ACTIVE IMPROVEMENT OF AIR-CONDITIONING SYSTEM ENERGY CONSUMPTION WITH ADAPTIVE THERMAL COMFORT APPROACH

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ABSTRACT

The MSc research project aims to suggest improvements to building air-conditioning control systems, to reduce energy consumption while maintaining the comfort level of the occupants. Recent studies have shown that a more "adaptive" approach towards temperature control might be favourable both in terms of energy use and in occupant comfort. An ASHRAE Standard 90.1 compliant Building Energy Analysis Computer Program is utilized to determine potential energy savings with improved operation of the air-conditioning system. These predictions are compared with actual energy savings measured in a field trial carried out in an office building in Peninsular Malaysia. This country is considered to be optimum for such studies because it is where performance can be seen to be attributed to the system and not to external variations caused by the weather.

The field trial conducted consisted of 2 experiments: background measurement while an adaptive approach is adopted, and a transverse survey *(of thermal comfort)* with energy comparison. The background measurement experiment aimed to investigate the actual indoor climate behaviour when constant, ramp and cyclic changes were applied to the indoor set-point temperature. The other experiment aimed to compare and understand actual occupant responses to constant, cyclic and ramp variations as well as to measure the corresponding HVAC system energy savings.

Although simulations showed that energy reduction could be got through set-point manipulation and experiments showed that occupant comfort were maintained, the HVAC system chosen failed to accommodate the prescribed trajectories. Thus it was not possible to demonstrate the practicability of the approach. However internal temperatures did fluctuate, so to a large extent the occupant surveys were valid and revealed occupant views on temperatures that varied with time. Since decision to choose the selected office building for the field trial was determined after stages of detail comparison to other similar buildings, findings in this research project could certainly be useful for Malaysian government to gauge the actual condition and performance of present HVAC control systems installed in their buildings. A number of buildings were examined and all appeared to suffer from similar problem. Poor building performance must be the key conclusion of this dissertation.

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PREFACE

This dissertation describes research whose overall aim is to suggest improvements to building air-conditioning control systems, to reduce energy consumption while maintaining occupant comfort level. Recent studies have shown that a more 'adaptive' approach towards temperature control might be favourable both in terms of energy use and in occupant comfort. Conclusive studies have been performed in countries in Western Europe where outside temperature fluctuations are relatively large throughout the year. For these countries, effective energy conservation with occupant comfort can be improved by scheduling changes to the indoor set-point temperature on the basis of changes in the outside temperature. However, this strategy is not applicable to countries located near the equator like Malaysia, where outside temperature variations throughout the year are relatively small. An alternative form of adaptation is required here. Experiments conducted by a group of researchers in an air-conditioned office building have suggested that adjusting the indoor space temperature in a prescribed manner could be one of the alternative forms of adaptation. However, they did not describe how they were able to obtain their indoor temperature prescribed patterns in their particular building. Only indoor temperatures were reported, so the performance of the plant was unclear. There was no mention of any indoor temperature set-point changes, or how they found buildings with suitable plants, or about their experimental set-up, or about changes in outside temperature. This knowledge would be required to make their approach practicable. This dissertation investigates if an approach similar to theirs is acceptable to the end user, practicable and financially worthwhile. A number of simulations and field trials were carried out to do this. The simulations were performed in the UK, while the field trials were performed in Malaysia. The dissertation describes the great deal of preparation that was needed before setting off to Malaysia, including liaison with engineers in that country. Importantly it also underlines the need 'not to take things for granted'.

Time and resources were limited, so in the end conclusions could not be drawn about user acceptability, because of difficulties encountered during the field trials: the internal temperatures in the building could not be made to follow the prescribed trajectories. This inability must be the key conclusion of this dissertation. However internal temperatures did fluctuate so the occupant surveys still revealed occupant views on temperatures that varied with time. Indeed the temperature history obtained in the experiments conducted by the author is close to that prescribed by other researchers. In other words, these experiments were valid more by chance than by design. Occupant responses suggested that they would tolerate such a temperature variation. The question then is, would they tolerate faster temperature variations? The same experiments produced such a variation; again the occupants were tolerant. This is all relatively superficial and many more experiments would be need before conclusions could be drawn.

Three case studies of one building installed with a variable refrigerant flow system *(VRF)* and two buildings installed with water cooled chiller systems *(WCCH)* are described in Chapter 2. Using a HVAC computer program, energy analyses and simulations of the three buildings were conducted to estimate potential energy savings that might be obtained if the indoor temperature is made to fluctuate in a prescribed manner, e.g. in either a ramp or cyclic mode. All three case studies are seen to have significant potential energy savings when either the ramp or cyclic modes are applied.

A field trial to verify this potential energy saving is described in Chapter 3. The selection of one of the case studies, the Legal Affairs Division Office (BHEUU), for the field trial is discussed. A number of steps were taken before the field trial was performed: first the HVAC configuration and control system of the BHEUU were carefully examined; then the primary thermal comfort variables, which would be measured during the field trial, were looked into to get a better understanding; finally a MATLAB Simulink computer model of a simple HVAC system was developed to gain an understanding of how the system should perform. A key conclusion obtained from this simple model simulation is that a good space temperature response to either the ramp or cyclic induced variations is highly dependent on the air-change or supply air flowrate of the HVAC system. The field trial conducted consisted of 2 experiments: environmental monitoring was performed, and a transverse thermal comfort survey was carried out with energy comparison. Environmental monitoring aimed to investigate the actual indoor climate behaviour when constant, ramp and cyclic indoor set-point temperature changes were applied. The other experiment aimed to compare and understand actual occupant responses to the constant, cyclic and ramp variations and to measure the corresponding HVAC energy savings.

The air-conditioning systems installed in a number of buildings in Putrajaya were examined before a suitable test zone could be identified. In other words it was clear that such an advanced control strategy could not be implemented easily for any zone in any building. There are a number of limiting factors including poor maintenance, lack of consideration of the building dynamic response in the HVAC system design and poor system set-up, which is likely caused by a nonchalant attitude during system testing and commissioning. These factors will be discussed further in Chapter 5.

Different types of HVAC system are discussed in Chapter 1. The variable refrigerant flow system *(VRF)* and the water cooled chiller system *(WCCH)* are concluded to have a greater potential to contribute towards the active improvement of energy consumption. The VRF system would be most compatible with advanced control system. It is on this basis that the Court Complex, Kuala Lumpur was considered first to be the test zone. Unfortunately, Public Works of Malaysia *(PWD)* preferred the field trial to be conducted at Menara Sri Wilayah, which has a BHEUU system.

Experimental results are presented in Chapter 4. The environmental monitoring results suggest that changes in dry bulb and operative temperature were fairly similar during all set-point temperature modes. Changing the building indoor set-point temperature cyclically is found to have an insignificant impact on the indoor operative temperature and relative humidity. As for the transverse survey experiment, the results generally suggest that the occupants' comfort response to all modes were fairly similar. The poor space temperature response to the various set-point changes meant that the occupants could not feel the differences between the dynamic modes and the constant mode. However, it is also concluded that there was a high probability of improvement in energy consumption was taken place when either of the dynamic indoor set-point temperature modes *(i.e. ramp and cyclic)* was applied.

Although energy reduction was achieved while the occupant comfort was maintained, the project was not a complete success because the HVAC system chosen has failed to accommodate the required response. However, findings in this research project are useful for the government of Malaysia to gauge the actual condition and performance of present HVAC control systems installed in their buildings. Since the selection of BHEUU for the trial building was decided after stages of detailed comparison to other similar buildings, the author now could argue whether or not the average performance of building HVAC control system in Malaysia could even meet the initial requirements that they were designed for.

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AUTHOR`S DECLARATION

I declare that this thesis is entirely the product of my own work, except where indicated, and has not been submitted by myself or any other person for any degree at this or any other university or college.

Muhammad Fadzli bin Muhammad Saleh

Definitions/Abbreviations

Abbreviations	Full descriptions
^oC	Degree Celsius
$^oC/h$	Degree Celsius per hour
^oF	Degree Fahrenheit
ΔT	Temperature Drop
$\dot{m}$	Mean Fluid Flowrate
$\dot{Q}$	Mean Heat Transfer Rate
$(S+T)_R$	Roof Solar and Transmission Loads
$(S+T)_W$	Wall Solar and Transmission Loads
ACA	Adaptive Control Algorithm
ACCH	Air Cooled Chiller System
ACH	Air Changed per Hour
ACT	Adaptive Comfort Temperature
A_{cov}	Body surface Area covered by clothing
AHU	Air Handling Unit
APD	Actual Percentage of Dissatisfied
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BHEUU	Bahagian Hal Ehwal Undang-Undang (*Legal Affairs Division Office*)
BMS	Building Management System
Btu	British Thermal Unit
Btuh	British Thermal Unit per Hour
CBP	Bypassed outdoor air
CFM	Cubic Feet per Minute
Clo	Clothing Insulation Unit
CO_2	Carbon dioxide
COP	Coefficient of Performance
Cp	Specific Heat
DX	Direct Expansion
EER	Energy Efficiency Ratio
ENE	East North East
FCU	Fan Coil Unit
ft^2	Square Feet
GDC	Gas District Cooling
HAP	Hourly Analysis Program

Abbreviations	**Full descriptions**
HVAC	Heating, Ventilation and Air Conditioning
$I(S+L)_G$	Sensible and Latent heat via Glass by Infiltration
$I(S+L)_W$	Sensible and Latent heat via Wall by Infiltration
I_{cl}	Ensemble Thermal Insulation
I_{clu}	Effective Thermal Insulation
kBtu	Kilo British Thermal Unit
kW	Kilowatt
kW(e)	Kilowatt of Electric power input
kW(r)	Kilowatt of system Refrigerant load
kWh	Kilowatt Hour
l/s	Litre per second
m/s	Meter per second
MATLAB	Matrix Laboratory (*numerical computing environment and fourth-generation programming language)*
MBH	One thousand BTU per Hour
OA	Outdoor Temperature
PI	Proportional Integral controller
PJH	Putrajaya Holdings
PMV	Predicted Mean Vote
ppm	Particles per minute
PPD	Predicted Percentage of Dissatisfied
PWD	Public Works Department
RDHG	Return Duct Heat Gain
RDLG	Return Duct Leakage Gain
RH	Relative Humidity
RT	Ton of Refrigerant
SDHG	Supply Duct Heat Gain
SDLL	Supply Duct Leakage Loss
S_G	Solar Loads via Glass
T_A	Air Temperature
T_F	Transmission Load via Floor
T_G	Transmission Load via Glass
T_G	Globe Temperature
T_{ML}	Mean Radiant Temperature
T_O	Outside Temperature
T_{OP}	Operative Temperature

Abbreviations	Full descriptions
T_P	Transmission Load via Partition
T_{Set}	Set-point Temperature
T_W	Wall Temperature
v_A	Air velocity
VAV	Variable Air Volume
VCU	VRF Compressor Unit complete with inverter
VCCU	VRF Ceiling Cassette Unit
VFCU	VRF Fan Coil Unit
VRF	Variable Refrigerant Flow
VSD	Variable Speed Drive
VWMU	VRF Wall Mounted Unit
WCCH	Water Cooled Chiller System
WCP	Water Cooled Packaged System
WNW	West North West

CHAPTER 1
INTRODUCTION

1.1 Research Background

Air Conditioning Systems are becoming more and more prevalent in buildings. Throughout the world, offices, cinemas, studios, shopping malls, etc. are now provided with air conditioning systems to meet the comfort demand or desire of their occupants. The energy consumed by an air-conditioning system is taken very seriously by those involved in the design and operation of these buildings. The goal must be to provide thermal comfort for occupants, while minimizing energy consumption. Researchers from around the globe have been exploring the thermal physiological and psychological responses of people in their environment and have concluded that occupant thermal comfort is influenced by 6 primary variables. As stated in ASHRAE Standard 55 [3] these 6 primary variables are:

i. Metabolic Rate
ii. Clothing Insulation
iii. Air Temperature
iv. Mean Radiant Temperature
v. Air Speed
vi. Humidity.

Detailed explanations about these primary variables are given in Chapter 3. According to Nicol and Humphreys [4], energy consumption, building sustainability and occupant comfort are interrelated and highly dependent on the provision of good indoor environment characterization. They propose an adaptive approach to thermal comfort, based on the natural tendency of humans to adapt to changing conditions of their environment. This thesis describes research into an adaptive approach to alter the indoor climate characterization of a building in a way to improve comfort, energy consumption as well as building sustainability.

Research into thermal comfort is not new. In 1936, Bedford [5] conducted a field survey involving the collection of thermal environment data and the thermal responses of subjects going about their working days. Interventions by the researcher were kept to the minimum; the thermal responses of the subjects were measured by asking them to vote comfort on a descriptive scale: -3 much too cool, -2 too cool, -1 comfortably cool, 0 comfortable, 1 comfortably warm, 2 too hot, 3 much too hot. Decades later Nicol and Humphreys [4] confirmed that this type of thermal comfort survey still forms the basis of modern adaptive approaches to thermal comfort. In their early work, Nicol and Humphrey [6] argued that building occupants should be allowed to adapt to their surroundings. The same argument also reported in their related studies [7-16]. This contradicted the conventional view that environmental conditions should be maintained steady as recommended by thermal comfort standards. Others have developed and applied this principle widely around the globe. The common aim has been to find those thermal environment conditions that subjects find neutral or comfortable. Researchers often utilize statistical methods to analyse data that is subject to the natural variability of thermal conditions. This analysis is then used to predict the 'comfort temperatures' or 'comfort conditions' that should be acceptable in similar circumstances elsewhere.

Thermal comfort studies can take 2 forms: longitudinal and transverse. Longitudinal surveys involve repeated observations of the same variables over long periods of time. Subjects involved in this type of survey are asked to record their thermal comfort on a questionnaire that might be provided several times in one day. The longitudinal survey is often conducted for one complete year, although other durations are possible. On the other hand, a transverse survey involves only one time observation of subject variables. This type of survey is usually conducted monthly for over a year. The results of a transverse survey represent a larger sample of the population, but contain less information about each subject. In Pakistan, Nicol et al. [11] conducted two adaptive thermal comfort field experiments: a longitudinal survey was carried out in the summer and winter, while a transverse survey was performed monthly for over a whole year. In this longitudinal survey, the subjects were asked to fill the questionnaire in every hour of during their waking day. Five cities representing particular climatic regions were selected for these surveys. Nicol et al. found the results from both surveys closely agreed. Transverse surveys have been proven to be reliable and require simple and inexpensive instruments. They can be carried out anywhere in the world even with minimal funding. One of Nicol et al. conclusions [11] was that the design indoor temperature of commercial buildings in Pakistan should be set according to the expected monthly mean outdoor temperature to obtain a potential energy reduction of 20-25%.

In a more recent study McCartney and Nicol [17] conducted both longitudinal and transverse surveys as a precursor to the development of an adaptive control algorithm (ACA) for Europe that provided an alternative to the fixed set-point temperature control of building air-conditioning system. One of the major aims of ACA was to provide a straight forward methodology for building engineers to utilize the adaptive comfort ideology.

Again both survey methods were observed to have very similar findings for the ACA development. The results of this study showed that the use of ACA has the potential for energy consumption improvement in air-conditioned building without jeopardising the thermal comfort of building occupants.

Mui and Chan [18] followed a similar path in the development of an adaptive control algorithm for Hong Kong. Although both longitudinal and transverse surveys were used, the model was formulated from the transverse investigation and then verified with a longitudinal survey. The model was named 'Adaptive Comfort Temperature (ACT)' to reflect the different approach. Like the ACA for Europe, ACT also aimed to provide a better alternative to the conventional fixed temperature set-point control of air-conditioned buildings. In one of the conclusions, Mui and Chan states that a total potential of 7% energy saving could be accomplished with ACT model integration.

Similar field experiments regarding thermal comfort were also conducted in Singapore for both naturally ventilated and air-conditioned buildings by de Dear et al. [19, 20]. Only transverse surveys were conducted in these experiments. For air-conditioned buildings, de Dear et al. found that even when relevant indoor climate standards are maintained, the climate was slightly on the cold side; the mean thermal comfort on a seven-point scale was observed to be -0.34.

In Malaysia, Hussein et al. [21] conducted an adaptive thermal comfort field experiment on air-conditioned class rooms in campus buildings. All the occupants in nine different rooms were asked to fill in a survey form while the classroom climate parameters were measured. Instead of measuring the four usual environmental parameters (i.e. globe temperature, dry bulb temperature, air movement and relative humidity), only temperature and relative humidity were measured at four different locations in the class room. The authors suggest that the temperature and relative humidity range of thermal comfort in this study is slightly different to the summer comfort zone stated in the ASHRAE Standard. However, the authors also concluded that the results obtained were consistent with other researchers, which indicates the ability of people to adapt or acclimatize with the environment they live in.

Tan and Kosonan [2] have argued that a failure to accommodate an adaptive thermal comfort approach in air-conditioned building designs in tropical hot-and-humid climates, leads to a lower temperature demand with associated cooling energy wastage. They investigated a dynamic control principal in which the room air temperature is varied with the time of day (Figure 1-1).

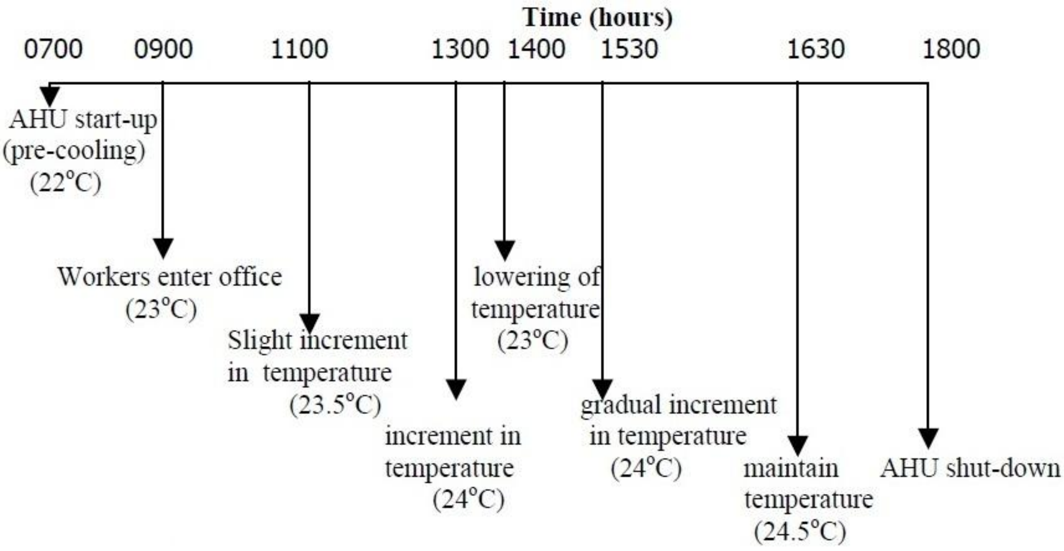


Figure 1-1: Dynamic room air temperature control during experiment [2]

They conclude that such variations in the indoor set-point temperature can lead to a higher neutral temperature of the comfort vote as compared to the common static indoor set point temperature.

An alternative approach to the variation in indoor set point temperature was proposed in 1994 by Fountain et al.[22]. Their aim was not to perform scientific experiments into thermal comfort, but simply to ramp indoor temperature set-points to reduce energy consumption in short-term occupancy. In their design of the thermostat control system, the indoor temperature is allowed to drift up to a maximum allowable temperature set point at a rate that is thermally indistinguishable. The aim is to minimize energy consumption during occupied periods without compromising on comfort. However no results were reported.

There are also two main thermal comfort standards related to this research which are ASRHRAE Standard 55 and EN-ISO 7730. Both standards contain specific recommendations on temperature variation, drift and ramps from a comfort perspective.

1.2.1 ASHRAE Standard 55

According to this standard, temperature fluctuation with time could provide negative impacts toward occupants' indoor thermal comfort if it is not managed properly. This standard [3] specifies the following about temperature variations with time:

- Cyclic Variations - "*Cyclic variations refer to those situations where the operative temperature repeatedly rises and falls, and the period of these variations is not greater than 15 minutes. If the period of the fluctuation* *cycle exceeds 15 minutes, the variation is treated as a drift or ramp in operative temperature.*" [3].

Allowable Peak-to-Peak Variation in Operative Temperature, °C (°F)
1.1 (2.0)

Table 1-1 : Allowable cyclic operative temperature variation

- Drifts or Ramps - "*Temperature drifts and ramps are monotonic, noncyclic changes in operative temperature. The requirements of this section also apply to cyclic variations with a period greater than 15 minutes. Generally, drifts refer to passive temperature changes of the enclosed space, and ramps refer to actively controlled temperature changes.*" [3]. The maximum change in operative temperature allowed during a period of time is specified below:

Time Period	0.25 h	0.5 h	1 h	2 h	4 h
Maximum Operative Temperature Change Allowed	1.1°C (2.0°F)	1.7°C (3.0°F)	2.2°C (4.0°F)	2.8°C (5.0°F)	3.3°C (6.0°F)

Table 1-2: Limits on temperature drifts and ramps

1.2.2 BS EN-ISO 7730, 2005

The requirements about temperature fluctuations in this standard are differentiated in a similar way:

- Cyclic Variations – maximum allowable peak-to-peak cyclic variation in operative temperature is 1.0 ^{0}C [23].
- Drifts and Rams – the rate of temperature change is preferably lower than 2.0^{0}C/h, where the temperature should stay between the comfort limits as described in the standard. For example, comfort temperature limits of an office in summer would be between 23 – 26 ^{0}C [23].

Previous studies suggest that an adaptive approach based on thermal comfort could lead to significant improvement in energy consumption. Studies which have been carried out in France, Greece, Portugal, Sweden, United Kingdom and even Hong Kong, where outside temperature fluctuations are relatively large throughout the year, aimed to improve both occupant comfort as well as energy consumption by varying an indoor set-point temperature according to outside temperature [18] [17]. Research in countries located closer to the equator, like Thailand, Singapore and Malaysia, do not see any advantage in varying the indoor set point temperature as a function of outdoor temperature, because the differences in outside temperature throughout a year are relatively small. However, the stable outside temperature in these countries may be beneficial for adaptive studies where the focus can be on variables other than outdoor temperature. For instance, as described before experiments performed by F. Tan and R. Kosonan in tropical countries [2] suggest that adaptive temperatures can address physiological needs while helping to improve energy consumption. Stable outdoor temperatures are very useful when investigating wether adaptation in thermal comfort can improve the energy consumption of building air-conditioning systems. Performance can be seen to be attributed to the system and not the external variation. Located close to the equator, Malaysia is arguably ideal for the adaptive studies to be carried out for this MSc-by-Research project.

Peninsular Malaysia has a tropical climate with a uniformly high temperature and high humidity throughout the year, and an abundant rainfall averaging 2500 mm per annum. The maximum annual temperature variation is less than 3^0C, which occurs on the east coast of Peninsular Malaysia during the North East Monsoon where cold surges arising from Siberia often affect the climate. Other parts often experience only 2^0C annual temperature variation or less. Although the seasonal temperature variation is relatively small, the diurnal change in temperature is high, about 5^0C to 10^0C on the coastal and 8^0C to 12^0C inland. Even with these higher temperature fluctuations, significant energy savings through indoor set-point temperature variation as a function of outdoor temperature are unlikely, because the considerable change of temperature only occurs at night, so temperature changes during office hours are still insignificant [24].

1.2 Air-Conditioning System in Non-Residential Buildings of Peninsular Malaysia

The specification of a particular air-conditioning system depends upon a number of factors including the size of the space, heat generation within the enclosed area and so on. In general for non-residential buildings in Malaysia, air-conditioning system can be categorized as:

i. window unit systems

ii. split unit systems

iii. packaged systems

iv. chiller systems

These four main types of air conditioning system are divided into several sub-categories that usually depend on system capacity and design, as well as on the heat transfer mechanism of the system. A diagram showing the main types and sub-categories of air-conditioning system is given in Figure 1-2. The sub-categories will now be described.

1.2.3 Conventional Split Unit System

These systems have two parts: an outdoor unit and an indoor unit. The outdoor unit houses components like the compressor, condenser and expansion valve. The indoor unit comprises the evaporator or cooling coil and the cooling fan [25]. There can be more than one indoor unit per system. These systems are sometimes known as multi-split systems. Normally, they are installed in a small space and require individual control of the air-conditioning system. Further information about this type of system and energy conservation can be found in [26-28]. Figure 1-3 shows a typical schematic drawing of the system.

1.2.4 Split Ducted System

This system is very similar to a conventional split unit system, but instead of having an indoor unit blowing directly into the space, a fan coil unit blows conditioned air into spaces through ducting and diffusers. It is usually installed in a separate room and requires a dedicated control system. It can be installed as a centralized air-conditioning system in a small building. Figure 1-4 shows a typical schematic drawing of the system.

1.2.5 Air Cooled Package System

As the name implies, in a packaged air conditioning system all the important components of the system are enclosed in a single casing like a window unit. Thus the compressor, cooling coil, air handling unit and air filter are all housed in a single casing and assembled at the factory. The condenser of the refrigeration system is cooled by atmospheric air. The cooling unit comprising of an expansion valve, evaporator, an air handling blower and filters are located together with the compressor outside a building. From outside, the conditioned air is blown through ducting to the various spaces that are to be cooled [29]. Amount of installation of this system in non-residential buildings has been decreasing year on year due to the availability of higher capacity split ducted systems. This system may also be installed as a centralized air-conditioning system in a small building.

1.2.6 Water Cooled Package System

The condenser is of shell and tube type, with refrigerant flowing through the tube side and cooling water flowing through the shell side. The water has to be supplied continuously in these systems to maintain functionality of the air conditioning system. The shell and tube type of condenser is compact in shape and is enclosed in a single casing along with the compressor, expansion valve, and air handling unit including a cooling coil. This whole packaged air conditioning unit looks like a box with the control panel located on the outside [29]. The air handling unit comprising of the centrifugal blower and air filter is located above the cooling coil. The centrifugal blower has the capacity to handle the large volume of air required for cooling a number of spaces. From the top of this packaged system, the duct extends to the various spaces that are to be cooled. As with an air cooled packaged system, it is normally installed as a centralized air-conditioning system in a small building, but with a slightly bigger in cooling capacity demand. Figure 1-5 shows a typical schematic drawing of the system.

1.2.7 Variable Refrigerant Flow System (VRF)

VRF systems are larger capacity, more complex versions of ductless multi-split systems, with the additional capability of connecting ducted style fan coil units. They are inherently more sophisticated than multi-splits, with multiple compressors, many evaporators, and complex oil and refrigerant management and control systems [30]. The term variable refrigerant flow refers to the ability of the system to control the amount of refrigerant flowing to each of the evaporators, enabling the use of many evaporators of differing capacities and configurations, individualized comfort control, simultaneous heating and cooling in different zones, and heat recovery from one zone to another [31]. This kind of system is usually installed as a centralized air-conditioning system in a big building which requires an intermittent usage and distributed control system. Further information about this type of system can be found in [32-40]. Figure 1-6 shows a typical schematic drawing for a variable refrigerant flow air-conditioning system.

1.2.8 Air Cooled Chiller System

Here, chillers transfer heat from process water (*return chilled water*) to the surroundings. An air cooled chiller consists of a compressor, evaporator, blower fan, chilled water pumps, control panel and condenser, which are all housed together as a package that supplies chilled water to the air handling units located in various floors or locations[41]. The air handling unit then supplies conditioned air to spaces through ducts and diffusers. Warm air in the spaces is drawn back into the air handling unit through return air grills and ducts [42]. Air-cooled chiller systems are generally installed as centralized air conditioning systems in large buildings where the additional heat discharged and optimum efficiency of power consumption are not a significant factor. In return, the system requires less maintenance than water-cooled chiller systems and eliminates the need for a cooling tower and condenser water pump. They generally consume approximately 10% more power than a water-cooled unit as the heat transfer coefficient (h) for water is much better then air. Articles [43-48] describe further about this type of system and the energy conservation.

1.2.9 Water Cooled Chiller System

The chillers in this system absorb heat from process water and transfer it to a separate water source such as a cooling tower, river, pond, etc. Similar to an Air Cooled Chiller System, this system is generally used for large capacity applications. It is more suited to areas with good resources of water and where the client requires optimum power consumption [49]. This system consists of six major parts: chillers, chilled water pumps, condenser water pumps, cooling tower, air handling unit and control panel [41]. The air handling units supply conditioned air to the required spaces through ducts and diffusers. Warm air in the spaces is drawn back into the air handling unit through the return air grills and ducts. Water cooled chiller systems require water treatment to eliminate biological fouling and to reduce corrosion in the system. Figure 1-7 shows a typical schematic drawing for this system. Articles [49-52] give further details about this type of system. Due to the recent desire for sustainable building implementation, the application of this type of system is sometimes extended to several innovations that usually occur in a huge project development with many air-conditioned buildings. In non-residential buildings in Malaysia, water cooled chiller system cans be further divided into three sub-categories.

1.2.1.1 Ordinary Cooling

Non-residential buildings that have this type of system usually have their own chiller plant room with chillers that serve one or more dedicated buildings. The chillers operate during office hours and are supplied from the local electricity power network.

1.2.1.2 Ice Thermal District Cooling

Here, one central plant room has a number of chillers and other equipment to serve various buildings in large project developments. In addition to the normal water cooled chiller equipment, this type of application has other equipment including plate heat exchangers, secondary chilled water pumps, ice storage tanks and longer chilled water pipes. Chillers in the plant room operate at night to make ice that is stored in a tank. During office hours, the ice in the storage tank is melted and pumped to the heat exchangers located inside the buildings. The advantage of this system is that electricity consumed mainly during off peak periods is cheaper, which provides savings in operational cost. It also helps to contribute significant reduction of CO2 emission to the environment. The reason is that electricity generated at night generally has a lower heat rate (i.e. lower fuel use per power output), compared to day electric generated. Further explanations regarding this type of thermal energy storage can be found in [53-58].

1.2.1.3 Gas District Cooling

As with ice thermal district cooling, this type of application has one central plant room and it is usually applied to large developments. System operation is similar to the ordinary one; the only difference is that the type of chiller used is now an absorption chiller. These chillers are grouped together in a big plant room with other necessary equipment like chilled water pumps, cooling towers and condenser water pumps. The chilled water is supplied to plate heat exchangers located in various buildings, through an underground chilled water pipe. There are also cases that the chilled water is directly supplied to the Air Handling Units without the use of a heat exchanger, but for such system the maintenance work is expected to be more tricky and difficult. The advantage of this type of application is that natural gas is used to replace electricity to heat the absorptions chillers. This certainly minimises building operational cost, since in most cases the price of natural gas is way below that of electricity.

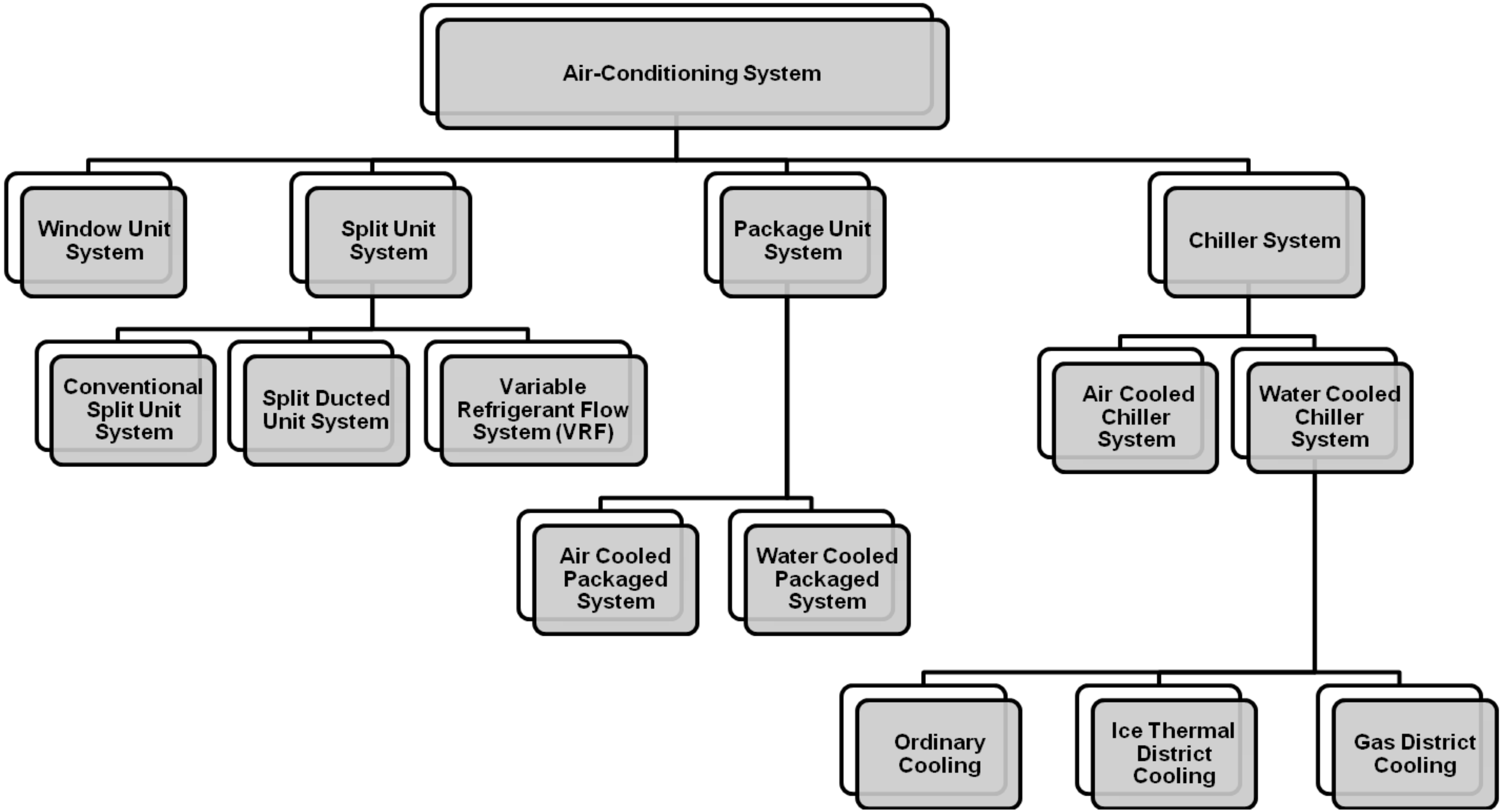


Figure 1-2 shows the various categories of air-conditioning system normally installed in government buildings

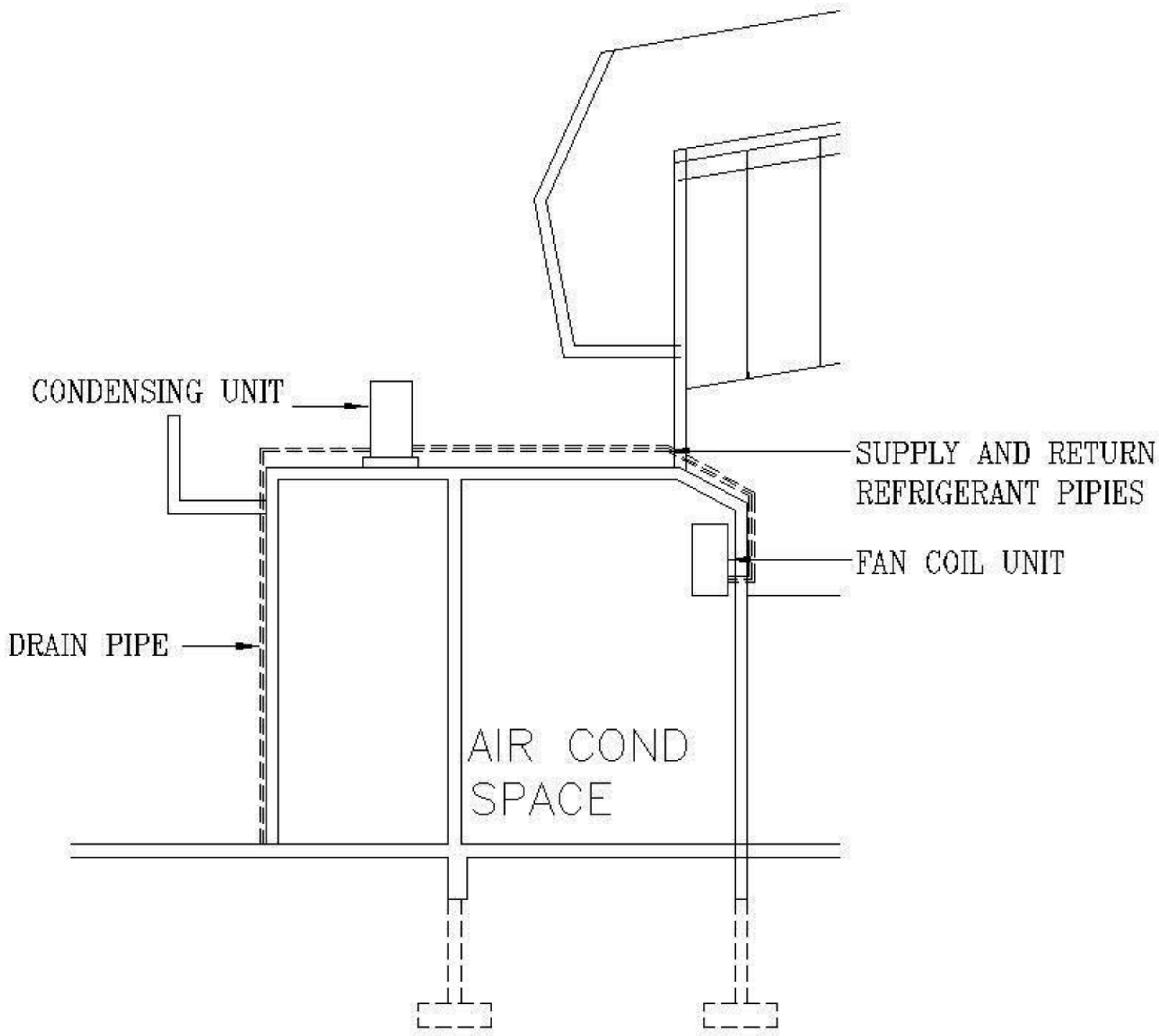


Figure 1-3: A typical schematic drawing for conventional split unit air-conditioning system

