50	0.87	0.38	0.49
75	1.03	0.35	0.56
89	0.89	0.32	0.51

From Table 4.7, it is found that maximum reduction of yearly cooling energy is by implementing 75mm insulation layer. The resulting optimum insulation thickness does comply with a study by Eskin and Turkmen (2006) which found that maximum cooling load reduction of 20 % to 36 % by introducing 75 mm thermal insulation at the indoor side of the wall. However, from Table 4.7, yearly cooling load reduction obtained for Block 23 is very insignificant which ranges from 0.35% to 1.03%. In a research paper by Perez and Capeluto (2008), it is recommended that total wall thermal conductivity is at 0.85 W/m.K along with night ventilation to give optimum reduction of cooling load. Referring to the current wall thermal conductivity, it is

0.144 W/m.K which is much below the suggested value. From Table 4.7, further increase in insulation thickness beyond 75mm does not result in additional reduction of annual building cooling energy implies that further increase in thermal resistance of the wall will add no further cooling load reduction. Furthermore, it also shows that further reduction of wall total thermal conductivity (increase in thermal resistance) results in no more significant reduction of building annual cooling load. Therefore, providing thermal insulation into the walls (of UTP academic building) is not a practical design approach to reduce building cooling load.

4.2.7 Effect of Night Ventilation

Night ventilation is one of a method for reducing cooling load during start up. The main idea is that most of the heat absorbed by the floor, furniture and etc during day time will be released at night time via convection and results in space heating at night. Hence, to excavate the heat released inside the zone, night ventilation is introduced which also meant to bring in fresh air from outside. At night, the ambient air is much colder (24°C to 26°C (Energy Plus Weather Data for Kuala Lumpur)), therefore, bringing in outside air will cools down the heated space. Hence, during start up, the space temperature is at a reasonably low temperature and resulting in less cooling load during start up. In this simulation, ventilation rate is increased in steps from 1000 L/s to 6000 L/s. The value of air flow is taken from the design value of AHU exhaust flow rate of Block 23 AHU. Figure 4.6 shows the result of implementing different ventilation rates for night ventilation for about 2 hours from 5 am to 7 am before AHU start up. Table 4.8 summarizes the result of the simulation as well as the resulting cooling energy reduction as a result of implementing night ventilation.

Table 4.8: Effect night ventilation on cooling energy requirement for Block 23

VENTILATION RATE	NO NIGHT VENTILATION	1000 L/s	2000 L/s	3000 L/s	6000 L/s
ANNUAL COOLING LOAD (RTH)	254,367.91	242,976.66	236,757.52	231,858.43	170,218.30
% Reduction		4.48	6.92	8.85	33.08

From Figure 4.6, it is observed that higher ventilation rates results in higher reduction in yearly cooling energy. This is the result of a much lower air temperature during start up which then reduces start up cooling load. Figure 4.6 illustrates night time temperature profile from 12 am to 7 am produced by Energy Plus. From the figure, space temperature is reduced during the start of the ventilation system. This is due to the fact that the air the air that is brought in is much colder (25°C – 26°C) replaces the warm air in the space resulting in space temperature drop. Therefore, during start up, less cooling energy required as the indoor air has being precooled by the cold night ambient air that being brought in.

4.2.8 Effect of Space Overcooling

ASHRAE *Standard 55* states that indoor design temperature is at 24°C. Therefore lower space temperature should be avoided which will impose much higher cooling energy as well as result in uncomfortable condition for the occupants. Energy Plus simulation is done to analyze the effect of over cooling of a space towards building yearly cooling energy. The temperature set point of Block 23 is reduced in step from 24°C to 20°C. Figure 4.9 shows the effect of overcooling on block 23 yearly cooling energy. Table 4.9 summarizes the resulting cooling energy requirement by block 23 due to the effect of space overcooling.

Table 4.9: Effect of overcooling on building cooling energy (Block 23)

SET POINT TEMPERATURE	24°C	22°C	20°C
ANNUAL COOLING ENERGY (RTH)	291,738	396,934	491,502
% INCREASE		36 %	68 %

From Table 4.9, significant increase on annual cooling energy requirement for Block 23 is obtained. When the set point temperature is increased to 22°C, 36% increase of annual cooling energy is obtained. Further reduction of temperature set point shows more cooling energy is required. The result shows that overcooling of a space involves huge amount of additional energy. Therefore, space temperature should be maintained no less than 24°C to avoid unnecessary wastage at the same time to maintain the occupants' level of comfort.

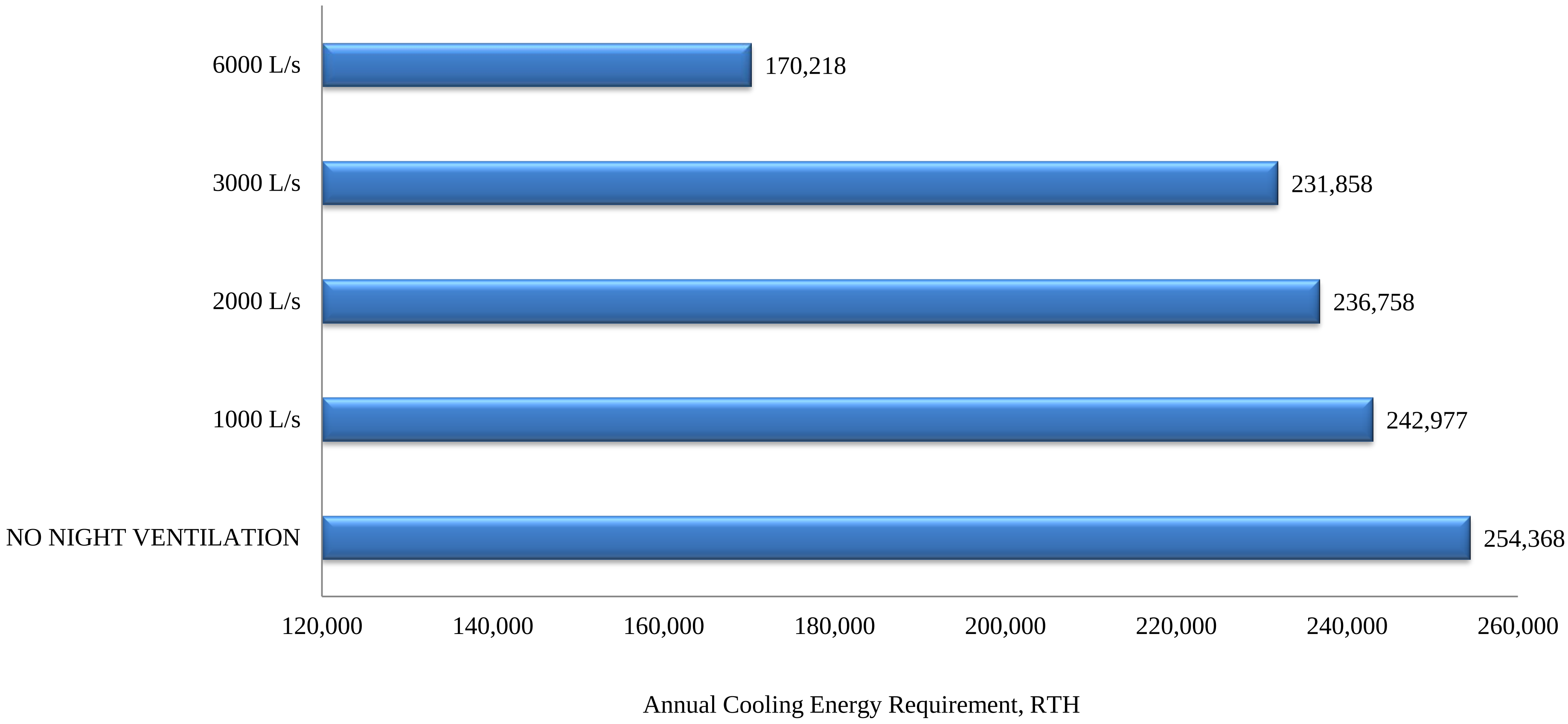


Figure 4.6 Effect of night ventilation on cooling energy requirement for Block 23

