IMPLICATION OF DESIGN AND OPERATION ON COOLING LOAD AND ENERGY COST FOR ACADEMIC BUILDING AT UTP

by

Muhammad Aizuddin Bin Muaz

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirements for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

JANUARY 2008

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CERTIFICATE OF APPROVAL

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Approved by,

…………………………
Ir. Dr. Shaharin Anwar Bin Sulaiman

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
JANUARY 2008

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

……………………………………………

MUHAMMAD AIZUDDIN BIN MUAZ

ACKNOWLEDGEMENT

I would like to express my utmost gratitude to the highest power, Allah the God Almighty for giving me the strength to push this project to the finish ribbon. Without His blessings, I would not be able to complete this paper in the proper ways.

To my supervisor, Ir. Dr. Shaharin Anwar bin Sulaiman I would like to thank you a lot for your guidance, and patience you have for me. I am certain that I would not be able to finalize this project without your good-natured tolerance.

This paper is a compiled effort of many people besides me. For that I would also like to express my special thanks to Mr. Hatta from Property Management and Maintenance Department for the access to air conditioning control room, Mr. Zafri and Mr. Syed for your time answering questions and explaining processes regarding the operation of air conditioning system of UTP.

Last but not least, thank you to all individual that helped me in any way, either directly or indirectly.

ABSTRACT

Cooling load of a building is very sensitive to the design and the operation of the building itself. Every building from academic complex is unique, in a sense that different designs and operations have different cooling loads. And it is very desirable to determine the cooling load, so the operation of air conditioning system reflects on the building's specific energy requirement. This will provide a good balance between occupants comfort and the related cost of running it. The objective is to determine the repercussion of design and operation on cooling load and energy cost of Building 17. This project captures air conditioning operation data and translates it to a more understandable output, so that operators understand what is happening with the operation of air conditioning system. The samples data show that the peak operation time is between $3 \text{ to } 7 \text{ pm}$, with the maximum indoor temperature of 27°C and average flowrate of chilled air at 388 l/s for that particular time period. It is clear that the operation of the system is heavily influenced by outdoor weather and the electrical appliances inside the building, with several outliers caused by improper actions by users, faulty equipments and system trips.

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ABBREVIATION AND NOMENCLATURES

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
$^\circ C$	degree Celsius
$^\circ F$	degree Fahrenheit
CLTD/CLF	Cooling Load Temperature Differential/Cooling Load Factor
GDC	Gas District Cooling
HVAC	Heating, Ventilation, and Air Conditioning
TFM	Transfer Function Method
TETD/TA	Total Equivalent Temperature Differential/Time Averaging
UTP	Universiti Teknologi PETRONAS

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

UTP is located in Tronoh, a small a small tin-mining town located about 26 km south of the Perak state capital Ipoh in Malaysia, with coordinate of latitude 4.36N and longitude 101.02E.

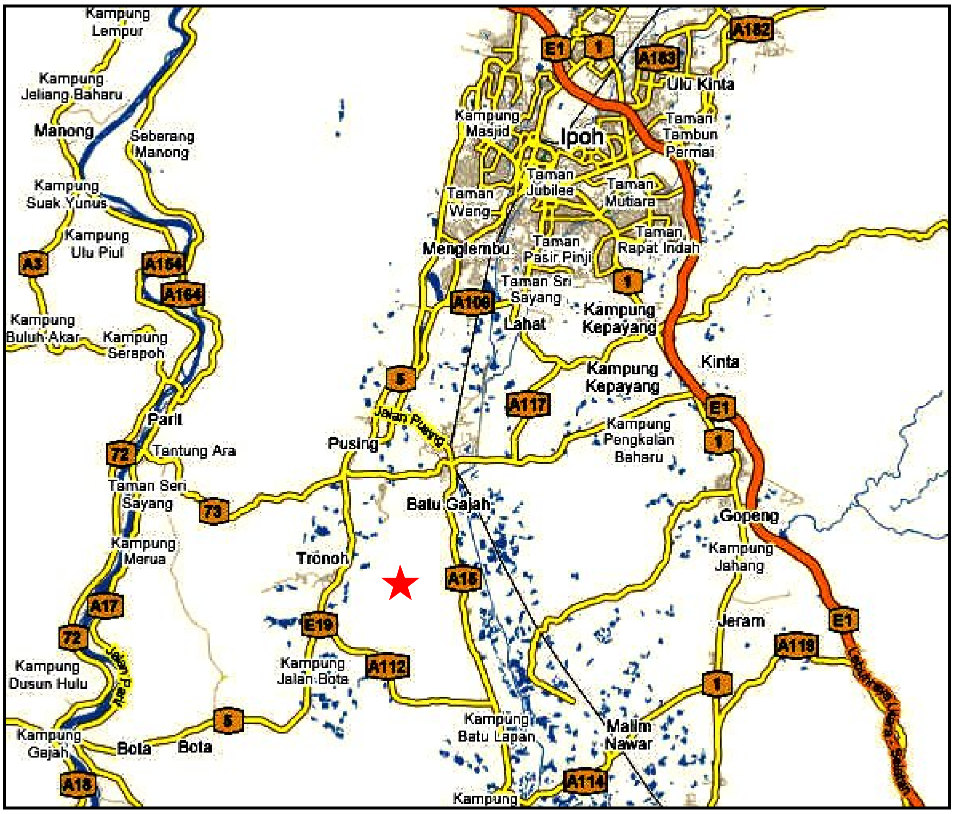

Figure 1.1: Location of Tronoh and its surroundings. Source: Google Maps (http://maps.google.com/maps)

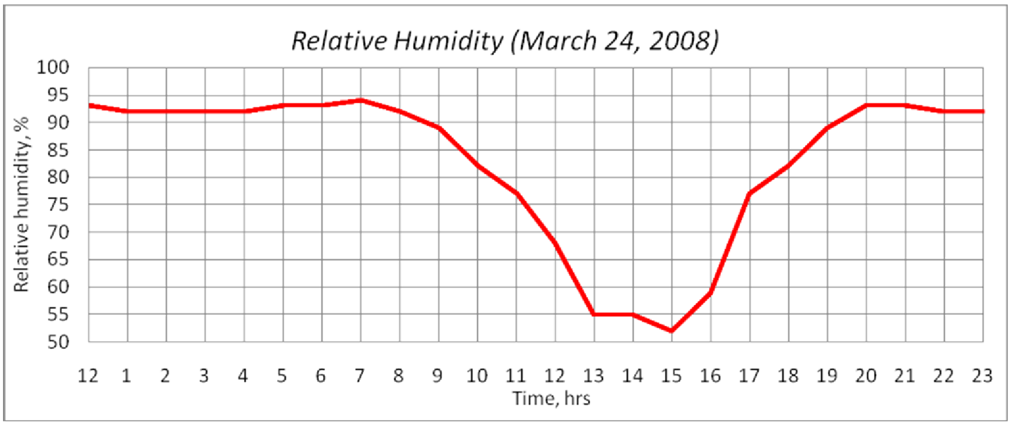

Figure 1.2: Relative humidity for Tronoh area, dated March 24, 2008. Source: Malaysian Meteorological Department (http://www.met.gov.my)

UTP observes a minimum temperature of $24^{\circ}C$ and a maximum of $33.7^{\circ}C$ on a daily basis with average relative humidity of 83.8%. Built with layers of glasses, the academic complex is a structure that continually heated up from as early in the morning until late afternoon. Because of that, the academic complex requires a proper air conditioning system to provide a good balance between the comfort and the cost incurred for running the system.