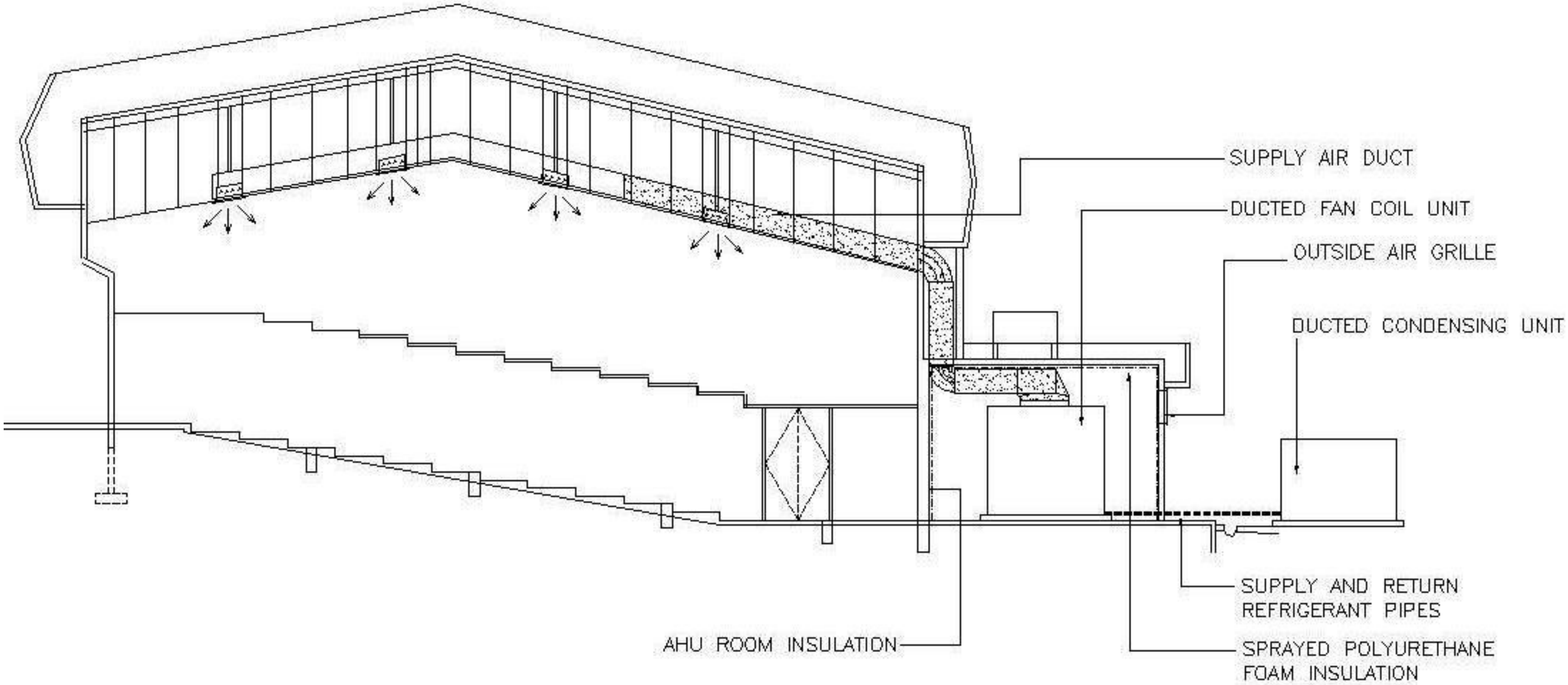


Figure 1-4: A typical schematic drawing for split ducted air-conditioning system

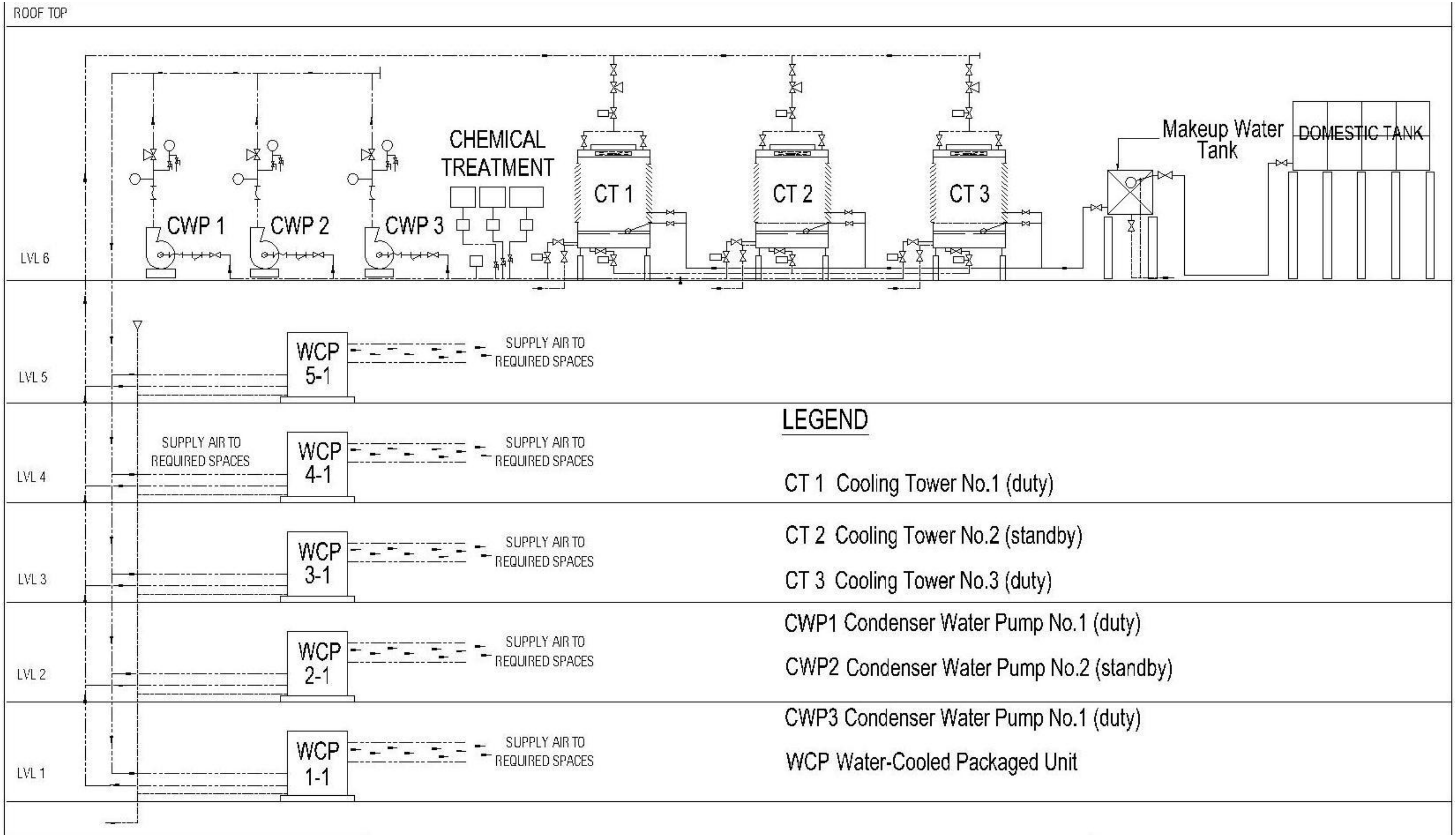


Figure 1-5: A typical schematic drawing of water cooled packaged system

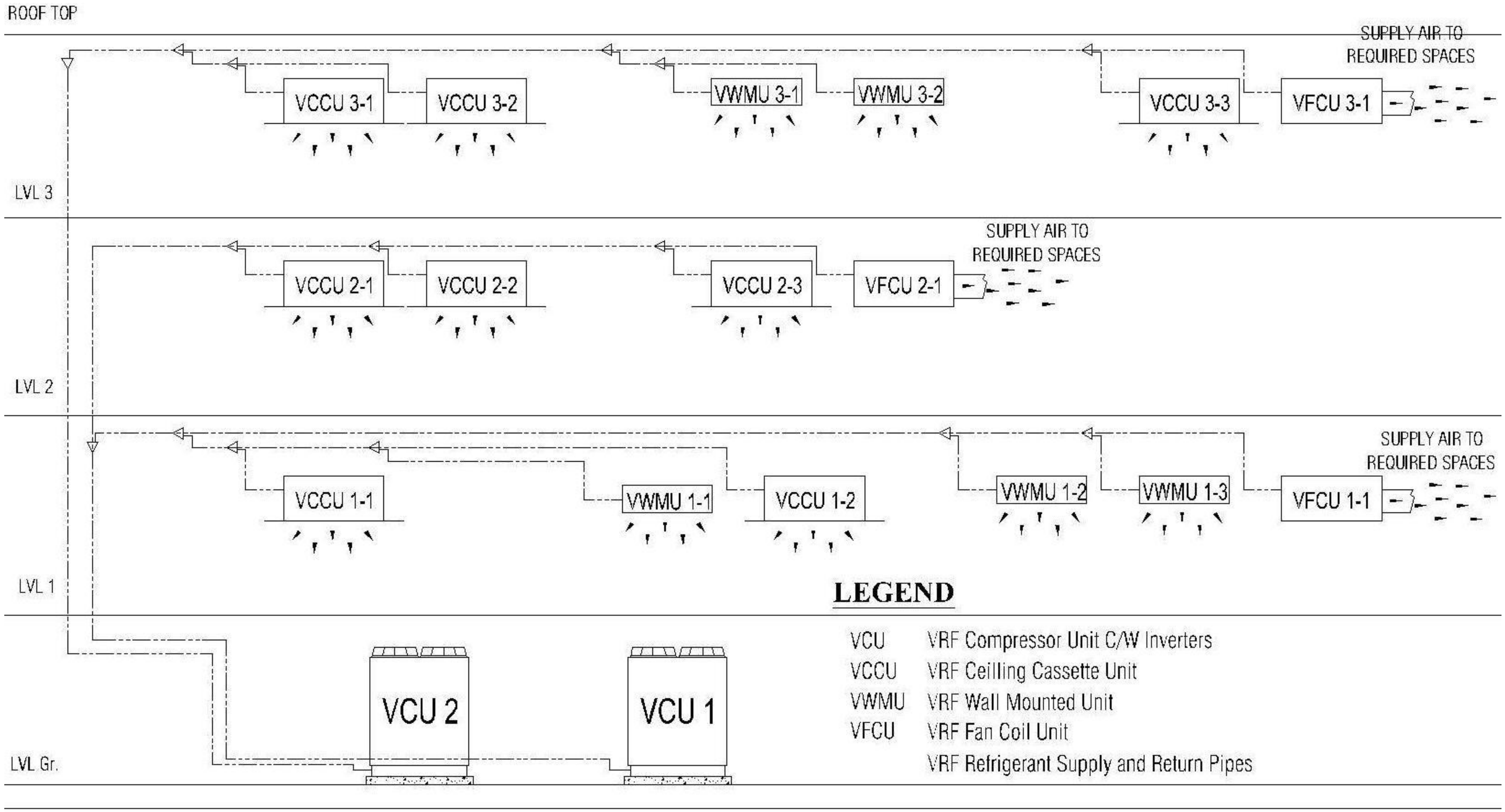


Figure 1-6: A typical schematic drawing for variable refrigerant flow air-conditioning system

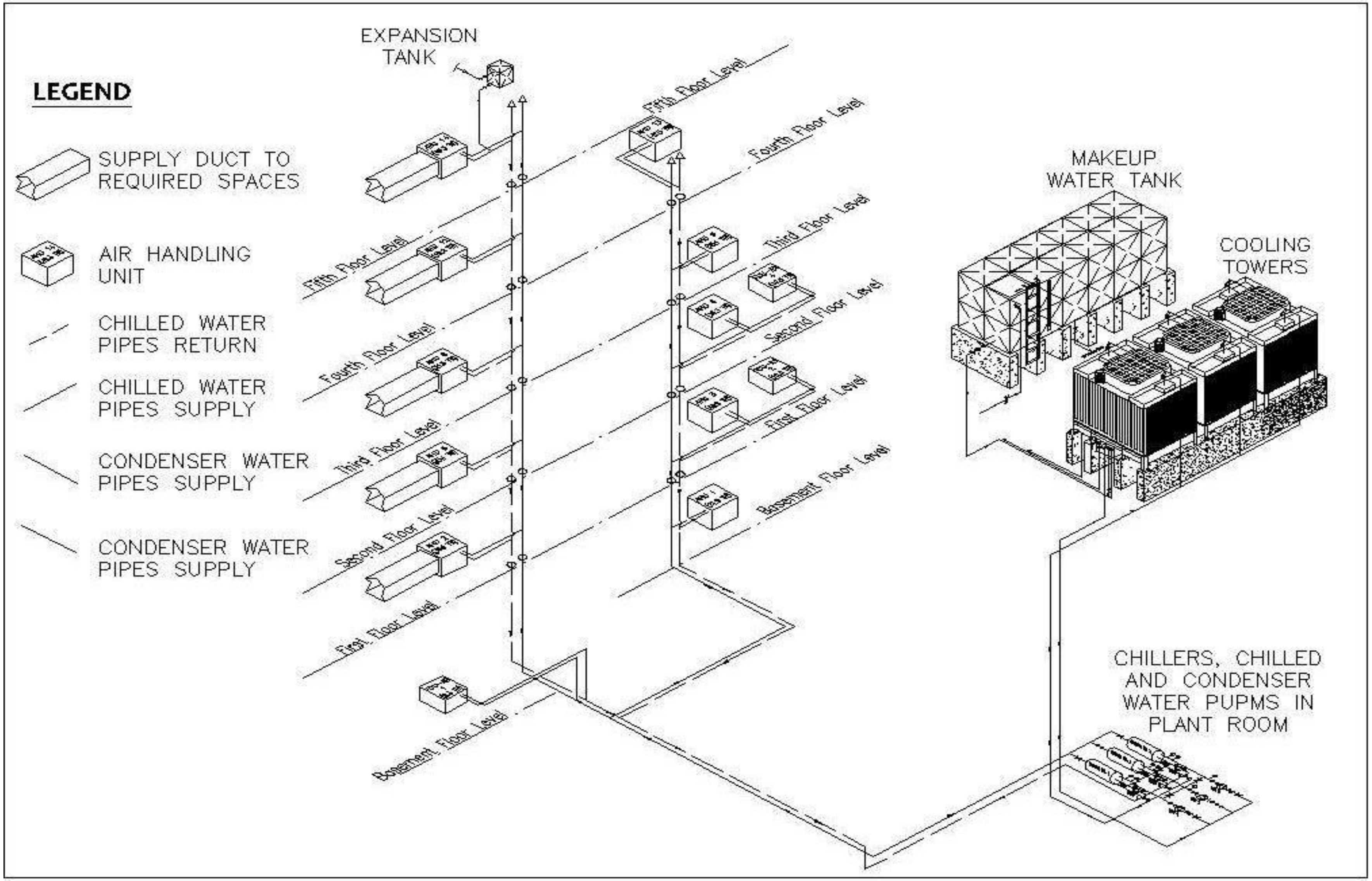


Figure 1-7: A typical schematic drawing for water cooled chiller air-conditioning system

1.3 Air-Conditioning System Comparison

Clearly any energy savings must be relative to what can be saved potentially. The Coefficient of Performance *(COP)* is defined as the ratio between System Refrigeration Load *(kW(r))* and Electrical Power Input to the system *(kW(e))* [59]. Greater savings can be obtained from a plant with a low COP, although such plants are inefficient in the first place. Only four types of air-conditioning system are compared to see the most significant potential for further research and improvement. These four have more than 250 tons of refrigerant *(RT)* cooling load capacity that might be considered to have significant potential towards improvements in energy consumption.

These four types of air-conditioning system are as follows:

i. Water Cooled Packaged Air-Conditioning System *(WCP)*

ii. Air Cooled Chiller Air-Conditioning System *(ACCH)*

iii. Water Cooled Chiller Air-Conditioning System *(WCCH)*

iv. Multi-Split Variable Refrigerant Flow Air-Conditioning System *(VRF)*

An internal study regarding the overall air-conditioning system COP for most of the above types has recently been performed by Ismail [60] for government buildings in Malaysia. The results were as follows:

Type of Air Conditioning System Installed	**WCP**	**ACCH**	**WCCH**
Overall System COP	3.7	2.7	5.4

Table 1-3 shows the overall system COP for various types of Air Conditioning System

The overall system COP for each type is obtained by averaging system COPs for similar types of air-conditioning system installed in several government buildings in Malaysia. The air-conditioning system COP for each building is calculated on the basis of field measurements like air flow rate, on-coil temperature, off-coil temperature and actual power consumed. Unfortunately, the study did not cover the overall COP for the VRF type of air-conditioning system.

However, the COP for this type of system can be found in manufacturers' technical data and sheets. A typical overall system COP for a full cooling mode system in Malaysia can be obtained from [61]. The mean overall system COP of VRF type is approximately 3.45 when running on full load and it is also observed from the technical data and manual that the COP does not drop much when working on part load operation. For some part load capacity, the system COP is even higher than full load COP. WCCH is seen to have the highest Overall System COP. Even with the highest COP a number of studies indicate that WCCH types consume more energy compared with VRF types of air-conditioning system. One of them done by Amarnath et al. [62] for a 200 RT cooling system in a generic commercial building, showed that a VRF type could save 30-40% of the energy used by a chiller based system. Another case study by Roth et al. [63] on the 17^{th} floor of a 9,290 m^2 office building in Brazil demonstrate a full year, hourly simulation comparison of 538 RT VRF type system to both screw and centrifugal chillers showed an energy saving potential of 30% for the VRF type of system. Rationally, the degree of thermal efficiency should relate to energy saving potential in such mechanical systems. Nevertheless, in this study it is shown to have an opposite result when VRF type and WCCH are compared. This result suspected to happen because of the two main factors described below.

1.3.1 Individual Local Control

VRF systems allow indoor units to be operated at different cooling loads or temperature set-points. Simultaneously some indoor units might have 24^oC and some might have 26^oC as set-point temperatures where others might be switched off completely. WCCH usually only allows one set-point temperature for every spaces.

1.3.2 Part Load Efficiency

In normal air-conditioning system application, full load operation of the system is probably 10% of the total operating hours while more than 90% of it will be in part load operation [64]. In VRF system, thermal efficiency does not drop much in part load operation and for some part load cooling capacity, the thermal efficiency is found to be even higher than full in load operation. Thermal efficiency for WCCH in part load operation on the other hand is very poor and consumes more energy especially when operated in a building which requires a high fluctuated cooling capacity.

As a result, variable refrigerant flow systems *(VRF)* and water cooled chiller systems *(WCCH)* have better potentials when seeking to improve the energy consumption actively compared to other types of air-conditioning system. In the next chapter, simulations of buildings installed with these types of air-conditioning system are discussed. The simulations aim to investigate potential energy savings by applying the adaptive approach to thermal comfort.

CHAPTER 2
ADAPTIVE BUILDING AIR-CONDITIONING SYSTEM ENERGY SIMULATION

2.1 Chapter Introduction

This chapter seeks to estimate potential energy savings that might be obtained if indoor temperatures are made to fluctuate in a prescribed manner. Ramp and cyclic fluctuations are considered. The building energy analysis and simulation tools 'Carrier E20 II Hourly Analysis Program (HAP)' is first introduced. Three case studies of real buildings using HAP are presented and discussed.

2.2 Building Cooling Load

The building cooling load can be defined as the amount of heat energy that has to be removed from a building to maintain its desired indoor temperature. The heat energy stored in a building space is composed of sensible heat energy and latent heat energy. Sensible heat energy refers to heat energy related with molecular movement [65]. As an example, the temperature measured with a thermometer is a measure of sensible heat energy. Latent heat energy on the other hand is the energy required to change the state of a substance from solid to liquid or liquid to vapour. There is no change in temperature when these changes occur and hence the change in state cannot be measured by a thermometer [65].

A good way to understand and recognise the differences of these two energies is by looking at an example of a process to boil a jug of water. When a jug of water at 18^oC is heated continuously until it reaches the boiling temperature, the water temperature will be raised steadily from 18^oC to 100^oC. The amount of heat energy applied to the jug of water in this scenario is referred as sensible heat energy. If the same jug of water continues to be heated for a few more minutes, even after it has reached the boiling temperature, the water temperature will remain constant at 100^oC and some of the water will vaporise in the air. The heat transmitted to the water during this period is referred as latent heat energy. The graph below illustrates the example of this heated jug of water scenario.

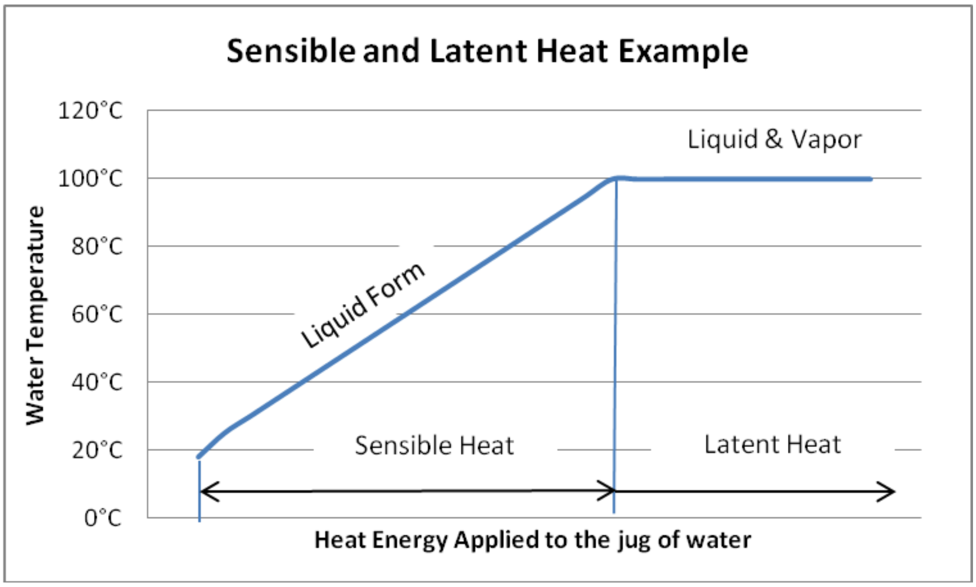
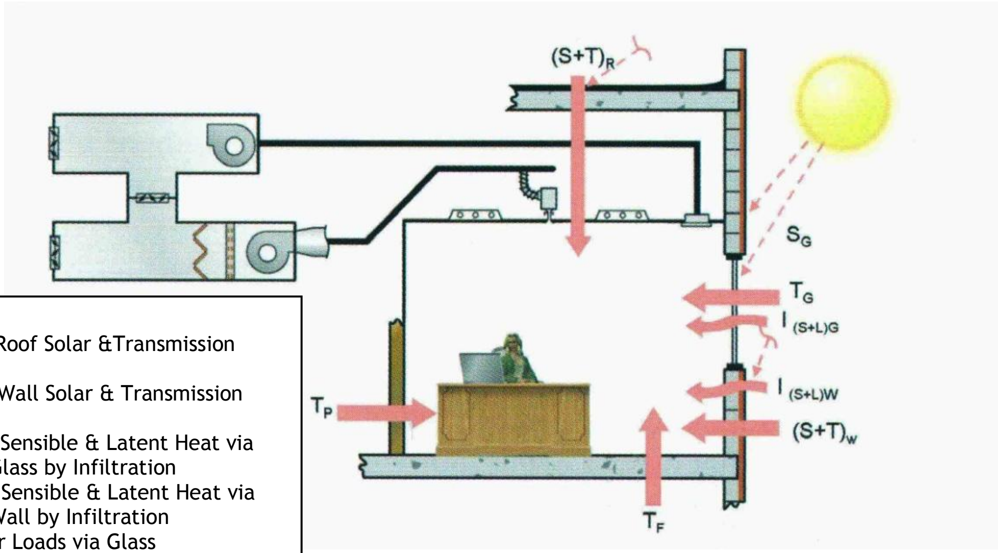


Figure 2-1 : An example of sensible and latent heat when continuous heat is transferred to a jug of water

Building cooling load itself is a summation of heat transfer elements into or out of the building spaces. These heat transfer elements are called load components which can be assembled into one of three basic groups, internal space loads, external space loads and system loads [66].

2.2.1 External Space Loads

This group of loads can be further broken into three: weather related, infiltration related, and adjacent space related. Weather related loads arise from direct solar and transmission loads through building glass, walls and roof. The direct solar load component represents the amount of radiant energy transmitted to the space whereas the transmission loads component represent the amount of energy transmitted by conduction to the space due to temperature differences between the inside and the outside surfaces of the space. Infiltration related components i.e. infiltration and exfiltration loads, occur through any opening in the building envelope, through doors, windows and pipe sleeves or gaps or cracks. High outside wind speeds can not only affect infiltration, but also transmission as air flow over the exterior envelope of the building affects heat trasnsfer. Adjacent space related loads relate to heat transfer through any interior partition. This includes inside wall partitions and ceilings and horizontal assemblies between building floors. This type of load component is important when a conditioned space is adjacent to an unconditioned or partially conditioned space.



Legend:
(S+T)R = Roof Solar &Transmission Loads
(S+T)w = Wall Solar & Transmission Loads
I(S+L)G = Sensible & Latent Heat via Glass by Infiltration
I(S+L)w = Sensible & Latent Heat via Wall by Infiltration
SG = Solar Loads via Glass
TG = Transmission Load via Glass
TF = Transmission Load via Floor
TP = Transmission Load via partition

Figure 2-2: External Space Load Components [66]

2.2.2 *Internal Space Loads*

In non-residential buildings, internal space loads usually contribute the largest amount in building cooling load. The following paragraphs describe eight types of internal space load component.

2.2.1.1 People

Heat is generated within the human body by oxidation of food in the visceral organs and tissues are a constant source of heat and it is often metabolic rate. This heat is transferred to human skin and other surfaces of human body and dissipated to the space by conduction, convection, radiation and evaporation.

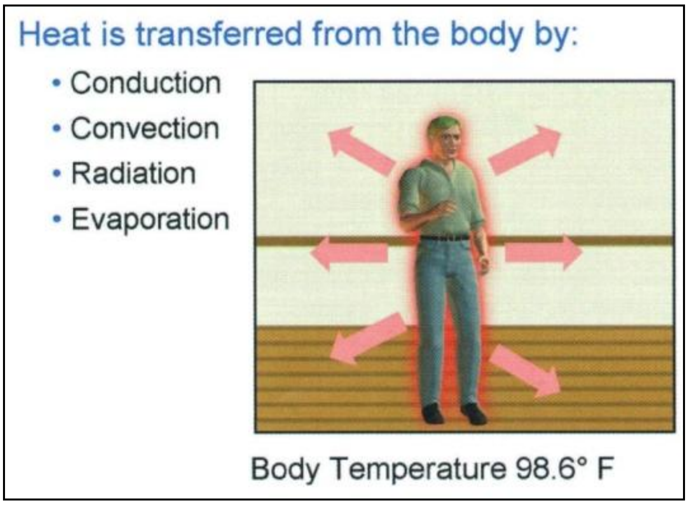


Figure 2-3: Heat transfer from people [66]

2.2.1.2 Lighting

Lights bulbs or any other lighting appliances convert electrical power into light. The heat generated from this conversion is sensible heat and dissipated via radiation to the surrounding surfaces, by conduction to adjacent materials as well as by convection to the surrounding air.

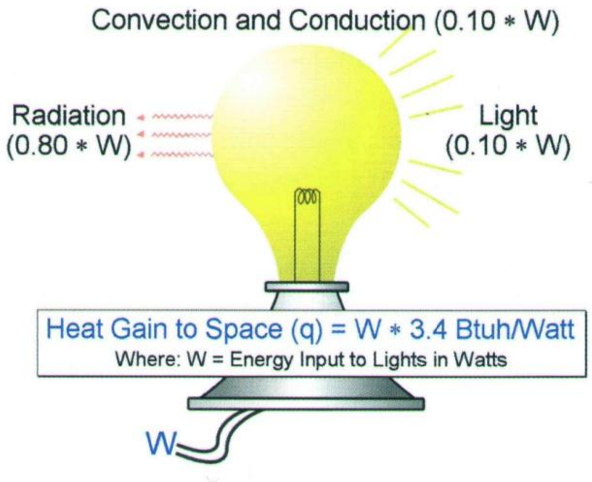


Figure 2-4: Heat dissipation by incandescent light bulb [66]

2.2.1.3 Electrical Equipment (Plug Load)

Heat is generated from devices such as printers, computers, scanners, copy machines, and any other appliances that use electrical energy. The amount of heat dissipated from electrical equipment can usually be found in manufacturer documentation. The information can be found in the technical catalogue or sometime a formal request to the manufacturer is required. Note that the electrical power consumption written the on equipment's nameplate should not be used as heat dissipation unless it is clearly specified as such.

Figure 2-5: An example of electrical equipment nameplate

2.2.1.4 Electrical Motor

Sensible heat is generated from electrical motors. The heat transmitted depends on numerous factors including motor horsepower, motor efficiency, motor operating hours within a time period and how heavily the motor is loaded. It also depends on the location of the motor and its driven equipment, for instance whether it is located inside or outside the condition space or airstream. Motor heat load data can be found in engineering handbooks such as Carrier Air-Conditioning Handbook and ASHRAE 90.1 Energy Standard. Table 2-1 shows an example of data provided to calculate the motor heat load component.

2.2.1.5 Piping, Tanks and Evaporation

In most commercial buildings, this type of load component is often assumed to be negligible due to the level of insulation provided on both cold and hot piping as well as tanks. However, in some buildings where equipment like furnaces and dryer are installed, pipe and tanks are usually not insulated. Exposed pipes and tanks contribute sensible heat to the space by convection and radiation from the outside surface. Dryer could also contribute latent heat from the drying process.

Motor Nameplate or Rated Horsepower	Standard Efficiency	EPACT Min. Efficiency	Premium Efficiency	Heat Gain From Standard Eff. Motor in Location Btu/hr		
				A	B	C
1/20	35.0	-	-	364	127	236
1/12	35.0	-	-	606	212	394
1/8	35.0	-	-	909	318	591
1/6	35.0	-	-	1,212	424	788
1/4	54.0	-	-	1,178	636	542
1/3	56.0	-	-	1,515	848	667
1/2	60.0	-	-	2,121	1,273	848
3/4	72.0	-	-	2,651	1,909	742
1	75.0	82.5	-	3,393	2,545	848
1 1/2	77.0	84.0	-	4,958	3,818	1,140
2	79.0	84.0	-	6,443	5,090	1,353
3	81.0	86.5	89.5	9,426	7,635	1,791
5	82.0	87.5	89.5	15,518	12,725	2,793
7 1/2	84.0	88.5	91.7	22,723	19,088	3,636
10	85.0	89.5	91.7	29,941	25,450	4,491
15	86.0	91.0	93.0	44,390	38,175	6,215
20	87.0	91.0	93.0	58,506	50,900	7,606
25	88.0	91.7	93.6	72,301	63,625	8,676
30	89.0	92.4	93.6	85,787	76,350	9,437
40	89.0	93.0	94.5	114,382	101,800	12,582
50	89.0	93.0	94.5	142,978	127,250	15,728
60	89.0	93.6	95.0	171,573	152,700	18,873
75	90.0	94.1	95.4	212,083	190,875	21,208
100	90.0	94.1	95.4	282,778	254,500	28,278
125	90.0	94.5	95.4	353,472	318,125	35,347
150	91.0	95.0	95.8	419,505	381,750	37,755
200	91.0	95.0	96.2	559,341	509,000	50,341
250	91.0	95.4	96.2	699,176	636,250	62,926

Table 2-1: Electric motor efficiency data from engineering handbook

2.2.1.6 Steam Leaks, Absorption and Evaporation

Steam leaks into the space produce both sensible and latent heat. On the other hand, if large quantities of moisture absorbent material are brought into the space (e.g. large quantities of paper in a photocopier centre) sensible heat is released due to absorption process in the papers. Moisture evaporation can take place without external heating or cooling; the process utilizes the sensible heat available and produces latent heat to the space. Although the total room heat load remains the same, the amount of latent heat is proportionately increased at the loss of sensible heat.

2.2.3 System Loads

The last group of building load components derives from the air-conditioning system operational characteristic. When an air-conditioning system is switched on, both sensible and latent heats are inevitably generated. Some of the components have both sensible as well as latent heat and some have only one of them. Table 2-2 below shows different system load components with type of heat energy.

Load Components	**Type of**	**Description**
Ventilation Outdoor Air ***(OA)***	Sensible & Latent	Introduced to maintain indoor air quality in the space.
Duct Heat Gain ***(SDHG & RDHG)***	Sensible	Heat gains or losses in supply and return air duct.
Duct Leakage Loss ***(SDLL & RDLG)***	Sensible	Increases the flow requirement of supply fan, thus increases fan heat gain
Fan Horse power Heat Gain ***(SAFH)***	Sensible	Add heat to airstream due to work done on the air to raise its pressure.
Motor Heat Gain	Sensible	Heat added due to electrical losses of the fan motor located in the airstream.
Bypassed Outdoor Air (***CBP***)	Sensible & Latent	Heat gains due to some air entering the coil passes through the coil untreated
Ceiling Plenums (***L*** & $(S+T)_R$ & $(S+T)_W$)	Sensible	Heat absorbed as the return air passes through or over the lights fixture and heat from roof load components
Under-floor Plenum	Sensible	When an access flooring system is used as a supply plenum, heat gains through the plenum boundaries.

Table 2-2: Load components grouped under System Loads and type of energy generated

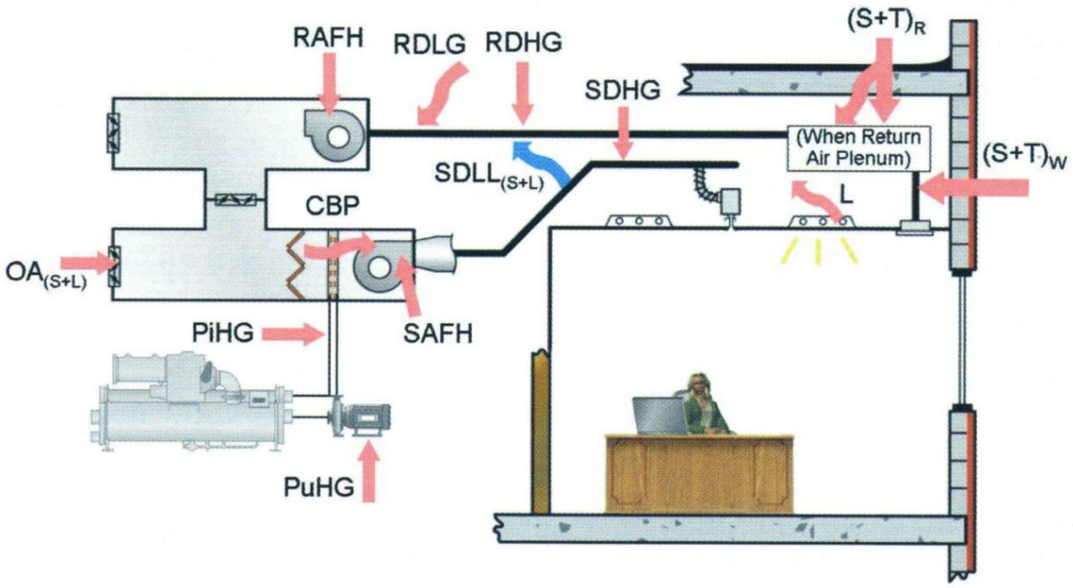


Figure 2-6: System load components [66]

2.3 *Heating, Ventilation and Air-Conditioning (HVAC) Energy Analysis Computer Program*

An accurate load estimation is required for the optimal installation and operation of building air conditioning system. This will provide correct cooling and heating requirements, well sized equipment and yield efficient air, water and electrical distribution over the system. At present there are six estimation methods that are commonly used by engineers to estimate building load:

a) Instantaneous Method

b) Storage Load Factor/ Equivalent Temperature Difference Method

c) Cooling Load Temperature Differential/ Cooling Load Factor Method

d) Radiant Time Series

e) Transfer Function

f) Heat Balance

Each method has different accuracy and complexity, so engineers use them selectively, depending on the situation. The instantaneous method is the simplest and least accurate, while the heat balance method is the most complex and accurate of all the methods. Detailed explanations can be find in many heat transfer text books or related engineering handbooks such as [66]. Figure 2-7 below plots relative accuracy against complexity for the common methods.

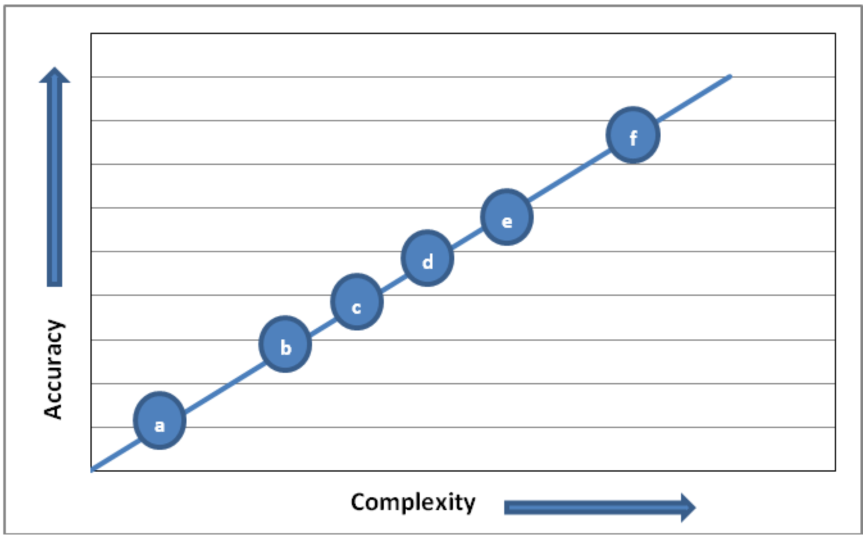


Figure 2-7: Accuracy versus complexity of command load estimation methods [66]

Some of these methods are too complicated to perform by hand. Often at the early design stage where changes in cooling and heating requirements are inevitable, less complicated methods provide sufficient accuracy. However, when it comes to a detailed energy analysis of a building HVAC system, dynamic models are required to ensure the results obtained are usable. A transfer function method is often used for transient load estimation in energy analysis of a building HVAC system. This method is a simplification of a full dynamic heat balance method, and uses mathematical Laplace transformations to shorten the heat balance solution process. The method requires computer software which executes faster than the equivalent heat balance software without sacrificing too much loss of accuracy.

Individual load components can be calculated and then summed to get total loads. For example in Figure 2-8 the lights are turned on for 5 hours. The heat from the lights is split between convective *(instantaneous)* and radiant *(heat stored in the walls, office chair and desk, etc.)* transfer. Just like solar load coming through a window, the radiant portion is stored and released over time. Hence, as the lights remain switched on, the resultant load is a mixture of convective from instantaneous light heat and radiant heat released from storage. Note that even after the lights are switched off, there is still residual stored heat need to be removed. In the transfer function method, loads are calculated over a 24-hour period to simulate heat storage dynamics. This accommodates the possibility that loads which occur during unoccupied periods might affect loads during the subsequent occupied period [66].

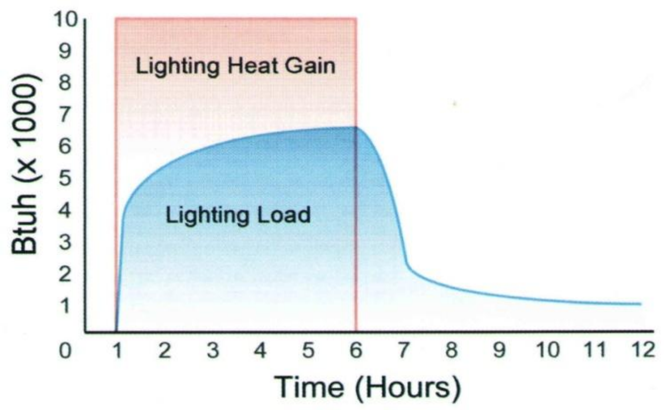


Figure 2-8: Lighting load transfer function [66]

In this research project, the Building Energy Analysis Computer Program 'Carrier E20 II Hourly Analysis Program' (*HAP*) is used to estimate potential energy savings. This transient function based computer program complies with ASHRAE standard 90.1 and consists of a system design tool and energy simulation tool in one package. Both the system design tool and the energy simulation tool are required to estimate potential energy savings. The first stage is to specify and size the HVAC System for the conditioned space to meet expected building loads at specified set point temperatures. Each load component is estimated and summed to obtain conditioned space load. Load profiles are computed for one design cooling day in each calendar month by applying an ASHRAE-endorsed transfer function load calculation method to design weather data and design day operating schedules. Design weather data includes design temperature data, coincident humidity data and clear sky solar radiation data. Design day operating schedules represent the variation of internal heat gains during the design day, which might relate to lighting, HVAC equipment, and occupancy.

Air System Simulation Results

Month	Central Cooling Coil Load (kBTU)	Supply Fan (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	37032	256	1901	1061
February	37104	275	1793	993
March	43755	331	2048	1129
April	38521	268	1892	1050
May	42786	313	1972	1095
June	42373	312	1963	1084
July	38087	264	1901	1061
August	41087	293	2048	1129
September	37073	248	1963	1084
October	37602	256	1901	1061
November	36777	245	1963	1084
December	37829	263	1977	1095
Total	**470025**	**3324**	**23319**	**12923**

Table 2-3: Example of monthly energy simulation result

Hourly energy consumption over 1 year is now computed in the second stage. The simulation is driven by specified weather data and operating schedules for the different days of the week. The operating schedule may be defined manually to match actual building space operation. Provided by AHSRAE, the HAP weather data consists of updated average weather data from most parts of the world. The simulation produces three types of report: monthly, daily and hourly. Table 2-3, Table 2-4, and Table 2-5 show examples of monthly, daily and hourly simulation results respectively. Indoor set point temperature changes can be accommodated so that potential energy savings can be estimated.

Daily Air System Simulation Results for January

Day	Central Cooling Coil Load (kBTU)	Supply Fan (kWh)	Lighting (kWh)	Electric Equipment (kWh)
1	384	2	14	11
2	406	2	9	11
3	1376	9	85	45
4	1346	8	85	45
5	1458	9	85	45
6	1546	10	85	45
7	1617	12	85	45
8	653	5	14	11
9	711	6	9	11
10	1660	12	85	45
11	1441	9	85	45
12	1503	10	85	45
13	1242	7	85	45
14	1280	8	85	45
15	603	5	14	11
16	602	5	9	11
17	1575	11	85	45
18	1502	10	85	45
19	1407	9	85	45
20	1435	9	85	45
21	1349	8	85	45
22	526	4	14	11
23	501	4	9	11
24	1589	12	85	45
25	1704	13	85	45
26	1565	11	85	45
27	1547	11	85	45
28	1507	11	85	45
29	623	5	14	11
30	668	6	9	11
31	1708	13	85	45
Total	37032	256	1901	1061

Table 2-4: Example of daily energy simulation result

Hourly Air System Simulation Results for Monday, January 10

Hour	Central Cooling Coil Load (MBH)	Supply Fan (kW)	Lighting (kW)	Electric Equipment (kW)
0000	0.0	0.0	0.2	0.5
0100	0.0	0.0	0.2	0.5
0200	0.0	0.0	0.2	0.5
0300	0.0	0.0	0.2	0.5
0400	0.0	0.0	0.2	0.5
0500	0.0	0.0	0.2	0.5
0600	0.0	0.0	0.2	0.5
0700	100.7	0.7	4.5	1.0
0800	117.8	0.8	9.4	1.9
0900	139.6	1.1	10.1	3.7
1000	147.4	1.2	7.3	4.7
1100	149.5	1.2	7.3	3.7
1200	156.9	1.3	6.6	4.7
1300	152.3	1.2	7.3	1.9
1400	147.2	1.2	7.3	3.7
1500	134.6	1.0	7.3	4.7
1600	127.9	0.9	7.3	4.7
1700	115.3	0.7	5.2	3.7
1800	90.5	0.5	1.7	0.9
1900	80.8	0.5	1.0	0.9
2000	0.0	0.0	0.7	0.5
2100	0.0	0.0	0.7	0.5
2200	0.0	0.0	0.3	0.5
2300	0.0	0.0	0.2	0.5
Total	**1660.3**	**12.1**	**85.0**	**45.2**

Table 2-5: Example of hourly energy simulation result

2.4 Ramp and Cyclic Mode of Indoor Set-Point Temperature Variations

The term 'indoor set point temperature' refers to that temperature set in an air-conditioning control system by a user, occupant or technical responsible person, as the indoor desired temperature in one zone of conditioned space. The design intention is that the air-conditioning system should meet this preset desired temperature, then maintain it. At present, a good air-conditioning system is expected to maintain the indoor temperature within an allowable tolerance of +/-1.5^{0}C temperature difference from the set-point. It is common practice to have one fixed indoor set-point temperature for each conditioned zone in most air-conditioned buildings. For small zones where the conditioned space is occupied by one person, the set point temperature can easily be set to meet individual thermal comfort.