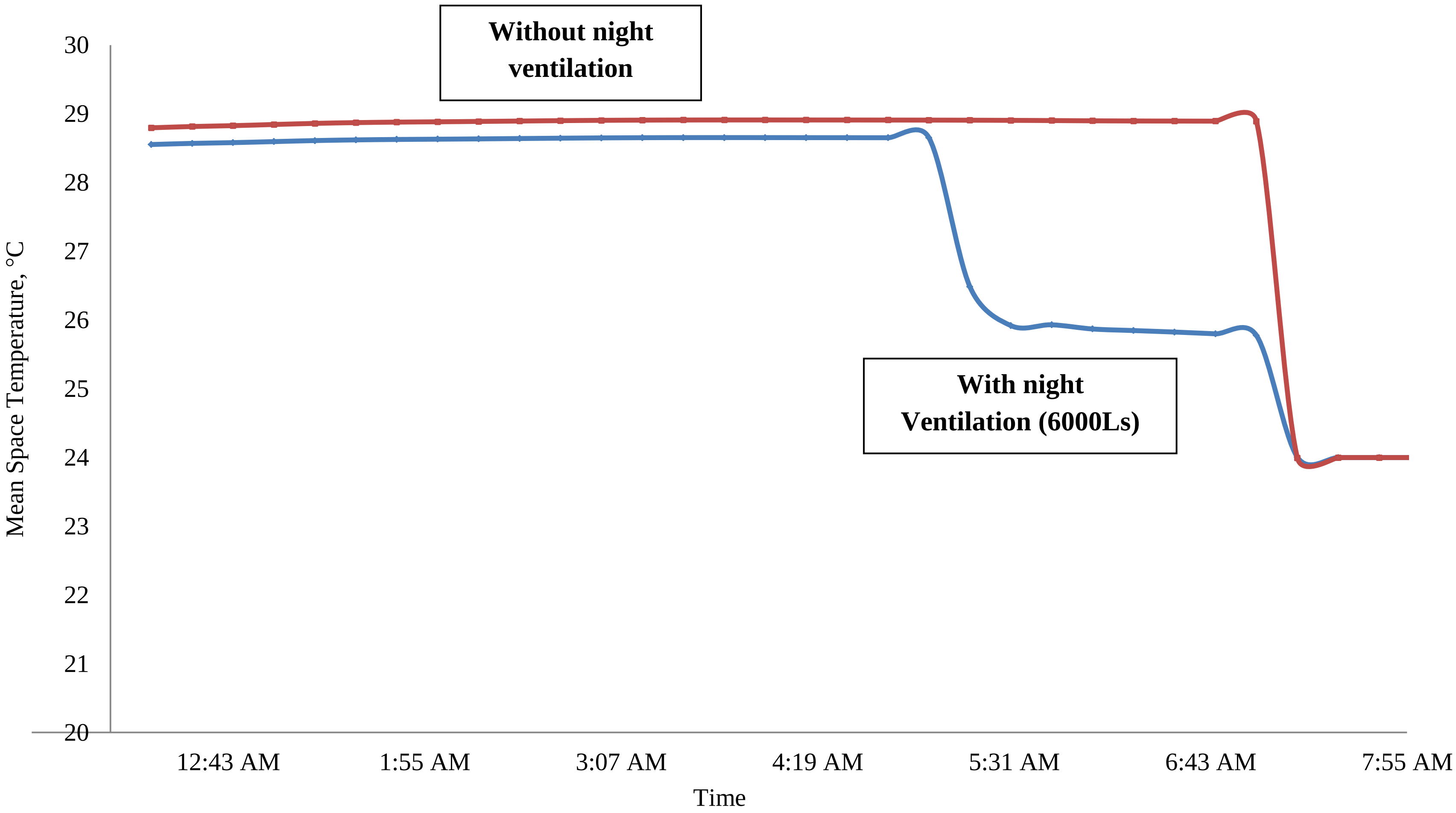


Figure 4.7: Nighttime temperature profile for Block 23 (Produced by Energy Plus)

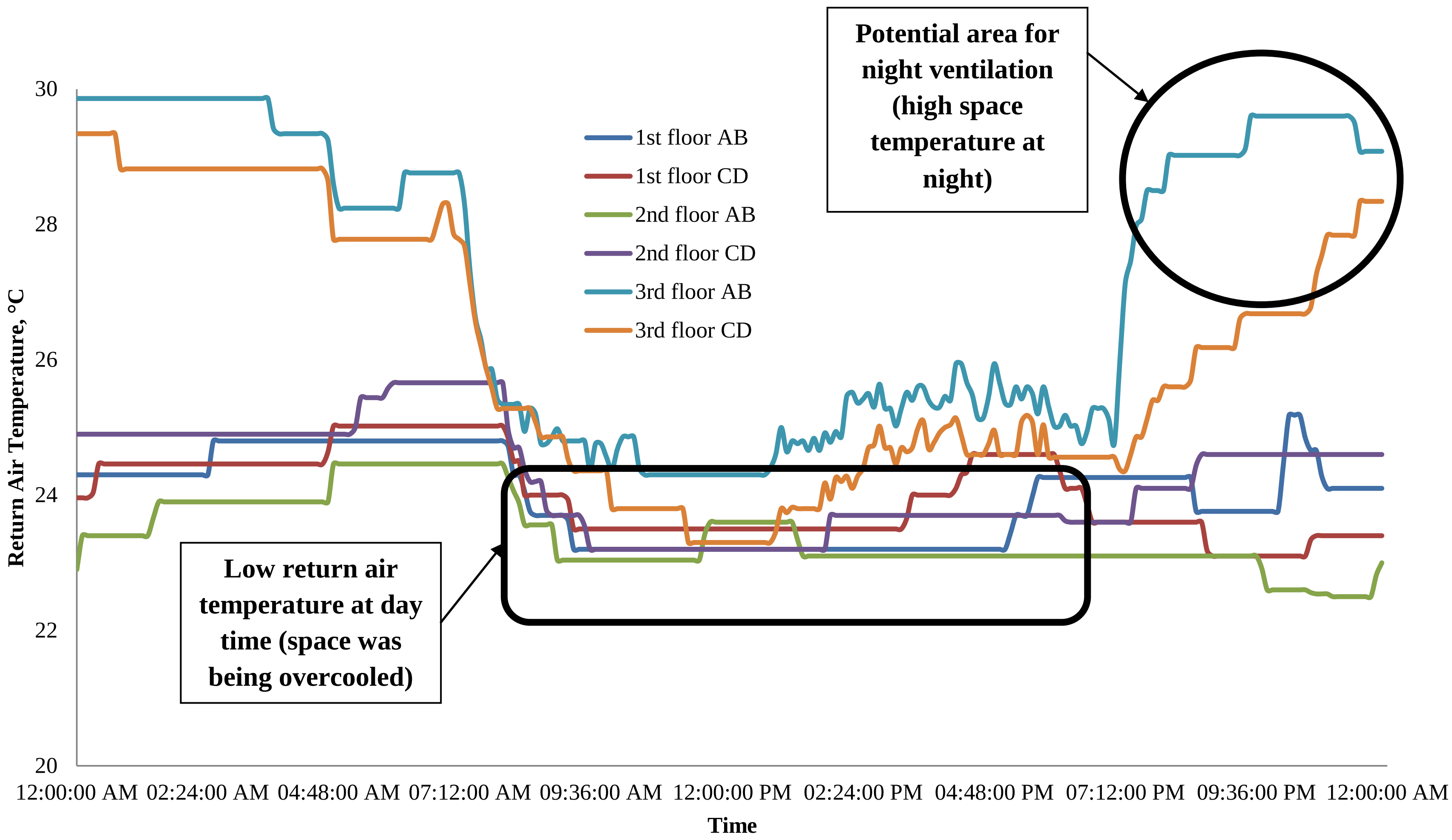


Figure 4.8: Return Air Temperature Profile for Block 23 on April 15th 2009 (Maintenance Department UTP)