Figure 1.3: Academic complex at UTP

1.2. PROBLEM STATEMENT

At UTP, heat continually enters into the rooms directly through glass walls at academic buildings from the outside. In order to maintain the air of the rooms at a comfortable temperature range, this accumulated heat must be continually removed from the rooms. This amount of heat to be removed is termed as *cooling load*.

The new academic buildings are unique. They are built from layers of glasses and observe direct sunlight maximum $33^\circ C$ for several hours daily. The buildings are designed in such a way that the only way to get fresh air from outside into the buildings is through air conditioning system. During normal operation, the buildings receive feeds of chilled water from as early 7.30am in the morning until 6.00pm from GDC.

Because of this unique design and operation pattern, it is very desirable to be able to determine the actual cooling load of the buildings and reflect it to the air conditioning system so that it runs at the most optimum configurations. By doing this, the academic buildings will have the most comfortable air condition with the smallest operating cost possible.

This project approaches the air conditioning related problems from operator's perspective. By analyzing the acquired data, it could produce actual and current air conditioning system operation patterns and findings, which indirectly should be able to help the operator maintaining the system.

1.3. OBJECTIVE AND SCOPE OF STUDY

1.3.1. Objective

The main objective of this project is to investigate the implication of design and operation on cooling load and energy cost for academic building at UTP. The minor objective of this project is to be able to calculate the cooling load for academic building at UTP. Several practical ways to reduce energy consumption are also discussed briefly.

1.3.2. Scope of Study

This project has two part which deals mainly with Building 17 of the academic complex. For the first part, this project determines the cooling loads of several selected rooms from the building. Another part of this project investigates the effect of design and operation on cooling load and energy cost of the building.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1. INTRODUCTION TO AIR CONDITIONING

Air conditioning is the process of treating air in an internal environment to establish and maintain required standards of temperature, humidity, cleanliness, and motion. (Pita, 1998)

2.2. AIR DISTRUBUTION SYSTEM EQUIPMENT

Lang (1995) suggests that the major pieces of equipment required to complete the air distribution for air-conditioning system are:

- Fan
- Supply duct
- Supply outlets
- Room space
- Return outlets
- Return ducts
- Filters, and
- Cooling coil

2.2.1. Fan

The fan moves air to and from an enclosed space. In an air conditioning system, the fan moves air that consists of 1) all outdoor air, 2) re-circulated air, and 3) a combination of outdoor and indoor air. The fan pulls air from the outdoors and from the room at the same time.

Since drafts in the room cause discomfort, and poor air movement slows the body heat rejection process, it is necessary to regulate the amount of air supplied by the fan. To accomplish this regulation, a fan is selected that can deliver to correct amount of air. By controlling the speed of the fan, the air stream in the room can be regulated to provide good circulation without draft.

2.2.2. Supply duct

The supply duct directs the air from the fan to the room. The supply duct should be as short as possible and have a minimum numbers of turns to insure that the air can flow freely.

2.2.3. Supply outlets

Supply outlets help to distribute the air evenly in a room. Some outlets fan the air and other outlets direct the air in a jetstream. Still other outlets combine these actions. As a result of these actions, the outlets are able to exert some control on the direction of the air delivered by the fan. The directional control plus the location and the number of outlets in the room contribute greatly to the comfort or discomfort resulting from the air pattern.

2.2.4. Room space

The room or the space to be conditioned is one of the most important parts of the cycle. By definition, a room is an enclosed space set apart by partitions. If an enclosed space does not exist, then it is impossible to complete the air cycle. This is due to the fact that the conditioned air from the supply outlets simply flows into the atmosphere. In fact, the material and the quality of workmanship used to enclose the space are also important since these factors help to control the loss of heat or cold that is confined in the enclosed space.

2.2.5. Return outlets

Return outlets allow room air to enter the return duct. The main function of the return outlet is to allow air to pass from the room. These outlets are usually located on the opposite wall from the supply outlet.

2.2.6. Filters

Filter clean the air by removing dust and dirt particles. Filters are located within the return air duct. These devices are made from many materials including spun glass and composition plastic. Other filter materials maintain an electrostatic charge, and attract and capture dust and dirt particles from the air flowing through them.

2.2.7. Cooling coil

The cooling coil is located either ahead of or after the fan. In all installation, however, these devices are placed after the filter. Such an arrangement prevents excessive dust and dirt particles from covering the coil surface. Return air from the room passes over the surface of the cooling coil. The air is cooled to the required temperature. If there is too much moisture in the room, it is removed automatically as the air is cooled by the coil.

2.3. SOURCES OF HEAT

The heat sources to be described basically are those which comprise the cooling load. Some heat sources, such as people, lights, and small domestic appliances, are so variable that they are not considered when determining the load in small residences. In large commercial buildings, however, the heat generated by these heat sources is significant and is stable enough to be an important factor.

2.3.1. Outdoor heat sources

The major part of the cooling load arises from heat sources outside a structure. The greatest heat source is the sun which is generally known as solar heat. Solar heat enters a structure directly (radiation through glass) and by conduction through the building materials.

The solar heat entering a structure through glass is immediately absorbed in the room. Its effect is felt at once. The heat entering by conduction through the wall and roof on the other hand, is not immediately absorbed in the room. The amount of heat enters a structure is measured in terms of a U-factor. Each different type of building material has its own U-factor. It is defined as the amount of heat that flows through one square foot of building surface.

2.3.2. Indoor heat sources

Indoor heat sources include people, lights, appliances, and motors. People are source of both sensible and latent heat. The heat produced by a person depends upon the energy that is being exerted. A person at rest causes less heat than a person being very active.

All light give off heat. The heat emitted by incandescent bulbs is directly related to the wattage of the bulbs. The heat produced by fluorescent lamps is approximately 25% greater than that expected from the rated wattage. This heat increase is due to the additional electricity required by the ballast. The heat load from all types of lights varies according to the usage.

Motor, appliances, and office machines are additional sources of indoor heat. This heat load is a direct function of the energy that is used. Motor heat generally is based on horsepower rating. Heat from the appliances and office machines is directly related to the fuel or energy consumed, and the actual load is affected by usage.

2.4. HEAT STORAGE

Every structure can absorb and retain heat. A long time may be required to heat to penetrate to the inside surface of a wall or roof. In some cases, the heating effect may not be felt until after sunset. Thus, the interior as well as the inside surface of the wall or roof contains heat. In addition, all objects in the building contain heat. If this heat is present when the air conditioning equipment is shut down at night, a percentage of the heat is retained. The heat becomes part of the heat load present when the equipment starts again in the morning.