However, when the conditioned space is large and houses many occupants, individual thermal comfort satisfaction is more difficult, primarily because thermal comfort differs from individual to individual. Individual discomfort can lead to energy wastage when the occupant seeks to adapt to prevailing conditions. J.F Nicol and M.A Humphrey refer to ways in which this might happen in their paper [4] as 'adaptive opportunities'. These include the ability to open a window, draw a blind, use a fan, changing clothing style, body posture and other factors which influence the interaction between occupant and conditioned space.

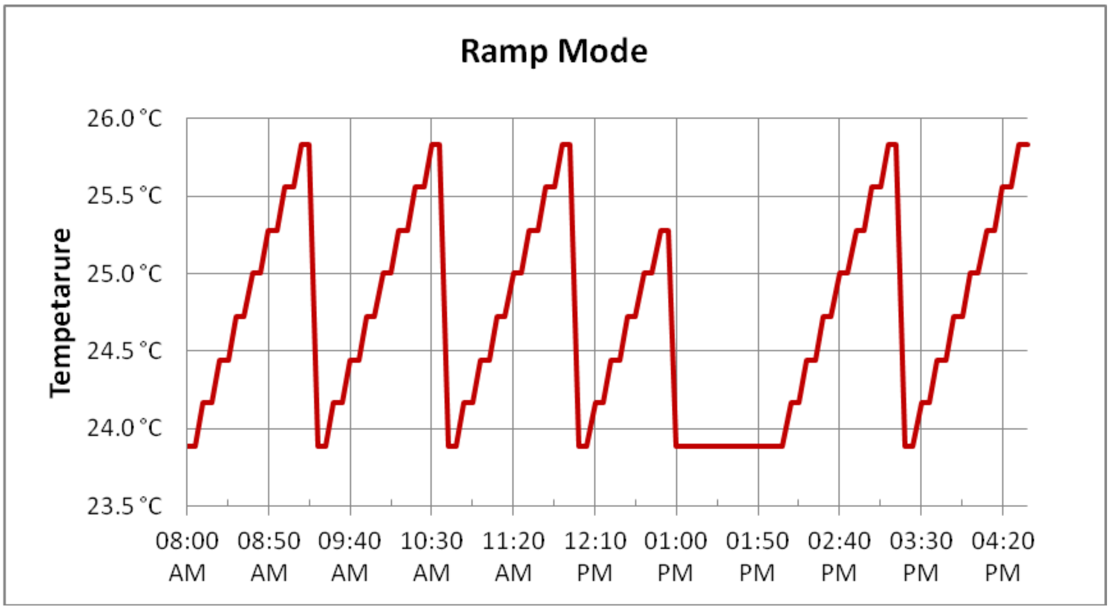


Figure 2-9: Ramp mode of indoor set-point temperature during normal office hour

With appropriate application, adaptive opportunities might be exploited to improve the building air-conditioning system energy consumption. In this MSc-By-Research project, this natural tendency of people to adapt to changing conditions in their environment is exploited as an instrument to improve energy consumption while maintaining occupant comfort. It is argued that energy savings might be obtained by manipulating temperature set-points, provided that occupants are prepared to adapt to these manipulations. To assess potential savings, simulations were performed with various set-point change scenarios. Two dynamic modes of indoor set-point temperature, i.e. ramp and cyclic modes are introduced to replace a fixed set-point temperature. Figure 2-9 and Figure 2-10 show an example of ramp and cyclic adjustments to indoor set-point temperature over time during normal office hours. The maximum and the minimum value of both adjustment modes are set to be within the acceptable indoor operative temperature range (i.e. 72.5 ^{0}F to 78.5 ^{0}F), and rate of change are calculated using the interpolation method suggested in ASHRAE Standard 55-2004 [3]. Figure 2-11 and Figure 2-12 show the acceptable range of operative temperature and humidity. The interpolation is calculated based on the assumption of average office attire (0.7 clo), 55% relative humidity and air velocity not exceeding 0.2m/s.

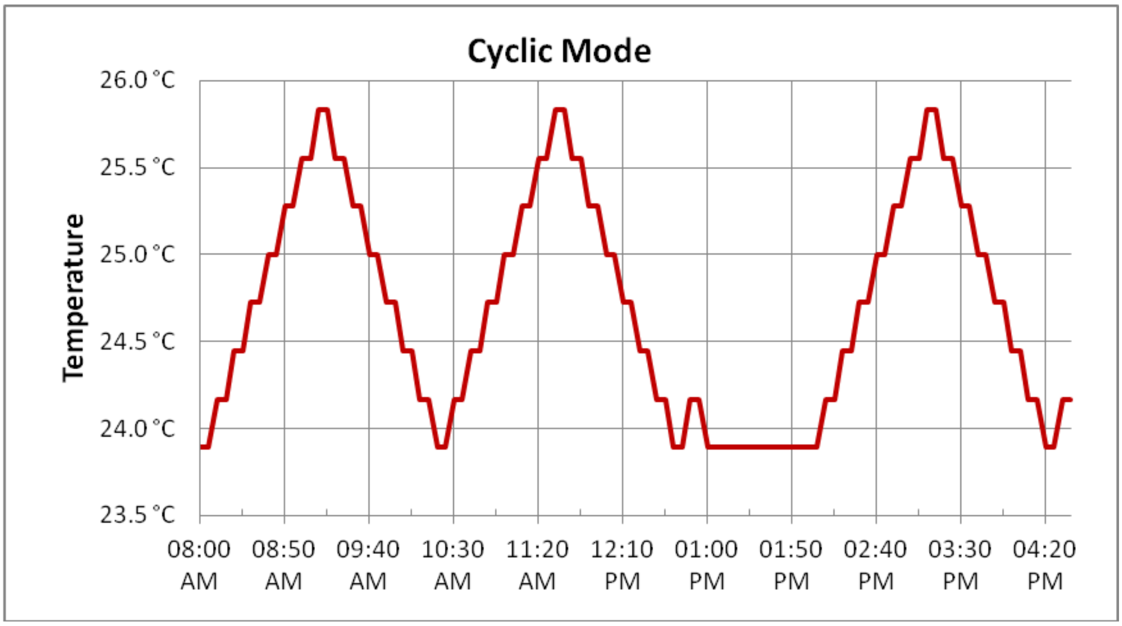


Figure 2-10: Cyclic mode of indoor set-point temperature during normal office hour

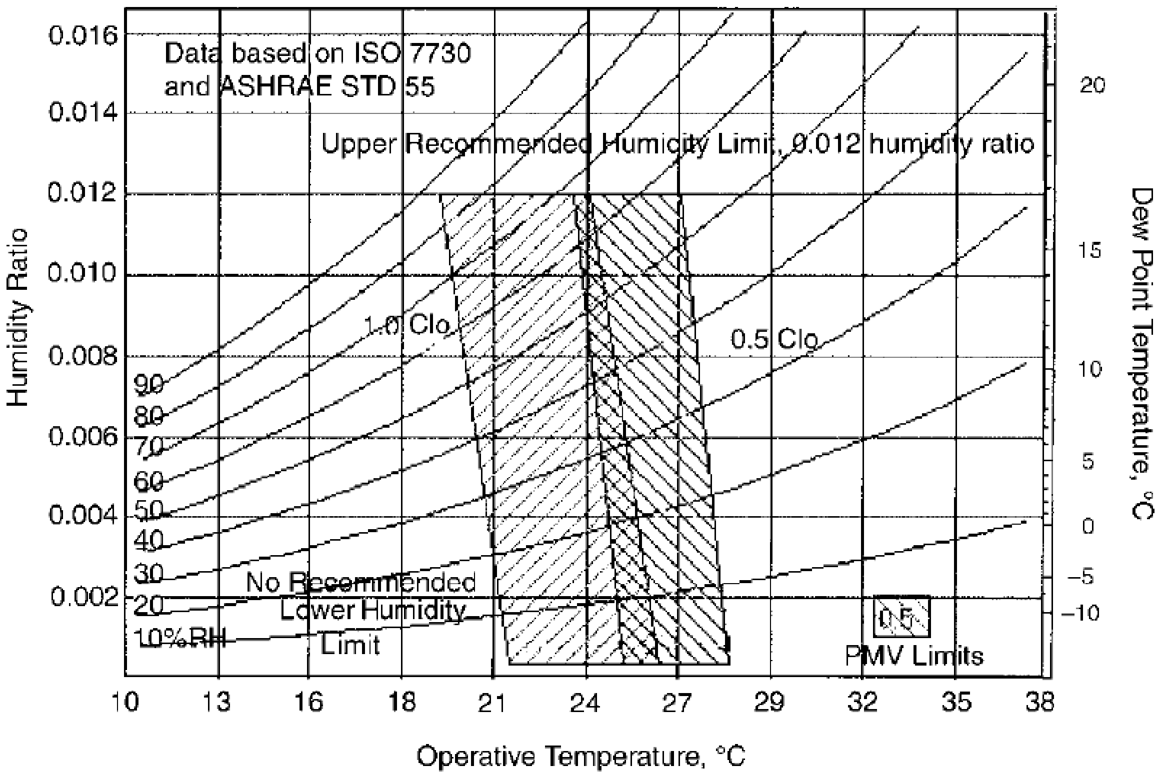


Figure 2-11: Acceptable range of operative temperature in degree Celsius and humidity [3]

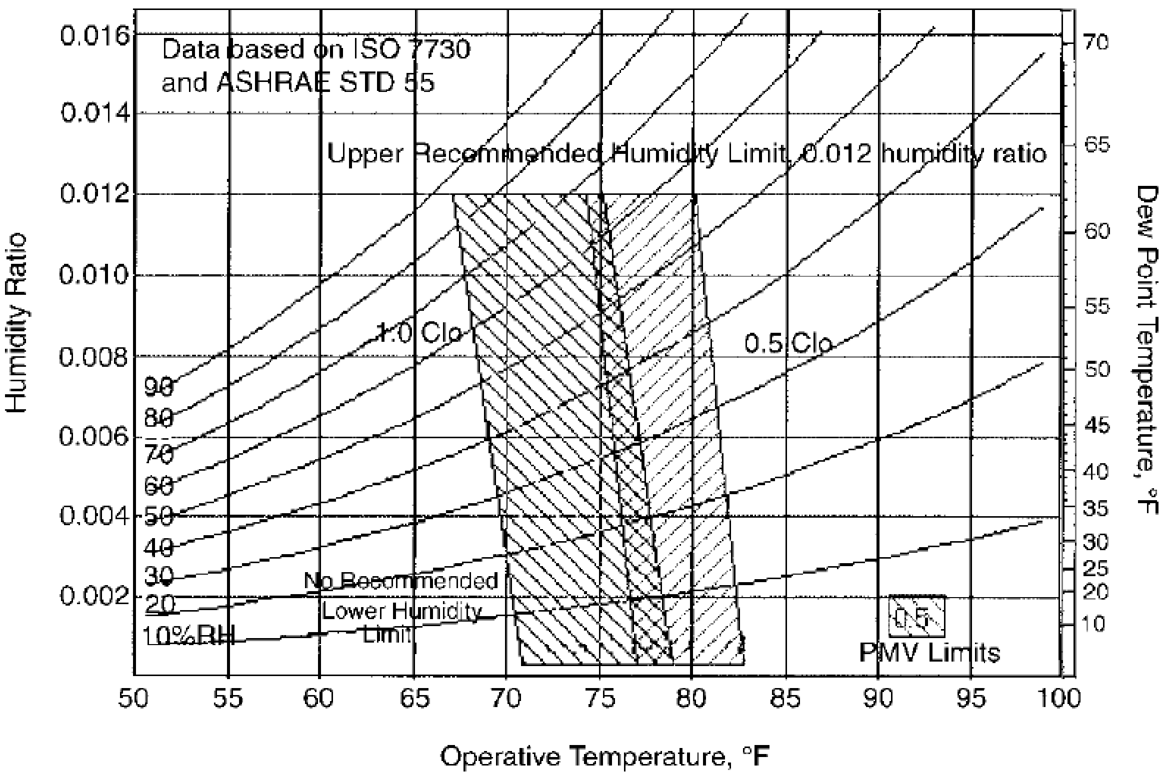


Figure 2-12: Acceptable range of operative temperature in degree Fahrenheit and humidity [3]

The Carrier E20II HAP HVAC energy analysis computer program was used to investigate the energy savings that might arise from these modes. Three buildings located in Peninsular Malaysia were selected for this exercise:

i. Kuala Lumpur Courts Complex, Duta Road (*Jalan Duta*), Kuala Lumpur Malaysia.

ii. Menara Seri Wilayah (formerly known as Menara PJH), Precinct 2, Wilayah Persekutuan Putrajaya, Malaysia.

iii. Legal Affairs Division Office (BHEUU), Presint 3, Wilayah Persekutuan Putrajaya, Malaysia

2.5 Case Study 1: Kuala Lumpur Court Complex

At present this building has a combination of variable refrigerant flow (VRF) and water cooled chiller air-conditioning systems. However in this exercise, only conditioned spaces installed with VRF Systems were studied. The Kuala Lumpur Courts Complex has a total of approximately 5,316 Ton VRF cooling capacity. Building construction began in March 2004 at a final cost of RM290 million. The building was opened for use in April 2007, and was fully operational on 3rd May 2007. The building has 9 floors at the centre and 5 floors at both left and right wings. Level 5 from the left wing of the building was selected for the energy simulation analysis.

Figure 2-13 shows the floor plan of level 5 of the left wing.

A building is divided into units referred to as "spaces" in the computer program. A space consists of a number of "elements" such as walls, roofs, windows, and internal heat gains which influence heat transfer into and out of the space. In addition, a space is served by one or more air distribution terminals and does not always have to relate to a single room. In some applications it is more appropriate for a space to represent a group of rooms, a floor or even an entire building. A total of 31 spaces were defined for the level 5-left wing.

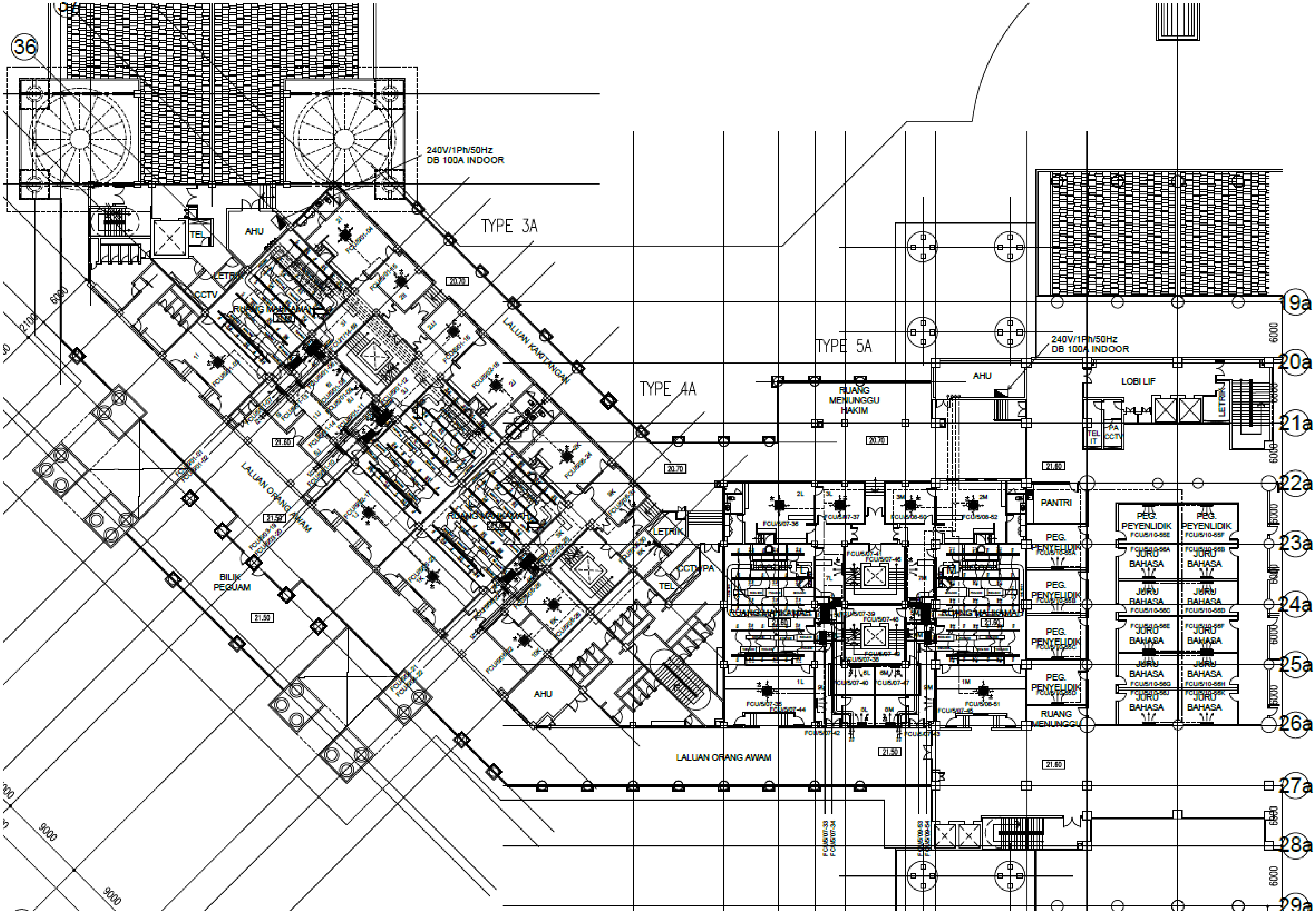


Figure 2-13: The floor plan of level 5, left wing, Kuala Lumpur Court Complex

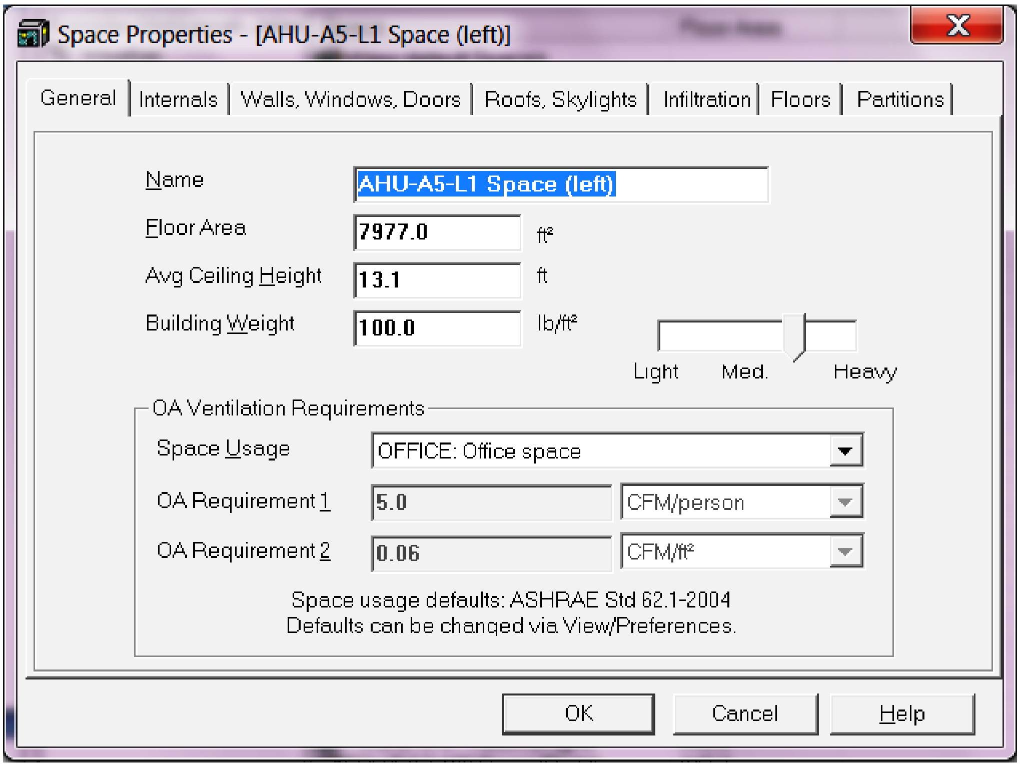


Figure 2-14: Space Properties Form in Carrier E20II Computer Program when the General tab is selected

A Space Form *(Figure 2-14)* was used to input the characteristics of all heat flow elements in each space. The form contains multiple categories of information for the space represented in separate tabs. There are seven tabs for the seven categories of space data:

i. General - contains the space name, total floor area, average floor to ceiling height and the building weight.

ii. Internals - contains information about internal heat gains from overhead lighting, task lighting, electrical equipment, occupants, and miscellaneous sources. Figure 2-15 shows an example of the form when Internals tab is selected.

iii. Walls, Windows, Doors - contains data for external walls with associated windows, external shading devices and doors. Figure 2-16 shows the form when this tab is selected.

iv. Roof, Skylights - contains information about horizontal or sloped roofs and any skylights which are part of these roof exposures. Figure 2-17 shows an example of the form when this tab is selected.

v. Infiltration - contains infiltration specifications for cooling design, heating design and energy simulation conditions. Figure 2-18 shows an example of the form when this tab is selected.

vi. Floors - contains information about heat transfer through slab floors, basement floors or floors above an unconditioned region. Figure 2-19 shows an example of the form when the Floors tab is selected.

vii. Partitions - contains data about heat flow through walls or ceilings adjacent to unconditioned regions. Figure 2-20 shows an example of the form when the Partitions tab is selected.

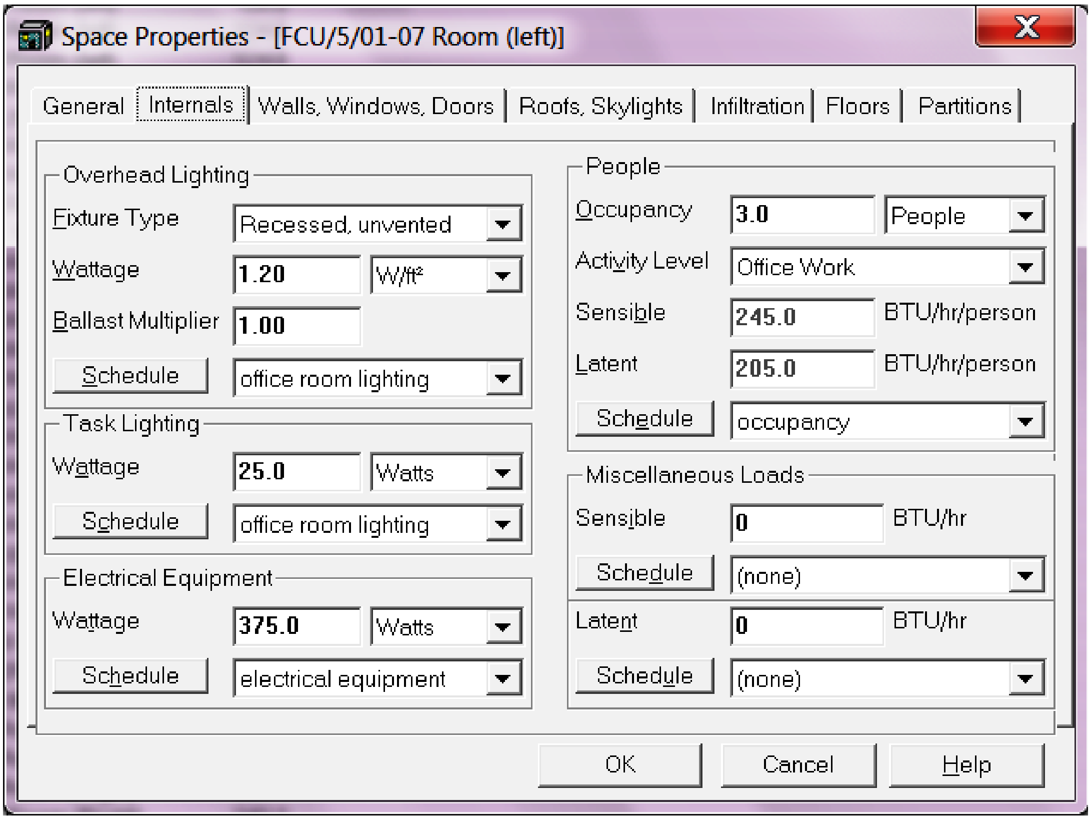


Figure 2-15: An example of the form when the Internals tab is selected

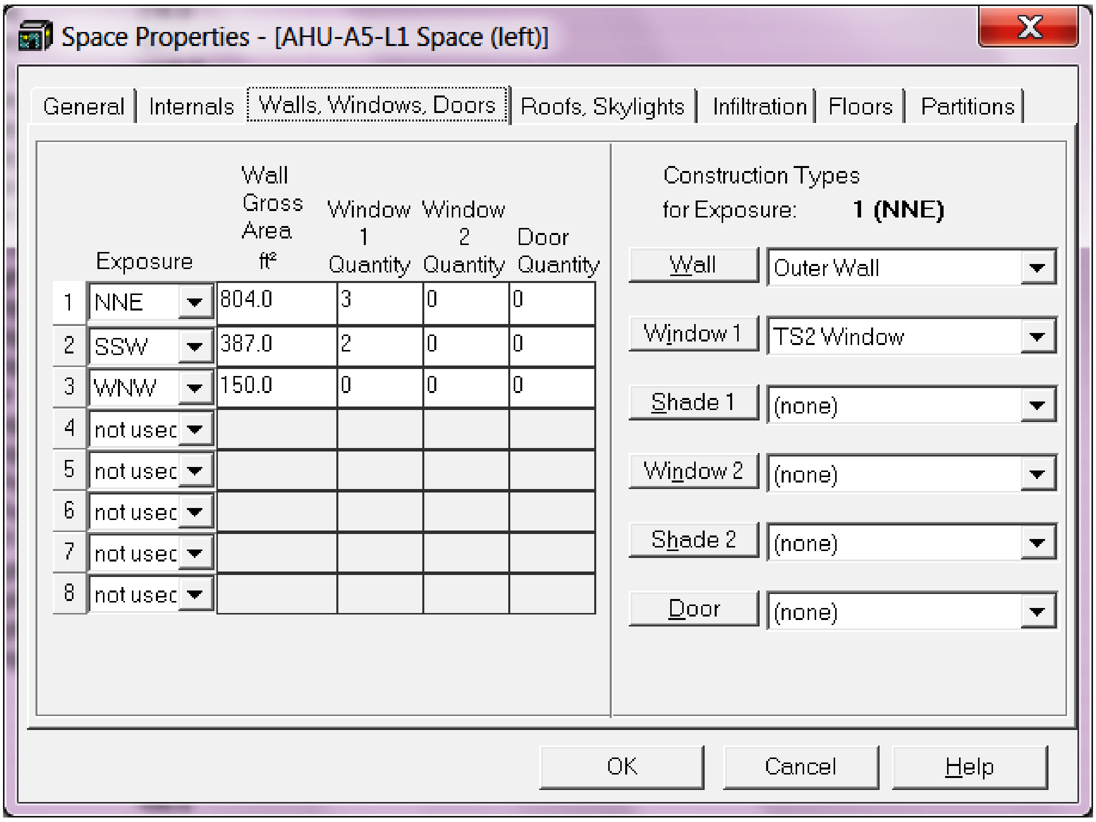


Figure 2-16: An example of the form when the Walls, Windows, Doors tab is selected

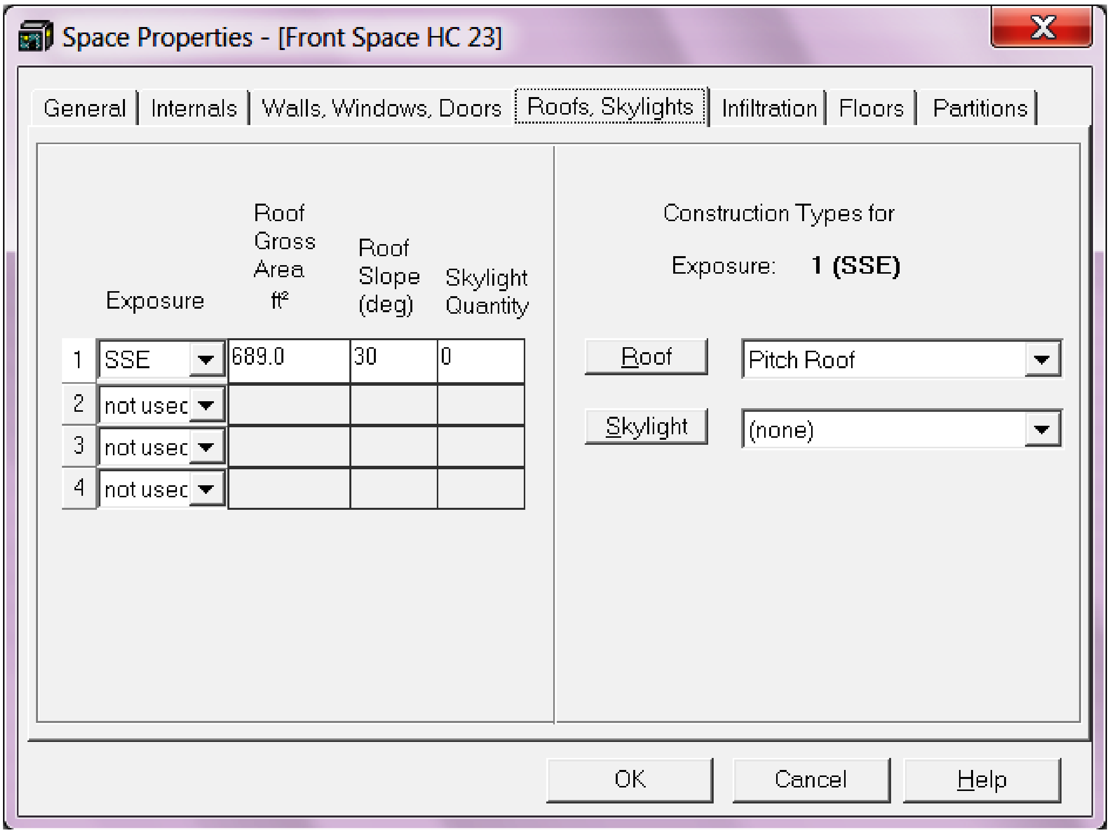


Figure 2-17: An example of the form when the Roofs, Skylights tab is selected

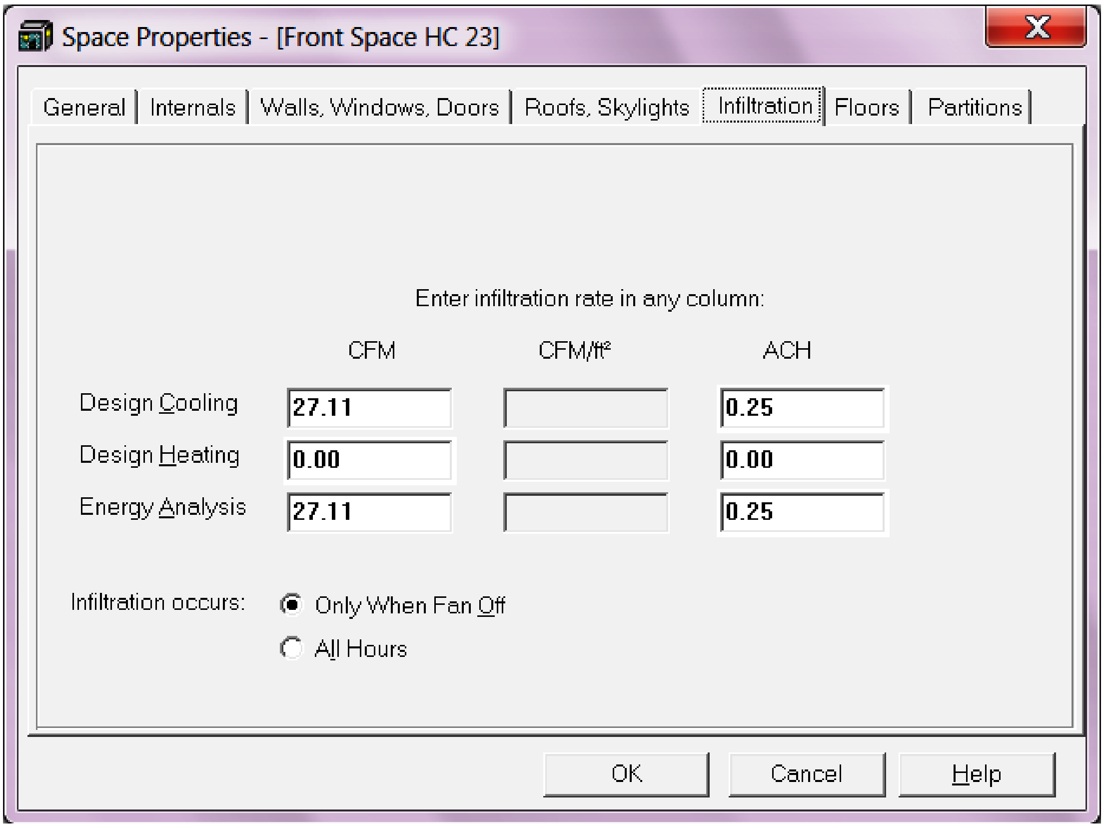


Figure 2-18: An example of the form when the Infiltration tab is selected

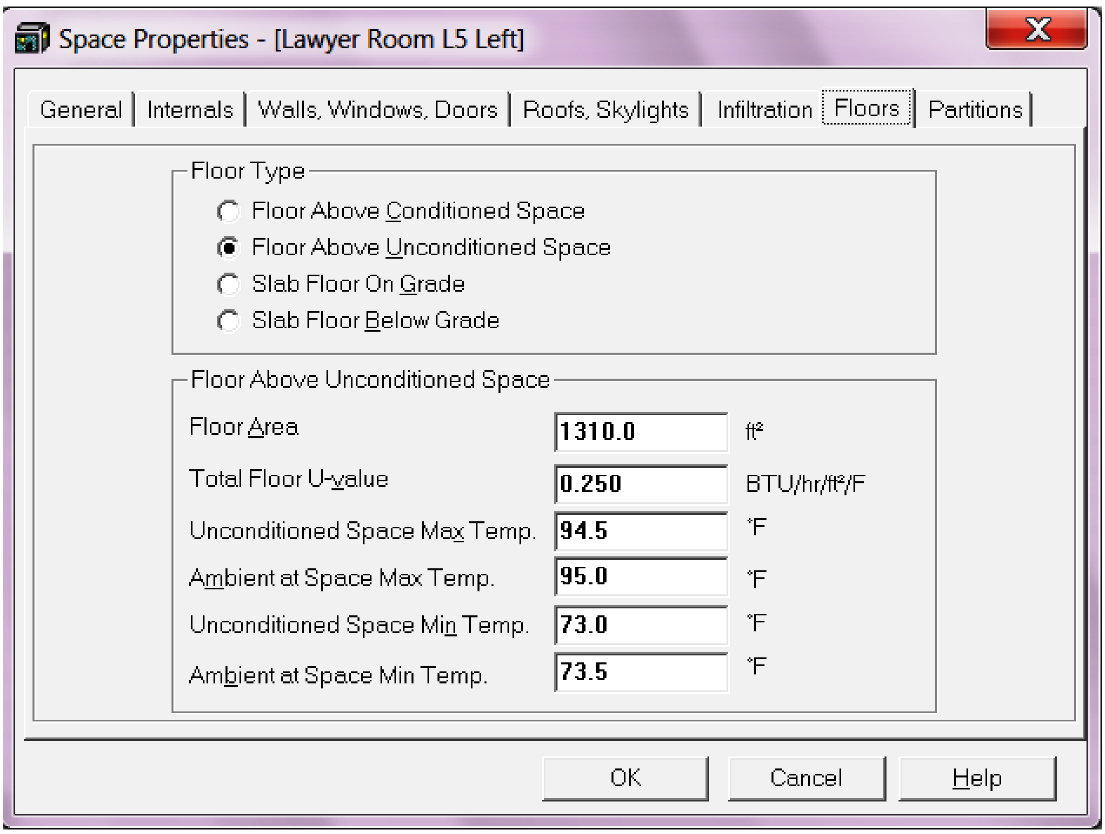


Figure 2-19: An example of the form when the Floors tab is selected

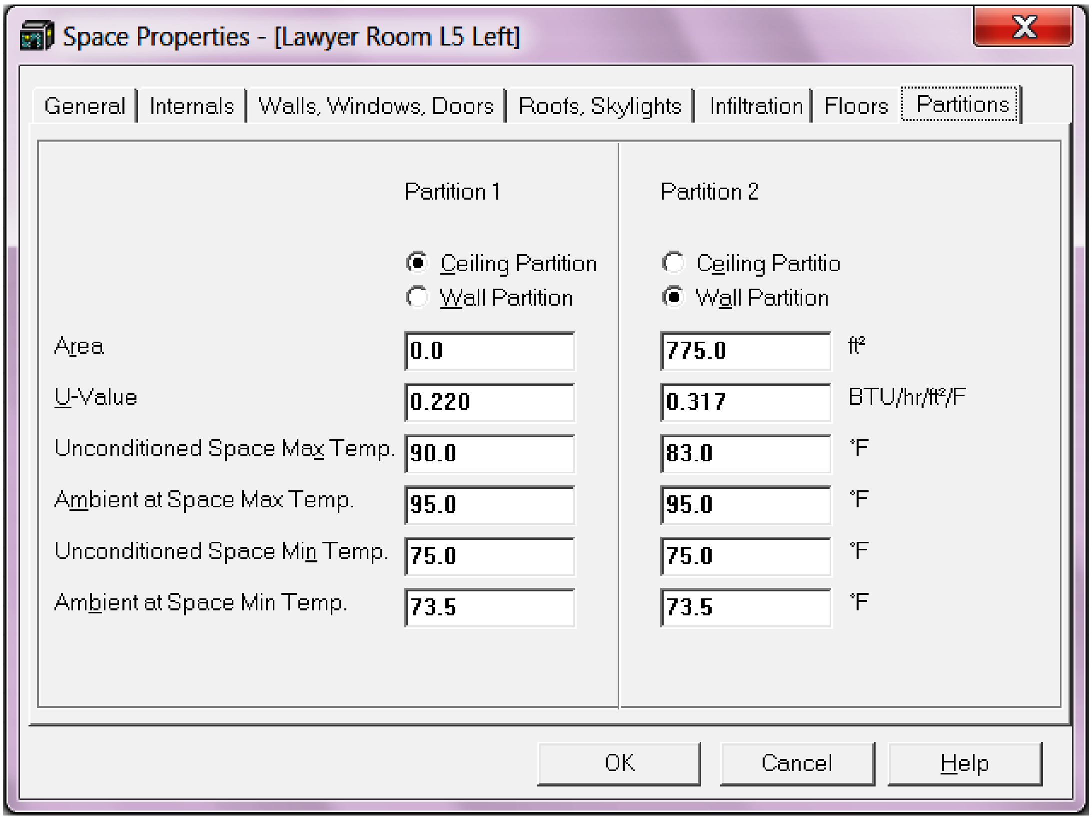


Figure 2-20: An example of the form when the Partitions tab is selected

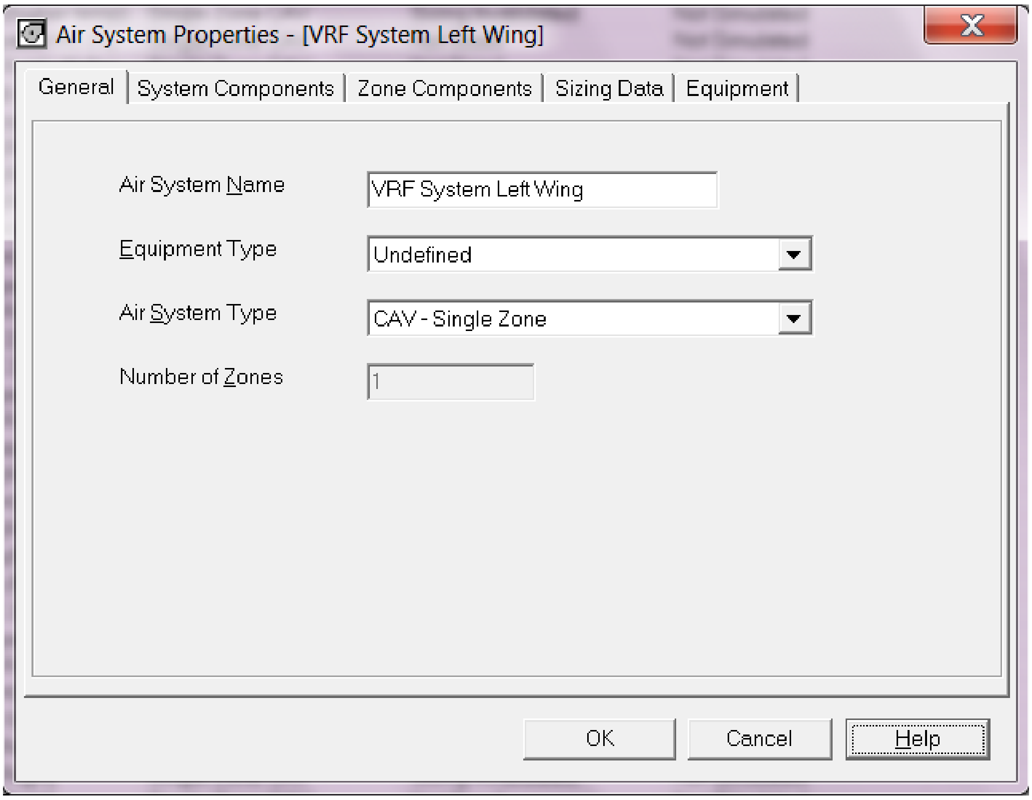


Figure 2-21: Air System Properties Form in Carrier E20II Computer Program when the General tab is selected

The air supply to each air-conditioned space is now specified. An Air System is defined as the equipment and controls which provide cooling and heating to a region of a building. It can serve one or more zones where each zone is a group of one or more spaces having a single thermostatic control. Examples of air systems include central station air handlers, packaged rooftop units, packaged vertical units, split systems, packaged Direct Expansion *(DX)* fan coils and water source heat pumps. Components in an air system include fans and coils as well as associated ductwork, supply terminals and controls. In practice the simulation only required a single air supply because the studies required a uniform environment temperature in all spaces.