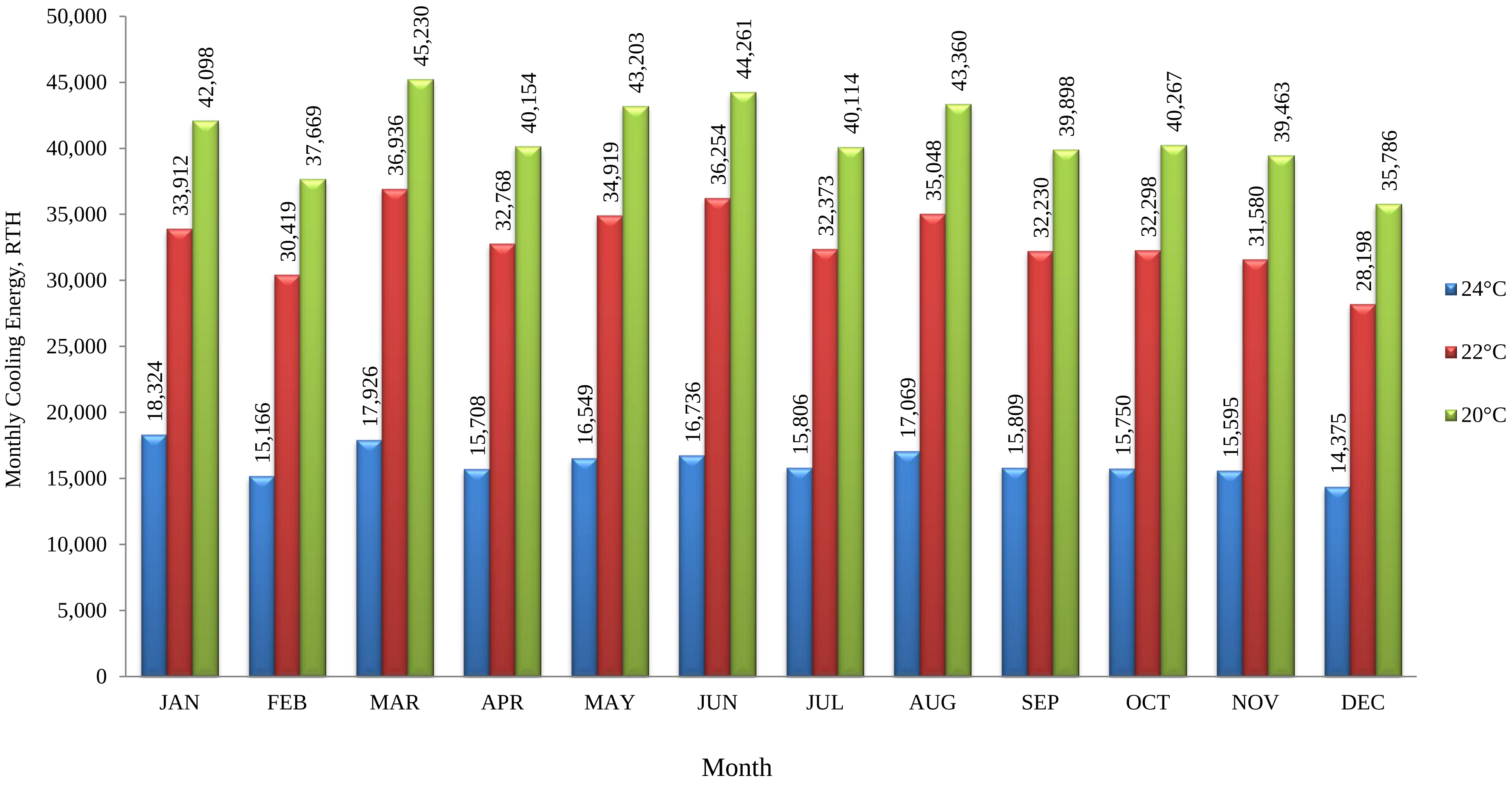


Figure 4.9: Effect of overcooling on building cooling energy (Block 23)

4.2.9 Effect of Infiltration Load

Infiltration load is one of the elements of space cooling load. Normally, in design phase, designers will incorporate infiltration load based on level of air tightness of a building. However, in actual daily usage, additional infiltration load may also being imposed to the system from door or windows openings. In analyzing the severity of additional cooling load from door or window air infiltration, simulation is done to Block 23 assuming each floor has one door being opened during day time (8am – 5pm). Value of infiltration is taken as 1 CFM per ft^2 of door area (Pita, 2002). The result of this simulation is shown in Figure 4.10.

From the simulation computed by Energy Plus, annual cooling energy for Block 23 was increased from 194,814 RTH to 291,738 RTH after including the additional infiltration load from door openings. The increase is about 49.7% which cost for additional RM 32,954.24. Therefore, it is observed that infiltration load from door or window openings may imposed a significant increase of cooling load of a space. Therefore, users should avoid leaving the doors open for a long time to minimize infiltration load. Figure 4.11 shows a door that was left open during class.