This component of the start-up load can be decreased by operating the air conditioning equipment during the night or during the early morning hours before the building is occupied. Since solar heat load is not a factor during these periods, the total building heat load is considerably below the load that the equipment is capable of handling. Therefore it is possible to reduce the temperature of the walls, roof, and objects in the building to the point at which they are no longer a heat load.

2.5. EFFECT OF DESIGN AND OPERATION ON COOLING LOAD

2.5.1. Shading effects due to nearby buildings and energy implications

Lam (1999) produces the paper to investigate the shading effects due to neighboring building in seven main business districts in Hong Kong. It has been found that the degree of shading at the local peak design condition ranges from 25 to 31%. Computer simulation techniques using the DOE-2.1E building energy program and a generic office building have been employed to analyze the amount of HVAC plant oversizing (as a result of solar heat overestimation) and to access the likely energy penalty. It has been found that the total building cooling load is overestimated by about 2%. The corresponding plant oversizing seems to be marginal, and the impacts on the total building energy budget are not significant.

2.5.2. Evaluation of interactions between lighting and HVAC systems in a large commercial building

This study was done by Zmeureanu and Peragine (1998) to determine the net energy savings which are expected to be obtained following the retrofit of the lighting system. The study was performed by computer simulation using the MICRO-DOE2 program. The result show that the net energy saving are only about 70% of the gross lighting energy savings for most cases of recessed fluorescent fixtures. Hence, the improvement of the lighting system might be less cost effective than initially expected.

2.5.3. Study of the potential savings on energy demand and HVAC energy consumption by using coated glazing for office buildings in Madrid

The paper focuses on the electrical energy saving potential by employing coated glazing in a double-glazed curtain wall office building in Madrid. Energy simulation software, DOE2.1E was used for the study and Cordoba, Macias and Espinosa (1998) found that a saving of approximately 12% in electrical usage is observed with use of a combination of solar control glass with thermal insulation.

2.5.4. Interactions between lighting and space conditioning energy use in US commercial buildings

This paper characterizes the effect of lighting/HVAC interactions on the annual heating/cooling requirements of buildings through computer simulations using DOE-2.1E building energy analysis program. According to Sezgen and Koomey (1998), lighting/HVAC interactions in different climatic regions are substantially different than the averages. Generally, in warm climates the interactions will induce monetary savings and in cold climates the interactions will induce monetary penalties.

2.5.5. Thermal and behavioral modeling of occupant-controlled heating, ventilating and air conditioning systems

Glicksman and Taub (1995) found that energy use of task HVAC with occupant sensors is found to be less than that of a conventional HVAC system by 13%. Individual HVAC control requires about 10% more energy than uniform conditions.

CHAPTER 3
METHODOLOGY AND PROJECT WORK

3.1. RESEARCH METHODOLOGY

The objectives of this project are divided into two parts. The first objective serves as the preparation before going for the second objective. This project calculated the cooling load of several selected rooms in Building 17. The required information, such as the dimension of the rooms, materials including heat transfer coefficients were obtained from engineering drawings.

The second part, observations were done to investigate the effect of design and operation on cooling load and energy cost of the building. Raw data such temperature and airflow rate readings for the rooms were obtained from academic complex air conditioning control room. The data then were plotted against time, and

3.2. COOLING LOAD CALCULATIONS

The cooling load of the building was calculated using Cooling Load Temperature Differential/Cooling Load Factor (CLTD/CLF). This method is employed instead of other methods suggested by ASHRAE for calculating cooling load of a building, because the simplicity compared to Transfer Function Method (TFM) and Total Equivalent Temperature Differential/Time Averaging (TETD/TA).

3.2.1. Conduction through exterior structure

The cooling load caused by conduction heat gains through the exterior roof, walls, and glass are each found from the Equation 3:

$$Q = U \times A \times CLTD_c \tag{3}$$

where

Q	=	cooling load for roof, wall, or glass, Btu/hr
U	=	overall heat transfer coefficient for roof, wall, or glass, $Btu/hr \cdot ft^2 \cdot {}^\circ F$
A	=	area of roof, wall, or glass, ft^2
$CLTD_c$	=	corrected cooling load temperature difference, ${}^\circ F$

3.2.2. Conduction through interior structure

The heat that flow from interior unconditioned spaces to the conditioned space through partitions, floors, and ceilings can be found from Equation 4:

$$Q = U \times A \times TD \tag{4}$$

where

Q	=	heat gain (cooling load) through partition, floor, or ceiling, Btu/hr
U	=	overall heat transfer coefficient for partition, floor, or ceiling, $Btu/hr \cdot ft^2 \cdot {}^\circ F$
A	=	area of roof, wall, or glass, ft^2
TD	=	temperature difference between unconditioned and conditioned space, ${}^\circ F$

3.2.3. Solar radiation through glass

Radiant energy from the sun passes through transparent materials such as glass and becomes a heat gain to the room. It value varies with time, orientation, shading, and storage effect. The solar cooling load can be found from Equation 5:

$$Q = SHGF \times A \times SC \times CLF \tag{5}$$

where

Q	=	solar radiation cooling load for glass, Btu/hr
$SHGF$	=	maximum solar heat gain factor, $Btu/hr \cdot ft^2$
A	=	area of glass, ft^2
SC	=	shading coefficient
CLF	=	cooling load factor for glass

3.2.4. Lighting

The cooling load due to heat gain from lighting can be found from Equation 6:

$$Q = 3.4 \times W \times BF \times CLF \tag{6}$$

where

Q	=	cooling load from lighting, Btu/hr
W	=	lighting capacity, watts
BF	=	ballast factor
CLF	=	cooling load factor for lighting

3.2.5. People

The heat gain from people is composed of two parts, sensible heat and the latent heat resulting from perspiration. Some of the sensible heat may be absorbed by the heat storage effect, but not the latent heat. The equations for cooling loads from sensible and latent heat gains from people are the following:

$$Q_s = q_s \times n \times CLF \tag{7}$$

$$Q_l = q_l \times n \tag{8}$$

where

Q_s , Q_l	=	sensible and latent heat gains Btu/hr
q_s , q_l	=	sensible and latent heat gains per person, Btu/hr
n	=	number of people
CLF	=	cooling load factor for people

3.2.6. Equipment and appliances

The heat gain from equipment may be found directly from the manufacturer or the nameplate data, with allowance for intermittence use. Some equipment produces both sensible and latent heat. Values of heat output for typical appliances are found from *1993 ASHRAE Volume – Fundamentals*.