A System Form *(Figure 2-21)* was used to enter the characteristics of an air system. Separate tabs enable the input of difference types of system information. There are five tabs for the five categories of system data which are as follows:

i. General - contains the system name, its equipment classification and system type, and the number of zones.

ii. System Components - contains information about centrally located components in the system such as fans and coils, and information about the distribution duct system. Figure 2-22 shows an example of the form when the System Components tab is selected.

iii. Zone Components - contains data describing the spaces in each zone together with equipment such as supply terminals, thermostats and supplemental heating units. Figure 2-23 shows an example of the form when the Zone Components tab is selected.

iv. Sizing Data - contains criteria for sizing the system. It also contains system sizing values which can be directly entered for retrofit applications rather than being calculated by the program. Figure 2-24 shows an example of the form when the Sizing Data tab is selected.

v. Equipment Data - contains information about Direct Expansion (DX) cooling, heat pump, and combustion heating components of the system. This information is important energy simulation analyses. Figure 2-25 shows an example of the form when the Equipment Data tab is selected.

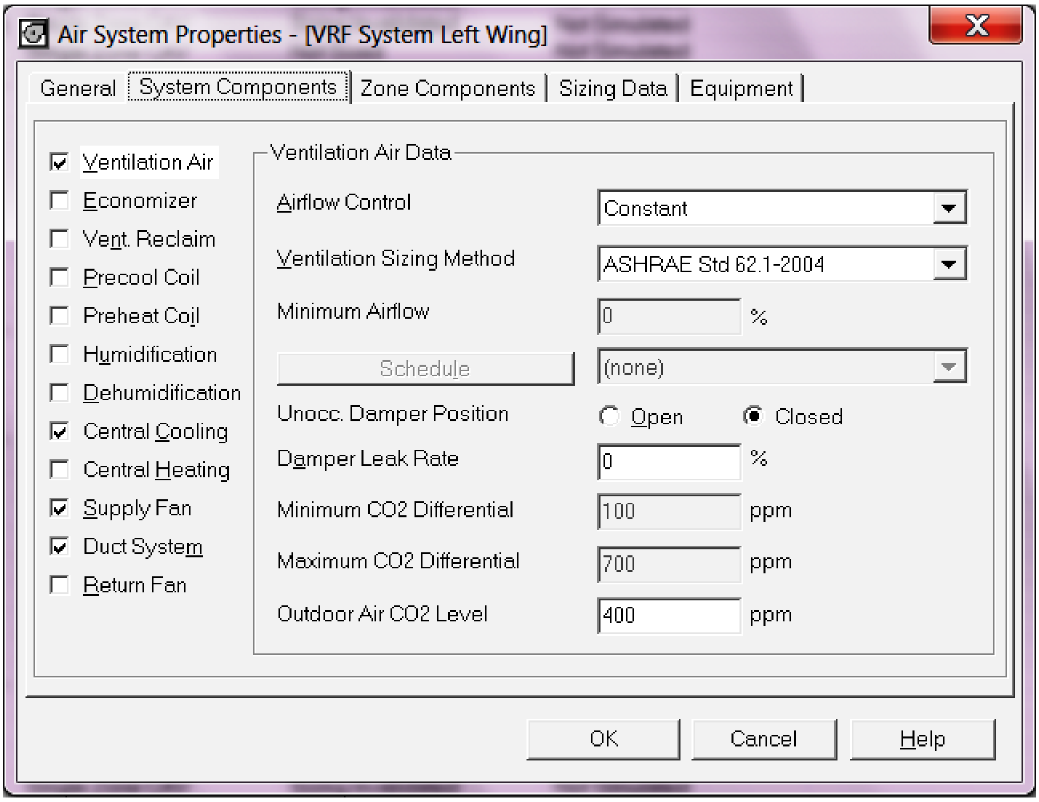


Figure 2-22: An example of the form when the System Components tab is selected

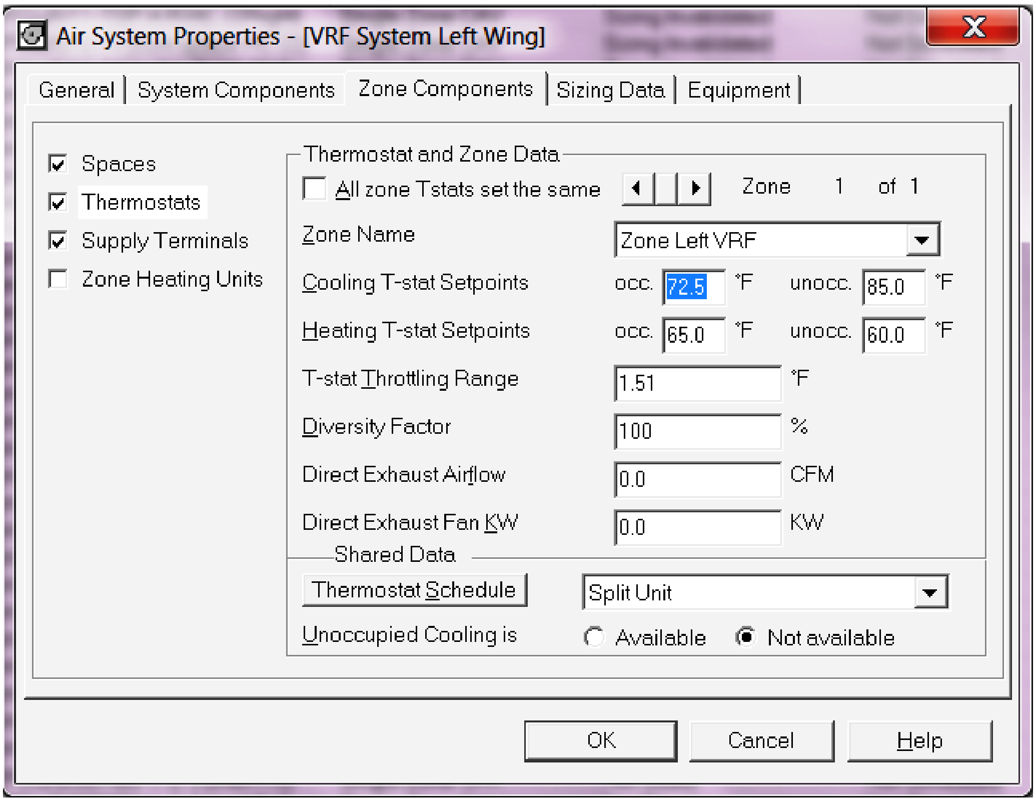


Figure 2-23: An example of the form when the Zone Components tab is selected

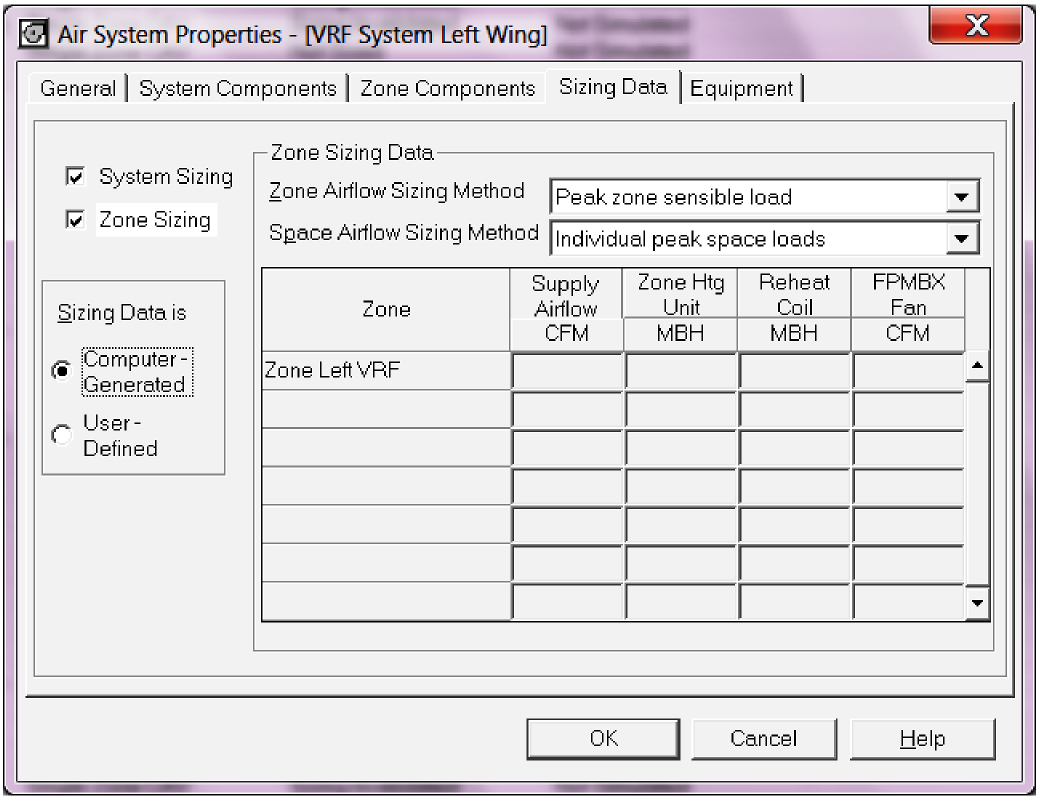


Figure 2-24: An example of the form when the Sizing Data tab is selected

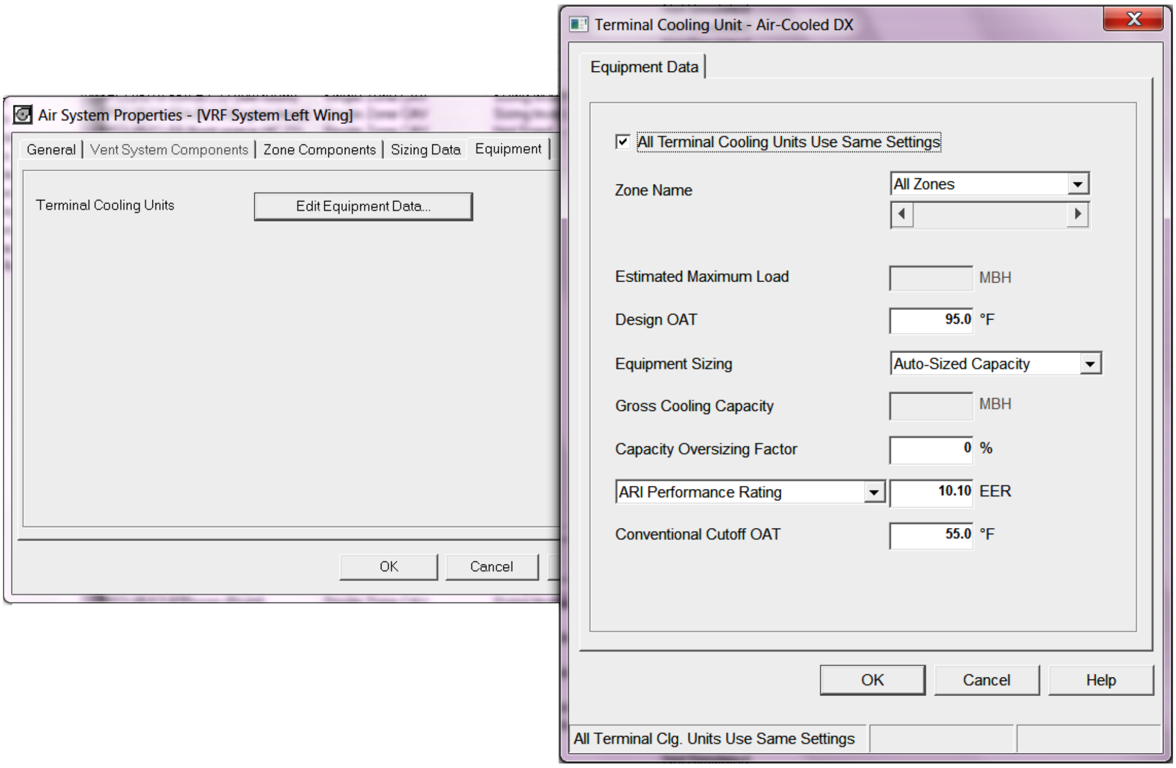


Figure 2-25: An example of the form when the Equipment tab is selected

The Energy Consumption Simulation of the spaces was generated after all related data in air system properties form were entered and saved. Note that thermostat value in the zone components tab which represent the indoor set-point temperature was first set to be equal to the current actual indoor set-point temperature of the selected conditioned spaces in level 5, left wing of the building i.e. 22.5^{o}C. Two exercises were conducted:

i. To investigate the energy potential improvement

ii. To investigate the impact of ramp and cycle indoor set-point temperature mode to HVAC energy consumption.

For the purpose of building potential energy investigation, only monthly simulation report was analysed to get the total HVAC energy consumption of the year. Table 2-6 shows the results of the simulation when the indoor set-point temperatures were held constant at 22.5^{o}C. In this report, the left wing of level 5 HVAC system energy consumption is illustrated as cooling coil load from January till December. The air-conditioning system energy consumption of the conditioned spaces are equal to the sum of the spaces cooling coil load and the power of HVAC fan motor used in that spaces.

The term ‘Cooling Coil Load’ refers to the amount of energy removed from the cooling coil which is the sum of space cooling load, supply and return system heat gain, and ventilation load. Since power used to generate the fan is relatively small compared to the cooling coil load, it is safe to take the Cooling Coil Load as the System Energy consumption of the conditioned spaces in the left wing of the level 5. The same simulation was repeated for different indoor set-point temperatures: 21.1^{o}C, 21.4^{o}C, 21.7^{o}C, 21.9^{o}C, 22.2^{o}C, 22.8^{o}C, 23.1^{o}C, 23.3^{o}C, 23.6^{o}C, 23.9^{o}C, 24.2^{o}C, 24.4^{o}C, 24.7^{o}C, 25^{o}C, 25.3^{o}C and 25.6^{o}C. The results of energy simulations for different set-point temperatures are summarised in Table 2-7 and Figure 2-26.

Monthly Simulation Results for VRF System Left Wing

Project Name: Komplex Mahkamah Jalan Duta (Level 5) 02/01/2012
Prepared by: JKR CAWANGAN MEKANIKAL 03:52PM

Air System Simulation Results

Month	Central Cooling Coil Load (kBTU)	Supply Fan (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	260365	0	6634	14584
February	249380	0	6231	13463
March	299894	0	7098	15147
April	284100	0	6809	14586
May	288319	0	6634	14584
June	289178	0	6809	14586
July	276317	0	6880	14866
August	277490	0	6851	14866
September	269879	0	6809	14586
October	271683	0	6634	14584
November	266785	0	6809	14586
December	273044	0	7098	15147
Total	3306434	0	81296	175585

Table 2-6: Monthly energy simulation result for VRF System of Level 5, left wing of Kuala Lumpur Courts Complex

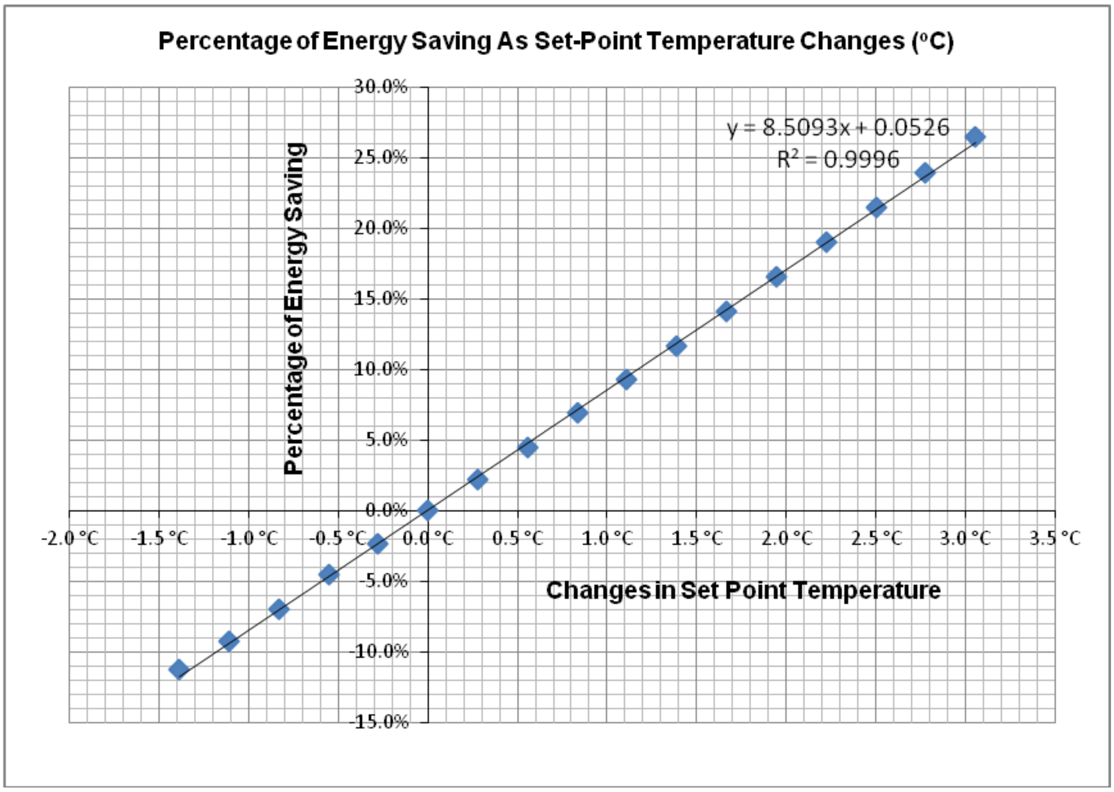


Figure 2-26: Percentage of annual energy saving as set-point temperature of Level 5, left wing of Kuala Lumpur Courts Complex change

No.	Set Point Temperature	Set Point Temperature	Set Point Temperature Different	Set Point Temperature Different	Energy Consumption in one year (cooling coil load)	Energy Saving by changing set point temperature	Energy saving by percentage
1	70.0 °F	21.1 °C	-2.5 °F	-1.4 °C	3,674,121 kBtu	-371,746 kBtu	-11.3%
2	70.5 °F	21.4 °C	-2.0 °F	-1.1 °C	3,609,100 kBtu	-306,725 kBtu	-9.3%
3	71.0 °F	21.7 °C	-1.5 °F	-0.8 °C	3,534,427 kBtu	-232,052 kBtu	-7.0%
4	71.5 °F	21.9 °C	-1.0 °F	-0.6 °C	3,452,148 kBtu	-149,773 kBtu	-4.5%
5	72.0 °F	22.2 °C	-0.5 °F	-0.3 °C	3,381,582 kBtu	-79,207 kBtu	-2.4%
6	72.5 °F*	22.5 °C*	0.0 °F	0.0 °C	3,302,375 kBtu	0 kBtu	0.0%
7	73.0 °F	22.8 °C	0.5 °F	0.3 °C	3,230,132 kBtu	72,243 kBtu	2.2%
8	73.5 °F	23.1 °C	1.0 °F	0.6 °C	3,153,882 kBtu	148,493 kBtu	4.5%
9	74.0 °F	23.3 °C	1.5 °F	0.8 °C	3,075,230 kBtu	227,145 kBtu	6.9%
10	74.5 °F	23.6 °C	2.0 °F	1.1 °C	2,996,036 kBtu	306,339 kBtu	9.3%
11	75.0 °F	23.9 °C	2.5 °F	1.4 °C	2,917,129 kBtu	385,246 kBtu	11.7%
12	75.5 °F	24.2 °C	3.0 °F	1.7 °C	2,837,101 kBtu	465,274 kBtu	14.1%
13	76.0 °F	24.4 °C	3.5 °F	1.9 °C	2,755,901 kBtu	546,474 kBtu	16.5%
14	76.5 °F	24.7 °C	4.0 °F	2.2 °C	2,675,828 kBtu	626,547 kBtu	19.0%
15	77.0 °F	25.0 °C	4.5 °F	2.5 °C	2,594,111 kBtu	708,264 kBtu	21.4%
16	77.5 °F	25.3 °C	5.0 °F	2.8 °C	2,511,463 kBtu	790,912 kBtu	23.9%
17	78.0 °F	25.6 °C	5.5 °F	3.1 °C	2,429,330 kBtu	873,045 kBtu	26.4%

*current set point temperature for Kuala Lumpur Courts Complex

Table 2-7: Annual energy consumption and potential energy saving of the conditioned spaces when the set point temperature is changed

It can be seen (*table 2-7*) that the current energy consumption is 3,302,375 kBtu energy consumption per annum at its current indoor set-point temperature. Increasing the set-point temperature by 0.5^{o}F (*about 0.3^{o}C*) could potentially save about 76,250 to 82,648 kBtu annual energy consumption of the floor. The graph also shows that an increase in indoor set-point temperature has a positive linear proportional relationship to the percentage in energy saving.

The second exercise focused on hourly operation during a single day, 7th June 2010. This day had one of the highest cooling load requirements in year 2010. Hourly energy consumption simulation reports were generated instead. To achieve the aim of this exercise, the hourly energy consumption during the day for each mode was analysed and compared.

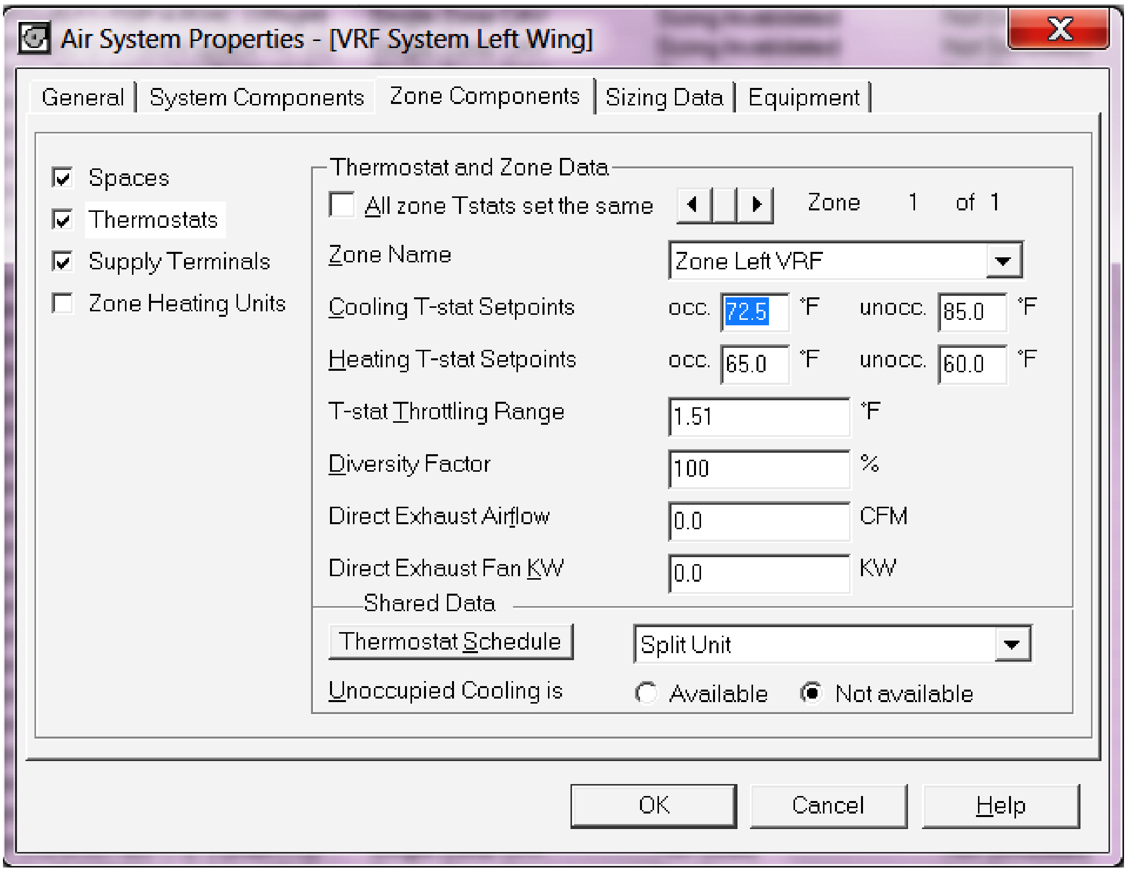


Figure 2-27: The component tab where the values of the thermostat were changed

The HVAC computer program has a major limitation in the indoor set-point temperature input has to remain constant for each simulation. Ramp and cyclic set-point adjustments were simulated by performing many different simulations and then performing a manual summation of energy consumption (

Table 2-9 *and Table 2-10*). Repeated simulations were conducted to get the different hourly energy consumptions when the thermostat value was changed to suit ramp or cyclic adjustment. Table 2-8 and Figure 2-30 show examples of the hourly energy consumption simulation report generated for an indoor set-point temperature value of 24^{o}C.

When ramp indoor set-point temperature mode analysis was carried out, the thermostat values entered in the program was increased at 0.3^{o}C intervals from 22.5^{o}C until reaching a maximum allowable indoor comfort temperature of 25.6^{o}C [3]. In real time, changes were made to these values in every 10 minutes. The thermostat value was reset back at 22.5^{o}C after it reached the maximum allowable temperature. Figure 2-28 shows thermostat values in relation with time during the analysis day for the ramp mode. The same approach was adopted for the cyclic mode. However, when the maximum allowable temperature was reached, the values were entered to decrease steadily by 0.3^{o}C for every ten minutes in real time until it reached back 22.5^{o}C. Figure 2-29 shows the thermostat values in relation with time during the analysis day for the cyclic mode of indoor set-point temperature.

For fixed mode indoor set-point temperature, the thermostat value was set to 22.5^{o}C constant throughout the day. The simulation was executed every time that the thermostat value was changed and the hourly energy consumption value generated from it was observed and noted. Figure 2-27 shows the view of the Zone Component tab where the values of the thermostat were changed. The hourly energy consumption simulation reports of all indoor set-point temperatures involving all modes were analysed and tabled as shown in

Table 2-9 and Table 2-10. Note that the manual hourly cooling load summations conducted for both modes (*i.e. ramp and cyclic*) did not take the building dynamics into account. However, this should not have a significant effect to the energy calculation. Furthermore, the interval of ten minutes between the set-point temperature changes is too short for any considerable response from the walls dynamics. This is discussed further in Chapter 3, section 3.4.

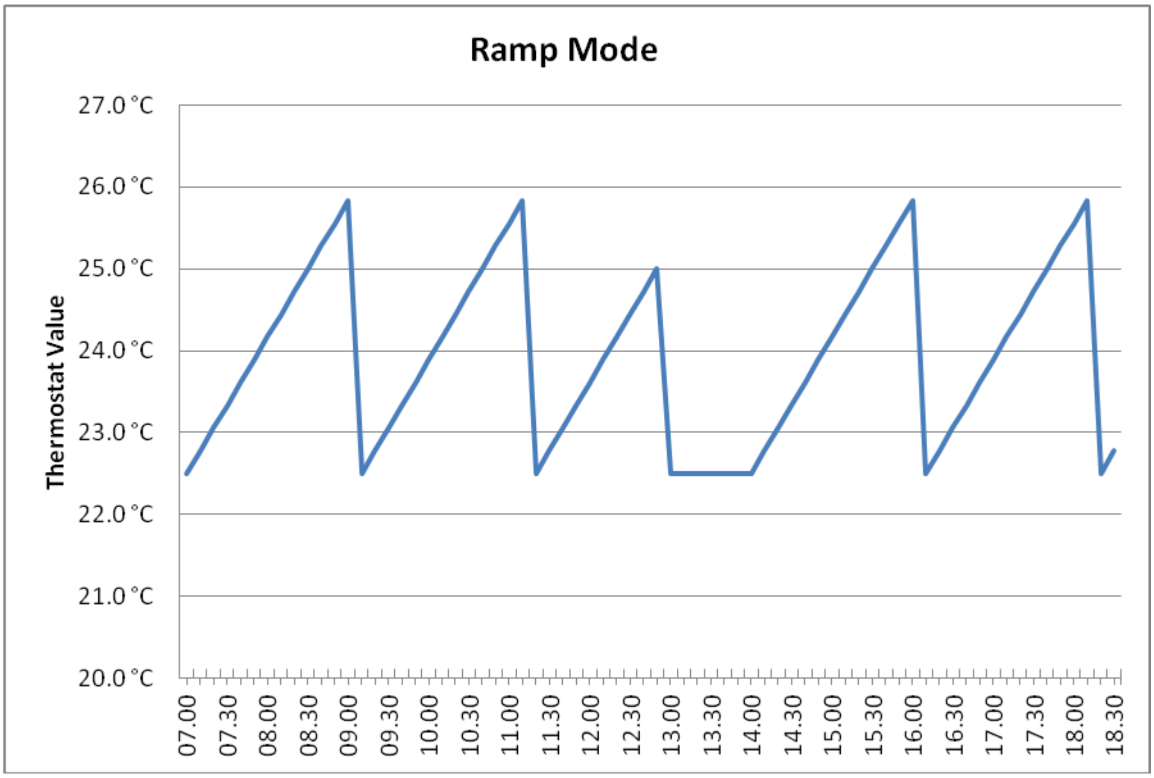


Figure 2-28: Thermostat value of the Kuala Lumpur Court Complex energy simulation in relation with time during the analysis day for the ramp mode

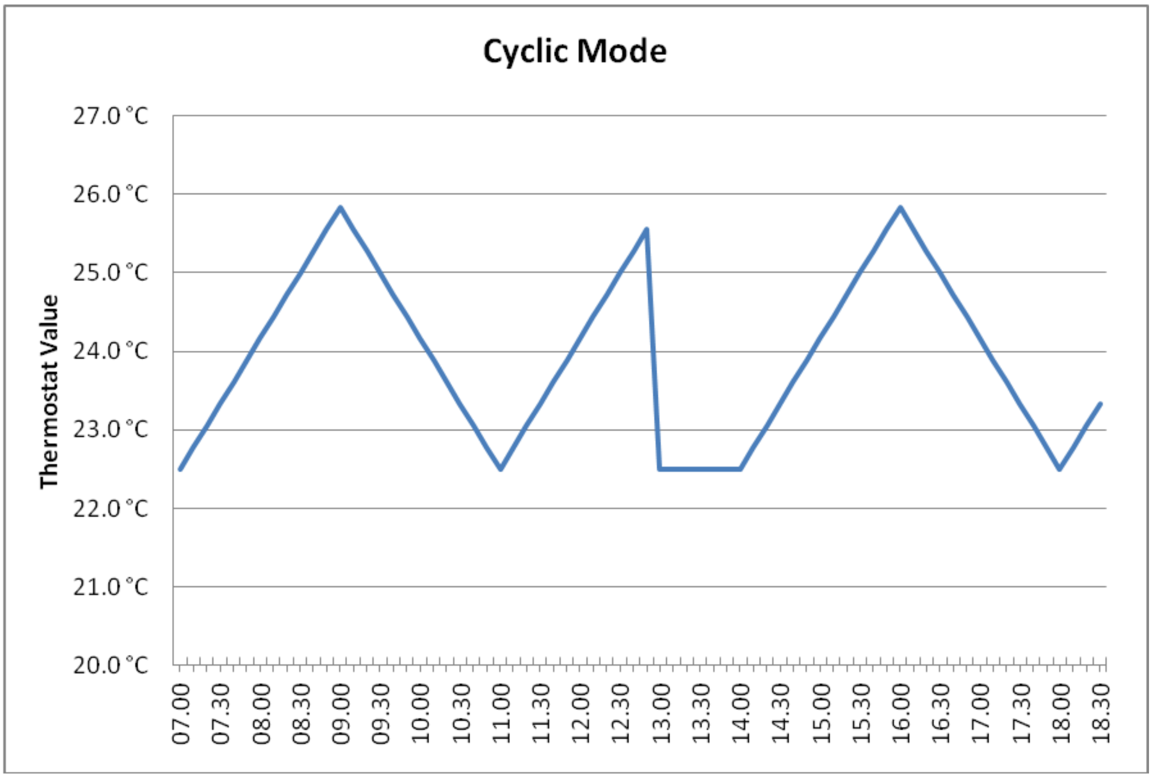


Figure 2-29: Thermostat value of the Kuala Lumpur Court Complex energy simulation in relation with time during the analysis day for the cyclic mode

Observed from

Table 2-9, total cooling coil load for fixed indoor set-point temperature and the ramp mode for one day are 10,883,466.7 Btu and 9,659,266.67 Btu respectively. Hence, potential energy saving when the ramp mode is applied to the conditioned spaces in left wing of level 5, Kuala Lumpur Court Complex is 1,224,200 Btu per day which is about an 11.2% energy consumption improvement. Similarly in Table 2-10, total cooling coil load of fixed mode indoor set-point temperature is observed to be higher than the cyclic mode. The total load of cyclic mode indoor set-point temperature is 9,641,633.33 Btu. Hence, potential energy saving when the cyclic mode is applied to the conditioned spaces in left wing of level 5, Kuala Lumpur Court Complex is 1,241,833.33 Btu per day which is about an 11.4% improvement of energy consumption. These results also show that cyclic mode of indoor set-point temperature has the highest potential in improvement of HVAC energy consumption as compared to the fixed and the ramp mode. However the difference in energy saving between these two dynamic modes is very small and insignificant.

Hourly Air System Simulation Results for Monday, June 7

Hour	Central Cooling Coil Load (MBH)	Supply Fan (kW)	Lighting (kW)	Electric Equipment (kW)
0000	0.0	0.0	0.9	4.2
0100	0.0	0.0	0.9	4.2
0200	0.0	0.0	0.9	4.2
0300	0.0	0.0	0.9	4.2
0400	0.0	0.0	0.9	4.2
0500	0.0	0.0	0.9	4.2
0600	482.5	0.0	0.9	3.3
0700	584.3	0.0	9.1	7.5
0800	737.9	0.0	23.9	24.1
0900	940.5	0.0	23.9	49.8
1000	978.6	0.0	23.9	50.6
1100	1003.9	0.0	23.9	50.6
1200	1014.7	0.0	18.7	50.6
1300	909.2	0.0	20.1	41.5
1400	973.3	0.0	20.1	33.2
1500	1020.9	0.0	22.4	32.4
1600	1030.4	0.0	22.4	50.6
1700	1021.2	0.0	15.8	50.6
1800	885.9	0.0	12.9	25.7
1900	838.4	0.0	12.9	25.7
2000	0.0	0.0	11.1	25.7
2100	0.0	0.0	11.1	5.0
2200	0.0	0.0	9.3	5.0
2300	0.0	0.0	0.9	4.2
Total	**12421.8**	**0.0**	**288.9**	**561.2**

Table 2-8: An Example of Hourly HVAC System Simulation Results at thermostat value of 24°C

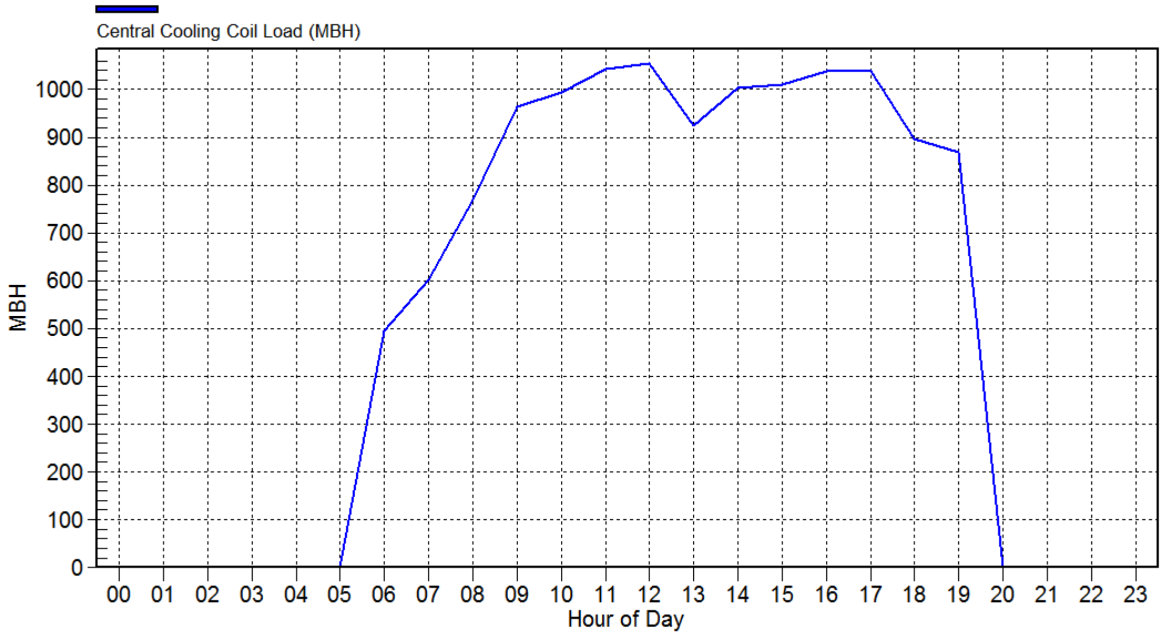


Figure 2-30: Hourly Simulation report in graph form at thermostat value of 24°C, 7th June, thru Monday