Figure 4.11: A door was left opened during class

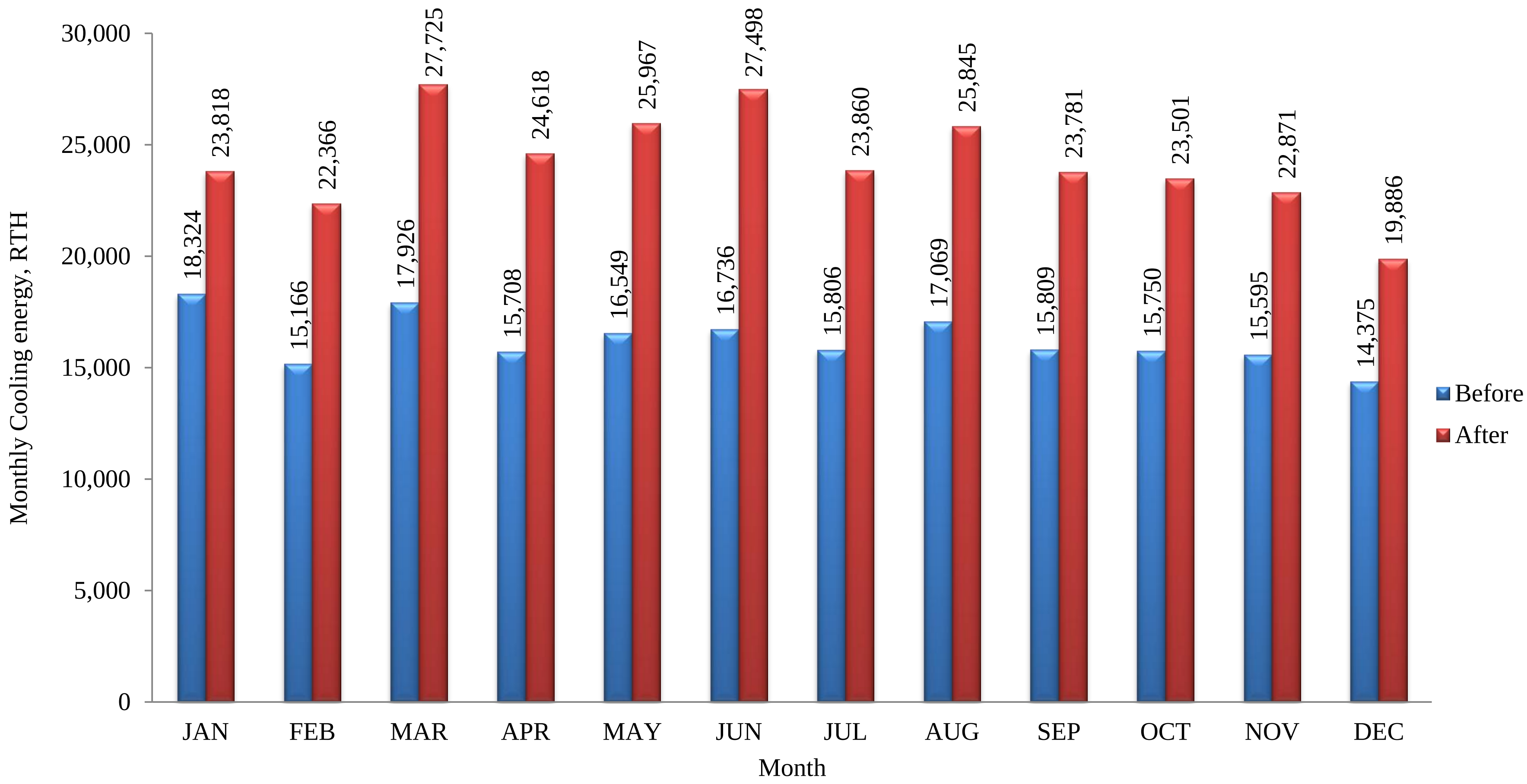


Figure 4.10: Effect of infiltration load from door opening

CHAPTER 5
OPERATIONAL ANALYSIS

This chapter presents the findings for investigation on the operational side of UTP air conditioning system. This chapter can be divided into four sections. The weekend occupancy investigation outcome is presented in section 5.1. In section 5.2, weekdays occupancy pattern of Mechanical Engineering buildings are being analyzed. The energy savings estimation by isolating unoccupied rooms of block 17 is presented in section 5.3.

5.1 Weekdays Occupancy Pattern

Figure 5.1 shows weekly occupancy pattern of UTP Mechanical Engineering Buildings. Summary of weekly occupancy pattern is presented by Table 5.1. From Table 5.1, average occupied hours of all rooms is 14 hours per week. On the other hands, the rooms were being scheduled either continuous or intermittently. Max gap (in hours) between classes is 5 hours while the minimum gap is 1 hour. From the investigation being done, lecture rooms yields the highest occupied hours per week at an average of 25 hours per week per room. Normally, lecture rooms usage is almost constant until the end of each semester. Meanwhile, the labs occupancy patterns were not constant throughout the semester. This was due to the fact that some labs were started between second and third week of the semester. Labs occupancy normally varies throughout the semester. Some labs were only occupied for only half of the semesters and being left unoccupied for the rest of the semester. In terms of usage efficiency, such patterns of rooms' occupancy are very inefficient.

Table 5.1: Summary of Room Occupancy of UTP Mechanical Engineering Buildings

	No. class per week	**Usage (Hours/ week)**	**Unused (Hours/ Week)**	**Max Hours/ session**	**Min Hours/ session**	**Max Gap Between Classes (hours)**	**Min Gap Between Classes (hours)**
Average	7	14	26	3	2	2	1
Min	1	4	13	2	1	0	0
Max	24	32	36	8	4	5	2

From Table 5.1, it was observed that average unused hour were about 26 hours (out of 40 hours per week for Monday to Friday, 8 am to 5pm). Meanwhile, there were also some labs usages that are not being scheduled especially for Final Year Project students as well as the post graduate students. This may lead to uncontrollable rooms' usages. For instance, Petroleum Engineering Post Graduate students (approximately 10 students) request for air conditioning at first floor Block 15 up to 24 hours. Such practice signifies an inefficient occupancy pattern. Far worst, with such request, the whole floor is being air conditioned although other rooms are not being occupied. This particular practice imposed a significant energy wasting which should be avoided in the first place.

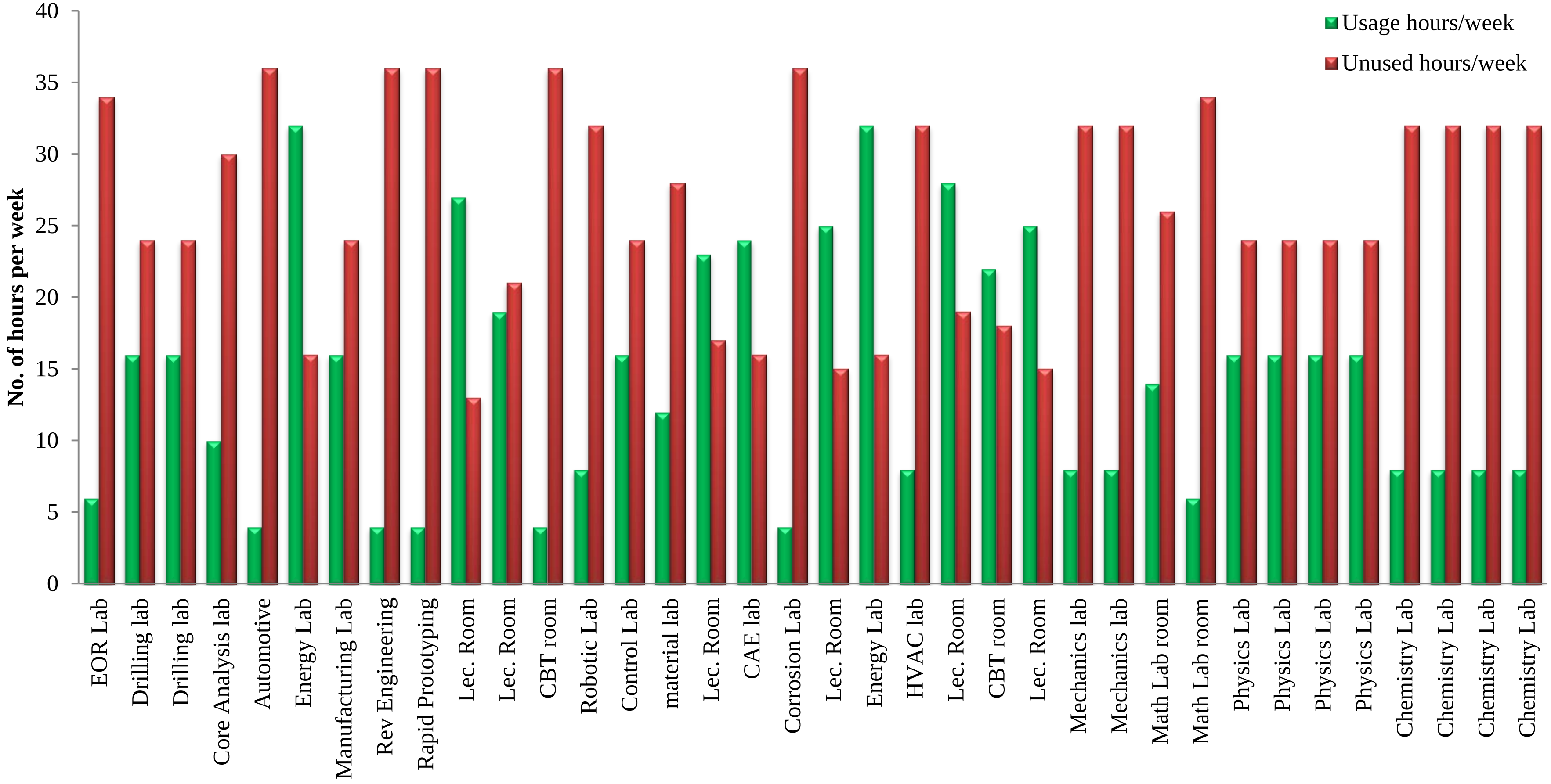


Figure 5.1: Occupancy Pattern of UTP Mechanical Engineering Buildings

5.3 Unoccupied Rooms

From the observation that was done to UTP Mechanical Engineering buildings, 22 unoccupied rooms which cover about 4071 m^2 were found. Table 5.2 shows the list of the unoccupied rooms of each building. For energy saving analysis, it was done for the Block 17 first floor which has approximately 60% of the total floor area being unoccupied for the whole semester. The AHU is schedule is from 7.42 am to 7 pm (AB side) while for CD side, the schedule is from 7.42 am to 11.30 pm. Layout for base case of level 1 block 17 after isolating the unoccupied rooms is illustrated in Figure 4.6. Figure 4.7 shows the VAV layout before and after isolation of the unoccupied rooms. Energy plus simulation result for energy saving estimation is shown in Figure