3.3. EFFECT OF DESIGN AND OPERATION

Several rooms are specially selected to investigate the effect of several factors to the rooms, which are:

No.	*Room*	*Usage*
1	Lecturer's office	Two rooms at different locations
2	Computer lab	Two rooms at different locations

Table 3.1: List of rooms selected to investigate the effect of design and operation on cooling load

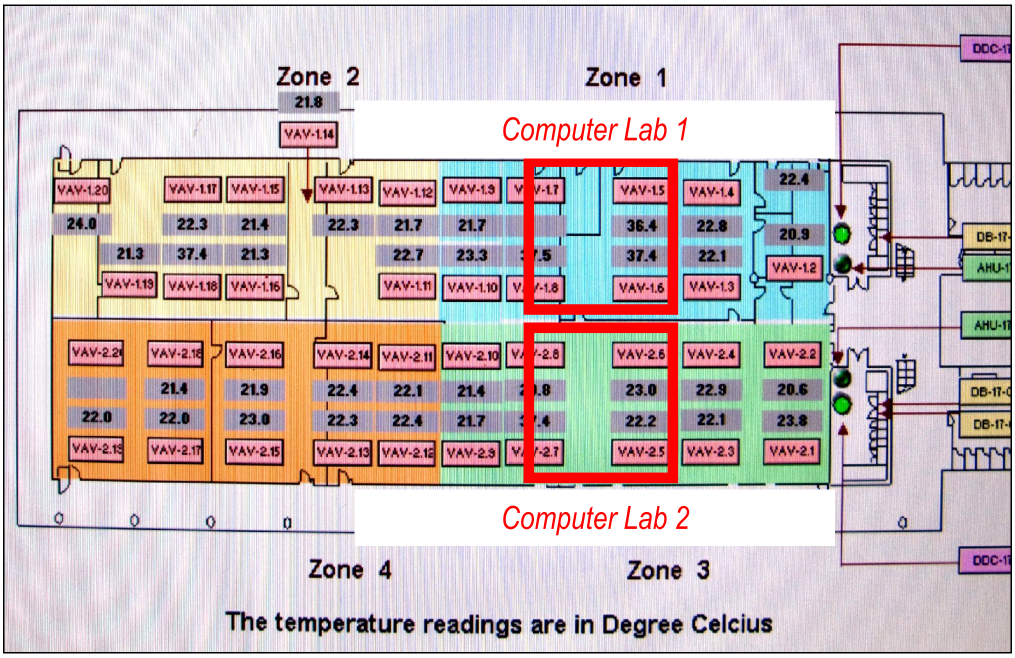

Figure 3.1: Plan view of the location of computer lab on the first floor of Building 17. Source: Honeywell Building Control System

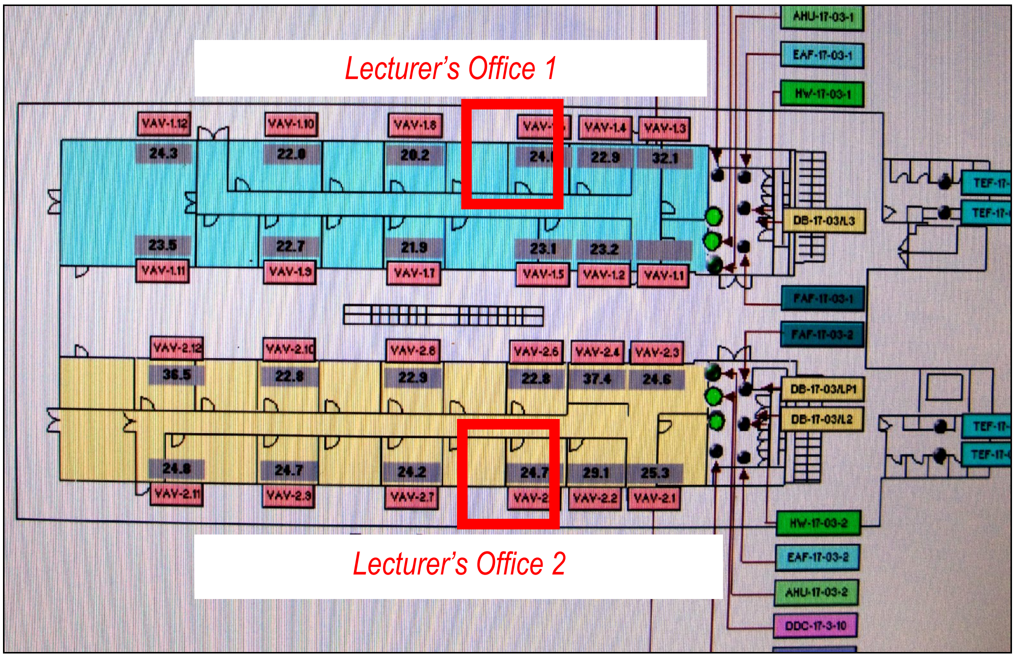

Figure 3.2: Plan view of the location of lecturer's office on the third floor of Building 17. Source: Honeywell Building Control System

3.4. PROJECT GANTT CHART

No.	*Activity*	*Week*														
		1	*2*	*3*	*4*	*5*	*6*	*7*		*8*	*9*	*10*	*11*	*12*	*13*	*14*
1	Selection of Project Topic								*Mid-semester break*							
2	Preliminary Research Work															
3	Submission of Preliminary Report															
4	Seminar 1															
5	Project Work															
6	Submission of Progress Report															
7	Seminar 2															
8	Project work continues															
9	Submission of Interim Report Final Draft															
10	Oral Presentation															

Table 3.2: Project activities and milestones for the first part of the project

No.	Activity	Week														
		1	*2*	*3*	*4*	*5*	*6*	*7*		*8*	*9*	*10*	*11*	*12*	*13*	*14*
1	Project Work Continue								*Mid-semester break*							
2	Submission of Progress Report 1				☆											
3	Project Work Continue															
4	Submission of Progress Report 2									☆						
5	Seminar															
6	Project work continue															
7	Poster Exhibition											☆				
8	Submission of Dissertation (soft bound)													☆		
9	Oral Presentation														☆	
10	Submission of Project Dissertation (Hard Bound)															☆