No	Operation Time	Constant Set Point Temperature	Constant Set Point Temperature	Ramps set point temperature	Ramps set point temperature	Cooling Coil Load (constant)	Cooling Coil Load (ramps)	Potential Energy Savings	Percentage Potential Energy Savings
1	07.00	22.5 °C	72.5 °F	22.5 °C	72.5 °F	-	-	-	-
2	07.10	22.5 °C	72.5 °F	22.8 °C	73.0 °F	100316.7 BTU	100316.7 BTU	0.0 BTU	0.0%
3	07.20	22.5 °C	72.5 °F	23.1 °C	73.5 °F	100316.7 BTU	94750.0 BTU	5566.7 BTU	5.5%
4	07.30	22.5 °C	72.5 °F	23.3 °C	74.0 °F	100316.7 BTU	87750.0 BTU	12566.7 BTU	12.5%
5	07.40	22.5 °C	72.5 °F	23.6 °C	74.5 °F	100316.7 BTU	89516.7 BTU	10800.0 BTU	10.8%
6	07.50	22.5 °C	72.5 °F	23.9 °C	75.0 °F	100316.7 BTU	84583.3 BTU	15733.3 BTU	15.7%
7	08.00	22.5 °C	72.5 °F	24.2 °C	75.5 °F	100316.7 BTU	75450.0 BTU	24866.7 BTU	24.8%
8	08.10	22.5 °C	72.5 °F	24.4 °C	76.0 °F	128066.7 BTU	107733.3 BTU	20333.3 BTU	15.9%
9	08.20	22.5 °C	72.5 °F	24.7 °C	76.5 °F	128066.7 BTU	97866.7 BTU	30200.0 BTU	23.6%
10	08.30	22.5 °C	72.5 °F	25.0 °C	77.0 °F	128066.7 BTU	96750.0 BTU	31316.7 BTU	24.5%
11	08.40	22.5 °C	72.5 °F	25.3 °C	77.5 °F	128066.7 BTU	94116.7 BTU	33950.0 BTU	26.5%
12	08.50	22.5 °C	72.5 °F	25.6 °C	78.0 °F	128066.7 BTU	95333.3 BTU	32733.3 BTU	25.6%
13	09.00	22.5 °C	72.5 °F	25.8 °C	78.5 °F	128066.7 BTU	87233.3 BTU	40833.3 BTU	31.9%
14	09.10	22.5 °C	72.5 °F	22.5 °C	72.5 °F	160666.7 BTU	112916.7 BTU	47750.0 BTU	29.7%
15	09.20	22.5 °C	72.5 °F	22.8 °C	73.0 °F	160666.7 BTU	160666.7 BTU	0.0 BTU	0.0%
16	09.30	22.5 °C	72.5 °F	23.1 °C	73.5 °F	160666.7 BTU	155933.3 BTU	4733.3 BTU	2.9%
17	09.40	22.5 °C	72.5 °F	23.3 °C	74.0 °F	160666.7 BTU	152166.7 BTU	8500.0 BTU	5.3%
18	09.50	22.5 °C	72.5 °F	23.6 °C	74.5 °F	160666.7 BTU	144450.0 BTU	16216.7 BTU	10.1%
19	10.00	22.5 °C	72.5 °F	23.9 °C	75.0 °F	160666.7 BTU	147866.7 BTU	12800.0 BTU	8.0%
20	10.10	22.5 °C	72.5 °F	24.2 °C	75.5 °F	165683.3 BTU	148916.7 BTU	16766.7 BTU	10.1%
21	10.20	22.5 °C	72.5 °F	24.4 °C	76.0 °F	165683.3 BTU	145316.7 BTU	20366.7 BTU	12.3%
22	10.30	22.5 °C	72.5 °F	24.7 °C	76.5 °F	165683.3 BTU	143700.0 BTU	21983.3 BTU	13.3%
23	10.40	22.5 °C	72.5 °F	25.0 °C	77.0 °F	165683.3 BTU	139916.7 BTU	25766.7 BTU	15.6%
24	10.50	22.5 °C	72.5 °F	25.3 °C	77.5 °F	165683.3 BTU	135833.3 BTU	29850.0 BTU	18.0%
25	11.00	22.5 °C	72.5 °F	25.6 °C	78.0 °F	165683.3 BTU	125866.7 BTU	39816.7 BTU	24.0%
26	11.10	22.5 °C	72.5 °F	25.8 °C	78.5 °F	173966.7 BTU	133283.3 BTU	40683.3 BTU	23.4%
27	11.20	22.5 °C	72.5 °F	22.5 °C	72.5 °F	173966.7 BTU	131066.7 BTU	42900.0 BTU	24.7%
28	11.30	22.5 °C	72.5 °F	22.8 °C	73.0 °F	173966.7 BTU	173966.7 BTU	0.0 BTU	0.0%
29	11.40	22.5 °C	72.5 °F	23.1 °C	73.5 °F	173966.7 BTU	168050.0 BTU	5916.7 BTU	3.4%
30	11.50	22.5 °C	72.5 °F	23.3 °C	74.0 °F	173966.7 BTU	167616.7 BTU	6350.0 BTU	3.7%
31	12.00	22.5 °C	72.5 °F	23.6 °C	74.5 °F	173966.7 BTU	161233.3 BTU	12733.3 BTU	7.3%
32	12.10	22.5 °C	72.5 °F	23.9 °C	75.0 °F	175683.3 BTU	161116.7 BTU	14566.7 BTU	8.3%
33	12.20	22.5 °C	72.5 °F	24.2 °C	75.5 °F	175683.3 BTU	157850.0 BTU	17833.3 BTU	10.2%
34	12.30	22.5 °C	72.5 °F	24.4 °C	76.0 °F	175683.3 BTU	151433.3 BTU	24250.0 BTU	13.8%
35	12.40	22.5 °C	72.5 °F	24.7 °C	76.5 °F	175683.3 BTU	149666.7 BTU	26016.7 BTU	14.8%
36	12.50	22.5 °C	72.5 °F	25.0 °C	77.0 °F	175683.3 BTU	144950.0 BTU	30733.3 BTU	17.5%
37	13.00	22.5 °C	72.5 °F	22.5 °C	72.5 °F	175683.3 BTU	139416.7 BTU	36266.7 BTU	20.6%
38	13.10	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
39	13.20	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
40	13.30	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
41	13.40	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
42	13.50	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
43	14.00	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
44	14.10	22.5 °C	72.5 °F	22.8 °C	73.0 °F	167183.3 BTU	167183.3 BTU	0.0 BTU	0.0%
45	14.20	22.5 °C	72.5 °F	23.1 °C	73.5 °F	167183.3 BTU	162200.0 BTU	4983.3 BTU	3.0%
46	14.30	22.5 °C	72.5 °F	23.3 °C	74.0 °F	167183.3 BTU	160933.3 BTU	6250.0 BTU	3.7%
47	14.40	22.5 °C	72.5 °F	23.6 °C	74.5 °F	167183.3 BTU	156750.0 BTU	10433.3 BTU	6.2%
48	14.50	22.5 °C	72.5 °F	23.9 °C	75.0 °F	167183.3 BTU	154866.7 BTU	12316.7 BTU	7.4%
49	15.00	22.5 °C	72.5 °F	24.2 °C	75.5 °F	167183.3 BTU	148266.7 BTU	18916.7 BTU	11.3%
50	15.10	22.5 °C	72.5 °F	24.4 °C	76.0 °F	168400.0 BTU	152333.3 BTU	16066.7 BTU	9.5%
51	15.20	22.5 °C	72.5 °F	24.7 °C	76.5 °F	168400.0 BTU	147550.0 BTU	20850.0 BTU	12.4%
52	15.30	22.5 °C	72.5 °F	25.0 °C	77.0 °F	168400.0 BTU	148683.3 BTU	19716.7 BTU	11.7%
53	15.40	22.5 °C	72.5 °F	25.3 °C	77.5 °F	168400.0 BTU	145366.7 BTU	23033.3 BTU	13.7%
54	15.50	22.5 °C	72.5 °F	25.6 °C	78.0 °F	168400.0 BTU	140533.3 BTU	27866.7 BTU	16.5%
55	16.00	22.5 °C	72.5 °F	25.8 °C	78.5 °F	168400.0 BTU	133250.0 BTU	35150.0 BTU	20.9%
56	16.10	22.5 °C	72.5 °F	22.5 °C	72.5 °F	168400.0 BTU	136650.0 BTU	31750.0 BTU	18.9%
57	16.20	22.5 °C	72.5 °F	22.8 °C	73.0 °F	172883.3 BTU	172883.3 BTU	0.0 BTU	0.0%
58	16.30	22.5 °C	72.5 °F	23.1 °C	73.5 °F	172883.3 BTU	171733.3 BTU	1150.0 BTU	0.7%
59	16.40	22.5 °C	72.5 °F	23.3 °C	74.0 °F	172883.3 BTU	168216.7 BTU	4666.7 BTU	2.7%
60	16.50	22.5 °C	72.5 °F	23.6 °C	74.5 °F	172883.3 BTU	163633.3 BTU	9250.0 BTU	5.4%
61	17.00	22.5 °C	72.5 °F	23.9 °C	75.0 °F	172883.3 BTU	163866.7 BTU	9016.7 BTU	5.2%
62	17.10	22.5 °C	72.5 °F	24.2 °C	75.5 °F	172883.3 BTU	156100.0 BTU	16783.3 BTU	9.7%
63	17.20	22.5 °C	72.5 °F	24.4 °C	76.0 °F	172983.3 BTU	152483.3 BTU	20500.0 BTU	11.9%
64	17.30	22.5 °C	72.5 °F	24.7 °C	76.5 °F	172983.3 BTU	148583.3 BTU	24400.0 BTU	14.1%
65	17.40	22.5 °C	72.5 °F	25.0 °C	77.0 °F	172983.3 BTU	149450.0 BTU	23533.3 BTU	13.6%
66	17.50	22.5 °C	72.5 °F	25.3 °C	77.5 °F	172983.3 BTU	145316.7 BTU	27666.7 BTU	16.0%
67	18.00	22.5 °C	72.5 °F	25.6 °C	78.0 °F	172983.3 BTU	140166.7 BTU	32816.7 BTU	19.0%
68	18.10	22.5 °C	72.5 °F	25.8 °C	78.5 °F	149616.7 BTU	118983.3 BTU	30633.3 BTU	20.5%
69	18.20	22.5 °C	72.5 °F	22.5 °C	72.5 °F	149616.7 BTU	114866.7 BTU	34750.0 BTU	23.2%
70	18.30	22.5 °C	72.5 °F	22.8 °C	73.0 °F	149616.7 BTU	149616.7 BTU	0.0 BTU	0.0%
					Total =	**10,883,466.7 Btu**	**9,659,266.67 Btu**	**1,224,200.00 Btu**	**11.2%**
						3,188.8 kWh	**2,830.1 kWh**	**358.7 kWh**	**11.2%**

Table 2-9: VRF HVAC System Energy Simulation Analysis with E20II HAP of Ramp Mode Set point Temperature at Level 5, Left Wing, Kuala Lumpur Court Complex (07 June 2010)

No	Operation Time	Constant Set-Point Temperature	Constant Set Point Temperature	Cyclic Set-Point Temperature	Cyclic set point temperature	Cooling Coil Load (constant)	Cooling Coil Load (ramps)	Potential Energy Savings	Percentage Potential Energy Savings
1	07.00	22.5 °C	72.5 °F	22.5 °C	72.5 °F	-	-	-	-
2	07.10	22.5 °C	72.5 °F	22.8 °C	73.0 °F	100316.7 BTU	100316.7 BTU	0.0 BTU	0.0%
3	07.20	22.5 °C	72.5 °F	23.1 °C	73.5 °F	100316.7 BTU	94750.0 BTU	5566.7 BTU	5.5%
4	07.30	22.5 °C	72.5 °F	23.3 °C	74.0 °F	100316.7 BTU	87750.0 BTU	12566.7 BTU	12.5%
5	07.40	22.5 °C	72.5 °F	23.6 °C	74.5 °F	100316.7 BTU	89516.7 BTU	10800.0 BTU	10.8%
6	07.50	22.5 °C	72.5 °F	23.9 °C	75.0 °F	100316.7 BTU	84583.3 BTU	15733.3 BTU	15.7%
7	08.00	22.5 °C	72.5 °F	24.2 °C	75.5 °F	100316.7 BTU	75450.0 BTU	24866.7 BTU	24.8%
8	08.10	22.5 °C	72.5 °F	24.4 °C	76.0 °F	128066.7 BTU	107733.3 BTU	20333.3 BTU	15.9%
9	08.20	22.5 °C	72.5 °F	24.7 °C	76.5 °F	128066.7 BTU	97866.7 BTU	30200.0 BTU	23.6%
10	08.30	22.5 °C	72.5 °F	25.0 °C	77.0 °F	128066.7 BTU	96750.0 BTU	31316.7 BTU	24.5%
11	08.40	22.5 °C	72.5 °F	25.3 °C	77.5 °F	128066.7 BTU	94116.7 BTU	33950.0 BTU	26.5%
12	08.50	22.5 °C	72.5 °F	25.6 °C	78.0 °F	128066.7 BTU	95333.3 BTU	32733.3 BTU	25.6%
13	09.00	22.5 °C	72.5 °F	25.8 °C	78.5 °F	128066.7 BTU	87233.3 BTU	40833.3 BTU	31.9%
14	09.10	22.5 °C	72.5 °F	25.6 °C	78.0 °F	160666.7 BTU	112916.7 BTU	47750.0 BTU	29.7%
15	09.20	22.5 °C	72.5 °F	25.3 °C	77.5 °F	160666.7 BTU	119516.7 BTU	41150.0 BTU	25.6%
16	09.30	22.5 °C	72.5 °F	25.0 °C	77.0 °F	160666.7 BTU	124183.3 BTU	36483.3 BTU	22.7%
17	09.40	22.5 °C	72.5 °F	24.7 °C	76.5 °F	160666.7 BTU	129083.3 BTU	31583.3 BTU	19.7%
18	09.50	22.5 °C	72.5 °F	24.4 °C	76.0 °F	160666.7 BTU	130733.3 BTU	29933.3 BTU	18.6%
19	10.00	22.5 °C	72.5 °F	24.2 °C	75.5 °F	160666.7 BTU	132283.3 BTU	28383.3 BTU	17.7%
20	10.10	22.5 °C	72.5 °F	23.9 °C	75.0 °F	165683.3 BTU	145316.7 BTU	20366.7 BTU	12.3%
21	10.20	22.5 °C	72.5 °F	23.6 °C	74.5 °F	165683.3 BTU	148916.7 BTU	16766.7 BTU	10.1%
22	10.30	22.5 °C	72.5 °F	23.3 °C	74.0 °F	165683.3 BTU	150816.7 BTU	14866.7 BTU	9.0%
23	10.40	22.5 °C	72.5 °F	23.1 °C	73.5 °F	165683.3 BTU	156233.3 BTU	9450.0 BTU	5.7%
24	10.50	22.5 °C	72.5 °F	22.8 °C	73.0 °F	165683.3 BTU	158533.3 BTU	7150.0 BTU	4.3%
25	11.00	22.5 °C	72.5 °F	22.5 °C	72.5 °F	165683.3 BTU	163750.0 BTU	1933.3 BTU	1.2%
26	11.10	22.5 °C	72.5 °F	22.8 °C	73.0 °F	173966.7 BTU	173966.7 BTU	0.0 BTU	0.0%
27	11.20	22.5 °C	72.5 °F	23.1 °C	73.5 °F	173966.7 BTU	168050.0 BTU	5916.7 BTU	3.4%
28	11.30	22.5 °C	72.5 °F	23.3 °C	74.0 °F	173966.7 BTU	161233.3 BTU	12733.3 BTU	7.3%
29	11.40	22.5 °C	72.5 °F	23.6 °C	74.5 °F	173966.7 BTU	163233.3 BTU	10733.3 BTU	6.2%
30	11.50	22.5 °C	72.5 °F	23.9 °C	75.0 °F	173966.7 BTU	156983.3 BTU	16983.3 BTU	9.8%
31	12.00	22.5 °C	72.5 °F	24.2 °C	75.5 °F	173966.7 BTU	161433.3 BTU	12533.3 BTU	7.2%
32	12.10	22.5 °C	72.5 °F	24.4 °C	76.0 °F	175683.3 BTU	151433.3 BTU	24250.0 BTU	13.8%
33	12.20	22.5 °C	72.5 °F	24.7 °C	76.5 °F	175683.3 BTU	149666.7 BTU	26016.7 BTU	14.8%
34	12.30	22.5 °C	72.5 °F	25.0 °C	77.0 °F	175683.3 BTU	144950.0 BTU	30733.3 BTU	17.5%
35	12.40	22.5 °C	72.5 °F	25.3 °C	77.5 °F	175683.3 BTU	139416.7 BTU	36266.7 BTU	20.6%
36	12.50	22.5 °C	72.5 °F	25.6 °C	78.0 °F	175683.3 BTU	142666.7 BTU	33016.7 BTU	18.8%
37	13.00	22.5 °C	72.5 °F	22.5 °C	72.5 °F	175683.3 BTU	138416.7 BTU	37266.7 BTU	21.2%
38	13.10	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
39	13.20	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
40	13.30	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
41	13.40	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
42	13.50	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
43	14.00	22.5 °C	72.5 °F	22.5 °C	72.5 °F	154033.3 BTU	154033.3 BTU	0.0 BTU	0.0%
44	14.10	22.5 °C	72.5 °F	22.8 °C	73.0 °F	167183.3 BTU	167183.3 BTU	0.0 BTU	0.0%
45	14.20	22.5 °C	72.5 °F	23.1 °C	73.5 °F	167183.3 BTU	162200.0 BTU	4983.3 BTU	3.0%
46	14.30	22.5 °C	72.5 °F	23.3 °C	74.0 °F	167183.3 BTU	159916.7 BTU	7266.7 BTU	4.3%
47	14.40	22.5 °C	72.5 °F	23.6 °C	74.5 °F	167183.3 BTU	156750.0 BTU	10433.3 BTU	6.2%
48	14.50	22.5 °C	72.5 °F	23.9 °C	75.0 °F	167183.3 BTU	154850.0 BTU	12333.3 BTU	7.4%
49	15.00	22.5 °C	72.5 °F	24.2 °C	75.5 °F	167183.3 BTU	148266.7 BTU	18916.7 BTU	11.3%
50	15.10	22.5 °C	72.5 °F	24.4 °C	76.0 °F	168400.0 BTU	152333.3 BTU	16066.7 BTU	9.5%
51	15.20	22.5 °C	72.5 °F	24.7 °C	76.5 °F	168400.0 BTU	147550.0 BTU	20850.0 BTU	12.4%
52	15.30	22.5 °C	72.5 °F	25.0 °C	77.0 °F	168400.0 BTU	148683.3 BTU	19716.7 BTU	11.7%
53	15.40	22.5 °C	72.5 °F	25.3 °C	77.5 °F	168400.0 BTU	145366.7 BTU	23033.3 BTU	13.7%
54	15.50	22.5 °C	72.5 °F	25.6 °C	78.0 °F	168400.0 BTU	140533.3 BTU	27866.7 BTU	16.5%
55	16.00	22.5 °C	72.5 °F	25.8 °C	78.5 °F	168400.0 BTU	133250.0 BTU	35150.0 BTU	20.9%
56	16.10	22.5 °C	72.5 °F	25.6 °C	78.0 °F	168400.0 BTU	136650.0 BTU	31750.0 BTU	18.9%
57	16.20	22.5 °C	72.5 °F	25.3 °C	77.5 °F	172883.3 BTU	136233.3 BTU	36650.0 BTU	21.2%
58	16.30	22.5 °C	72.5 °F	25.0 °C	77.0 °F	172883.3 BTU	140266.7 BTU	32616.7 BTU	18.9%
59	16.40	22.5 °C	72.5 °F	24.7 °C	76.5 °F	172883.3 BTU	148116.7 BTU	24766.7 BTU	14.3%
60	16.50	22.5 °C	72.5 °F	24.4 °C	76.0 °F	172883.3 BTU	151416.7 BTU	21466.7 BTU	12.4%
61	17.00	22.5 °C	72.5 °F	24.2 °C	75.5 °F	172883.3 BTU	152683.3 BTU	20200.0 BTU	11.7%
62	17.10	22.5 °C	72.5 °F	23.9 °C	75.0 °F	172883.3 BTU	152483.3 BTU	20400.0 BTU	11.8%
63	17.20	22.5 °C	72.5 °F	23.6 °C	74.5 °F	172983.3 BTU	155516.7 BTU	17466.7 BTU	10.1%
64	17.30	22.5 °C	72.5 °F	23.3 °C	74.0 °F	172983.3 BTU	155900.0 BTU	17083.3 BTU	9.9%
65	17.40	22.5 °C	72.5 °F	23.1 °C	73.5 °F	172983.3 BTU	164066.7 BTU	8916.7 BTU	5.2%
66	17.50	22.5 °C	72.5 °F	22.8 °C	73.0 °F	172983.3 BTU	164466.7 BTU	8516.7 BTU	4.9%
67	18.00	22.5 °C	72.5 °F	22.5 °C	72.5 °F	172983.3 BTU	167266.7 BTU	5716.7 BTU	3.3%
68	18.10	22.5 °C	72.5 °F	22.8 °C	73.0 °F	149616.7 BTU	149616.7 BTU	0.0 BTU	0.0%
69	18.20	22.5 °C	72.5 °F	23.1 °C	73.5 °F	149616.7 BTU	146600.0 BTU	3016.7 BTU	2.0%
70	18.30	22.5 °C	72.5 °F	23.3 °C	74.0 °F	149616.7 BTU	144133.3 BTU	5483.3 BTU	3.7%
					Total =	**10,883,466.7 Btu**	**9,641,633.33 Btu**	**1,241,833.33 Btu**	**11.4%**
						3,188.8 kWh	**2,825.0 kWh**	**363.9 kWh**	**11.4%**

Table 2-10: VRF HVAC System Energy Simulation Analysis with E20II HAP of Cyclic Mode Set point Temperature at Level 5, Left Wing, Kuala Lumpur Court Complex (07 June 2010)

2.6 Case Study 2: Menara Seri Wilayah

Menara Seri Wilayah is formerly known as Menara PJH was selected for case study 2. This building is located in Presint 2, Wilayah Persekutuan Putrajaya, Malaysia and is installed with Gas District Cooling HVAC System. Menara Seri Wilayah consists of two towers; North and South Tower with 10 stories high and was completed in 2004. The building has a total of one million square feet of office spaces, including a Multi Purpose Hall, an Auditorium and Commercial space on ground level. As in case study 1, only one section of the building (level 5 of North Tower), was selected for the energy consumption simulation analysis. Level 5 of the North Tower functions as office spaces: a Variable Air Volume (VAV) type of air side HVAC system is installed. Figure 2-31 shows the floor plan of Level 5, North Tower. The energy simulation analysis was conducted in a similar manner to the previous case study. The first exercise aimed to investigate the potential energy improvement: the simulation started with a thermostat value of 23.1^{o}C, the real indoor set-point temperature of spaces in Level 5 of the North Tower (Table 2-11). Then the same thermostat values used in the previous case study were entered into the energy simulation program. The results of energy simulations with all different set-point temperatures are totalled and summarised in Table 2-12. The table also shows an annual potential energy saving of the conditioned spaces when the set-point temperature is changed. Figure 2-32 shows these results in graphical form.

Monthly Simulation Results for AHU COMBINED

Project Name: North Tower Seri Wilayah
Prepared by: JKR CAWANGAN MEKANIKAL

Air System Simulation Results

Month	Central Cooling Coil Load (kBTU)	Supply Fan (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	229310	25775	5628	9411
February	215299	23940	5277	8729
March	250287	27052	6003	9854
April	239745	26015	5761	9479
May	241703	25775	5628	9411
June	243770	26015	5761	9479
July	238975	26414	5815	9632
August	239837	26414	5815	9632
September	233060	26015	5761	9479
October	233138	25775	5628	9411
November	233335	26015	5761	9479
December	240505	27052	6003	9854
Total	**2838962**	**312255**	**68838**	**113850**

Table 2-11: Monthly simulation results with the current indoor set-point temperature of level 5, North Tower

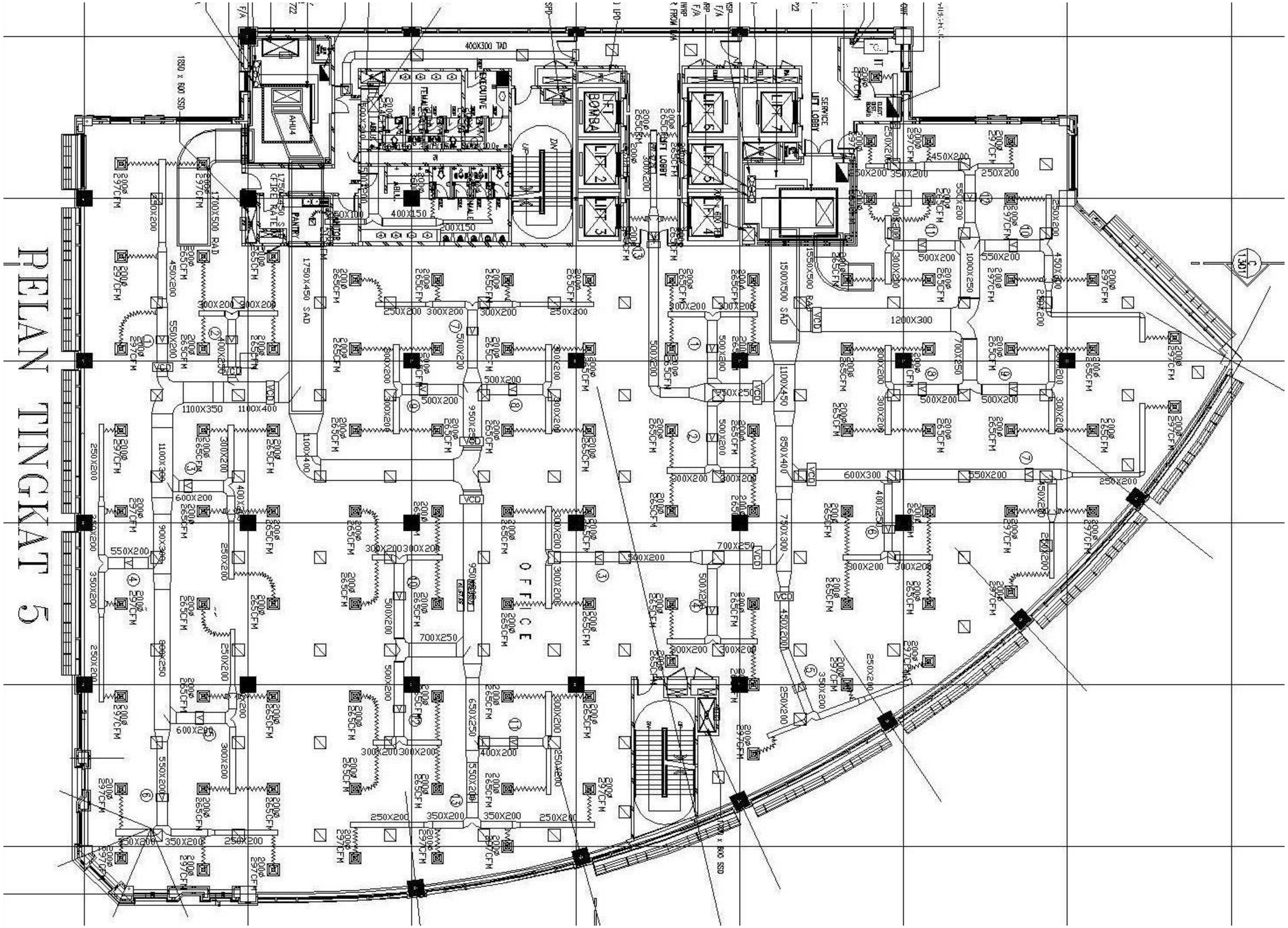


Figure 2-31: The floor plan of Level 5, North Tower, Menara Sri Wilayah

Table 2-12: Annual energy consumption and potential energy saving of the conditioned spaces when set point temperature is changed

No.	Set Point Temperature	Set Point Temperature	Set Point Temperature Different	Set Point Temperature Different	Energy Consumption in one year (cooling coil load)	Energy Saving by changing set point temperature	Energy saving by percentage
1	70.0 °F	21.1 °C	-3.5 °F	-1.9 °C	3,135,886 kBtu	-297,354 kBtu	-10.5%
2	70.5 °F	21.4 °C	-3.0 °F	-1.7 °C	3,093,635 kBtu	-255,103 kBtu	-9.0%
3	71.0 °F	21.7 °C	-2.5 °F	-1.4 °C	3,051,978 kBtu	-213,446 kBtu	-7.5%
4	71.5 °F	21.9 °C	-2.0 °F	-1.1 °C	3,009,391 kBtu	-170,859 kBtu	-6.0%
5	72.0 °F	22.2 °C	-1.5 °F	-0.8 °C	2,966,774 kBtu	-128,242 kBtu	-4.5%
6	72.5 °F	22.5 °C	-1.0 °F	-0.6 °C	2,924,482 kBtu	-85,950 kBtu	-3.0%
7	73.0 °F	22.8 °C	-0.5 °F	-0.3 °C	2,881,618 kBtu	-43,086 kBtu	-1.5%
8	73.5 °F*	23.1 °C*	0.0 °F	0.0 °C	2,838,532 kBtu	0 kBtu	0.0%
9	74.0 °F	23.3 °C	0.5 °F	0.3 °C	2,795,719 kBtu	42,813 kBtu	1.5%
10	74.5 °F	23.6 °C	1.0 °F	0.6 °C	2,751,949 kBtu	86,583 kBtu	3.1%
11	75.0 °F	23.9 °C	1.5 °F	0.8 °C	2,708,003 kBtu	130,529 kBtu	4.6%
12	75.5 °F	24.2 °C	2.0 °F	1.1 °C	2,663,501 kBtu	175,031 kBtu	6.2%
13	76.0 °F	24.4 °C	2.5 °F	1.4 °C	2,618,785 kBtu	219,747 kBtu	7.7%
14	76.5 °F	24.7 °C	3.0 °F	1.7 °C	2,573,362 kBtu	265,170 kBtu	9.3%
15	77.0 °F	25.0 °C	3.5 °F	1.9 °C	2,528,672 kBtu	309,860 kBtu	10.9%
16	77.5 °F	25.3 °C	4.0 °F	2.2 °C	2,483,180 kBtu	355,352 kBtu	12.5%
17	78.0 °F	25.6 °C	4.5 °F	2.5 °C	2,437,754 kBtu	400,778 kBtu	14.1%

*current set point temperature for Level 5 Menara Sri Wilayah

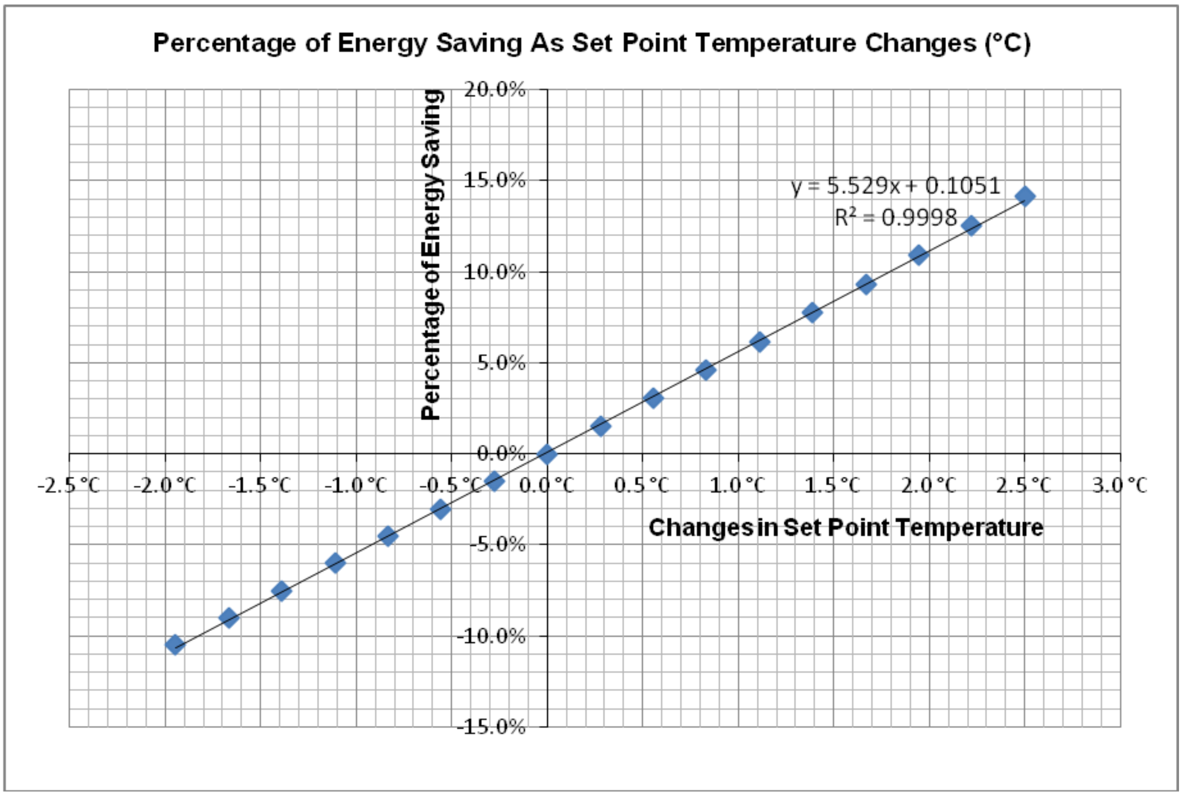


Figure 2-32: Percentage of annual energy saving as set-point temperature of Level 5, the North Tower changes

These simulations (*table 2-12*) suggest that the HVAC system of level 5 of the North Tower with its current indoor set-point temperature consumes 2,838,532 kBtu per annum. Raising something like the set-point temperature by 0.5°F (*about 0.3°C*) could potentially save about 43,770 to 45,492 kBtu per annum annual. Figure 2-32 shows a positive linear increase in energy saving with indoor set-point temperature.

The same date, 7th June 2010, was also selected for the hourly simulation, but this time the current real indoor set-point temperature of the level 5 was set to 23.1°C. Other than that the same temperatures were input as the previous case study. Figure 2-33 and Figure 2-34 shows thermostat value in relation with time during the analysis day for the ramp and cyclic mode of indoor set-point temperature respectively. The hourly energy consumption simulation reports of all indoor set-point temperatures involving all modes were analysed and tabled as shown in Table 2-13 and Table 2-14. Table 2-15 and Figure 2-35 show examples of the hourly energy consumption simulation report generated for indoor set-point temperature value of 23.1°C.

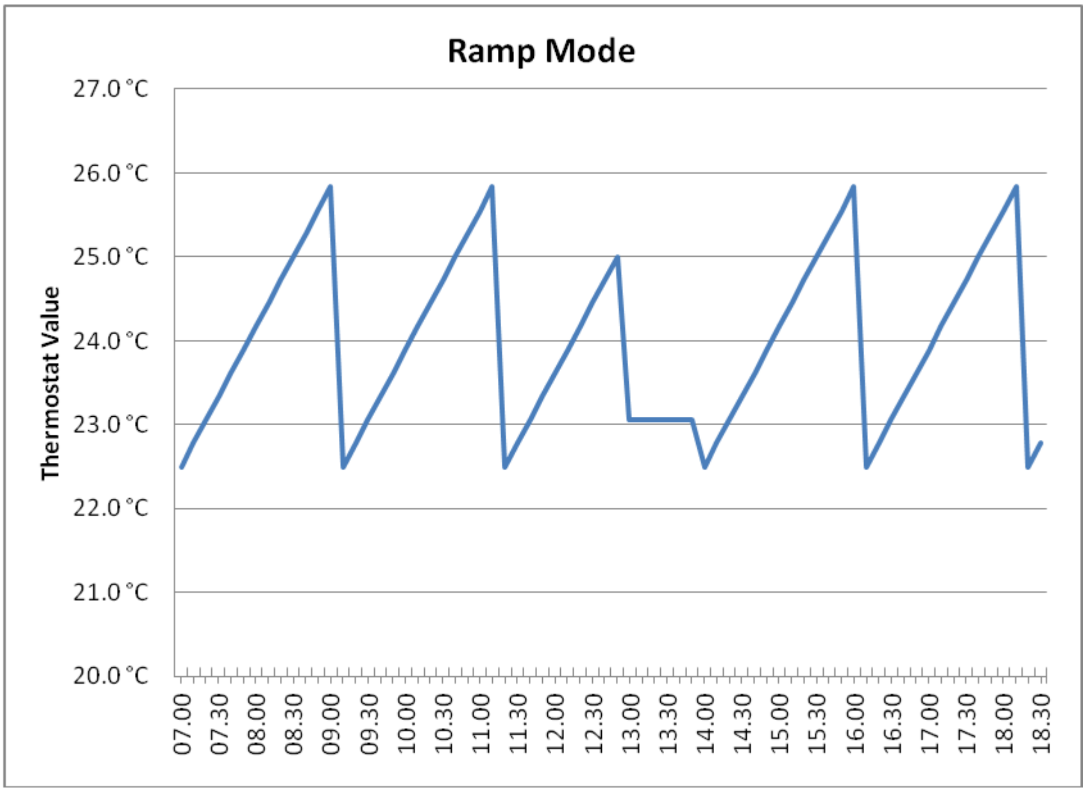


Figure 2-33: Thermostat value of Menara Sri Wilayah energy simulation in relation with time during the analysis day for the ramp mode

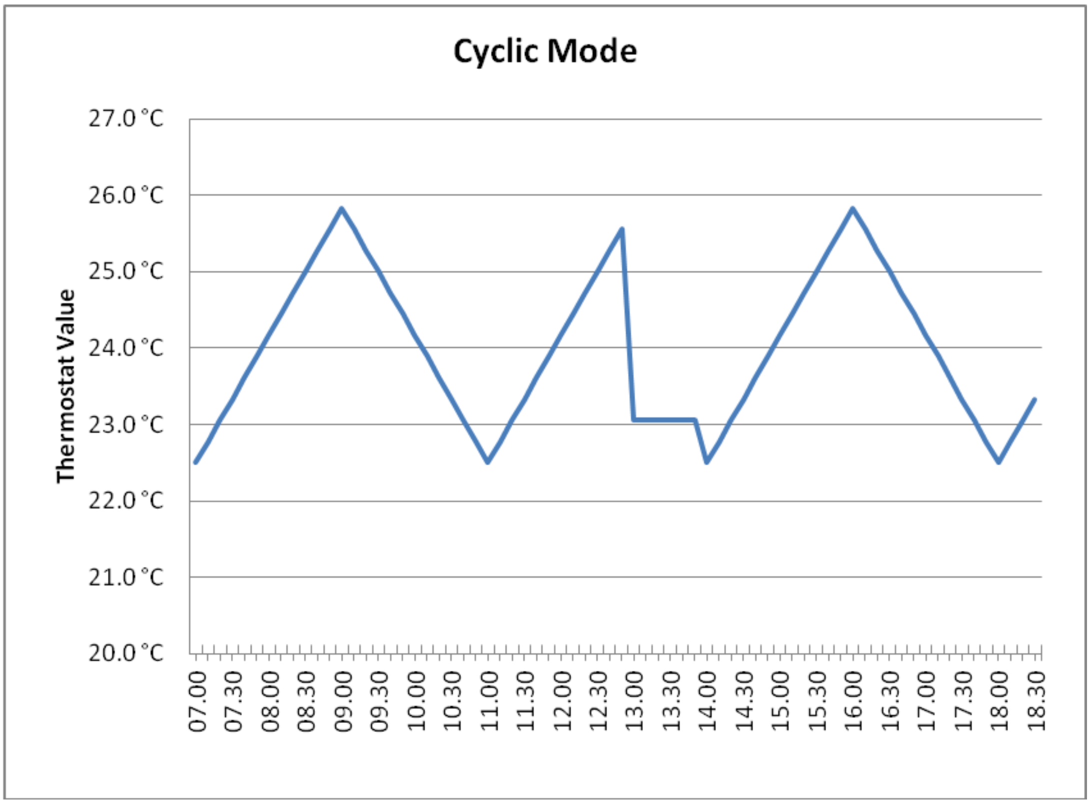


Figure 2-34: Thermostat value of Menara Sri Wilayah energy simulation in relation with time during the analysis day for the cyclic mode