Table 5.2: Summary of Unoccupied Room for UTP Mechanical Engineering Buildings

Block	No. of unoccupied rooms	Room List	Total Area, m^2
16	5	02-04	794
		02-05	
		02-08	
		02-9	
		02-10	
17	11	01-07	1,751
		01-08	
		01-09	
		01-12	
		02-03	
		02-05	
		02-09	
		02-06	
		02-17	
		02-19	
		02-20	
18	6	01-02	1,526
		01-03	
		01-04	
		02-02	
		02-03	
		02-04	
		Total	**4071**

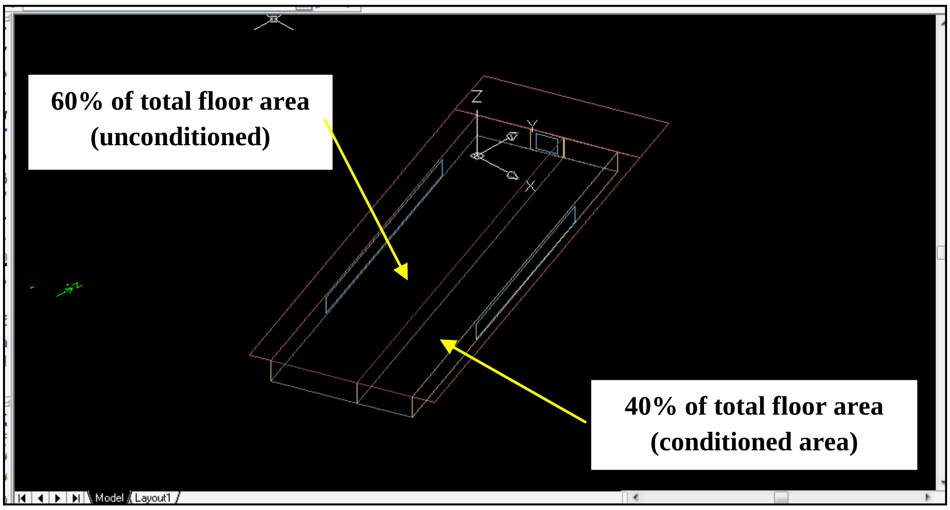


Figure 5.2: Base case model for Block 17 first floor after isolation of the unoccupied rooms

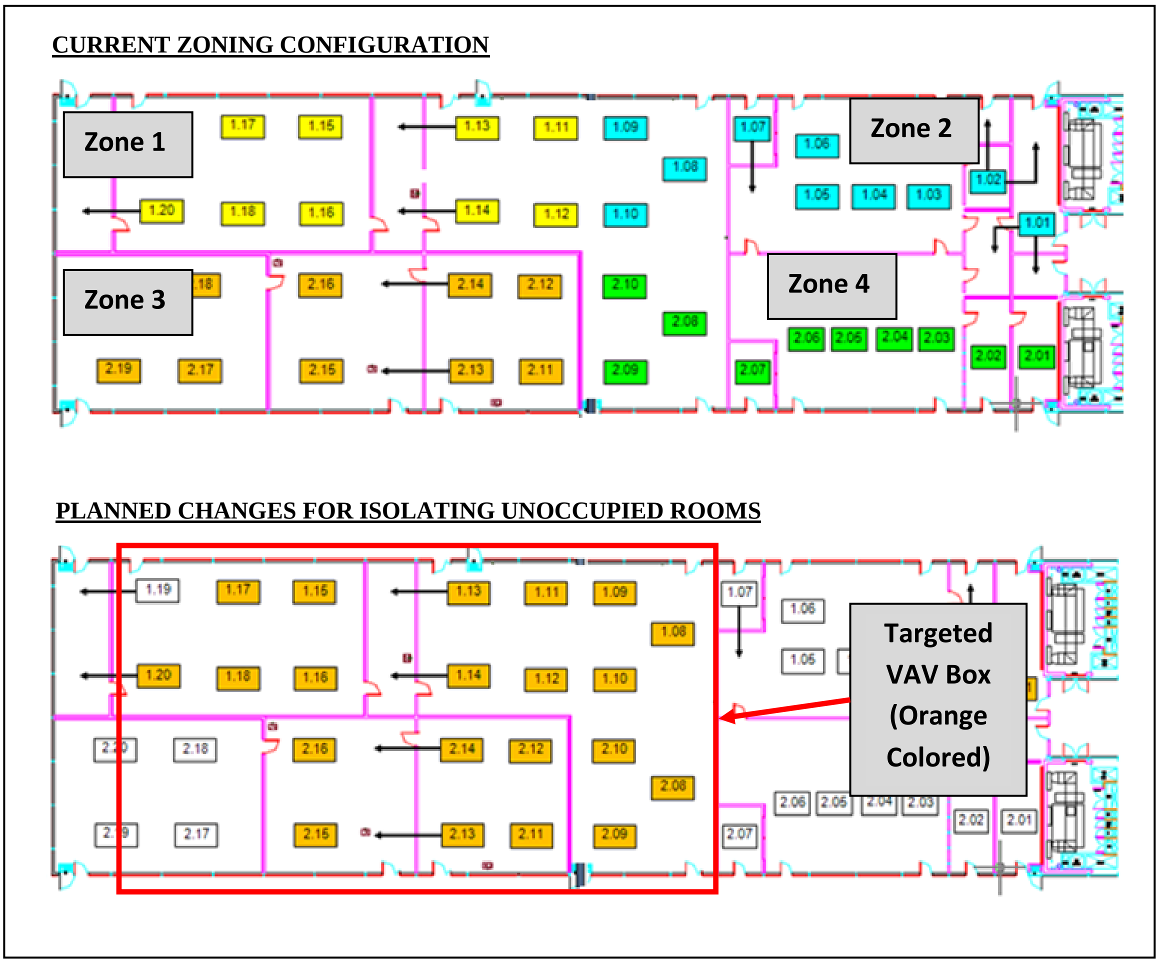


Figure 5.3: Base case model for Block 17 first floor after isolation of the unoccupied rooms