Table 3.3: Project activities and milestones for the final part of the project

CHAPTER 4
RESULT AND DISCUSSION

4.1. TEMPERATURE OBSERVATIONS

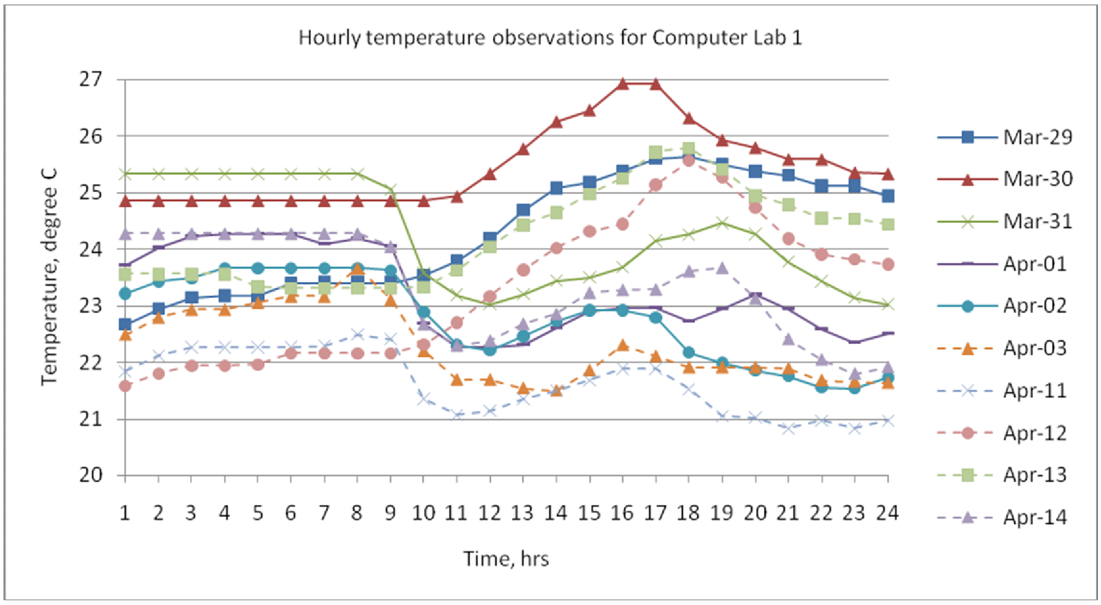

Figure 4.1: Hourly temperature observations for Computer Lab 1

From Figure 4.1, the temperature pattern for the computer lab can be sectioned into three distinct time periods. The first is at morning, followed by late morning and afternoon, and the last time period is at late afternoon.

The first time period is between 12am till 8am. This is where the temperature of the rooms is invariant. The temperature of the room starts to change as the supply of cooled air is blown starting at 7.30am. The temperature first drop about $1^\circ C$ before steadily increases and reaches its peak in the late afternoon. The temperature is at its highest point around 3-7pm. After that, the temperature is gradually decreasing to an invariant temperature as the supply of cooled air is stopped at 6pm.

Daily temperature variations of Computer Lab 1 of different days are caused by two factors, namely 1) varying outside temperatures, and 2) limitation of practical airflow rate of cooled air into the room. High outside temperature of a particular day caused the temperature of the room to be higher, and the limitation of practical airflow rate of the cooled air into the room directly caused the initial operating temperature of the next day to be higher, and vice versa.

At maximum airflow rate, the vibration at the discharge vent is significant and it produces noisy sound. The operator of the air conditioning system prefer avoiding the sound, hence the temperature variations. This is the tradeoff between meeting the preset temperature and the practical volume of cooled air coming into the room. By design, the system is able to meet the preset temperature however at the cost of noisy vibration at the discharge vent (Zafri, 2008).

On April 11, 2008 a synthetic computer lab operation was made by intentionally turn on all the computers in that particular day from 8am to 5pm. This was made to investigate the effect of the usage of computers to the temperature and the consequence cooled air flow rate of the room.

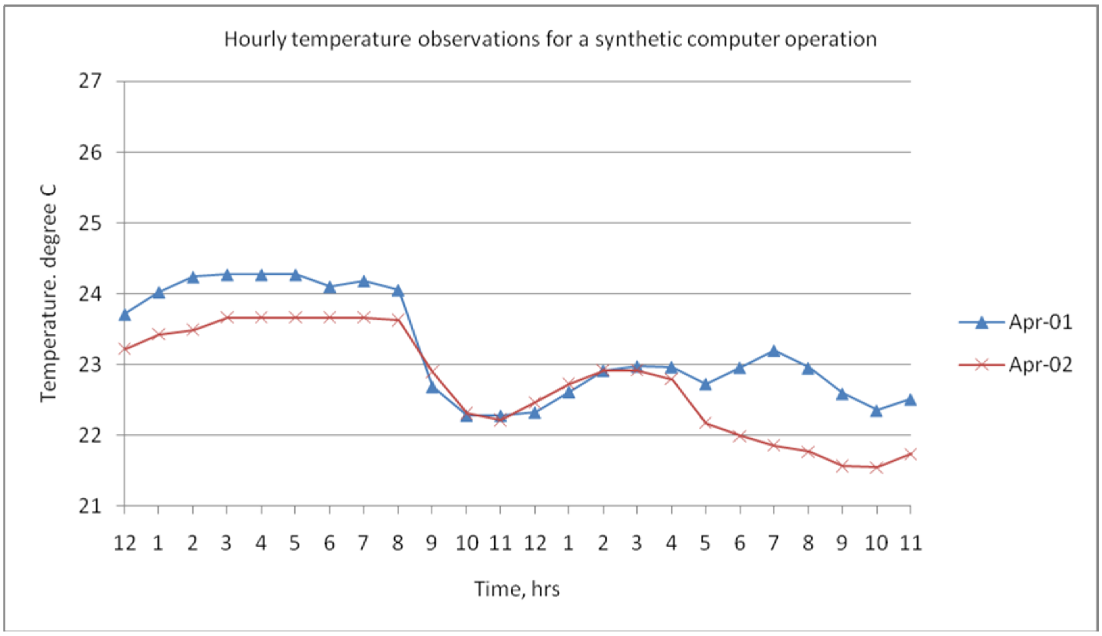

Figure 4.2: Hourly temperature observations for a synthetic computer operation, dated April 11, 2008

The blue line indicates the hourly temperature of the day synthetic computer operation was done, and the red line shows the next day. From the Figure 4.2, the hourly temperature differences between the two days are insignificant. The graph suggests that the operation of computers barely impact to the temperature of the computer lab. This is mainly because the amount of heat generated by the computers is insignificant compared to the outside heat sources. The temperature pattern of is pretty much the same because the room temperature is monitored by several sensors that automatically regulate the temperature of the room to certain temperature range (Zafri, 2008).