No	Operation Time	Constant Set Point Temperature	Constant Set Point Temperature	Ramps set point temperature	Ramps set point temperature	Cooling Coil Load (constant)	Cooling Coil Load (ramps)	Potential Energy Savings	Percentage Potential Energy Savings
1	07.00	23.1 °C	73.5 °F	22.5 °C	72.5 °F	-	-	-	-
2	07.10	23.1 °C	73.5 °F	22.8 °C	73.0 °F	111500.0 BTU	113016.7 BTU	-1516.7 BTU	-1.4%
3	07.20	23.1 °C	73.5 °F	23.1 °C	73.5 °F	111500.0 BTU	112516.7 BTU	-1016.7 BTU	-0.9%
4	07.30	23.1 °C	73.5 °F	23.3 °C	74.0 °F	111500.0 BTU	111500.0 BTU	0.0 BTU	0.0%
5	07.40	23.1 °C	73.5 °F	23.6 °C	74.5 °F	111500.0 BTU	105750.0 BTU	5750.0 BTU	5.2%
6	07.50	23.1 °C	73.5 °F	23.9 °C	75.0 °F	111500.0 BTU	100783.3 BTU	10716.7 BTU	9.6%
7	08.00	23.1 °C	73.5 °F	24.2 °C	75.5 °F	111500.0 BTU	98916.7 BTU	12583.3 BTU	11.3%
8	08.10	23.1 °C	73.5 °F	24.4 °C	76.0 °F	125733.3 BTU	116116.7 BTU	9616.7 BTU	7.6%
9	08.20	23.1 °C	73.5 °F	24.7 °C	76.5 °F	125733.3 BTU	113900.0 BTU	11833.3 BTU	9.4%
10	08.30	23.1 °C	73.5 °F	25.0 °C	77.0 °F	125733.3 BTU	110516.7 BTU	15216.7 BTU	12.1%
11	08.40	23.1 °C	73.5 °F	25.3 °C	77.5 °F	125733.3 BTU	108083.3 BTU	17650.0 BTU	14.0%
12	08.50	23.1 °C	73.5 °F	25.6 °C	78.0 °F	125733.3 BTU	105700.0 BTU	20033.3 BTU	15.9%
13	09.00	23.1 °C	73.5 °F	25.8 °C	78.5 °F	125733.3 BTU	103450.0 BTU	22283.3 BTU	17.7%
14	09.10	23.1 °C	73.5 °F	22.5 °C	72.5 °F	142150.0 BTU	116616.7 BTU	25533.3 BTU	18.0%
15	09.20	23.1 °C	73.5 °F	22.8 °C	73.0 °F	142150.0 BTU	146233.3 BTU	-4083.3 BTU	-2.9%
16	09.30	23.1 °C	73.5 °F	23.1 °C	73.5 °F	142150.0 BTU	145516.7 BTU	-3366.7 BTU	-2.4%
17	09.40	23.1 °C	73.5 °F	23.3 °C	74.0 °F	142150.0 BTU	142150.0 BTU	0.0 BTU	0.0%
18	09.50	23.1 °C	73.5 °F	23.6 °C	74.5 °F	142150.0 BTU	139700.0 BTU	2450.0 BTU	1.7%
19	10.00	23.1 °C	73.5 °F	23.9 °C	75.0 °F	142150.0 BTU	138183.3 BTU	3966.7 BTU	2.8%
20	10.10	23.1 °C	73.5 °F	24.2 °C	75.5 °F	141616.7 BTU	134983.3 BTU	6633.3 BTU	4.7%
21	10.20	23.1 °C	73.5 °F	24.4 °C	76.0 °F	141616.7 BTU	134883.3 BTU	6733.3 BTU	4.8%
22	10.30	23.1 °C	73.5 °F	24.7 °C	76.5 °F	141616.7 BTU	130483.3 BTU	11133.3 BTU	7.9%
23	10.40	23.1 °C	73.5 °F	25.0 °C	77.0 °F	141616.7 BTU	128900.0 BTU	12716.7 BTU	9.0%
24	10.50	23.1 °C	73.5 °F	25.3 °C	77.5 °F	141616.7 BTU	126833.3 BTU	14783.3 BTU	10.4%
25	11.00	23.1 °C	73.5 °F	25.6 °C	78.0 °F	141616.7 BTU	124783.3 BTU	16833.3 BTU	11.9%
26	11.10	23.1 °C	73.5 °F	25.8 °C	78.5 °F	147366.7 BTU	126083.3 BTU	21283.3 BTU	14.4%
27	11.20	23.1 °C	73.5 °F	22.5 °C	72.5 °F	147366.7 BTU	124566.7 BTU	22800.0 BTU	15.5%
28	11.30	23.1 °C	73.5 °F	22.8 °C	73.0 °F	147366.7 BTU	149900.0 BTU	-2533.3 BTU	-1.7%
29	11.40	23.1 °C	73.5 °F	23.1 °C	73.5 °F	147366.7 BTU	146333.3 BTU	1033.3 BTU	0.7%
30	11.50	23.1 °C	73.5 °F	23.3 °C	74.0 °F	147366.7 BTU	147366.7 BTU	0.0 BTU	0.0%
31	12.00	23.1 °C	73.5 °F	23.6 °C	74.5 °F	147366.7 BTU	143733.3 BTU	3633.3 BTU	2.5%
32	12.10	23.1 °C	73.5 °F	23.9 °C	75.0 °F	136450.0 BTU	136716.7 BTU	-266.7 BTU	-0.2%
33	12.20	23.1 °C	73.5 °F	24.2 °C	75.5 °F	136450.0 BTU	131316.7 BTU	5133.3 BTU	3.8%
34	12.30	23.1 °C	73.5 °F	24.4 °C	76.0 °F	136450.0 BTU	129516.7 BTU	6933.3 BTU	5.1%
35	12.40	23.1 °C	73.5 °F	24.7 °C	76.5 °F	136450.0 BTU	126916.7 BTU	9533.3 BTU	7.0%
36	12.50	23.1 °C	73.5 °F	25.0 °C	77.0 °F	136450.0 BTU	124966.7 BTU	11483.3 BTU	8.4%
37	13.00	23.1 °C	73.5 °F	23.1 °C	73.5 °F	136450.0 BTU	125966.7 BTU	10483.3 BTU	7.7%
38	13.10	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
39	13.20	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
40	13.30	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
41	13.40	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
42	13.50	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
43	14.00	23.1 °C	73.5 °F	22.5 °C	72.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
44	14.10	23.1 °C	73.5 °F	22.8 °C	73.0 °F	132716.7 BTU	136000.0 BTU	-3283.3 BTU	-2.5%
45	14.20	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132716.7 BTU	137133.3 BTU	-4416.7 BTU	-3.3%
46	14.30	23.1 °C	73.5 °F	23.3 °C	74.0 °F	132716.7 BTU	132716.7 BTU	0.0 BTU	0.0%
47	14.40	23.1 °C	73.5 °F	23.6 °C	74.5 °F	132716.7 BTU	133533.3 BTU	-816.7 BTU	-0.6%
48	14.50	23.1 °C	73.5 °F	23.9 °C	75.0 °F	132716.7 BTU	131550.0 BTU	1166.7 BTU	0.9%
49	15.00	23.1 °C	73.5 °F	24.2 °C	75.5 °F	132716.7 BTU	129666.7 BTU	3050.0 BTU	2.3%
50	15.10	23.1 °C	73.5 °F	24.4 °C	76.0 °F	139983.3 BTU	132316.7 BTU	7666.7 BTU	5.5%
51	15.20	23.1 °C	73.5 °F	24.7 °C	76.5 °F	139983.3 BTU	129666.7 BTU	10316.7 BTU	7.4%
52	15.30	23.1 °C	73.5 °F	25.0 °C	77.0 °F	139983.3 BTU	127883.3 BTU	12100.0 BTU	8.6%
53	15.40	23.1 °C	73.5 °F	25.3 °C	77.5 °F	139983.3 BTU	125700.0 BTU	14283.3 BTU	10.2%
54	15.50	23.1 °C	73.5 °F	25.6 °C	78.0 °F	139983.3 BTU	122566.7 BTU	17416.7 BTU	12.4%
55	16.00	23.1 °C	73.5 °F	25.8 °C	78.5 °F	139983.3 BTU	124183.3 BTU	15800.0 BTU	11.3%
56	16.10	23.1 °C	73.5 °F	22.5 °C	72.5 °F	143200.0 BTU	122100.0 BTU	21100.0 BTU	14.7%
57	16.20	23.1 °C	73.5 °F	22.8 °C	73.0 °F	143200.0 BTU	146866.7 BTU	-3666.7 BTU	-2.6%
58	16.30	23.1 °C	73.5 °F	23.1 °C	73.5 °F	143200.0 BTU	145483.3 BTU	-2283.3 BTU	-1.6%
59	16.40	23.1 °C	73.5 °F	23.3 °C	74.0 °F	143200.0 BTU	143200.0 BTU	0.0 BTU	0.0%
60	16.50	23.1 °C	73.5 °F	23.6 °C	74.5 °F	143200.0 BTU	141383.3 BTU	1816.7 BTU	1.3%
61	17.00	23.1 °C	73.5 °F	23.9 °C	75.0 °F	143200.0 BTU	139550.0 BTU	3650.0 BTU	2.5%
62	17.10	23.1 °C	73.5 °F	24.2 °C	75.5 °F	134450.0 BTU	129283.3 BTU	5166.7 BTU	3.8%
63	17.20	23.1 °C	73.5 °F	24.4 °C	76.0 °F	134450.0 BTU	128050.0 BTU	6400.0 BTU	4.8%
64	17.30	23.1 °C	73.5 °F	24.7 °C	76.5 °F	134450.0 BTU	125683.3 BTU	8766.7 BTU	6.5%
65	17.40	23.1 °C	73.5 °F	25.0 °C	77.0 °F	134450.0 BTU	123833.3 BTU	10616.7 BTU	7.9%
66	17.50	23.1 °C	73.5 °F	25.3 °C	77.5 °F	134450.0 BTU	124066.7 BTU	10383.3 BTU	7.7%
67	18.00	23.1 °C	73.5 °F	25.6 °C	78.0 °F	134450.0 BTU	120900.0 BTU	13550.0 BTU	10.1%
68	18.10	23.1 °C	73.5 °F	25.8 °C	78.5 °F	123366.7 BTU	106933.3 BTU	16433.3 BTU	13.3%
69	18.20	23.1 °C	73.5 °F	22.5 °C	72.5 °F	123366.7 BTU	103200.0 BTU	20166.7 BTU	16.3%
70	18.30	23.1 °C	73.5 °F	22.8 °C	73.0 °F	123366.7 BTU	124250.0 BTU	-883.3 BTU	-0.7%
					Total =	**9,294,000.0 Btu**	**8,803,500.00 Btu**	**490,500.00 Btu**	**5.3%**
						2,723.1 kWh	**2,579.4 kWh**	**143.7 kWh**	**5.3%**

Table 2-13: GDC HVAC System energy simulation analysis with E20II HAP of ramp mode set-point temperature at level 5, North Tower, Menara Sri Wilayah (07 June 2010)

No	Operation Time	Constant Set Point Temperature	Constant Set Point Temperature	Cyclic set point temperature	Cyclic set point temperature	Cooling Coil Load (constant)	Cooling Coil Load (ramps)	Potential Energy Savings	Percentage Potential Energy Savings
1	07.00	23.1 °C	73.5 °F	22.5 °C	72.5 °F	-	-	-	-
2	07.10	23.1 °C	73.5 °F	22.8 °C	73.0 °F	111500.0 BTU	113016.7 BTU	-1516.7 BTU	-1.4%
3	07.20	23.1 °C	73.5 °F	23.1 °C	73.5 °F	111500.0 BTU	112516.7 BTU	-1016.7 BTU	-0.9%
4	07.30	23.1 °C	73.5 °F	23.3 °C	74.0 °F	111500.0 BTU	111500.0 BTU	0.0 BTU	0.0%
5	07.40	23.1 °C	73.5 °F	23.6 °C	74.5 °F	111500.0 BTU	105750.0 BTU	5750.0 BTU	5.2%
6	07.50	23.1 °C	73.5 °F	23.9 °C	75.0 °F	111500.0 BTU	100783.3 BTU	10716.7 BTU	9.6%
7	08.00	23.1 °C	73.5 °F	24.2 °C	75.5 °F	111500.0 BTU	98916.7 BTU	12583.3 BTU	11.3%
8	08.10	23.1 °C	73.5 °F	24.4 °C	76.0 °F	125733.3 BTU	116116.7 BTU	9616.7 BTU	7.6%
9	08.20	23.1 °C	73.5 °F	24.7 °C	76.5 °F	125733.3 BTU	113900.0 BTU	11833.3 BTU	9.4%
10	08.30	23.1 °C	73.5 °F	25.0 °C	77.0 °F	125733.3 BTU	110516.7 BTU	15216.7 BTU	12.1%
11	08.40	23.1 °C	73.5 °F	25.3 °C	77.5 °F	125733.3 BTU	108083.3 BTU	17650.0 BTU	14.0%
12	08.50	23.1 °C	73.5 °F	25.6 °C	78.0 °F	125733.3 BTU	105700.0 BTU	20033.3 BTU	15.9%
13	09.00	23.1 °C	73.5 °F	25.8 °C	78.5 °F	125733.3 BTU	103450.0 BTU	22283.3 BTU	17.7%
14	09.10	23.1 °C	73.5 °F	25.6 °C	78.0 °F	142150.0 BTU	116616.7 BTU	25533.3 BTU	18.0%
15	09.20	23.1 °C	73.5 °F	25.3 °C	77.5 °F	142150.0 BTU	117050.0 BTU	25100.0 BTU	17.7%
16	09.30	23.1 °C	73.5 °F	25.0 °C	77.0 °F	142150.0 BTU	119633.3 BTU	22516.7 BTU	15.8%
17	09.40	23.1 °C	73.5 °F	24.7 °C	76.5 °F	142150.0 BTU	122533.3 BTU	19616.7 BTU	13.8%
18	09.50	23.1 °C	73.5 °F	24.4 °C	76.0 °F	142150.0 BTU	125433.3 BTU	16716.7 BTU	11.8%
19	10.00	23.1 °C	73.5 °F	24.2 °C	75.5 °F	142150.0 BTU	131783.3 BTU	10366.7 BTU	7.3%
20	10.10	23.1 °C	73.5 °F	23.9 °C	75.0 °F	141616.7 BTU	134883.3 BTU	6733.3 BTU	4.8%
21	10.20	23.1 °C	73.5 °F	23.6 °C	74.5 °F	141616.7 BTU	134983.3 BTU	6633.3 BTU	4.7%
22	10.30	23.1 °C	73.5 °F	23.3 °C	74.0 °F	141616.7 BTU	137850.0 BTU	3766.7 BTU	2.7%
23	10.40	23.1 °C	73.5 °F	23.1 °C	73.5 °F	141616.7 BTU	139816.7 BTU	1800.0 BTU	1.3%
24	10.50	23.1 °C	73.5 °F	22.8 °C	73.0 °F	141616.7 BTU	141616.7 BTU	0.0 BTU	0.0%
25	11.00	23.1 °C	73.5 °F	22.5 °C	72.5 °F	141616.7 BTU	144883.3 BTU	-3266.7 BTU	-2.3%
26	11.10	23.1 °C	73.5 °F	22.8 °C	73.0 °F	147366.7 BTU	149900.0 BTU	-2533.3 BTU	-1.7%
27	11.20	23.1 °C	73.5 °F	23.1 °C	73.5 °F	147366.7 BTU	146333.3 BTU	1033.3 BTU	0.7%
28	11.30	23.1 °C	73.5 °F	23.3 °C	74.0 °F	147366.7 BTU	147366.7 BTU	0.0 BTU	0.0%
29	11.40	23.1 °C	73.5 °F	23.6 °C	74.5 °F	147366.7 BTU	143733.3 BTU	3633.3 BTU	2.5%
30	11.50	23.1 °C	73.5 °F	23.9 °C	75.0 °F	147366.7 BTU	142316.7 BTU	5050.0 BTU	3.4%
31	12.00	23.1 °C	73.5 °F	24.2 °C	75.5 °F	147366.7 BTU	140466.7 BTU	6900.0 BTU	4.7%
32	12.10	23.1 °C	73.5 °F	24.4 °C	76.0 °F	136450.0 BTU	129516.7 BTU	6933.3 BTU	5.1%
33	12.20	23.1 °C	73.5 °F	24.7 °C	76.5 °F	136450.0 BTU	126916.7 BTU	9533.3 BTU	7.0%
34	12.30	23.1 °C	73.5 °F	25.0 °C	77.0 °F	136450.0 BTU	124966.7 BTU	11483.3 BTU	8.4%
35	12.40	23.1 °C	73.5 °F	25.3 °C	77.5 °F	136450.0 BTU	125966.7 BTU	10483.3 BTU	7.7%
36	12.50	23.1 °C	73.5 °F	25.6 °C	78.0 °F	136450.0 BTU	122500.0 BTU	13950.0 BTU	10.2%
37	13.00	23.1 °C	73.5 °F	23.1 °C	73.5 °F	136450.0 BTU	117250.0 BTU	19200.0 BTU	14.1%
38	13.10	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
39	13.20	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
40	13.30	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
41	13.40	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
42	13.50	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
43	14.00	23.1 °C	73.5 °F	22.5 °C	72.5 °F	132150.0 BTU	132150.0 BTU	0.0 BTU	0.0%
44	14.10	23.1 °C	73.5 °F	22.8 °C	73.0 °F	132716.7 BTU	136000.0 BTU	-3283.3 BTU	-2.5%
45	14.20	23.1 °C	73.5 °F	23.1 °C	73.5 °F	132716.7 BTU	137133.3 BTU	-4416.7 BTU	-3.3%
46	14.30	23.1 °C	73.5 °F	23.3 °C	74.0 °F	132716.7 BTU	132716.7 BTU	0.0 BTU	0.0%
47	14.40	23.1 °C	73.5 °F	23.6 °C	74.5 °F	132716.7 BTU	133533.3 BTU	-816.7 BTU	-0.6%
48	14.50	23.1 °C	73.5 °F	23.9 °C	75.0 °F	132716.7 BTU	131550.0 BTU	1166.7 BTU	0.9%
49	15.00	23.1 °C	73.5 °F	24.2 °C	75.5 °F	132716.7 BTU	129666.7 BTU	3050.0 BTU	2.3%
50	15.10	23.1 °C	73.5 °F	24.4 °C	76.0 °F	139983.3 BTU	132316.7 BTU	7666.7 BTU	5.5%
51	15.20	23.1 °C	73.5 °F	24.7 °C	76.5 °F	139983.3 BTU	129666.7 BTU	10316.7 BTU	7.4%
52	15.30	23.1 °C	73.5 °F	25.0 °C	77.0 °F	139983.3 BTU	127883.3 BTU	12100.0 BTU	8.6%
53	15.40	23.1 °C	73.5 °F	25.3 °C	77.5 °F	139983.3 BTU	125700.0 BTU	14283.3 BTU	10.2%
54	15.50	23.1 °C	73.5 °F	25.6 °C	78.0 °F	139983.3 BTU	122566.7 BTU	17416.7 BTU	12.4%
55	16.00	23.1 °C	73.5 °F	25.8 °C	78.5 °F	139983.3 BTU	124183.3 BTU	15800.0 BTU	11.3%
56	16.10	23.1 °C	73.5 °F	25.6 °C	78.0 °F	143200.0 BTU	122100.0 BTU	21100.0 BTU	14.7%
57	16.20	23.1 °C	73.5 °F	25.3 °C	77.5 °F	143200.0 BTU	122533.3 BTU	20666.7 BTU	14.4%
58	16.30	23.1 °C	73.5 °F	25.0 °C	77.0 °F	143200.0 BTU	124916.7 BTU	18283.3 BTU	12.8%
59	16.40	23.1 °C	73.5 °F	24.7 °C	76.5 °F	143200.0 BTU	129433.3 BTU	13766.7 BTU	9.6%
60	16.50	23.1 °C	73.5 °F	24.4 °C	76.0 °F	143200.0 BTU	131600.0 BTU	11600.0 BTU	8.1%
61	17.00	23.1 °C	73.5 °F	24.2 °C	75.5 °F	143200.0 BTU	133383.3 BTU	9816.7 BTU	6.9%
62	17.10	23.1 °C	73.5 °F	23.9 °C	75.0 °F	134450.0 BTU	128050.0 BTU	6400.0 BTU	4.8%
63	17.20	23.1 °C	73.5 °F	23.6 °C	74.5 °F	134450.0 BTU	129283.3 BTU	5166.7 BTU	3.8%
64	17.30	23.1 °C	73.5 °F	23.3 °C	74.0 °F	134450.0 BTU	133500.0 BTU	950.0 BTU	0.7%
65	17.40	23.1 °C	73.5 °F	23.1 °C	73.5 °F	134450.0 BTU	132450.0 BTU	2000.0 BTU	1.5%
66	17.50	23.1 °C	73.5 °F	22.8 °C	73.0 °F	134450.0 BTU	124066.7 BTU	10383.3 BTU	7.7%
67	18.00	23.1 °C	73.5 °F	22.5 °C	72.5 °F	134450.0 BTU	134383.3 BTU	66.7 BTU	0.0%
68	18.10	23.1 °C	73.5 °F	22.8 °C	73.0 °F	123366.7 BTU	124250.0 BTU	-883.3 BTU	-0.7%
69	18.20	23.1 °C	73.5 °F	23.1 °C	73.5 °F	123366.7 BTU	125316.7 BTU	-1950.0 BTU	-1.6%
70	18.30	23.1 °C	73.5 °F	23.3 °C	74.0 °F	123366.7 BTU	123366.7 BTU	0.0 BTU	0.0%
					Total	**9,294,000.0 Btu**	**8,759,016.67 Btu**	**534,983.33 Btu**	**5.8%**
						2,723.1 kWh	**2,566.4 kWh**	**156.7 kWh**	**5.8%**

Table 2-14: GDC HVAC System energy simulation analysis with E20II HAP of cyclic mode set-point temperature at Level 5, North Tower, Menara Sri Wilayah (07 June 2010)

Hourly Air System Simulation Results for Monday, June 7

Hour	Central Cooling Coil Load (MBH)	Supply Fan (kW)	Lighting (kW)	Electric Equipment (kW)
0000	0.0	0.0	0.0	2.8
0100	0.0	0.0	0.0	2.8
0200	0.0	0.0	0.0	2.8
0300	0.0	0.0	0.0	2.8
0400	0.0	0.0	0.0	2.8
0500	0.0	0.0	0.0	2.8
0600	0.0	0.0	0.0	2.3
0700	669.0	79.8	10.5	7.9
0800	754.4	79.8	20.2	16.5
0900	852.9	79.8	20.2	34.0
1000	849.7	79.8	20.2	34.6
1100	884.2	79.8	20.2	34.6
1200	818.7	79.8	16.2	23.3
1300	792.9	79.8	10.1	28.4
1400	796.3	79.8	10.1	22.7
1500	839.9	79.8	16.2	22.1
1600	859.2	79.8	16.2	34.6
1700	806.7	79.8	18.2	34.6
1800	740.2	79.8	20.2	17.6
1900	679.0	79.8	12.5	17.6
2000	0.0	0.0	10.5	17.6
2100	0.0	0.0	10.1	3.4
2200	0.0	0.0	10.5	3.4
2300	0.0	0.0	0.0	2.8
Total	**10343.2**	**1037.4**	**242.0**	**375.0**

Table 2-15: An Example of Hourly HVAC System Simulation Results at a thermostat value of 23.1°C

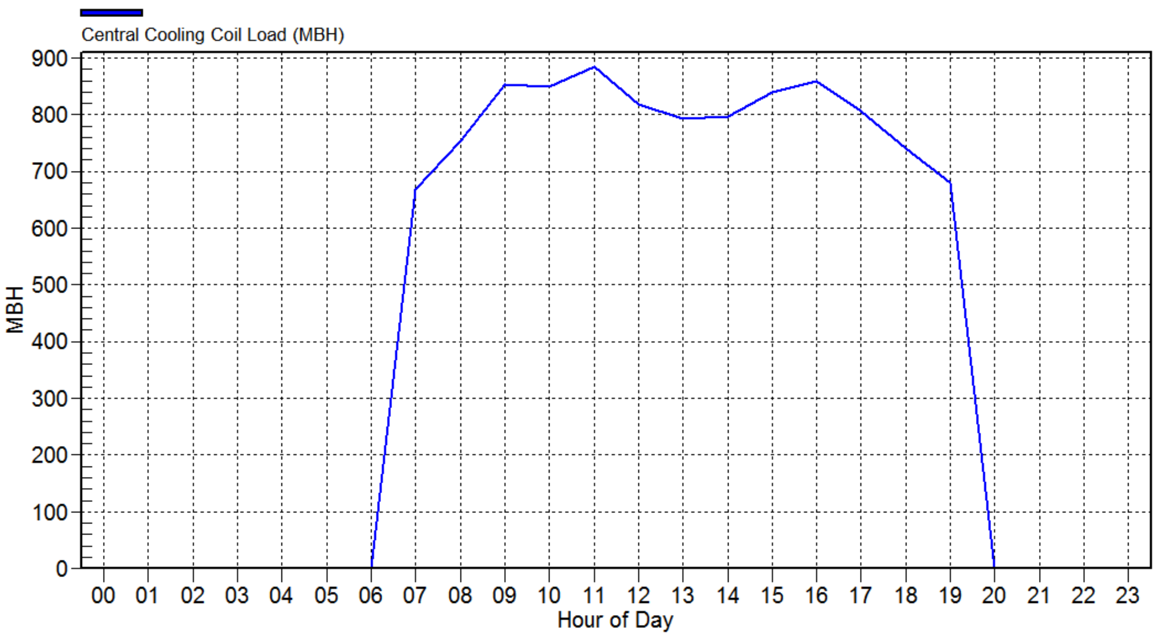


Figure 2-35: Hourly Simulation report in graph form at a thermostat value of 23.1°C, 7th June, through Monday

From Table 2-13 and Table 2-14, it is clear that adopting either a ramp or a cyclic mode would potentially require less energy than with a conventional fixed indoor set-point temperature. For one day, the total cooling coil load with a fixed indoor set-point temperature was 9,294,000 Btu, compared with a ramp mode in Table 2-13 was 8,803,500 Btu respectively. Hence, potential energy saving when the ramp mode is applied to the conditioned spaces in Level 5 of North Tower, Menara Sri Wilayah is 490,500 Btu per day which is about 5.3% energy consumption improvement. Similarly in Table 2-14, the total cooling coil load obtained with a fixed mode indoor set-point temperature is observed to be higher than that obtained with the cyclic mode. The total cooling coil load predicted when the indoor set-point temperature was varied cyclically is 8,759,016.67 Btu. Hence, potential energy saving when the cyclic mode is applied to the conditioned spaces in the spaces is 534,983.33 Btu per day which is about 5.8% improvement of energy consumption. These results also show that cyclic mode of indoor set-point temperature has the highest potential in improvement of HVAC energy consumption as compared to the fixed and the ramp mode. However the difference in energy saving between these two dynamic modes is very small and insignificant.

2.7 Case Study 3: Legal Affairs Division Office (BHEUU)

Legal Affairs Division Office also known as BHEUU is located in Presint 3, Wilayah Persekutuan Putrajaya, Malaysia and was selected for case study 3. BHEUU is a 10 storey building with mainly as offices. HVAC System configuration in this building is very similar to that in Menara Sri Wilayah. This building has a Centralised Air-conditioning Chilled Water System, which also is part of the Putrajaya Gas District Cooling System. Similar to other buildings in Putrajaya, the chilled water is supplied from one centralised Gas District Cooling Chiller Plant. For the air side, the air-conditioning system installed provides a Variable Air Volume System (VAV) and has one or more Air Handling Unit (AHU) installed with effective numbers of VAV Terminal in each floor. BHEUU is also installed with an intelligent Building Management System which allows the building facilities manager to monitor and control almost all electrical and mechanical systems including the HVAC System. As with the previous case studies, the energy consumption simulation analysis was only carried out for one significant section of the building, which in this case was the 6th floor. Figure 2-36 shows its floor plant.

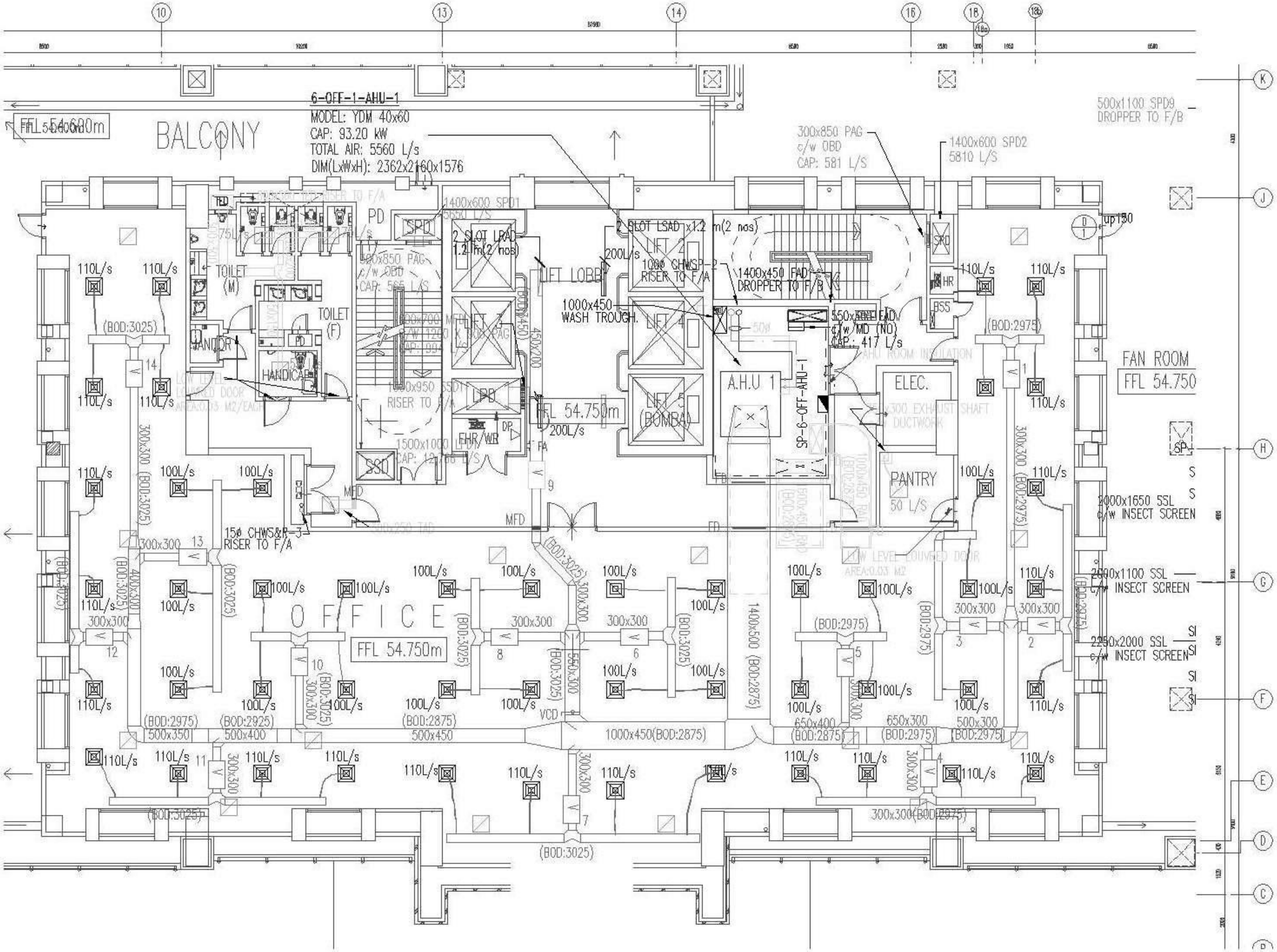


Figure 2-36: The floor plan of level 6, Legal Affairs Division Office (BHEUU)

The energy simulation analysis was conducted in the same manner as the previous studies. In the first exercise, the same thermostat values were applied, except this time the current actual indoor set-point temperature was 23.9°C. Table 2-16 shows the results of the simulation with actual indoor set-point temperature of the spaces. The results of energy simulations with all difference set-point temperatures are totalled and summarised in table 2-17. The table also shows an annual potential energy saving of the conditioned spaces when the set-point temperature is changed. In addition, data from it were used to plot a graph shown in Figure 2-37.

Monthly Simulation Results for AHU Level 6

Project Name: BHEUU
Prepared by: JKR CAWANGAN MEKANIKAL

Air System Simulation Results

Month	Central Cooling Coil Load (kBTU)	Supply Fan (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	27723	190	1901	1061
February	28619	212	1793	993
March	34168	261	2048	1129
April	29386	202	1892	1050
May	33175	241	1972	1095
June	33085	244	1963	1084
July	28851	199	1901	1061
August	31442	223	2048	1129
September	27834	186	1963	1084
October	28250	191	1901	1061
November	27513	183	1963	1084
December	28484	198	1977	1095
Total	358531	2530	23319	12923

Table 2-16: Monthly simulation results with actual indoor set-point temperature of level 6, BHEUU

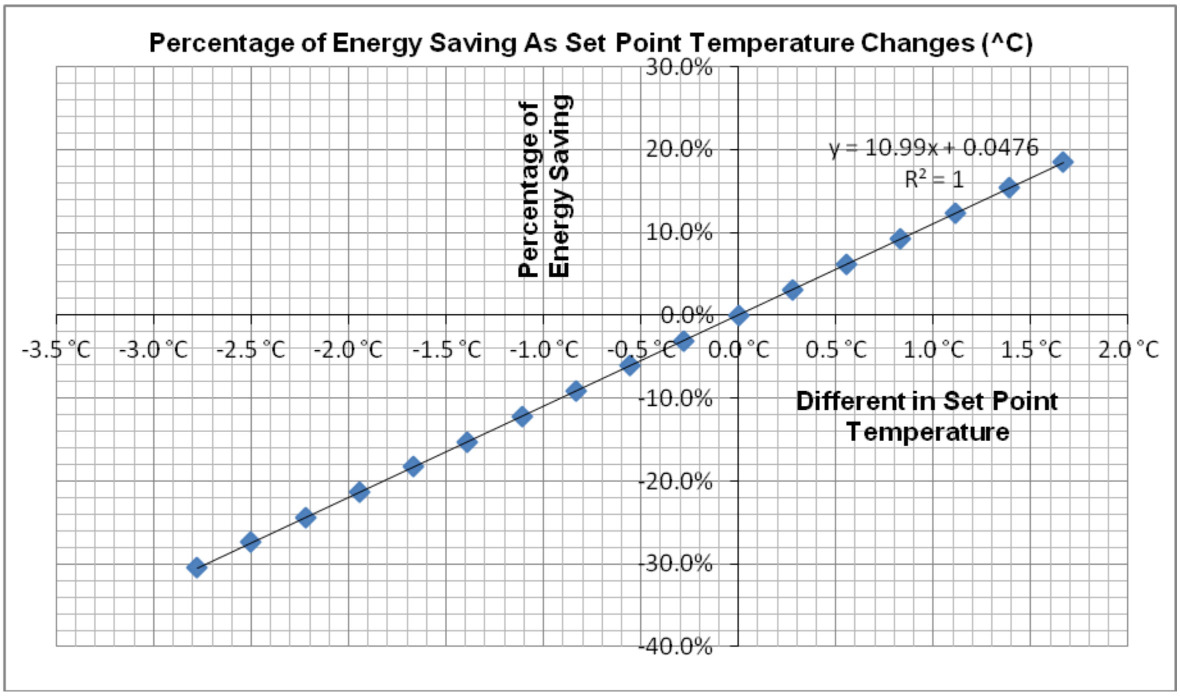


Figure 2-37: Percentage of annual energy saving as set-point temperature of Level 6, BHEUU change

No.	Set Point Temperature	Set Point Temperature	Set Point Temperature Different	Set Point Temperature Different	Energy Consumption in one year (cooling coil load)	Energy Saving by changing set point temperature	Energy saving by percentage
1	70.0 °F	21.1 °C	-5.0 °F	-2.8 °C	627,161 kBtu	-157,136 kBtu	-30.4%
2	70.5 °F	21.4 °C	-4.5 °F	-2.5 °C	611,613 kBtu	-141,588 kBtu	-27.4%
3	71.0 °F	21.7 °C	-4.0 °F	-2.2 °C	596,020 kBtu	-125,995 kBtu	-24.3%
4	71.5 °F	21.9 °C	-3.5 °F	-1.9 °C	580,386 kBtu	-110,361 kBtu	-21.3%
5	72.0 °F	22.2 °C	-3.0 °F	-1.7 °C	564,718 kBtu	-94,693 kBtu	-18.3%
6	72.5 °F	22.5 °C	-2.5 °F	-1.4 °C	549,013 kBtu	-78,988 kBtu	-15.3%
7	73.0 °F	22.8 °C	-2.0 °F	-1.1 °C	533,274 kBtu	-63,249 kBtu	-12.2%
8	73.5 °F	23.1 °C	-1.5 °F	-0.8 °C	517,504 kBtu	-47,479 kBtu	-9.2%
9	74.0 °F	23.3 °C	-1.0 °F	-0.6 °C	501,704 kBtu	-31,679 kBtu	-6.1%
10	74.5 °F	23.6 °C	-0.5 °F	-0.3 °C	485,877 kBtu	-15,852 kBtu	-3.1%
11	75.0 °F*	23.9 °C*	0.0 °F	0.0 °C	470,025 kBtu	0 kBtu	0.0%
12	75.5 °F	24.2 °C	0.5 °F	0.3 °C	454,150 kBtu	15,875 kBtu	3.1%
13	76.0 °F	24.4 °C	1.0 °F	0.6 °C	438,252 kBtu	31,773 kBtu	6.1%
14	76.5 °F	24.7 °C	1.5 °F	0.8 °C	422,336 kBtu	47,689 kBtu	9.2%
15	77.0 °F	25.0 °C	2.0 °F	1.1 °C	406,404 kBtu	63,621 kBtu	12.3%
16	77.5 °F	25.3 °C	2.5 °F	1.4 °C	390,459 kBtu	79,566 kBtu	15.4%
17	78.0 °F	25.6 °C	3.0 °F	1.7 °C	374,499 kBtu	95,526 kBtu	18.5%

*current set point temperature for Level 6 BHEUU

Table 2-17: Annual energy consumption and potential energy saving of the conditioned spaces when set point temperature is changed

Observed from (*table 2-17*), HVAC system of level 6 BHEUU with its current indoor set-point temperature has 470,025 kBtu energy consumption per annum. Rising the set-point temperature by 0.5°F (*about 0.3°C*) could potentially save about 15,875 to 15,960 kBtu annual energy consumption of the floor. The graph also shows that increase in indoor set-point temperature has a positive linear proportional relation to the energy saving percentage.

For the second exercise, the date 24th of August 2011 was selected for the hourly simulation. A part from the current real indoor set-point temperature of the level 5 which was set to 23.9°C in the simulation program, others was again similarly conducted as the previous case study. Figure 2-38 and Figure 2-39 show thermostat value in relation with time during the analysis day for the ramp and cyclic mode of indoor set-point temperature respectively. Note that the simulation analyses for this case study were carried out in a shorter period than others which was between 8.00am to 4.40pm. The ramp and cyclic modes indoor set-point temperature also were set to start at 23.9°C. The hourly energy consumption simulation reports of all indoor set-point temperatures involving all modes were analysed and tabled as shown in Table 2-19 and Table 2-20. Table 2-18 and Figure 2-40 show examples of the hourly energy consumption simulation report generated for indoor set-point temperature value of 23.9°C.

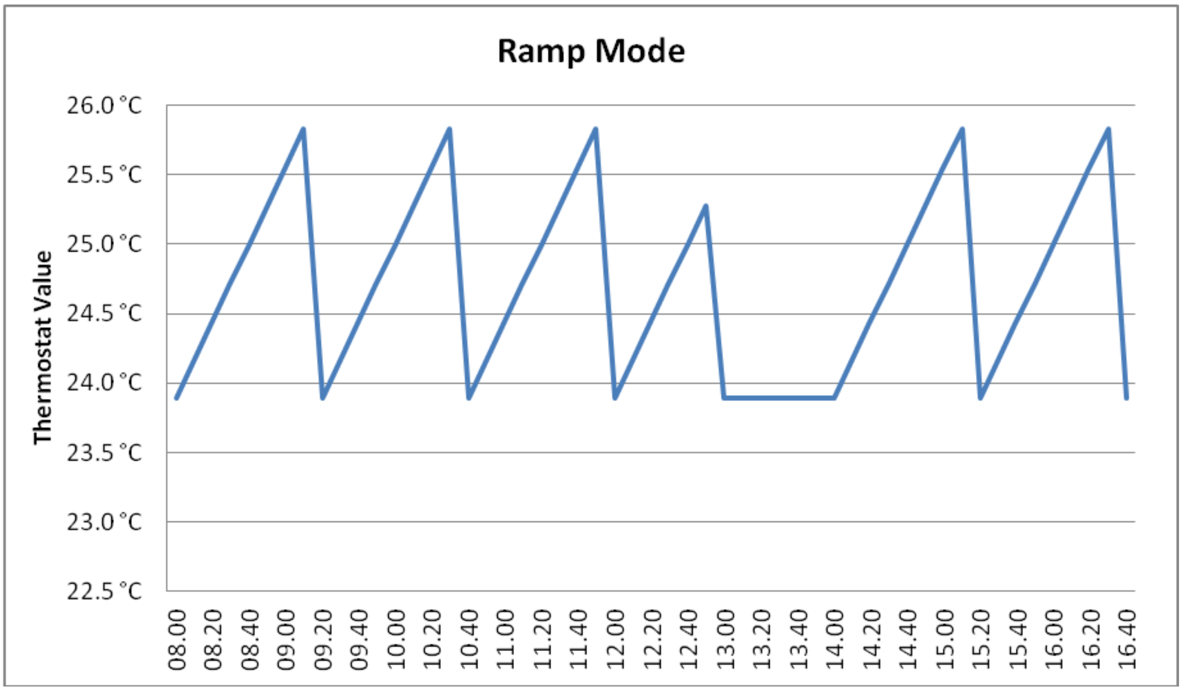


Figure 2-38: Thermostat value of level 6 BHEUU energy simulation in relation with time during the analysis day for the ramp mode

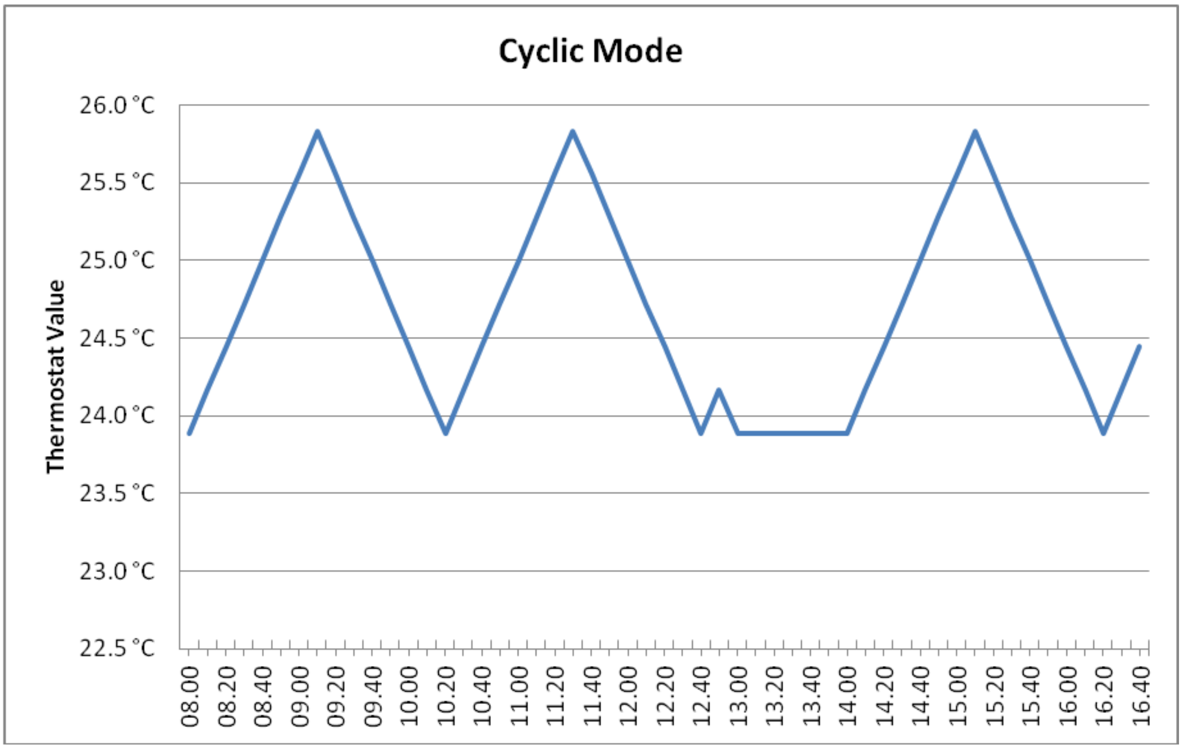


Figure 2-39: Thermostat value of level 6 BHEUU energy simulation in relation with time during the analysis day for the ramp mode

From Table 2-19 and Table 2-20, it is understandable that both ramp and cyclic modes are potentially consuming less energy than conventional fixed indoor set-point temperature. For one day, the total cooling coil load for fixed indoor set-point temperature and the ramp mode in table 2-19 are 1,198,000 Btu and 1,097,783.33 Btu respectively. Hence, potential energy saving when the ramp mode is applied to the conditioned spaces in Level 6, BHEUU is 100,216.67 Btu per day which is approximately 8.4% energy consumption improvement. Similarly in Table 2-20, total cooling coil load of fixed mode indoor set-point temperature is observed to be higher than the cyclic mode. The total cooling coil load of the cyclic mode indoor set-point temperature is 1,100,750 Btu. Hence, the potential energy saving when the cyclic mode is applied to the conditioned spaces in the spaces is 97,250.00 Btu per day, which is about 8.1% improvement of energy consumption. Compared with the previous case studies, these results show that the ramp mode of indoor set-point temperature has the highest potential in improvement of HVAC energy consumption as compared to the fixed and the cyclic mode. However the difference in energy saving between these two dynamic modes is very small and insignificant. Inconsistent of this outcome with other case studies may perhaps due to its shorter hours of the simulation analysis conducted.