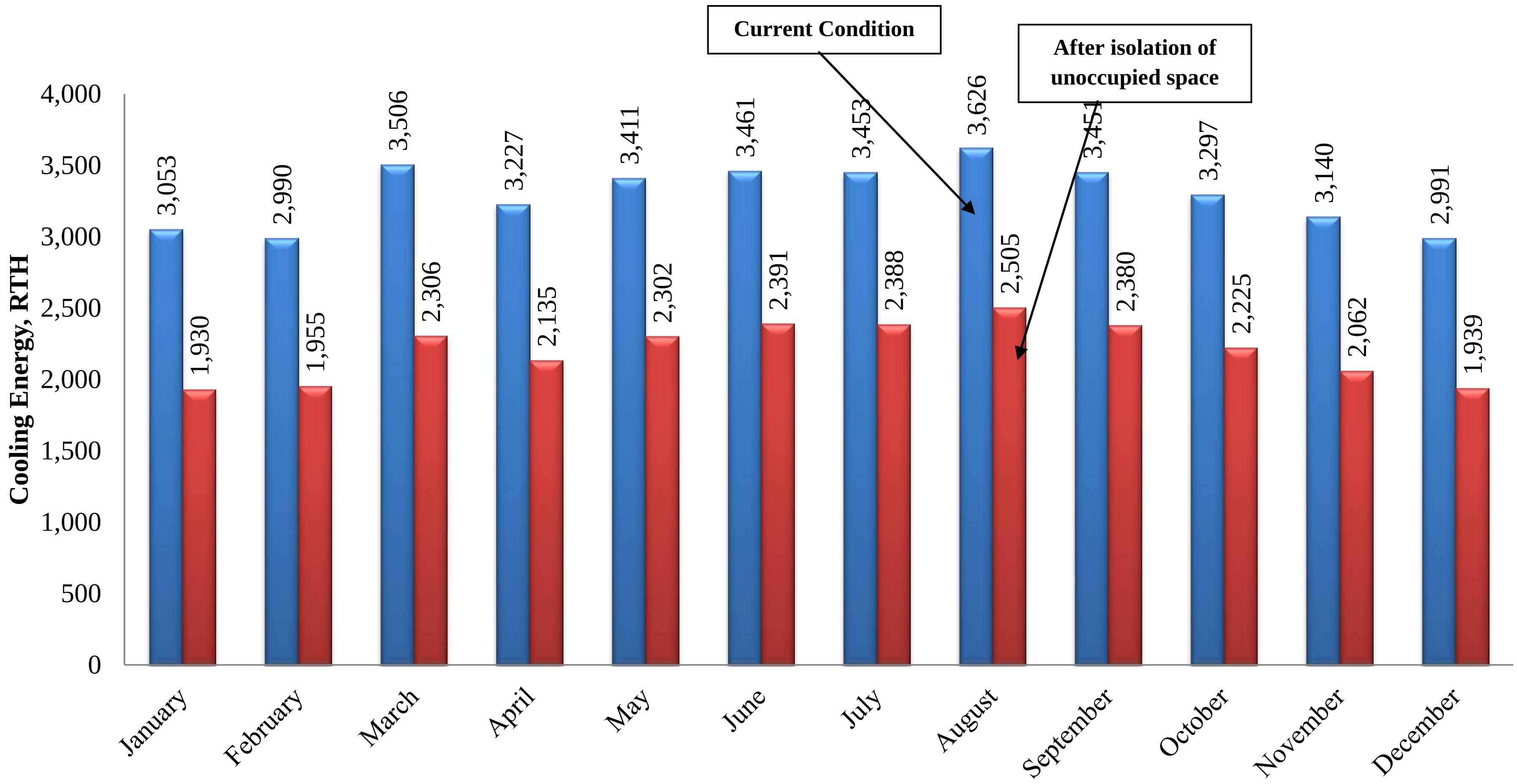


Figure 5.4: Base case model for Block 17 first floor after isolation of the unoccupied rooms

From Figure 5.4, significant reduction of annual cooling load at about 33% was obtained which accounts for 13,089 RTH (45,814 kWh). The amount of yearly cost saving is approximately at RM 15,576.8. Figure 5.5 and 5.6 illustrates the comparison of daily AHU VSD profile before and after isolation of the unoccupied rooms. Cooling valve daily profile comparison before and after changes being implemented is shown in Figure 5.7 and 5.8. Meanwhile, Table 5.3 and 5.4 summarizes total weekly fan energy consumption and cooling valve total weekly percentage of opening respectively.

Table 5.3: Block 17 first floor AHU fan energy consumption comparison

	AHU (Side)		**AHU (Side)**		**AHU (Side)**	
	AB	**CD**	**AB**	**CD**	**AB**	**CD**
	Week 1 (9-15/3/2009)		**Week 2 (30/3/2009 - 5/4/2009)**		**Week 3 (13/4/2009 - 19/4/2009)**	
Total kWh (Electricity)	321.17	826.86	239.57	749.20	241.75	708.10
% Energy Saving			**25.40**	**9.40**	**24.70**	**14.40**
Cost (RM)	109.20	281.13	81.45	254.73	82.19	240.76
Cost Saving (RM)			**24.75**	**26.4**	**27.0**	**40.37**

Table 5.4: Block 17 first floor AHU cooling valve total percentage of opening comparison

	AHU (Side)		**AHU (Side)**		**AHU (Side)**	
	AB	**CD**	**AB**	**CD**	**AB**	**CD**
	Week 1 (9-15/3/2009)		**Week 2 (30/3/2009 - 5/4/2009)**		**Week 3 (13/4/2009 - 19/4/2009)**	
Total Opening, %	19,989	43,511	13,393	38,790	12,558	33,991
Approximate cooling energy saving, %			33	11	37	22

From Table 5.3, average of 25% electrical energy saving was achieved (AB side) while for CD side, average of 12% was obtained. In term of cost, average saving for AB side was RM 26/week. Meanwhile, for CD side, average RM34/week of cost saving is achieved. Besides that, weekly cooling valve profile was also being analyzed to estimate saving in chilled water consumption. By assuming the constant chilled water flow rate inside the cooling coil, a rough estimation is done by comparing total cooling valve opening percentage before and after the changes being implemented. From Table 5.4, average of 35% of cooling valve opening percentage was achieved for AB side while 17% reduction was obtained for CD side AHU.

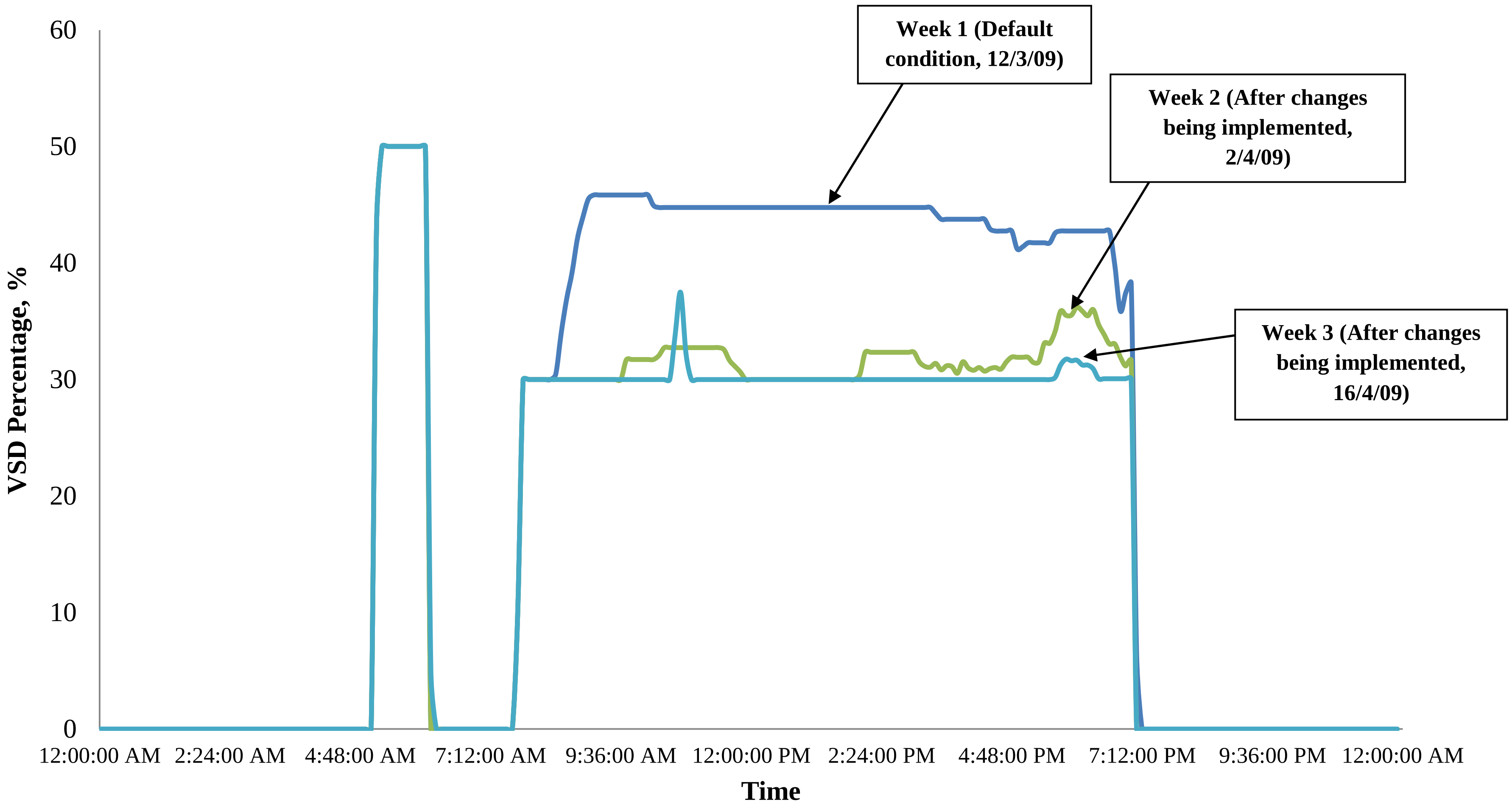


Figure 5.5: Block 17 first floor AHU VSD daily profile comparison (AB side)