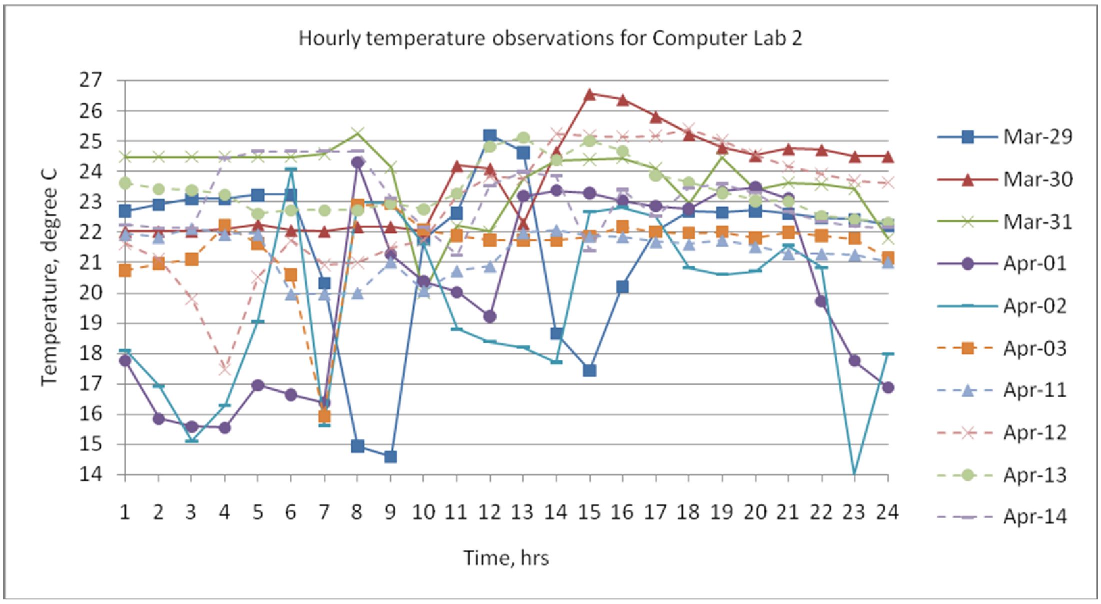

Figure 4.3: Hourly temperature observations for Computer Lab 2

Figure 4.3 is the hourly temperature readings of another computer lab from the same building as Computer Lab 1. The figure shows irregular temperature readings, which is very much different from Figure 4.2. There is no particular pattern of hourly temperature captured.

This however shows that there is something unusual with the operation of the air conditioning of the room. Zafri (2008) suggested that the soundest reason for this irregularity is of either a faulty sensor or damper. Air leakage to the outside is also another possibility, but it is rather unlikely as the personnel who control the room confirm that the room is well shut from any bulk air leakage.

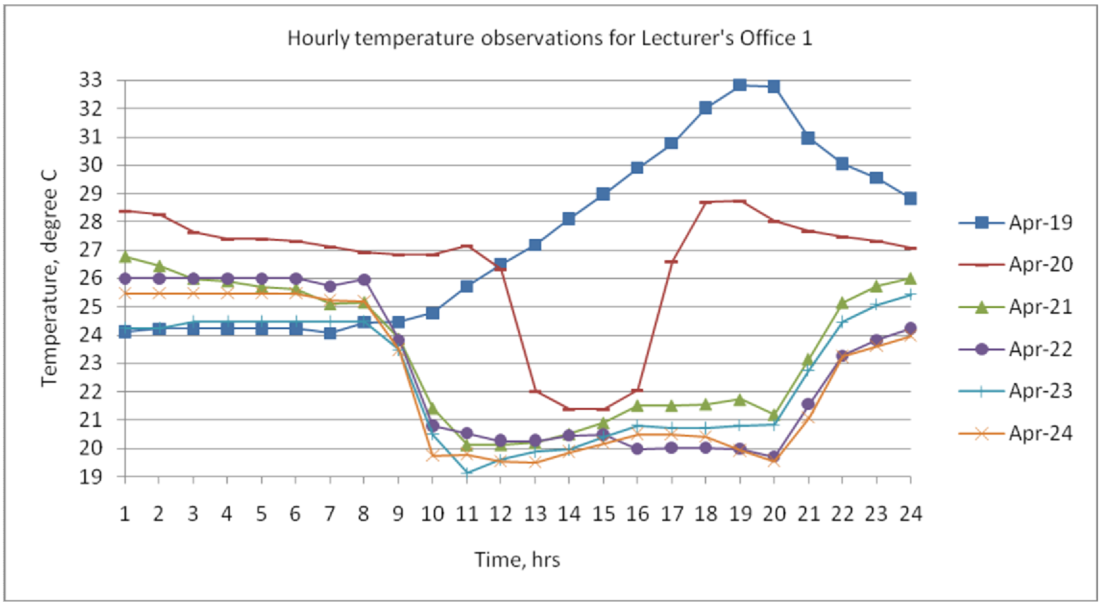

Figure 4.4: Hourly temperature observations for Lecturer's Office 1

Another observation is of lecturer's office at the top floor of Building 17. Figure 4.4 shows the hourly temperature readings, and it suggests a well maintained air conditioning operation. The 24-hour reading can be divided into three distinct regions; where 1) 12am until before the supply of the cooled air started at 7.30am, 2) from7.30am to 8pm, and 3) after 8pm till end of 12am.

The preset temperature of all rooms is Building 17 is at $21^\circ C$ and the graph clearly shows that temperature setting is met, as per operation hours is concerned.

The main reasons of the well maintained operation are largely due to the usage of shadings on the wall of the lecturer's office. The shadings block the sunlight from entering the rooms, and directly reduce the heat accumulation. Thus, only little effort is required to maintain the temperature at the desired level.

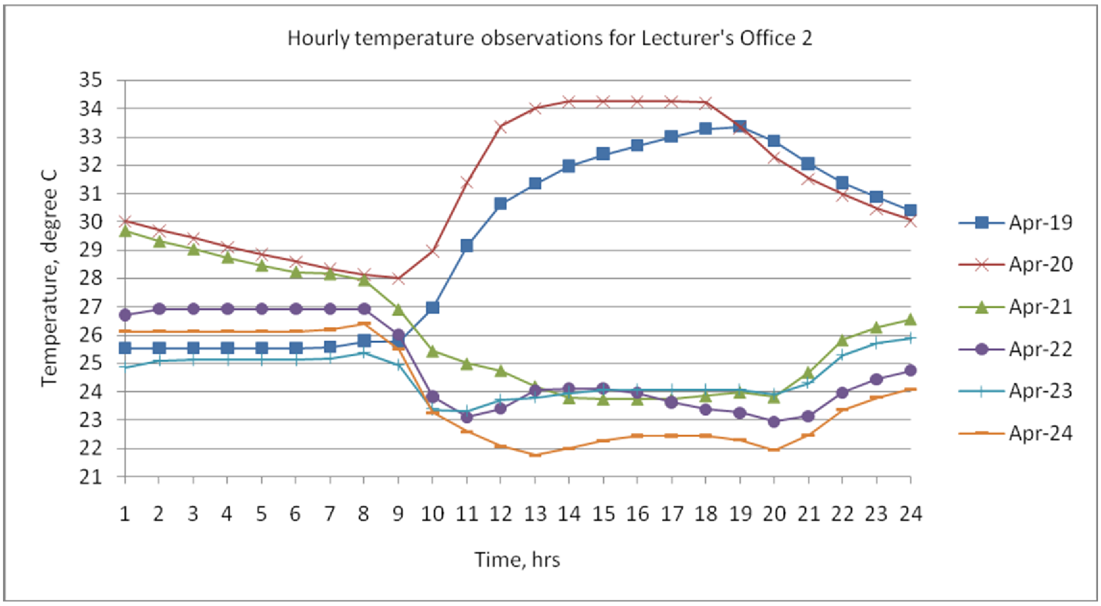

Figure 4.5: Hourly temperature observations for Lecturer's Office 2

Figure 4.5 is a similar reading of lecturer's office, but the readings are taken at the opposite side of Building 17. It is expected to have a similar pattern as Figure 4.4.

Figure 4.5 indeed shows a similar pattern of temperature readings with Figure 4.4, with the same two outliers. These outliers are caused by system trip, most likely caused by no electrical supply to the sensors in the rooms (Zafri, 2008).