Hour	Central Cooling Coil Load (MBH)	Supply Fan (kW)	Lighting (kW)	Electric Equipment (kW)
0000	0.0	0.0	0.2	0.5
0100	0.0	0.0	0.2	0.5
0200	0.0	0.0	0.2	0.5
0300	0.0	0.0	0.2	0.5
0400	0.0	0.0	0.2	0.5
0500	0.0	0.0	0.2	0.5
0600	0.0	0.0	0.2	0.5
0700	87.8	0.5	4.5	1.0
0800	113.8	0.7	9.4	1.9
0900	131.4	0.9	10.1	3.7
1000	137.2	1.0	7.3	4.7
1100	143.1	1.1	7.3	3.7
1200	148.7	1.2	6.6	4.7
1300	129.7	0.9	7.3	1.9
1400	137.2	1.0	7.3	3.7
1500	152.5	1.2	7.3	4.7
1600	156.6	1.3	7.3	4.7
1700	139.0	1.0	5.2	3.7
1800	102.2	0.7	1.7	0.9
1900	86.0	0.5	1.0	0.9
2000	0.0	0.0	0.7	0.5
2100	0.0	0.0	0.7	0.5
2200	0.0	0.0	0.3	0.5
2300	0.0	0.0	0.2	0.5
Total	1665.2	12.2	85.0	45.2

Hourly Air System Simulation Results for Wednesday, August 24

Table 2-18: An Example of Hourly HVAC System Simulation Results at a thermostat value of 23.9°C

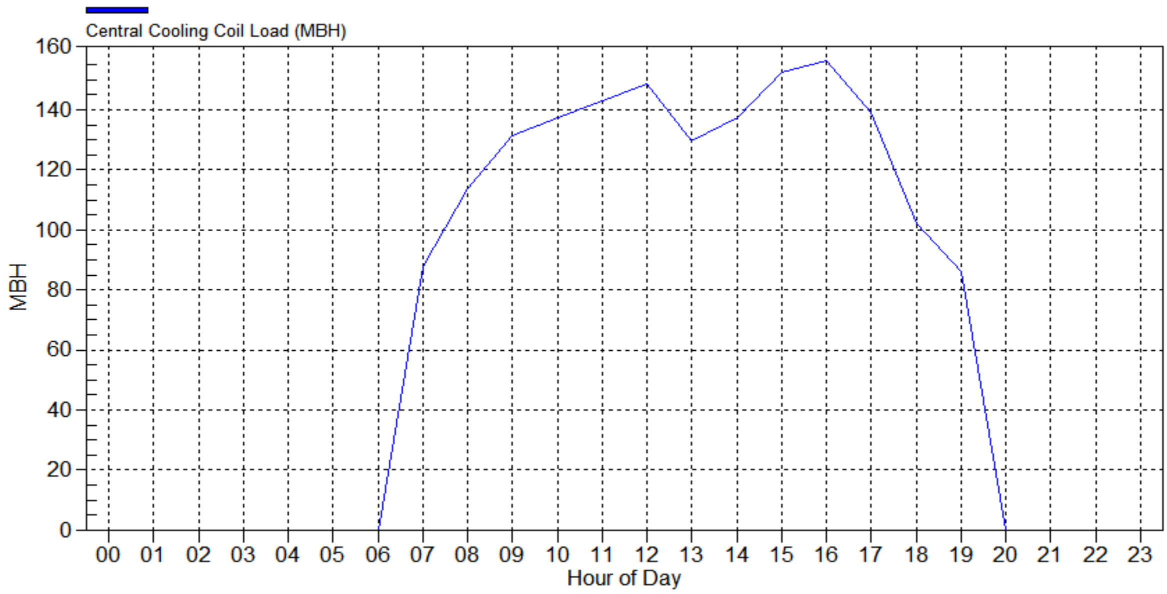


Figure 2-40: Hourly Simulation report in graph form at a thermostat value of 23.9°C, 24th August, through Wednesday

No	Operation Time	Constant Set Point Temperature	Constant Set Point Temperature	Ramps set point temperature	Ramps set point temperature	Cooling Coil Load (constant)	Cooling Coil Load (ramps)	Potential Energy Savings	Percentage Potential Energy Savings
1	08.00	23.9 °C	75.0 °F	23.9 °C	75.0 °F	-	-	-	-
2	08.10	23.9 °C	75.0 °F	24.2 °C	75.5 °F	18,966.7 Btu	18,966.7 Btu	0.0 BTU	0.0%
3	08.20	23.9 °C	75.0 °F	24.4 °C	76.0 °F	18,966.7 Btu	18,233.3 Btu	733.3 BTU	3.9%
4	08.30	23.9 °C	75.0 °F	24.7 °C	76.5 °F	18,966.7 Btu	17,516.7 Btu	1450.0 BTU	7.6%
5	08.40	23.9 °C	75.0 °F	25.0 °C	77.0 °F	18,966.7 Btu	16,783.3 Btu	2183.3 BTU	11.5%
6	08.50	23.9 °C	75.0 °F	25.3 °C	77.5 °F	18,966.7 Btu	16,066.7 Btu	2900.0 BTU	15.3%
7	09.00	23.9 °C	75.0 °F	25.6 °C	78.0 °F	18,966.7 Btu	15,333.3 Btu	3633.3 BTU	19.2%
8	09.10	23.9 °C	75.0 °F	25.8 °C	78.5 °F	21,900.0 Btu	17,666.7 Btu	4233.3 BTU	19.3%
9	09.20	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,900.0 Btu	16,966.7 Btu	4933.3 BTU	22.5%
10	09.30	23.9 °C	75.0 °F	24.2 °C	75.5 °F	21,900.0 Btu	21,900.0 Btu	0.0 BTU	0.0%
11	09.40	23.9 °C	75.0 °F	24.4 °C	76.0 °F	21,900.0 Btu	21,183.3 Btu	716.7 BTU	3.3%
12	09.50	23.9 °C	75.0 °F	24.7 °C	76.5 °F	21,900.0 Btu	20,483.3 Btu	1416.7 BTU	6.5%
13	10.00	23.9 °C	75.0 °F	25.0 °C	77.0 °F	21,900.0 Btu	19,766.7 Btu	2133.3 BTU	9.7%
14	10.10	23.9 °C	75.0 °F	25.3 °C	77.5 °F	22,866.7 Btu	20,133.3 Btu	2733.3 BTU	12.0%
15	10.20	23.9 °C	75.0 °F	25.6 °C	78.0 °F	22,866.7 Btu	19,450.0 Btu	3416.7 BTU	14.9%
16	10.30	23.9 °C	75.0 °F	25.8 °C	78.5 °F	22,866.7 Btu	18,766.7 Btu	4100.0 BTU	17.9%
17	10.40	23.9 °C	75.0 °F	23.9 °C	75.0 °F	22,866.7 Btu	18,083.3 Btu	4783.3 BTU	20.9%
18	10.50	23.9 °C	75.0 °F	24.2 °C	75.5 °F	22,866.7 Btu	22,866.7 Btu	0.0 BTU	0.0%
19	11.00	23.9 °C	75.0 °F	24.4 °C	76.0 °F	22,866.7 Btu	22,183.3 Btu	683.3 BTU	3.0%
20	11.10	23.9 °C	75.0 °F	24.7 °C	76.5 °F	23,850.0 Btu	22,533.3 Btu	1316.7 BTU	5.5%
21	11.20	23.9 °C	75.0 °F	25.0 °C	77.0 °F	23,850.0 Btu	21,883.3 Btu	1966.7 BTU	8.2%
22	11.30	23.9 °C	75.0 °F	25.3 °C	77.5 °F	23,850.0 Btu	21,216.7 Btu	2633.3 BTU	11.0%
23	11.40	23.9 °C	75.0 °F	25.6 °C	78.0 °F	23,850.0 Btu	20,550.0 Btu	3300.0 BTU	13.8%
24	11.50	23.9 °C	75.0 °F	25.8 °C	78.5 °F	23,850.0 Btu	19,883.3 Btu	3966.7 BTU	16.6%
25	12.00	23.9 °C	75.0 °F	23.9 °C	75.0 °F	23,850.0 Btu	19,216.7 Btu	4633.3 BTU	19.4%
26	12.10	23.9 °C	75.0 °F	24.2 °C	75.5 °F	24,783.3 Btu	24,783.3 Btu	0.0 BTU	0.0%
27	12.20	23.9 °C	75.0 °F	24.4 °C	76.0 °F	24,783.3 Btu	24,150.0 Btu	633.3 BTU	2.6%
28	12.30	23.9 °C	75.0 °F	24.7 °C	76.5 °F	24,783.3 Btu	23,500.0 Btu	1283.3 BTU	5.2%
29	12.40	23.9 °C	75.0 °F	25.0 °C	77.0 °F	24,783.3 Btu	22,866.7 Btu	1916.7 BTU	7.7%
30	12.50	23.9 °C	75.0 °F	25.3 °C	77.5 °F	24,783.3 Btu	22,216.7 Btu	2566.7 BTU	10.4%
31	13.00	23.9 °C	75.0 °F	23.9 °C	75.0 °F	24,783.3 Btu	21,583.3 Btu	3200.0 BTU	12.9%
32	13.10	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
33	13.20	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
34	13.30	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
35	13.40	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
36	13.50	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
37	14.00	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
38	14.10	23.9 °C	75.0 °F	24.2 °C	75.5 °F	22,866.7 Btu	22,866.7 Btu	0.0 BTU	0.0%
39	14.20	23.9 °C	75.0 °F	24.4 °C	76.0 °F	22,866.7 Btu	22,266.7 Btu	600.0 BTU	2.6%
40	14.30	23.9 °C	75.0 °F	24.7 °C	76.5 °F	22,866.7 Btu	21,666.7 Btu	1200.0 BTU	5.2%
41	14.40	23.9 °C	75.0 °F	25.0 °C	77.0 °F	22,866.7 Btu	21,066.7 Btu	1800.0 BTU	7.9%
42	14.50	23.9 °C	75.0 °F	25.3 °C	77.5 °F	22,866.7 Btu	20,466.7 Btu	2400.0 BTU	10.5%
43	15.00	23.9 °C	75.0 °F	25.6 °C	78.0 °F	22,866.7 Btu	19,850.0 Btu	3016.7 BTU	13.2%
44	15.10	23.9 °C	75.0 °F	25.8 °C	78.5 °F	25,416.7 Btu	21,900.0 Btu	3516.7 BTU	13.8%
45	15.20	23.9 °C	75.0 °F	23.9 °C	75.0 °F	25,416.7 Btu	21,300.0 Btu	4116.7 BTU	16.2%
46	15.30	23.9 °C	75.0 °F	24.2 °C	75.5 °F	25,416.7 Btu	25,416.7 Btu	0.0 BTU	0.0%
47	15.40	23.9 °C	75.0 °F	24.4 °C	76.0 °F	25,416.7 Btu	24,850.0 Btu	566.7 BTU	2.2%
48	15.50	23.9 °C	75.0 °F	24.7 °C	76.5 °F	25,416.7 Btu	24,250.0 Btu	1166.7 BTU	4.6%
49	16.00	23.9 °C	75.0 °F	25.0 °C	77.0 °F	25,416.7 Btu	23,666.7 Btu	1750.0 BTU	6.9%
50	16.10	23.9 °C	75.0 °F	25.3 °C	77.5 °F	26,100.0 Btu	23,816.7 Btu	2283.3 BTU	8.7%
51	16.20	23.9 °C	75.0 °F	25.6 °C	78.0 °F	26,100.0 Btu	23,233.3 Btu	2866.7 BTU	11.0%
52	16.30	23.9 °C	75.0 °F	25.8 °C	78.5 °F	26,100.0 Btu	22,650.0 Btu	3450.0 BTU	13.2%
53	16.40	23.9 °C	75.0 °F	23.9 °C	75.0 °F	26,100.0 Btu	22,083.3 Btu	4016.7 BTU	15.4%
					Total =	**1,198,000.0 Btu**	**1,097,783.33 Btu**	**100,216.67 Btu**	**8.4%**
						351.0 kWh	**321.6 kWh**	**29.4 kWh**	**8.4%**

Table 2-19: GDC HVAC System energy simulation analysis with E20II HAP of ramp mode set-point temperature at Level 6, BHEUU (24th August 2011)

No	Operation Time	Constant Set Point Temperature	Constant Set-Point Temperature	Cyclic Set-Point temperature	Cyclic Set-Point temperature	Cooling Coil Load (constant)	Cooling Coil Load (ramps)	Potential Energy Savings	Percentage Potential Energy Savings
1	08.00	23.9 °C	75.0 °F	23.9 °C	75.0 °F	-	-	-	-
2	08.10	23.9 °C	75.0 °F	24.2 °C	75.5 °F	18,966.7 Btu	18,966.7 Btu	0.0 BTU	0.0%
3	08.20	23.9 °C	75.0 °F	24.4 °C	76.0 °F	18,966.7 Btu	18,233.3 Btu	733.3 BTU	3.9%
4	08.30	23.9 °C	75.0 °F	24.7 °C	76.5 °F	18,966.7 Btu	17,516.7 Btu	1450.0 BTU	7.6%
5	08.40	23.9 °C	75.0 °F	25.0 °C	77.0 °F	18,966.7 Btu	16,783.3 Btu	2183.3 BTU	11.5%
6	08.50	23.9 °C	75.0 °F	25.3 °C	77.5 °F	18,966.7 Btu	16,066.7 Btu	2900.0 BTU	15.3%
7	09.00	23.9 °C	75.0 °F	25.6 °C	78.0 °F	18,966.7 Btu	15,333.3 Btu	3633.3 BTU	19.2%
8	09.10	23.9 °C	75.0 °F	25.8 °C	78.5 °F	21,900.0 Btu	17,666.7 Btu	4233.3 BTU	19.3%
9	09.20	23.9 °C	75.0 °F	25.6 °C	78.0 °F	21,900.0 Btu	16,966.7 Btu	4933.3 BTU	22.5%
10	09.30	23.9 °C	75.0 °F	25.3 °C	77.5 °F	21,900.0 Btu	17,666.7 Btu	4233.3 BTU	19.3%
11	09.40	23.9 °C	75.0 °F	25.0 °C	77.0 °F	21,900.0 Btu	18,366.7 Btu	3533.3 BTU	16.1%
12	09.50	23.9 °C	75.0 °F	24.7 °C	76.5 °F	21,900.0 Btu	19,066.7 Btu	2833.3 BTU	12.9%
13	10.00	23.9 °C	75.0 °F	24.4 °C	76.0 °F	21,900.0 Btu	19,766.7 Btu	2133.3 BTU	9.7%
14	10.10	23.9 °C	75.0 °F	24.2 °C	75.5 °F	22,866.7 Btu	21,500.0 Btu	1366.7 BTU	6.0%
15	10.20	23.9 °C	75.0 °F	23.9 °C	75.0 °F	22,866.7 Btu	22,183.3 Btu	683.3 BTU	3.0%
16	10.30	23.9 °C	75.0 °F	24.2 °C	75.5 °F	22,866.7 Btu	22,866.7 Btu	0.0 BTU	0.0%
17	10.40	23.9 °C	75.0 °F	24.4 °C	76.0 °F	22,866.7 Btu	22,183.3 Btu	683.3 BTU	3.0%
18	10.50	23.9 °C	75.0 °F	24.7 °C	76.5 °F	22,866.7 Btu	21,500.0 Btu	1366.7 BTU	6.0%
19	11.00	23.9 °C	75.0 °F	25.0 °C	77.0 °F	22,866.7 Btu	20,816.7 Btu	2050.0 BTU	9.0%
20	11.10	23.9 °C	75.0 °F	25.3 °C	77.5 °F	23,850.0 Btu	21,216.7 Btu	2633.3 BTU	11.0%
21	11.20	23.9 °C	75.0 °F	25.6 °C	78.0 °F	23,850.0 Btu	20,550.0 Btu	3300.0 BTU	13.8%
22	11.30	23.9 °C	75.0 °F	25.8 °C	78.5 °F	23,850.0 Btu	19,883.3 Btu	3966.7 BTU	16.6%
23	11.40	23.9 °C	75.0 °F	25.6 °C	78.0 °F	23,850.0 Btu	19,216.7 Btu	4633.3 BTU	19.4%
24	11.50	23.9 °C	75.0 °F	25.3 °C	77.5 °F	23,850.0 Btu	19,883.3 Btu	3966.7 BTU	16.6%
25	12.00	23.9 °C	75.0 °F	25.0 °C	77.0 °F	23,850.0 Btu	20,550.0 Btu	3300.0 BTU	13.8%
26	12.10	23.9 °C	75.0 °F	24.7 °C	76.5 °F	24,783.3 Btu	22,216.7 Btu	2566.7 BTU	10.4%
27	12.20	23.9 °C	75.0 °F	24.4 °C	76.0 °F	24,783.3 Btu	22,866.7 Btu	1916.7 BTU	7.7%
28	12.30	23.9 °C	75.0 °F	24.2 °C	75.5 °F	24,783.3 Btu	23,500.0 Btu	1283.3 BTU	5.2%
29	12.40	23.9 °C	75.0 °F	23.9 °C	75.0 °F	24,783.3 Btu	24,150.0 Btu	633.3 BTU	2.6%
30	12.50	23.9 °C	75.0 °F	24.2 °C	75.5 °F	24,783.3 Btu	24,783.3 Btu	0.0 BTU	0.0%
31	13.00	23.9 °C	75.0 °F	23.9 °C	75.0 °F	24,783.3 Btu	24,150.0 Btu	633.3 BTU	2.6%
32	13.10	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
33	13.20	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
34	13.30	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
35	13.40	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
36	13.50	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
37	14.00	23.9 °C	75.0 °F	23.9 °C	75.0 °F	21,616.7 Btu	21,616.7 Btu	0.0 BTU	0.0%
38	14.10	23.9 °C	75.0 °F	24.2 °C	75.5 °F	22,866.7 Btu	22,866.7 Btu	0.0 BTU	0.0%
39	14.20	23.9 °C	75.0 °F	24.4 °C	76.0 °F	22,866.7 Btu	22,266.7 Btu	600.0 BTU	2.6%
40	14.30	23.9 °C	75.0 °F	24.7 °C	76.5 °F	22,866.7 Btu	21,666.7 Btu	1200.0 BTU	5.2%
41	14.40	23.9 °C	75.0 °F	25.0 °C	77.0 °F	22,866.7 Btu	21,066.7 Btu	1800.0 BTU	7.9%
42	14.50	23.9 °C	75.0 °F	25.3 °C	77.5 °F	22,866.7 Btu	20,466.7 Btu	2400.0 BTU	10.5%
43	15.00	23.9 °C	75.0 °F	25.6 °C	78.0 °F	22,866.7 Btu	19,850.0 Btu	3016.7 BTU	13.2%
44	15.10	23.9 °C	75.0 °F	25.8 °C	78.5 °F	25,416.7 Btu	21,900.0 Btu	3516.7 BTU	13.8%
45	15.20	23.9 °C	75.0 °F	25.6 °C	78.0 °F	25,416.7 Btu	21,300.0 Btu	4116.7 BTU	16.2%
46	15.30	23.9 °C	75.0 °F	25.3 °C	77.5 °F	25,416.7 Btu	21,900.0 Btu	3516.7 BTU	13.8%
47	15.40	23.9 °C	75.0 °F	25.0 °C	77.0 °F	25,416.7 Btu	22,483.3 Btu	2933.3 BTU	11.5%
48	15.50	23.9 °C	75.0 °F	24.7 °C	76.5 °F	25,416.7 Btu	23,083.3 Btu	2333.3 BTU	9.2%
49	16.00	23.9 °C	75.0 °F	24.4 °C	76.0 °F	25,416.7 Btu	23,666.7 Btu	1750.0 BTU	6.9%
50	16.10	23.9 °C	75.0 °F	24.2 °C	75.5 °F	26,100.0 Btu	24,950.0 Btu	1150.0 BTU	4.4%
51	16.20	23.9 °C	75.0 °F	23.9 °C	75.0 °F	26,100.0 Btu	25,533.3 Btu	566.7 BTU	2.2%
52	16.30	23.9 °C	75.0 °F	24.2 °C	75.5 °F	26,100.0 Btu	26,100.0 Btu	0.0 BTU	0.0%
53	16.40	23.9 °C	75.0 °F	24.4 °C	76.0 °F	26,100.0 Btu	25,533.3 Btu	566.7 BTU	2.2%
					Total =	**1,198,000.0 Btu**	**1,100,750.00 Btu**	**97,250.00 Btu**	**8.1%**
						351.0 kWh	**322.5 kWh**	**28.5 kWh**	**8.1%**

Table 2-20: GDC HVAC System Energy Simulation Analysis with E20II HAP of Cyclic Mode Set point Temperature at Level 6, BHEUU (24th August 2011)

CHAPTER 3
FIELD TRIAL EXPERIMENTAL SET-UP

3.1 Chapter Introduction

This chapter describes the field trials that were carried out in the Legal Affairs Division Office (BHEUU). The chapter will first explain why this particular building was chosen. Its HVAC system will then be described, together with its HVAC control system. This chapter also aims to elucidate further about the primary thermal comfort variables which were measured. A MATLAB Simulink computer model of a simple HVAC system, which was developed to gain an understanding of how the system should perform, is also described. The field trial methodology is discussed. The instruments used for the trial are illustrated and characterised by their technical specifications.

3.2 Field Trial Building Selection

Choosing the right building was an iterative process, because the building owners had first to be persuaded that these trials would be of some use to them. To do this the author had to write a proposal that highlighted the benefits and intrusions. Two proposals were written before agreement could be reached: one in Menara Sri Wilayah, Putrajaya and the other one was the Court Complex in Jalan Duta, Kuala Lumpur. In Menara Sri Wilayah, the building is installed with a gas district cooling chilled water system whereas in the Court Complex, a combination of variable refrigerant flow system and water cooled chiller system is installed. Although the Public Works Department of Malaysia (PWD), on behalf of the government, had no objections with respect to either proposals, the director general preferred the Menara Sri Wilayah, because it was due to be refurbished.

Preparations for the field trial in Menara Sri Wilayah were then made remotely from Scotland. The author travelled to Malaysia in July 2011 to confirm suitability of the building and the systems installed with the research trial and experiments related. Menara Sri Wilayah was found to be unsuitable for this trial on that visit due to some technical issues that will now be described.

3.2.1 Interior renovation work

Menara Sri Wilayah was under major interior renovation especially the North Tower. Almost all floors of North Tower were either not occupied or semi-occupied. Particularly on level 6 and 7 of North Tower where the trial was scheduled to be performed. These two floors were selected for the trial due to their identical interior design and floor layout. The occupants of these two floors had been moved to a temporary working place in order to allow an interior renovation work to take place. As the field trial of this research requires significant interactions with the building occupants, the conditions above were not appropriate.

3.2.2 VAV terminal controller malfunction

A considerable number of variable air volume (*VAV*) terminal controllers were not functioning properly in both North and South Towers. Functionality of the terminal controller is crucial in the control of the indoor climate of the building.

3.2.3 Sensor malfunction

A considerable number of room temperature sensors were not working properly. Functionality of these sensors is important for building management system (*BMS*) operation. The BMS would always be in an error state without functioning temperature sensors.

3.2.4 Insufficient air flowrate

The flows of air from the air handling unit (*AHU*) to its related VAV terminals, on all floors in both towers were experiencing unbalanced distributions causing significant numbers of VAV terminal units to run with insufficient air flow. It was also observed that most of the VAV terminal units that had an insufficient flowrate were mostly located far away from the AHU.

The author had 2 choices: either to abandon the visit or to find another building. When time is of the essence, a good replacement building for Menara Sri Wilayah should be similar in terms of location as well as the type of air-conditioning system installed. PWD suggested a few buildings for replacement which were also located in Putrajaya.

i. Housing Loan Division Office, Presint 2 Putrajaya
ii. Economic Planning Unit Office, Block B5 and B6, Presint 1 Putrajaya
iii. Ministry of High Education Tower, Presint 5 Putrajaya
iv. Legal Affairs Division Office, Presint 3 Putrajaya.

Field visits to the suggested buildings were organised to confirm suitability. Their air-conditioning systems were also compared with each other and with Menara Sri Wilayah. In general, the buildings' air-conditioning and control systems were in a better state than those in Menara Sri Wilayah. Even so, most of them were still hardly suitable for this trial. Almost all AHUs installed with VSD were observed running on constant speed in the Housing Loan Division Office for instance, due to insufficient maintenance funds to replace their faulty variable speed drives (VSD). This building and all the other suggested buildings listed before were also suffering from the same air distribution problem. Like Menara Sri Wilayah, almost all VAV terminals located far-off from their AHUs seemed to be running with inadequate flowrates. Since the proposed experiments required that the building air-conditioning control system should be capable of fluctuating the indoor temperature by using flowrate as a main variable, inadequate flowrate of VAV terminals could give significant errors to the results.

Eventually the Legal Affairs Division Office (BHEUU), Presint 3 Putrajaya was selected to replace Menara Sri Wilayah for this field trial. As compared to the other buildings, the BHEUU has the smallest air-conditioned area with highest number of functional VAV terminals per AHU. This could not only minimize errors that might arise from inadequate flowrate, but also increase the opportunity for the building to have a good response to indoor set-point temperature adjustment. Levels 6 and 7 of this building were eventually chosen for this trial based on the similarity of the floor lay out, interior design as well as air-conditioning system design.

3.3 HVAC Control System in BHEUU

The HVAC system installed in this building is designed to regulate indoor climate: both air temperature and moisture content. Moisture is extracted from the outdoor air supply by a cooling coil which is either located in an air handling unit (AHU) or fan coil unit (FCU). The cooling coil dehumidification rate depends on the coil surface area as well as the surface temperature. The mechanical engineer, who was involved during the design process, was responsible for the determination of the correct condensation rate by sizing the coil relative to conditioned space requirements. On the other hand, air temperature is controlled by the volume of cooled air supplied to the conditioned spaces. This air supply which combines outside air and air returned from the conditioned spaces, is cooled by cooling coils supplied with chilled water. Waterside primarily consists of plate heat exchanger, chilled water variable speed pump and cooling coils.

3.3.1 Plate heat exchanger

Two numbers of plate heat exchanger are installed in this building with capacity of 505 RT each. Building cooling load contained in the secondary loop is transmitted to the primary loop via these plate heat exchangers. The primarily loop is the chilled water piping that connects the central gas district cooling (*GDC*) plant to all plate heat plate exchangers located in various buildings, and the secondary loop is the chilled water piping loop that connects the plate heat exchangers to all the cooling coils in one specific building. The chilled water temperature supplied from the GDC plant to the plate heat exchanger is ideally maintained constant at 7^{o}C and returned back at 14^{o}C while for the secondary loop the chilled water temperature is maintained at 8^{o}C supply and 15^{o}C return. With building management system (*BMS*) installed, these temperatures can be observed from the centralised monitor located in the control room. Figure 3-1 shows the layout of the pipe-work.

3.3.2 Chilled water variable speed pump

There are three variable speed drive (*VSD*) chilled water pumps installed here. Only two pumps are operated when the HVAC system is switched on, while the other one functions as a stand-by unit. Each of them has 60 *l/s* pumping capacity. This pumping system is also installed with one motorised valve to bypass the chilled water when the load falls below the minimum capacity of the VSD pumps. The pumps generate the flow and head required at anytime during operation. This is performed by the pump controller which regulates the pump speed via the adjustable frequency drive and modulates the bypass motorised valve. The controller regulates the pump speed and valve position in response to building cooling load conditions. The pump controller receives a signal from pressure differential sensor located across the chilled water supply and return pipes. Pipes connections of the pumping system are shown in Figure 3-1.

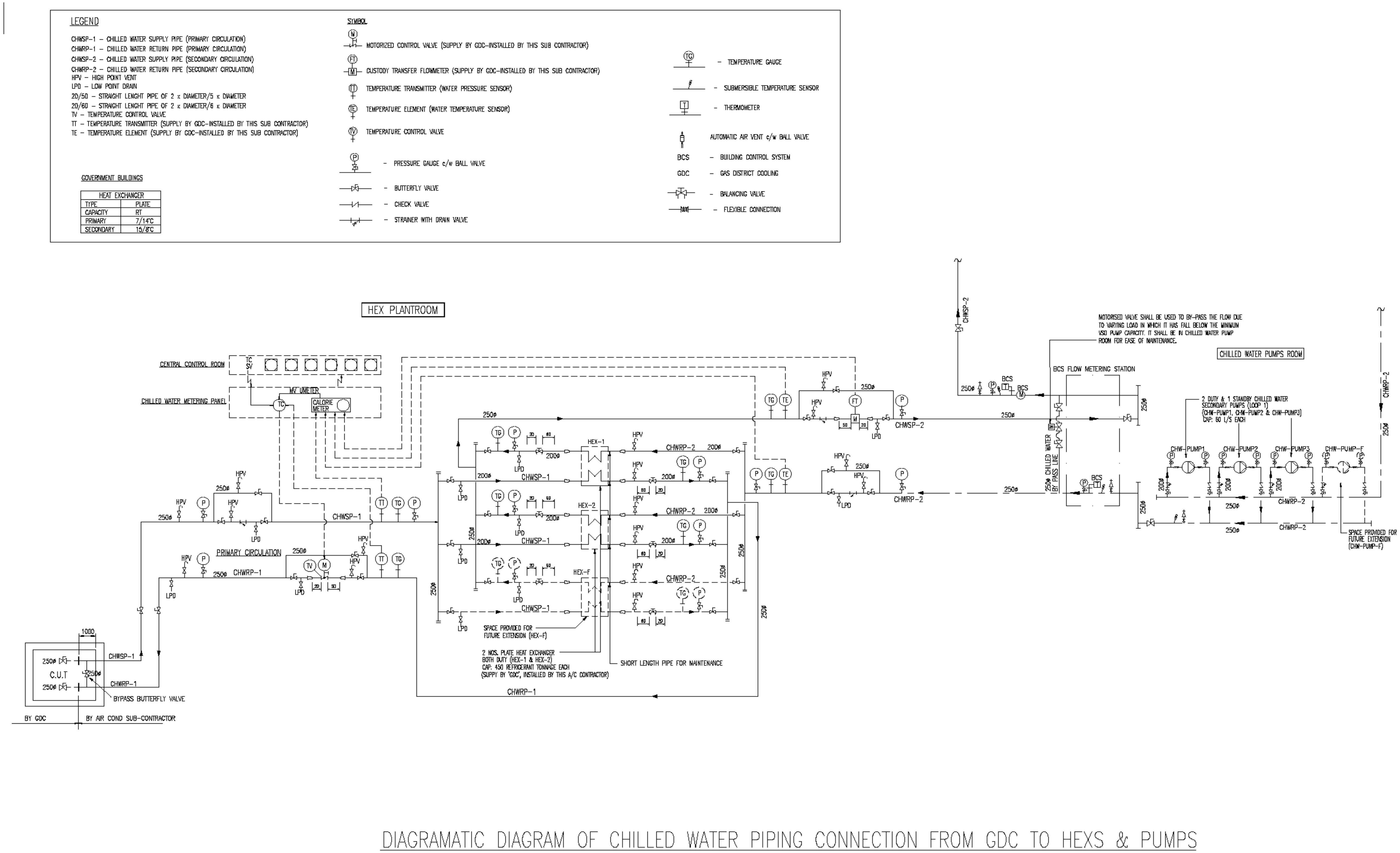


Figure 3-1: Diagrammatic diagram of chilled water piping connection from GDC Plant to Heat Exchangers and Pumps

3.3.3 Cooling coil

In total, there are 62 chilled-water cooling coils connected to this HVAC system. The cooling coil is either located in an AHU or FCU depending on the size of the conditioned space served. Similar to other cooling coils, the chilled-water cooling coils installed here are finned tube heat exchangers. They consist of rows of copper tubes that pass through numbers of aluminium formed fin sheets. Heat is transferred from the air to the water flowing through the tubes as air carrying the load from the airside passes through the coil and contacts the cold fin surfaces. The temperature of the air that exits the coil, which is normally referred as ‘off-coil temperature’, is controlled by a Proportional + Integral (PI) controller. The PI controller which is usually located adjacent to the AHU or FCU uses either a two or three way modulating valve to modulate the chilled water flow into the cooling coil. Figure 3-2 shows a typical chilled water piping connection for an AHU with a two way modulating valve installed. For this building, the set-point value for the off-coil temperature is specified by the building facilities engineer via the BMS System and the value varies within 15^{o}C to 18^{o}C in each floor. Figure 3-3 shows a screen view of the level 6 off-coil actual temperature and the set-point from the BMS system.

The waterside HVAC control system of this building is designed to maintain the desired off-coil temperature to each floor. The control system of the airside on the other hand is responsible to sustain the indoor air temperature relatively close to the indoor set-point temperature. To implement this task, BHEUU has variable air volume system (VAV) installed. Similar with the off-coil set-point temperature, the value of indoor set-point of each conditioned space is also entered to the system using the BMS. The VAV System installed has 2 primary components: a central supply fan and VAV room terminal units.

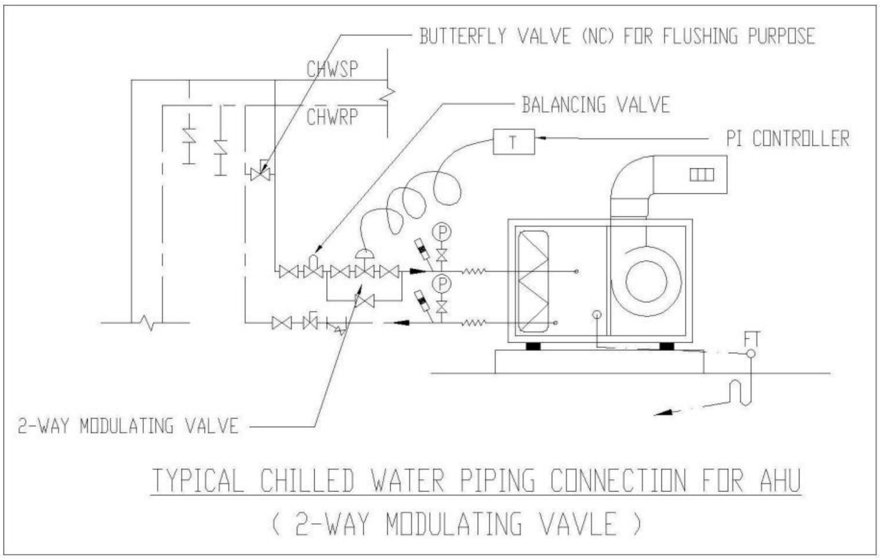


Figure 3-2: Typical chilled water piping connection of AHU installed with 2-way modulating valve

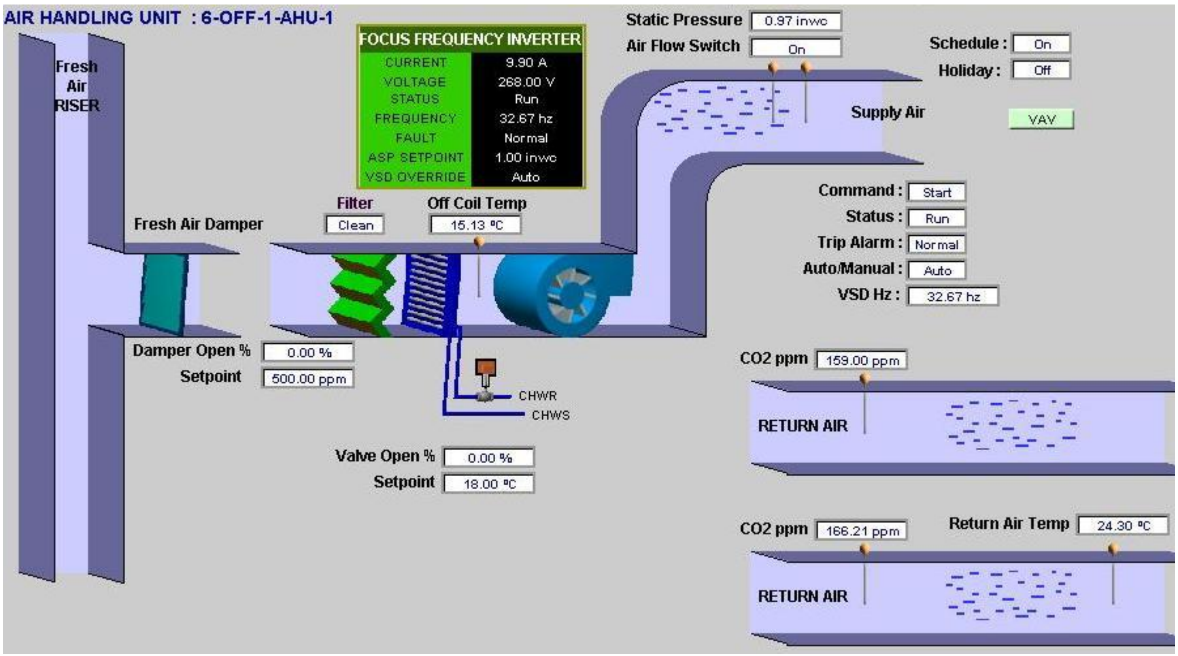


Figure 3-3: A screen view of level 6 off-coil actual temperature and the set-point from BMS system. It also shows the supply fan static pressure set-point and the relevant supply duct static pressure.

3.3.4 Central supply fan

The supply fan has a variable speed drive (VSD) and is usually located in the AHU room as part of the air handling unit. This drive responds to fluctuations in the air flow demand from each VAV terminals unit. A constant speed supply fan would not be suitable in this application because it would increase the static pressure in the ducting system when the terminal units modulated towards closed. Therefore it creates an increase in energy consumption as well as a risk of damage [67]. There are several control strategies available as mentioned in CIBSE Guide H, and one of them is the use of 'multiple pressure sensors' which are used in this building. Here, the fan speed is controlled using a PI controller connected to static pressure sensors positioned at each branch of the air duct, to maintain duct static pressure at the set-point. When the cooling load in the condition space drops, the room terminal units modulate towards closed, causing the duct pressure to increase. The PI controller then decreases the fan speed to maintain the pressure at the set-point. Figure 3-4 shows an example of multiple brunches duct layout with multiple pressure sensors control strategies applied. The value of the supply fan static pressure set-point as well as the relevant supply duct static pressure can be controlled and monitored by BMS system as shown in Figure 3-3.

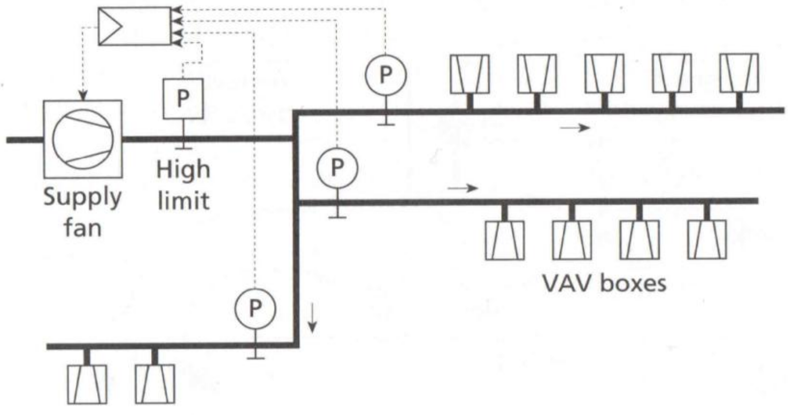


Figure 3-4: An example of multiple brunches duct layout with multiple pressure sensors control strategies applied. Supply fan is controlled to ensure that all pressure sensors meet or slightly exceed the set-point pressure. This ensures all branches receive an adequate air supply [67].

3.3.5 VAV room terminal unit

Every AHU in this building supplies several VAV Room Terminal Units to maintain the desired indoor climate of the condition spaces. In level 6 for instance, the only AHU supplies 19 room terminal units. There are several types of room terminal unit as described in CIBSE guide H: the one used here is the ‘pressure independent VAV terminal’[67]. All terminal units installed in this building are designed only for cooling purposes, i.e. they lack of reheat coil. Each terminal unit is fitted with their own local controller functions to control cool air supply by throttling the damper built in the terminal with the indoor air temperature as its control variable. The indoor set-point temperature of the terminal units are entered using the BMS as shown in Figure 3-6. The term pressure independent means that at a given damper position, the cool air supply to the space is a function of indoor air temperature only and not dependent to static air pressure in the supply duct. The system uses cascade controller to modulate the cool air supply to the conditioned spaces. The first stage of this controller reset the air flow set-point with indoor air temperature as a control variable using a PI controller. The second stage also uses PI controller to operate the damper position as a function of the measured supply air flow. Figure 3-5 shows an example of pressure independent VAV terminal unit with a cascade controller is used to reset the air flow set-point.