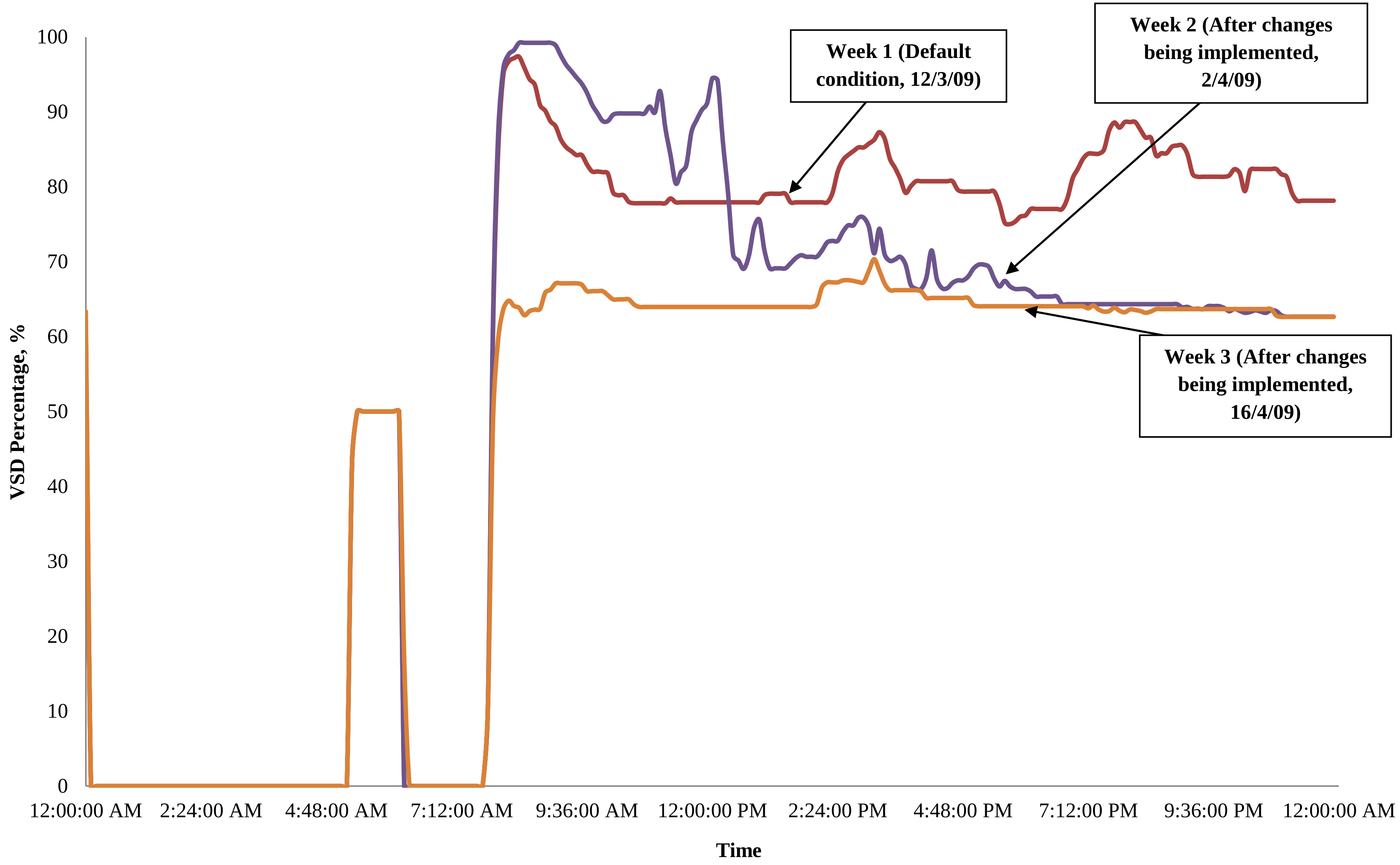


Figure 5.6: Block 17 first floor AHU VSD daily profile comparison (CD side)

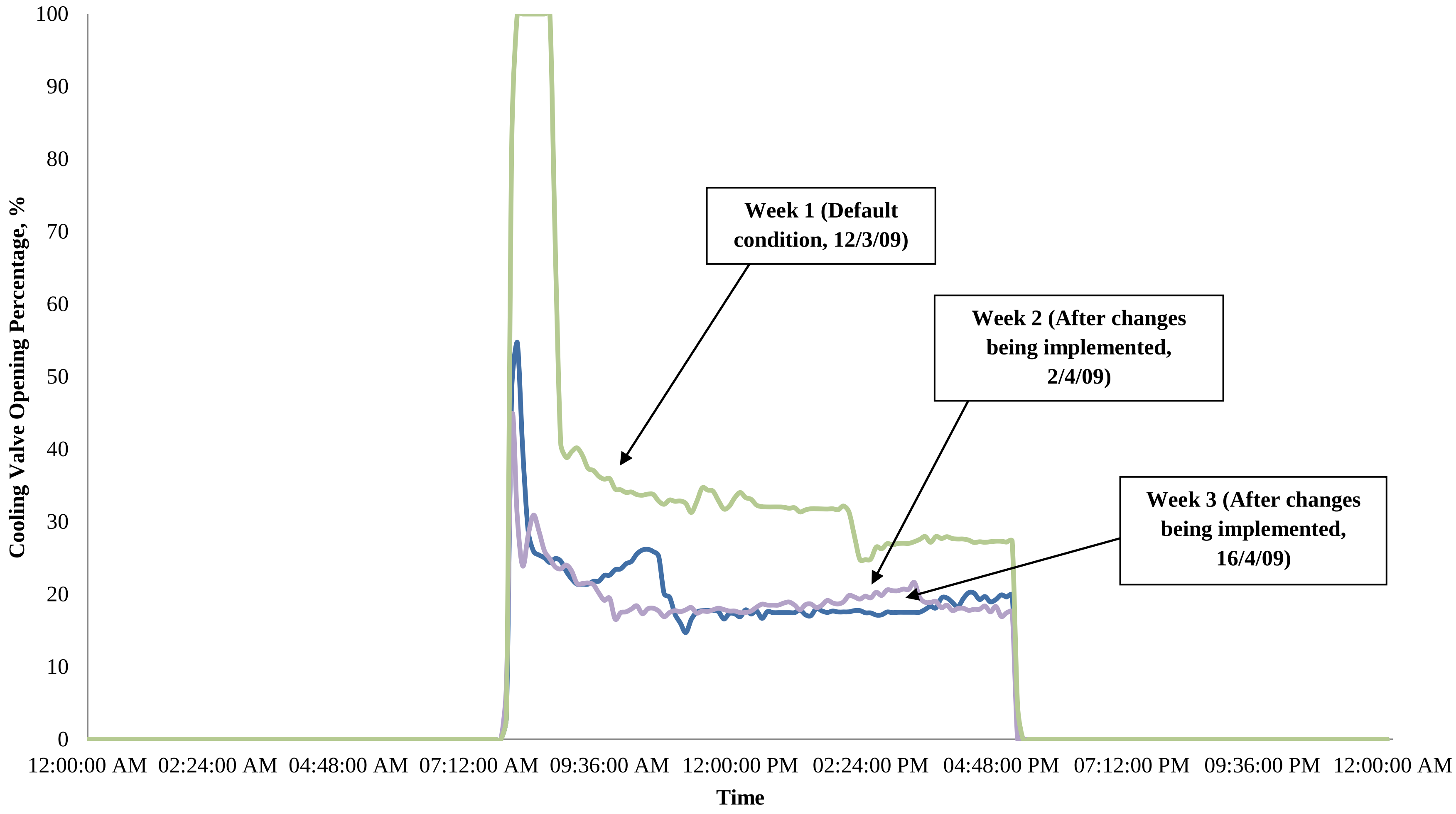


Figure 5.7: Block 17 first floor AHU cooling valve daily profile comparison (AB side)