Fortunately, the air conditioning distribution system is *adaptive* to the pattern of operation. This in turn means that even though the sensors are down, the airflow of the cooled air is continually supplied into the rooms, with respect to the previous states.

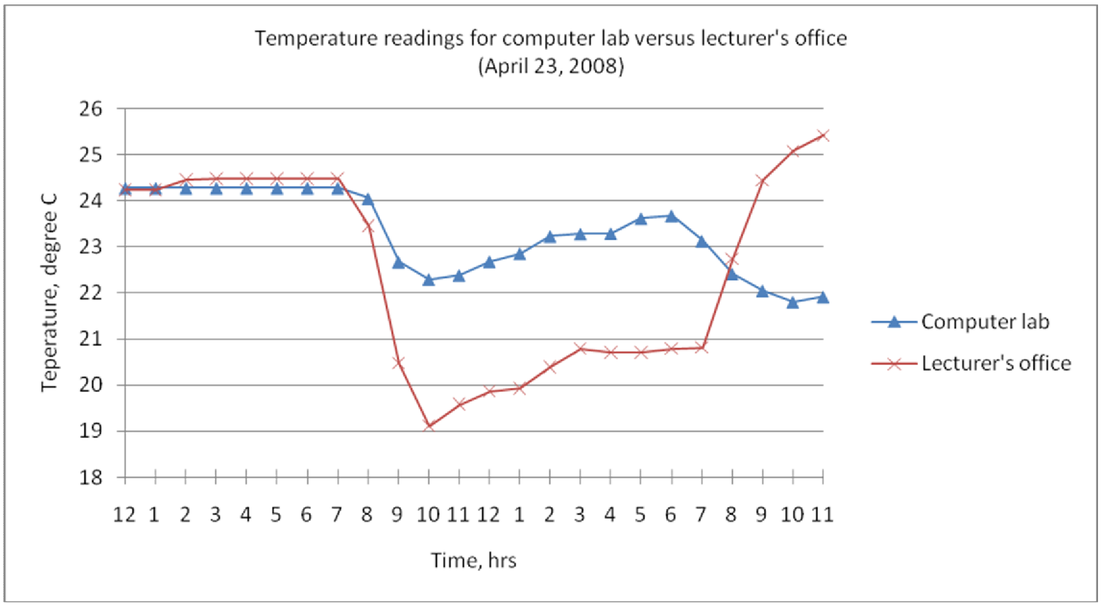

Figure 4.6: Hourly temperature observations for computer lab versus lecturer's office, dated April 23, 2008

Figure 4.6 shows a temperature comparison between Computer Lab 1 and Lecturer's Office 1, taken on April 23, 2008. The graph shows that the obvious temperature difference between the two locations is mainly during the supply hour of cooled air into the rooms.

The temperature of the lecturer's office is about 3°C lower compared to the computer lab, and it is conclusively agreed that the usage of shading at lecturer's office decreases the temperature (Zafri, 2008).

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

This project investigates the effect of design and operation of Building 17 on its cooling load and energy cost. It is clear that the cooling load & pattern of air conditioning of the building is heavily influenced by the outdoor heat sources. Indoor heat sources such as people and office appliances give off but insignificant amount of heat relative to the outdoor heat sources.

The pattern of operation of air conditioning is different for every different room. The difference is caused by the usage of shading, number electrical appliances and the size of the rooms.

Continuous usage of computers and projector, and number of people inside barely has impact to the computer lab because it is too small compared to outside heat.

The average temperature for lecturer's office is about $3^\circ C$ lower than the computer lab. This is primarily caused by the application of shading at the walls of lecturer's office and also because the smaller number of electrical appliances compared to the computer lab.

From the data collected, it is concluded that the air conditioning system is able to achieve the intended operation provided the system is well-maintained and is used properly.

5.2. RECOMMENDATION

To further reduce the cooling load for Building 17, it is recommendable to block the solar heat from entering it directly by radiation. This is achievable by applying shading to the wall. With shading applied to the walls, the temperature of lecturer's office is well maintained at average $23.8^{\circ}C$ for at least during the office hour. The temperatures at particular hours are $3^{\circ}\mathrm{C}$ average lower compared to computer lab, where no shading is applied.

To increase the efficiency of the air conditioning system, the operator should monitor the pattern of the temperature, practically for all rooms. Looking Figure 4.3, it is clear that there is something wrong with the air conditioning system at that particular room. The operators themselves unaware of this condition and suggested it is probably caused by faulty sensor or damper.

5.3. FUTURE WORK

Future work of this project should include more rooms and buildings, thus the operation of the air conditioning system as a whole could be understand a lot more.

It is recommended to use a proper energy simulation software to perform detailed analysis of building energy usage. eQUEST is one of many powerful software, which is the enhanced version of famous DOE-2.1E software. It is a freeware, so there is no need to buy any license to use the software.

Future work of this project should also do collaboration with the operator to monitor the operation of air conditioning system. It is beneficial to directly involve and helps determine the operation pattern of all rooms, indirectly improve the efficiency of the system.