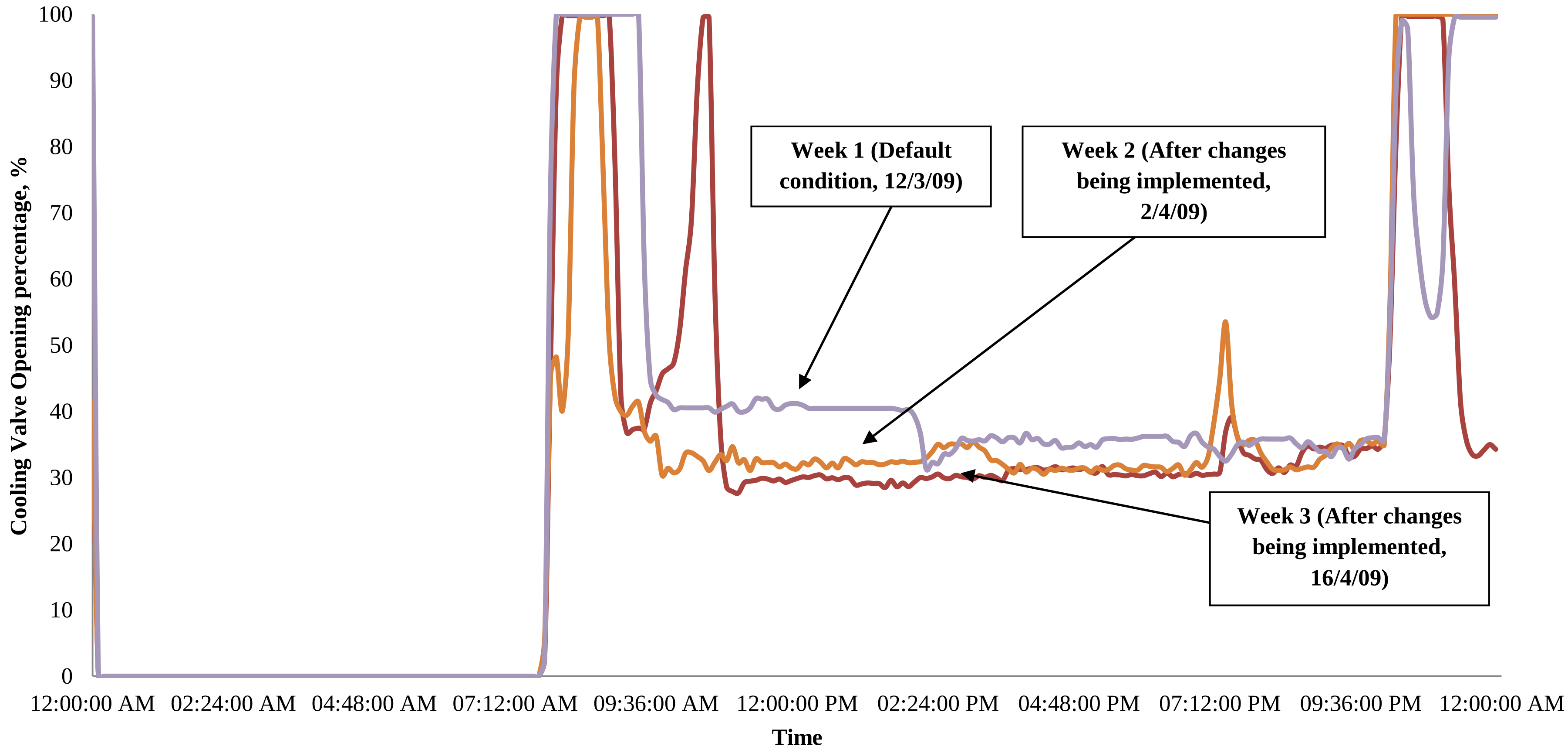


Figure 5.8: Block 17 first floor AHU cooling valve daily profile comparison (CD side)

CHAPTER 6
CONCLUSION

In this paper, UTP Academic Building cooling load is analyzed. The objective of this study is to analyze the potential of energy saving within the air-conditioning system and operational practices. Both manual and computer simulation method is implemented in order to determine each zone annual cooling energy requirement. For manual calculation, commercial building ASHRAE CLTD method as well as residential ASHRAE CLTD method are used due to its simplicity and relevancy for manual calculation. The building cooling load is also being analyzed through cooling load simulation via Energy Plus software. Due to unavailability of envelope material specifications, an experiment is conducted to determine the wall and roof thermal resistance. For the operational audit, unused rooms are located within building 17 to plan for restructuring the VAV boxes setting. From the three methods applied, commercial ASHRAE CLTD method gives a more realistic result as it is consistent with the heat balance model of Energy Plus software. Therefore, the next following analysis is done via these two method which also for the purpose of result reliability checking.

From the whole building cooling load simulation, Block 23 shows the highest annual cooling energy of 2,327,453 RTh. It is also observed the building orientation have a significant effect on building cooling load. Several types of window shading devices are also being analyzed. The results show that shadings with high reflectivity and low transmittance property exhibit the highest saving in cooling energy. For Block 23, 26.53% of annual saving can be achieved by installing High Reflectivity High Transmittance shades while 14.19% of saving can be obtained by installing High Reflectivity Slates blinds. Comparison is also being done between the actual design cooling load of the equipments against Energy Plus simulation value. It is noted that the design value have exceedingly designed at an average of 28% which is much higher than the normal overdesign percentage which ranges from 10% to 15

For the operational audit, several rooms of building 17 have being identified as unoccupied rooms. From that information, an experiment will be done to analyze energy saving via isolating the unoccupied rooms. Prior to implementing the changes, a rough estimation of the energy savings is computed via Energy Plus simulation on building 17 level 1. The result shows that with the reduction of approximately 60% of the conditioned area, about 33% of annual cooling energy is reduced. Besides that, there are couple of issues regarding the end users air conditioning practices which should be avoided in the first place. For instance, rooms' lightings should be switched off during unoccupied hours. Moreover, doors should not being kept open for a long time as this would increase infiltration load to the system. Some other issues pertaining operational practices are usage inconsistency of certain rooms or labs which is difficult to be scheduled which results in most of the time, the room is unoccupied. In energy perspective, this kind of practices reflects a wasteful energy practices. Therefore an in depth study should be performed to analyze the rooms occupancy pattern of the whole buildings.

As a conclusion, there are certain areas of the air conditioning system and the operational practices should be paid attention of. On the system, flow measurement devices should be installed to measure cooling load of each and every AHU of the whole academic campus. This would enable the operators to monitor the performance of the system as well as assist researchers and auditors to analyze the system. In the operational side, some guidelines should be imposed to all end users of the air conditioning which includes the students and staffs of UTP to implement energy saving practices. Finally, this research is yet to reach its final goal. Actual energy savings from the experiments is still yet to be obtained.

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APPENDIX