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APPENDIX - 1

Figure A1: Air conditioning system control room

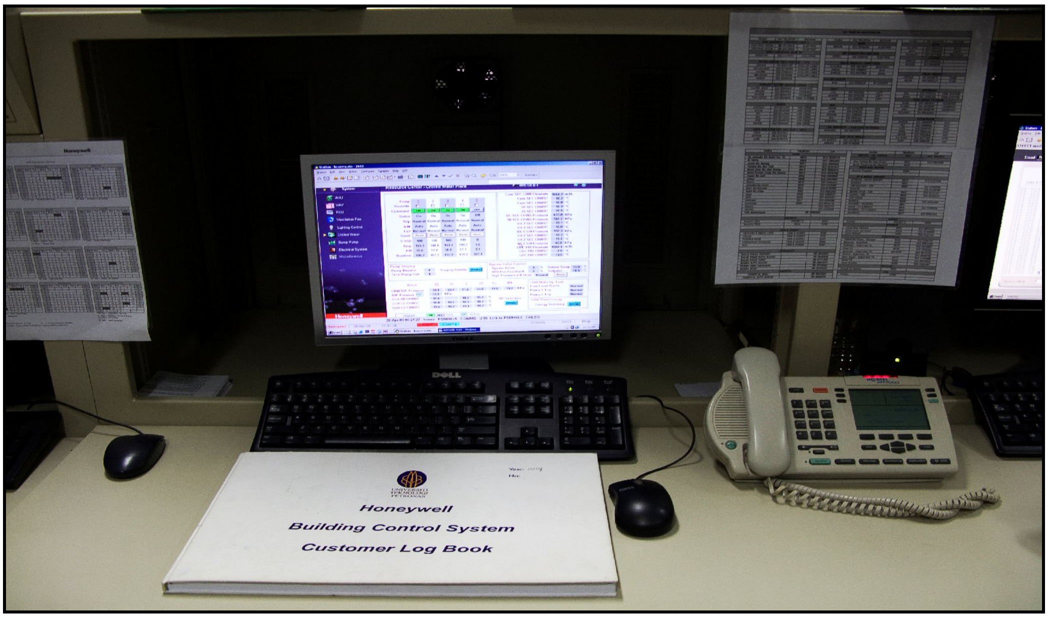

Figure A2: Air conditioning system control panel

Figure A3: Lecturer's office is on the top floor of Building 17

Figure A4: Computer lab is on the first floor of Building 17

Figure A5: The usage of shading at the wall of lecturer's office

Figure A6: Inside view of the computer lab

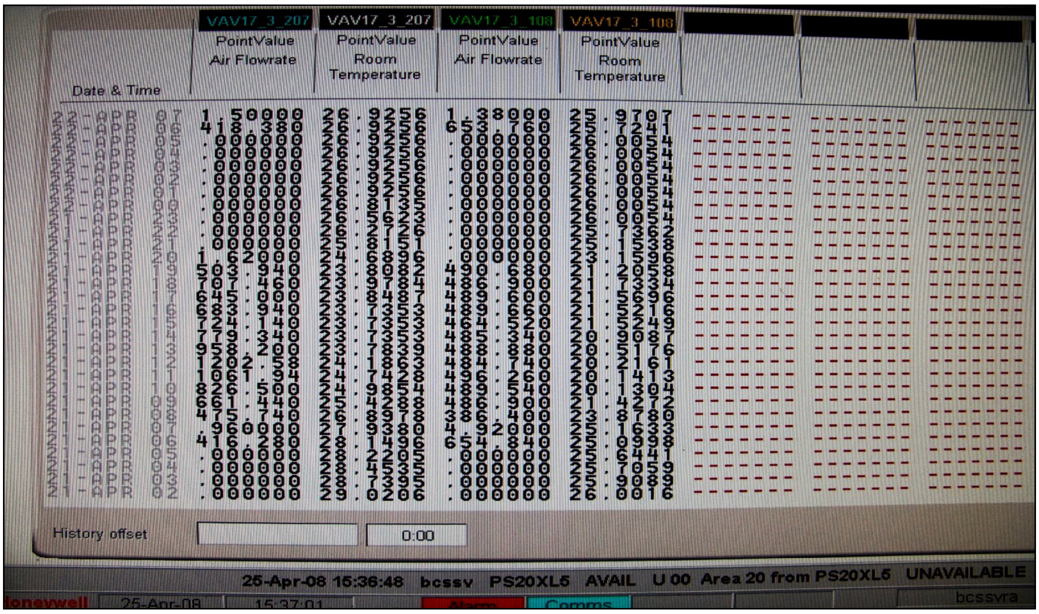

Figure A7: A screen capture of temperature and airflow rate data readings

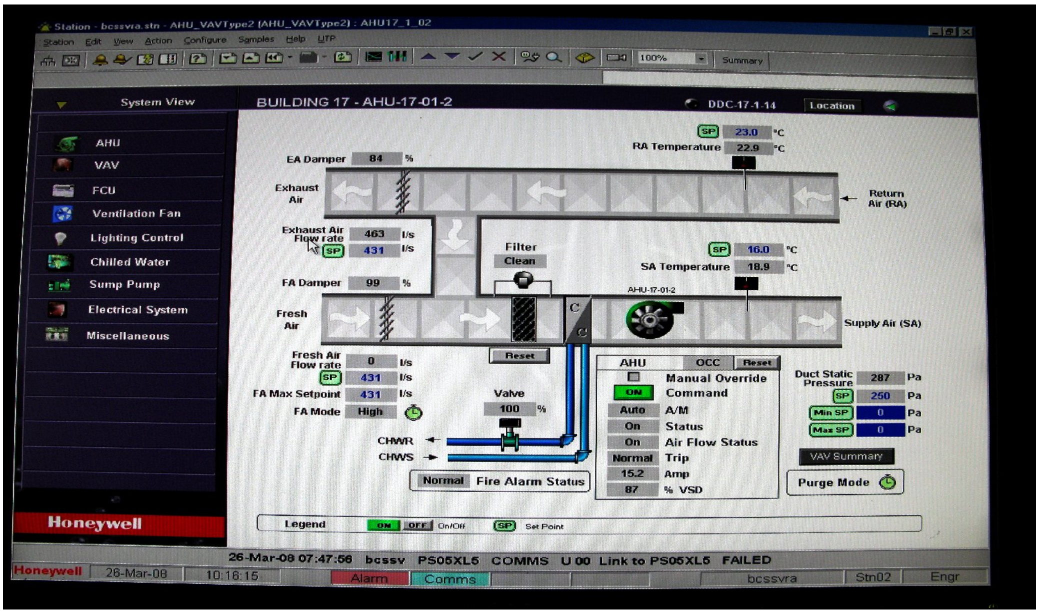

Figure A8: A screen capture of AHU information and control panel

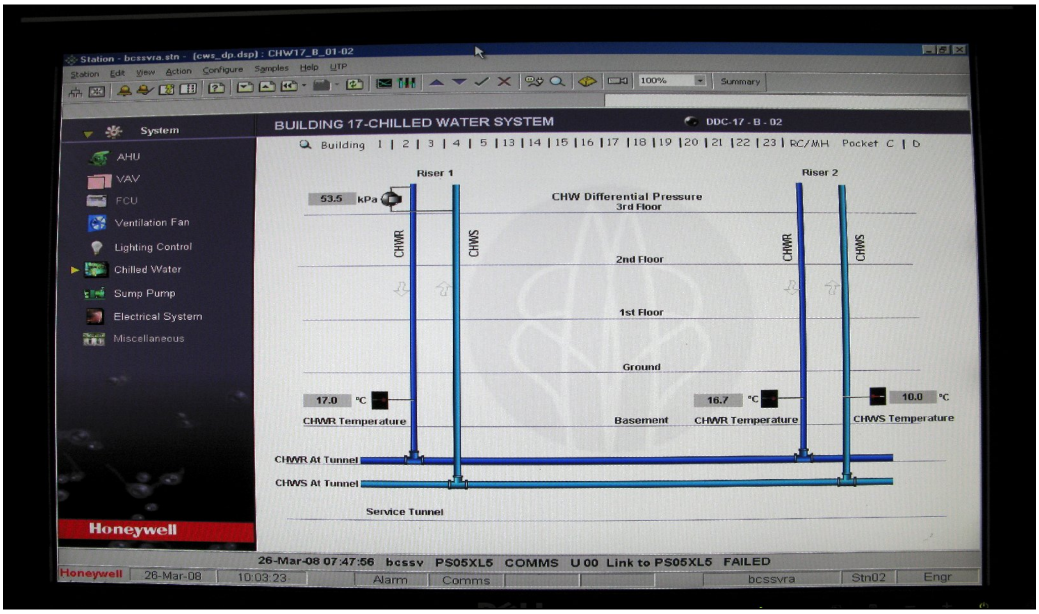

Figure A9: A screen capture of chilled water system information display