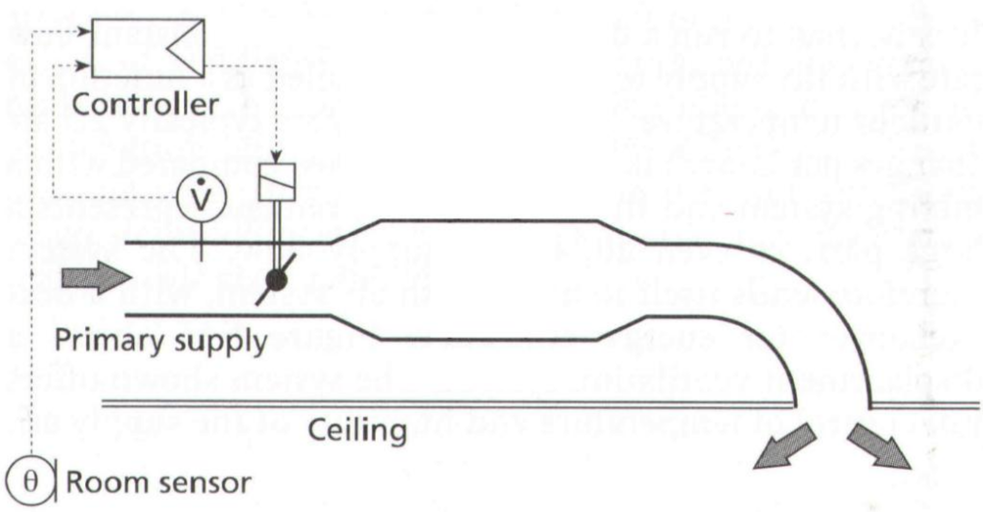
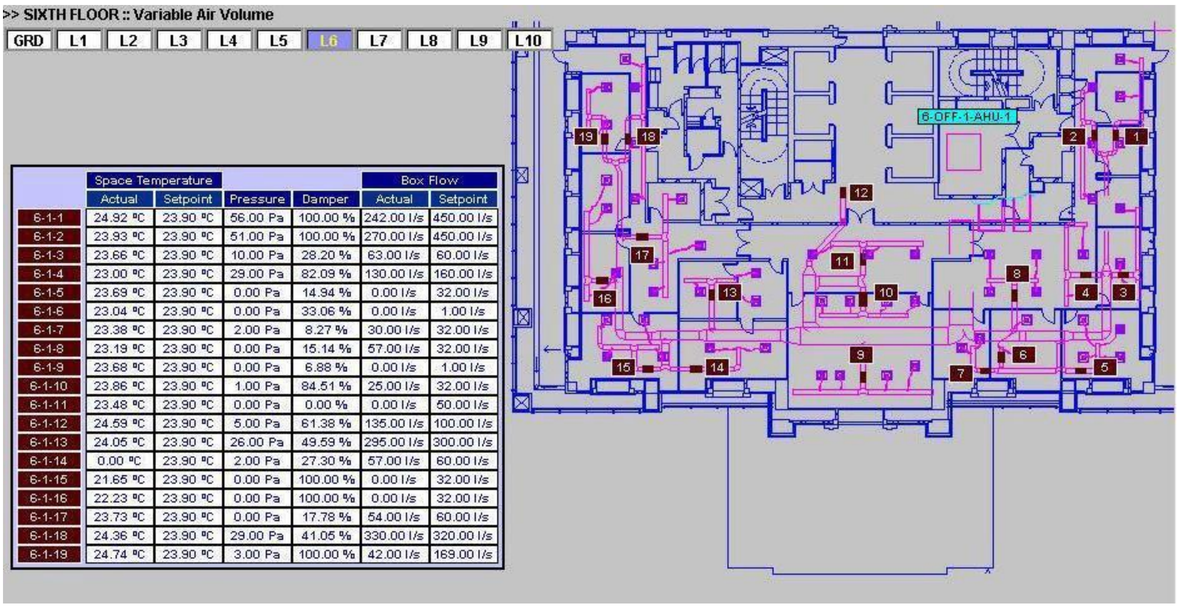


Figure 3-5: Pressure independent VAV terminal unit with a cascade controller is used to reset the air flow set-point [67]



	Space Temperature				Box Flow	
	Actual	Setpoint	Pressure	Damper	Actual	Setpoint
6-1-1	24.92 ºC	23.90 ºC	56.00 Pa	100.00 %	242.00 l/s	450.00 l/s
6-1-2	23.93 ºC	23.90 ºC	51.00 Pa	100.00 %	270.00 l/s	450.00 l/s
6-1-3	23.66 ºC	23.90 ºC	10.00 Pa	28.20 %	63.00 l/s	60.00 l/s
6-1-4	23.00 ºC	23.90 ºC	29.00 Pa	82.09 %	130.00 l/s	160.00 l/s
6-1-5	23.69 ºC	23.90 ºC	0.00 Pa	14.94 %	0.00 l/s	32.00 l/s
6-1-6	23.04 ºC	23.90 ºC	0.00 Pa	33.06 %	0.00 l/s	1.00 l/s
6-1-7	23.38 ºC	23.90 ºC	2.00 Pa	8.27 %	30.00 l/s	32.00 l/s
6-1-8	23.19 ºC	23.90 ºC	0.00 Pa	15.14 %	57.00 l/s	32.00 l/s
6-1-9	23.68 ºC	23.90 ºC	0.00 Pa	6.88 %	0.00 l/s	1.00 l/s
6-1-10	23.86 ºC	23.90 ºC	1.00 Pa	84.51 %	25.00 l/s	32.00 l/s
6-1-11	23.48 ºC	23.90 ºC	0.00 Pa	0.00 %	0.00 l/s	50.00 l/s
6-1-12	24.59 ºC	23.90 ºC	5.00 Pa	61.38 %	135.00 l/s	100.00 l/s
6-1-13	24.05 ºC	23.90 ºC	26.00 Pa	49.59 %	295.00 l/s	300.00 l/s
6-1-14	0.00 ºC	23.90 ºC	2.00 Pa	27.30 %	57.00 l/s	60.00 l/s
6-1-15	21.65 ºC	23.90 ºC	0.00 Pa	100.00 %	0.00 l/s	32.00 l/s
6-1-16	22.23 ºC	23.90 ºC	0.00 Pa	100.00 %	0.00 l/s	32.00 l/s
6-1-17	23.73 ºC	23.90 ºC	0.00 Pa	17.78 %	54.00 l/s	60.00 l/s
6-1-18	24.36 ºC	23.90 ºC	29.00 Pa	41.05 %	330.00 l/s	320.00 l/s
6-1-19	24.74 ºC	23.90 ºC	3.00 Pa	100.00 %	42.00 l/s	169.00 l/s

Figure 3-6: VAV Room terminal units table that shows the space actual and set-point temperature as well as actual and set-point supply air. In between of the temperature and the box blow are the terminal's damper position and static pressure. The floor plan shows the position of the VAV Room Terminals on level 6. This figure is a screen shot of BMS computer when resetting the indoor set-point temperature of VAV room terminal units in level 6.

3.4 Thermal Comfort

Thermal comfort is best defined as that condition of mind which expresses satisfaction with the thermal environment [23]. The environmental conditions required for comfort are not the same for everyone. When a space is occupied by a group of people, it is beyond the bound of possibilities to satisfy everyone's thermal comforts due to differences in their physiological and psychological needs [3]. However it is possible to specify a thermal condition that satisfies an acceptable proportion of the occupants. In specifying the thermal comfort condition, there are 6 primary variables *(i.e. metabolic rate, clothing insulation, ambient air temperature, mean radiant temperature, humidity and air velocity)* that need to be addressed and understood. These variables were used to quantify occupant thermal comfort satisfaction in BHEUU during the field trial experimentation which will be explained further in sub-section 3.4.1 to 3.4.6. Figure 3-15 shows a variant of the ASHRAE seven point comfort scale questionnaire, which was used in the studies to estimate the thermal comfort of a particular occupant. The questionnaire developed is inspired by a questionnaire used in a similar study done in Europe [17] and also by British Standard EN ISO 7730:2005 [23]. It uses a numerical scale to represent the thermal sensation response of a potential occupant, for instance: -3 = cold, -2 = cool, -1 = slightly cool, 0 = neutral, 1 = slightly warm, 2 = warm and 3 hot. It is also designed to accommodate the thermal variable measurements that were collected during the actual comfort survey. This includes the type of garments worn to obtain their clothing insulation estimation. In addition to this, the questionnaire also accommodates the space carbon dioxide (CO_2) concentration measurement in order to ascertain any possible relationship between indoor air quality and thermal comfort that could be dependent on one another [68].

3.4.1 Metabolic rate

Metabolic rate refers to the transformation rate of chemical energy into heat and mechanical work by metabolic activities within an organism. It is usually expressed per unit area of the total body surface such as $Btu/h.ft^2W/m^2$ [3]. Metabolic rate varies according to human activity and not to the physical environment. AHSRAE Standard 55 [3] gives the metabolic rates for a selection of typical people activities, which can be used for thermal comfort related calculation. In this research, the occupants involved were all office workers who performed sedentary activities most of the time. Even though metabolic rate is one of the primary thermal comfort variables in this research, it was considered safe to assume a constant value for all occupants due to their similar work activities.

3.4.2 Clothing insulation

Another variable that greatly contributes to thermal comfort is clothing insulation. As defined in [3] clothing insulation is a clothing assemble that acts to create resistance to sensible heat transfer of the whole body including the uncovered parts such as face, head and hands. It is expressed in Clo units. Empirical guidelines are provided in [69] for thermal comfort related calculations, which are based on insulation values of typical clothing ensembles. In this research, it is crucial to identify the insulation values of each occupant in relation with their vote in the thermal comfort sensation scale. For instance, this could tell whether or not someone really is experienced discomfort due to the indoor environmental condition or just suffering from high resistance clothing assembles. There are several methods to calculate ensemble clothing thermal insulation values in [69] and the flowchart shown in Figure 3-7 gives a stepwise approach to the determination of the heat resistance. In this research, the clothing insulation values were only estimated using the Annex B [69] approach. Although the Annex A approach [69] is recommended, it was incompatible with female occupants' office attire in Malaysia. The equation below was use to get the ensemble thermal insulation (I_{cl}) by summing the effective thermal insulation (I_{clu}) of the individual garments. Similar work but more sophisticated were conducted for Arabian Gulf clothing and reported in [70].

$$I_{cl} = 0.161 + 0.835 \sum I_{clu} \qquad \textit{(3-i)}$$

For individual garment that is not provided in the Annex B, the effective thermal insulation was calculated using equation *(3-ii)*, where A_{cov} is the body surface area covered by clothing as a percentage of total skin area. Annex H was used to estimate the A_{cov} values [69].

$$I_{clu} = 0.0061 \times A_{cov} \qquad \textit{(3-ii)}$$

3.4.3 Air temperature

The third thermal comfort variable which is equally important is air temperature. It is defined as the average temperature of the air surrounding an occupant [3]. In this research, the value of air temperature is measured in both Celsius (^{o}C) and Fahrenheit (^{o}F). It is also often referred to as dry bulb temperature.

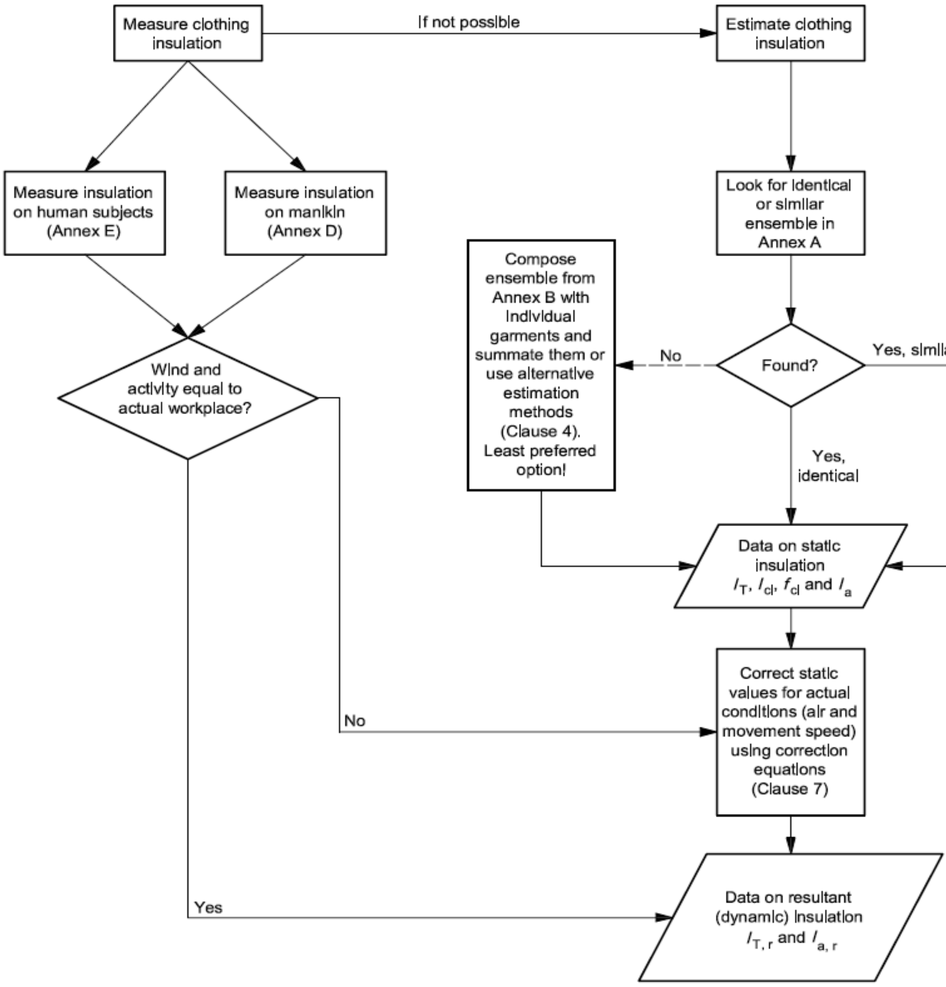


Figure 3-7: Flowchart showing how to approach the determination of clothing insulation values [69]

3.4.4 *Mean radiant temperature*

According to [3] mean radiant temperature refers to "*the temperature of a uniform, black enclosure that exchanges the same amount of thermal radiation with the occupant as the actual enclosure. It is a single value for the entire body and may be considered as a spatial average of the temperature of surfaces surrounding the occupant weighted by their view factors with respect to the occupant"*. In this research, the value of mean radiant temperature is also measured in both Celsius (^{o}C) and Fahrenheit (^{o}F).

3.4.5 *Air speed*

In thermal comfort, air speed is the variable which refers to an average air speed exposed to the occupant's body. The value of air speed in this research is measured in meter per seconds (m/s) unit.

3.4.6 Humidity

Humidity, the moisture content of the air, is the sixth variable of thermal comfort. In this research, humidity is measured as relative humidity.

3.5 Simulink Model HVAC System Trial

A MATLAB Simulink computer model of a simple HVAC System was developed before the real field trials were conducted, to gain an understanding of how the system should perform. The simulation shows the expected response when ramp and cyclic variations are applied to the indoor set-point temperature. Figure 3-12 shows the simulink model of the HVAC system. The model was first run for an air change rate of 3, T_o = 28^{o}C and T_{set} = cyclic mode. The cyclic mode was set to be constant at 23^{o}C for the first 210 minutes before the sinusoidal fluctuation started. Figure 3-8 and Figure 3-9 show the space temperature with its relevant indoor set-point temperature and wall temperature respectively varying with time.

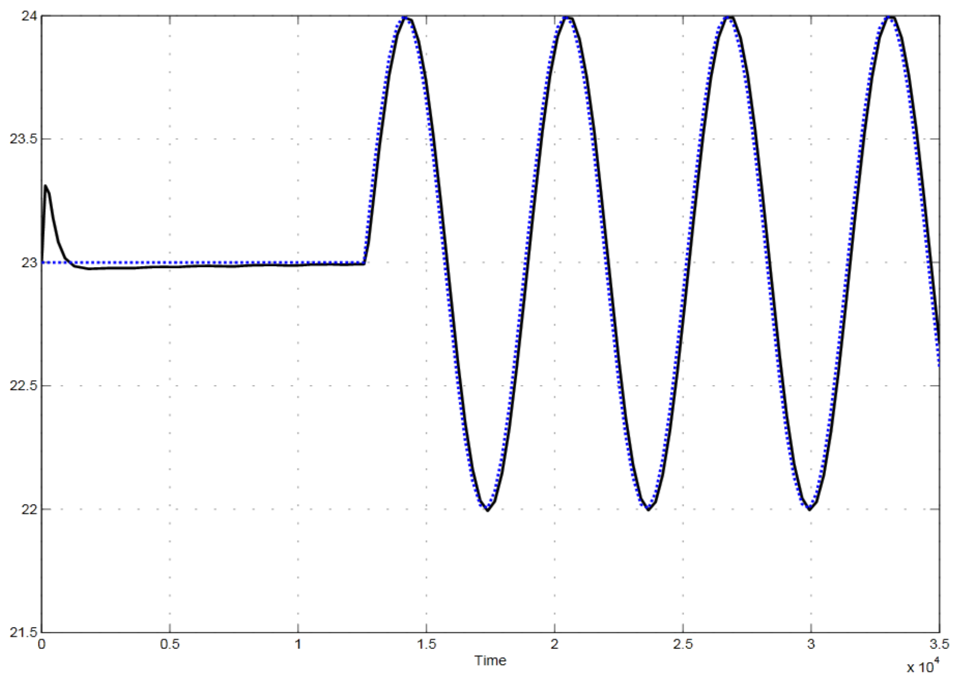


Figure 3-8: Space temperature prediction and indoor set-point temperature (^{o}C) variation with time (s)

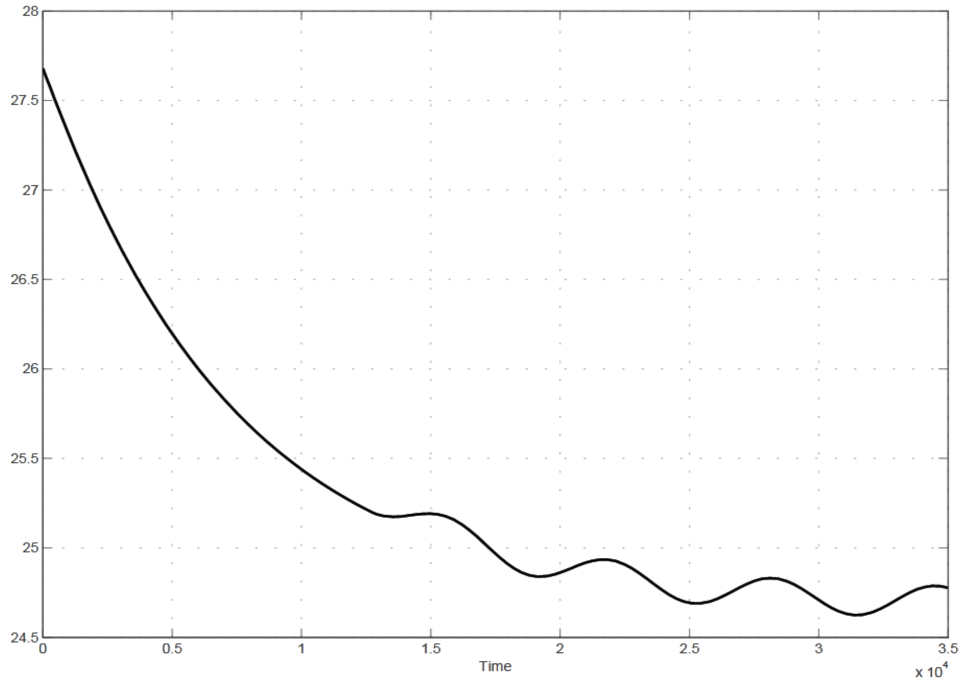


Figure 3-9: Space wall temperature (°C) variation with time (s)

The solid line in Figure 3-8 shows the space temperature while the dotted line represents the indoor set-point temperature of the space. It can be seen that the HVAC system manages to provide a good response with fluctuating indoor set-point temperature. However, the wall temperature in Figure 3-9 fails to track the cyclic mode applied. It also support the assumption that the dynamics of the walls occurred from the ramp or cyclic mode is negligible in the hourly energy simulation calculation (*as discussed in Chapter 2*). The same model was then run with the air change rate set to 1. This is to test the HVAC system response when the air change of the air-conditioned space is at the minimum.

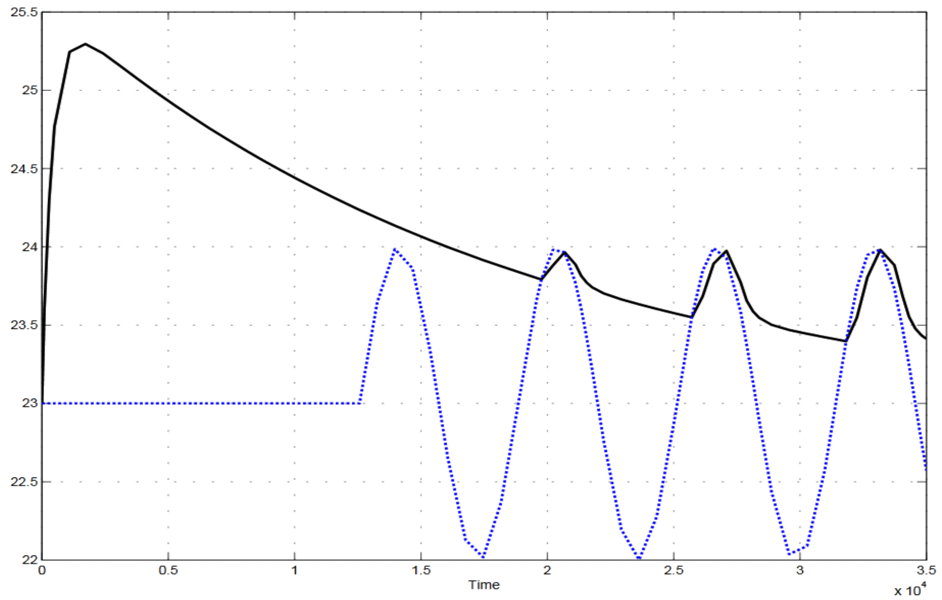


Figure 3-10: Space temperature prediction (dotted) and indoor set-point temperature (°C) varying with time (s) when change is set to 1.

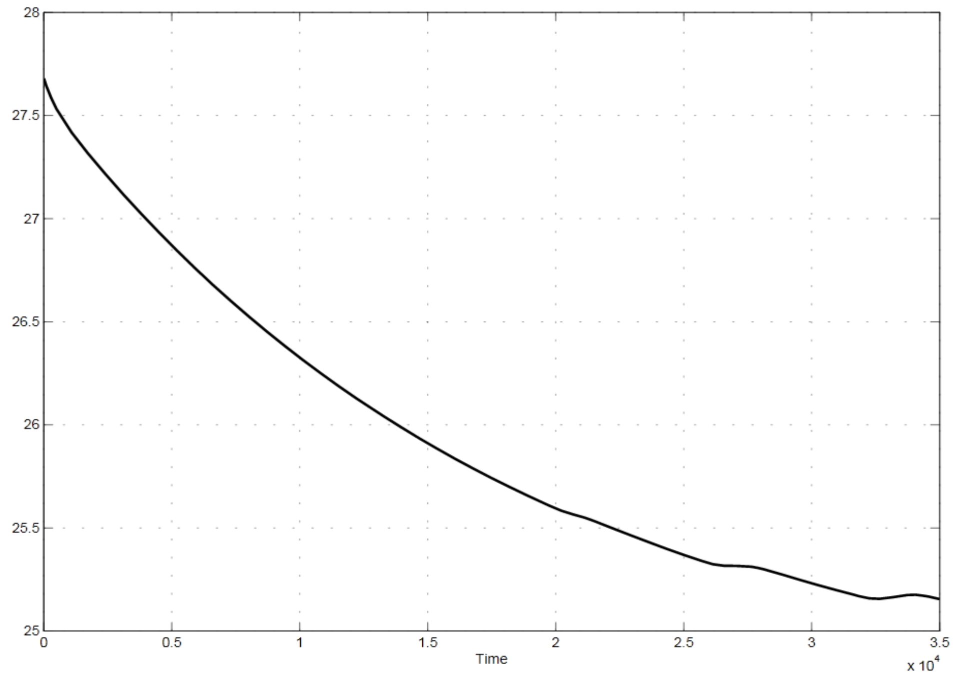


Figure 3-11: Space wall temperature (°C) variation with time (s) when change is set to 1

Figure 3-10 and Figure 3-11 show the space temperature with its relevant set-point and space wall temperature respectively when space air change is set to 1. From Figure 3-10, it can be seen that the HVAC system has failed to control the space temperature towards the fluctuation of the indoor set-point temperature. In Figure 3-11, the space wall temperature has consistently shown insignificant changes when the cyclic mode is applied.

A key conclusion obtained from this simple model simulation was that a good space temperature response to either the ramp or cyclic induced variations is highly dependent on the air-change or supply air flowrate of the HVAC system. The higher the air-change is, the better is the response. Note that sufficient air-change to maintain the space temperature at one constant set-point is not necessarily adequate to sustain the ramp or cyclic mode.

U_i = internal overall heat transfer coefficient value

U_o = external overall heat transfer coefficient value

T_o = outside temperature

T_w = wall temperature

Change = air change of the space

T_{set} = indoor set-point temperature

P gain = Proportional Gain

I Gain = Integrator Gain

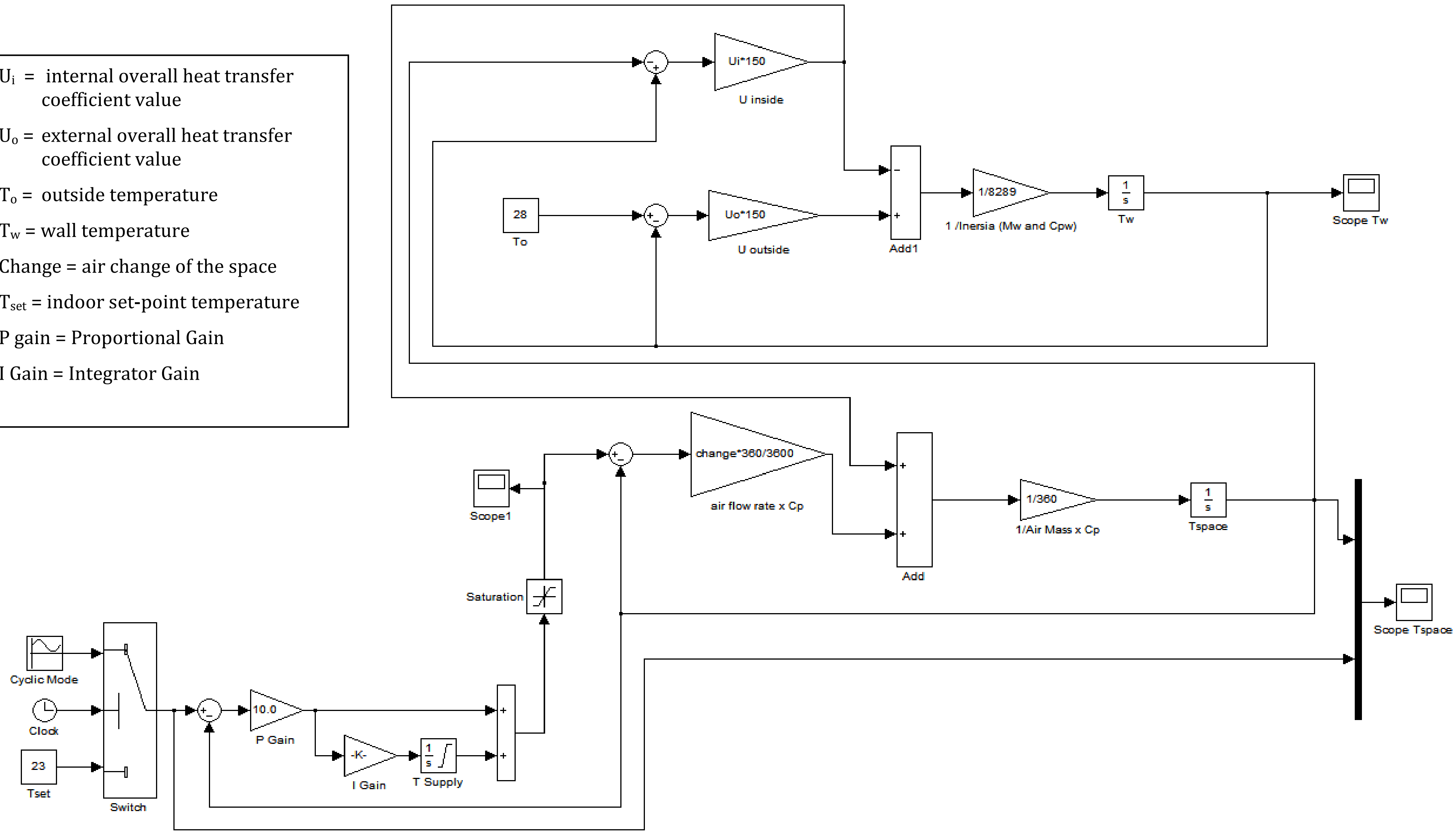


Figure 3-12: A simple Simulink HVAC System model

3.6 Field Trial Methodology

Two very similar floors were selected for this trial, so that the energy consumption in each floor can be reasonably compared when a different mode of set-point temperature change is applied on each floor. Floor selection was based on identical Air-Conditioning System Controls and interior design layouts. The field trial had two parts: 'transverse survey with energy comparison trial' and 'background measurement'. The transverse survey with energy comparison trial was conducted from 13th to 22nd September 2011. Background measurements were conducted from 23rd to 25th August 2011. Technical errors were found during the first experiment, so the experiment was repeated after these errors had been corrected from 6th to 8th December 2011.

3.6.1 Background measurements

This aimed to observe the normal indoor environment as measured by air temperature, mean radiant temperature, humidity and air velocity at 3 pre-determined locations on level 6, whilst the indoor set-point temperature of that floor was subjected to three different modes, i.e. constant mode, ramp mode and cyclic mode. However, during this experiment only three out of four thermal variables were measured because of a cost limitation on air velocity probes. Only thermal variables at three points of the designated floor were recorded due to the limited number of data loggers available. The set-up of these data loggers is described further in section 3.7.2.

Figure 3-14 shows placements of each data logger on level 6 during the first and repeat experiments. The first data logger was placed on a wall at an open space office area (*placement A*). The open space office area was shared by 4 occupants and located in a centre of the floor with no direct opening for sunlight such as windows or glassed walls. The second data logger was also placed in an open space area (*placement B*). It was also located in the centre of the floor, which had two occupants and a waiting area. The third data logger was placed on the wall of an office room located at west side of the floor (*placement C*): one of the room walls is equipped with a glassed window and was exposed to a direct sunlight in the afternoon and evening.

During the repeat experiment, placements A and C were maintained but the data logger at placement B was placed on the outside glass of the window in the same room as placement C. This was to measure the outside thermal variables during the repeat experiment (*referred as placement B' in the repeat results*). Figure 3-13 shows a photo of the first data logger position *(placement A)*.

Each experiment was performed over three days: one day for each mode (*i.e. constant, cyclic or ramp*) were required to conduct this exercise. On each mode, the air-conditioning system was set to operate from 6.00am till 6.00pm. The Building Management System installed was used to control the indoor set-point temperature to suit either ramp or cyclic mode from 8.00am to 4.30pm. When ramp set-point temperature mode was applied, the set-point temperature was increased steadily by 0.5 ^{0}F every ten minutes. The starting set-point temperature for this mode was set at 75 ^{0}F (23.9 ^{0}C). The set-point temperature was increased up to maximum allowable indoor set-point temperature which is 78.5 ^{0}F (25.8 ^{0}C).

The set-point temperature was reset back at the starting temperature after it reached the maximum allowable indoor set-point temperature. Similarly for cyclic mode, the set-point temperature was increased like the ramp mode but instead of resetting it straight back to 75 ^{0}F (23.9 ^{0}C) when it reached the maximum allowable indoor set point temperature, the set point temperature was decreased by 0.5 ^{0}F intervals every 10 minutes until it arrived back at 75 ^{0}F (23.9 ^{0}C).

Figure 3-13: The position of first data logger (placement A) at level 6 BHEUU during the field trial

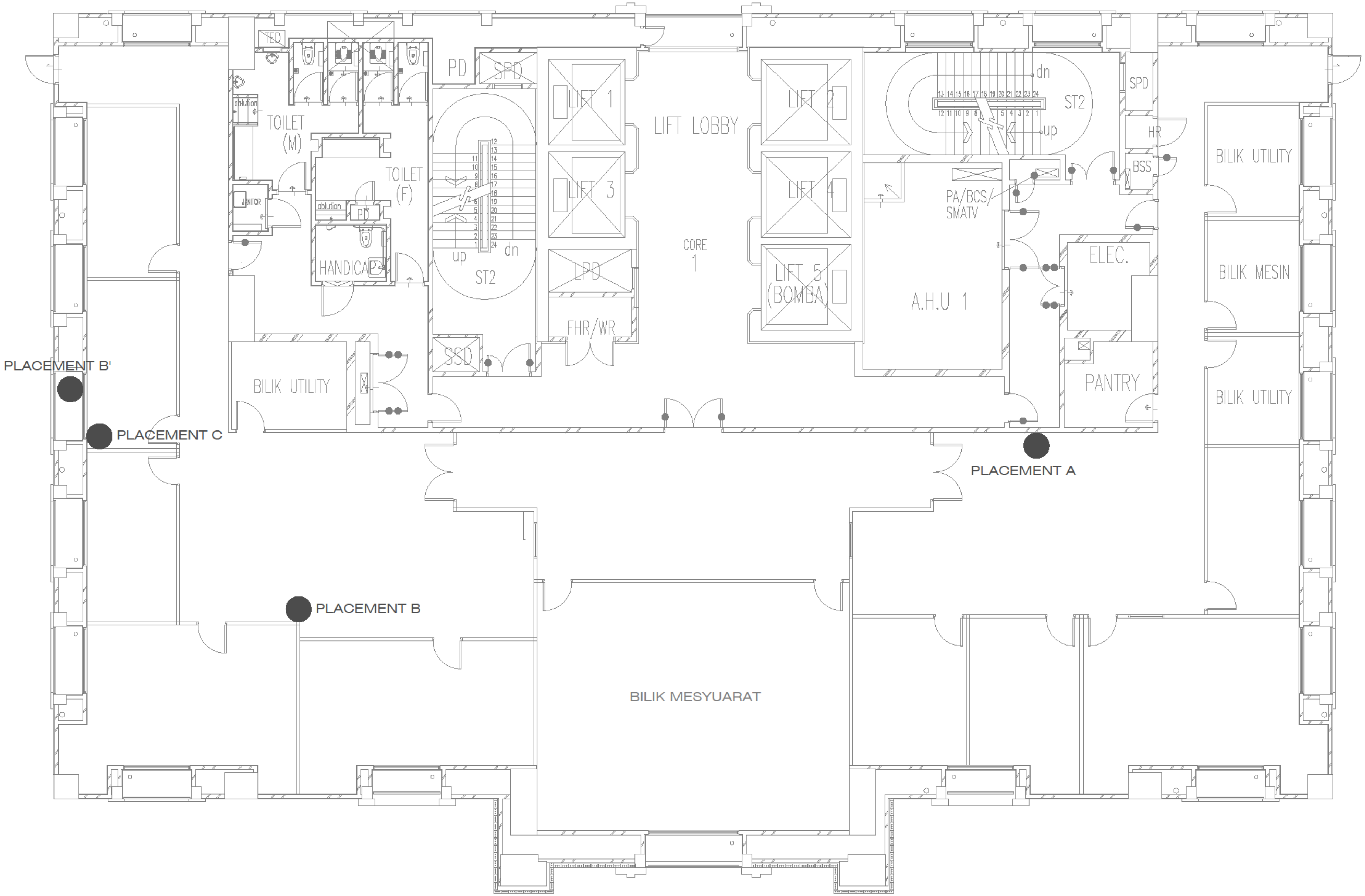


Figure 3-14: Floor plan of level 6 BHEUU, showing the data loggers positions (placement A, B, C and B')

The data loggers at their dedicated locations were set to start the measurement automatically with certain time and date programmed earlier using proprietary computer software. The results were recorded in the device itself and could be extracted using the same computer software. Due to some errors found only when the data were analysed, this trial was repeated again but this time only to measure two out of four thermal variables which were Dry Bulb Temperature and Relative Humidity. The mean radiant temperature measurement was taken out from the repeated trial due to the data obtained from the earlier trial was adequate.

3.6.2 Transverse survey with energy comparison trial

Both levels 6 and 7 were involved in this trial: level 6 was monitored as the 'control' floor, while set-point variations were applied to level 7. The air-conditioning system on level 7 was assigned with 2 different set-point temperature modes, cyclic and ramp. When either ramp or cyclic mode was assigned, then indoor set-point temperatures were varied in the same ways as described above, from 7.30 am till 6.00 pm concurrently for 2 working days. No surveys were performed on the first day to give occupants time to acclimatize, to minimize the transverse survey error due to their previous indoor climate experience. The surveyor team utilised the first day to do an energy usage pre-measurement of the floors. The pre-measurement aims to familiarize the team with the interface and operation of the installed Building Management System.

On the second day, the indoor set-point temperature modes at both levels were maintained as the first day, while the surveyors were assigned to do the transverse survey simultaneously using the questionnaire as described earlier in section 3.4 *(Figure 3-15)*. The surveyors started the survey in the morning at East North East (ENE) of the building where maximum solar heat gain due to sun rise was taken place and ended it at West North West (WNW) in the evening where maximum solar heat gain due to sun set was also taken place. The air-conditioning system energy consumption between 2pm to 4.30pm of both floors were recorded and compared. On the week after, the same procedures were repeated but with level 7 as controlled floor and level 6 as experimented floor.

The air-conditioning system energy consumption of a floor is equal to the sum of the actual floor cooling load and the floor fan motor power usage. The difference in fan motor power usage between floors is negligible, compared to the floor actual cooling load differences, as was ignored. The floor actual cooling load which was assumed to be equal to the floor air-conditioning system energy usage was measured at each Air handling Unit by applying the heat transfer flowrate equation:

$$\dot{Q} = \dot{m}\, Cp\, \Delta T$$

Where:

$\dot{Q}$ = mean heat transfer rate (kW)

$\dot{m}$ = mean fluid flowrate (kg/s)

Cp = specific heat for the fluid (kJ/kg^{0}C)

ΔT = temperature drop (^{0}C)

For this experiment, the mean air flowrate was measured at the main supply duct near the AHU as the mean fluid flowrate, the specific heat is the specific heat of air and the temperature drop is the temperature difference of off-coil air temperature and return air temperature.

Transverse Questionnaire

Occupant's Name: ....Gender: Male/Female

Date: .... Time: .... Floor Level: ....

<u>Please tick (√) as appropriate (*to be filled by the occupant*)</u>

1a. At present I feel:

Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot

1b. I would prefer to be:

Much Warmer	A bit Warmer	No Change	A bit cooler	Much Cooler

2. At present the air movement is:

Very low	Low	Slightly low	Neither high or low	Slightly high	High	Very high

3. At present the humidity is:

Very humid	humid	Slightly humid	Neither humid nor dry	Slightly dry	Dry	Very dry

4a. Garment layers of the occupant at present:

Number of layers		Tick as appropriate or else named it at this section			
Above waist	Below Waist	Singlet	Undershirt with short sleeves (T-Shirt)	Undershirt with long sleeves	Other (except panties and bra)

<u>This section is to be filled by the surveyor.</u>

4b. Garment of the occupant at present (*tick as appropriate*):

Shirt/Blouses		**Trousers**		**Jackets**	
Short sleeves		Shorts		Light Summer Jacket	
Light-weight, long sleeves		Light-weight		Jacket	
Normal, long sleeves		Normal		Smock	
Flannel shirt, long sleeves		Flannel			
Light-weight blouse, long sleeves				**Sundries**	
				Socks	
Sweaters		**Dresses/Skirts**		Thick, ankle socks	
Sleeveless vest		Light Skirts (summer)		Thick, long socks	
Thin sweater		Heavy Skirt (winter)		Nylon stockings	
Sweater		Light dress, short sleeves		Shoes (thin soled)	
Thick sweater		Winter dress, long sleeves		Shoes (thick soled)	
		Boiler suit		Boots	

5. Thermal variables measurements:

DB Temperature	Globe Temperature	Relative Humidity	Air Velocity	CO2
^{o}F	^{o}F	%	m/s	ppm

6. Nearest VAV Terminal Number to occupant:

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Figure 3-15: Transverse questionnaire used in the field trial to measure thermal comfort

3.7 Field Trial Experimental Apparatus

The main instruments used to measure energy consumption and thermal comfort variables (i.e. Air Temperature, Radiant Temperature, Humidity and Air Movement) were as follows:

i. 2 sling psychrometers
ii. 3 HOBO data loggers with a Globe thermometer attached: an air temperature probe with thermistor inside 38 mm diameter table tennis ball painted with matte black.
iii. 2 thermal comfort monitoring stations.
iv. supply and return air temperature sensors (part of the BMS).
v. supply air flowrate sensor (part of the BMS)

3.7.1 Sling psychrometer

According to BS 2842:1992, a sling psychromoter or whirling hygrometer is best described as an instrument that "*consists of two mercury-in-glass thermometers mounted side by side in a frame which is provided with a handle and spindle so that the frame and thermometers can be rotated at approximately 180 r/min about a horizontal axis. The bulb of one of the thermometers is covered by a closely fitting cylindrical sleeve, the end of which dips into a small water container attached to the end of the frame"* [1]. In this trial, sling psychrometer was used to calibrate dry bulb temperature and relative humidity reading errors between the HOBO Data Loggers. During the Transverse Survey, two sling psychrometers (one for each floor) also were used to replace the faulty force-ventilation psychrometer at both thermal comfort monitoring stations for measuring dry Bulb temperature and relative humidity. Two sling psychrometers were provided by Mechanical Branch, Public Works Department of Malaysia during the trial.

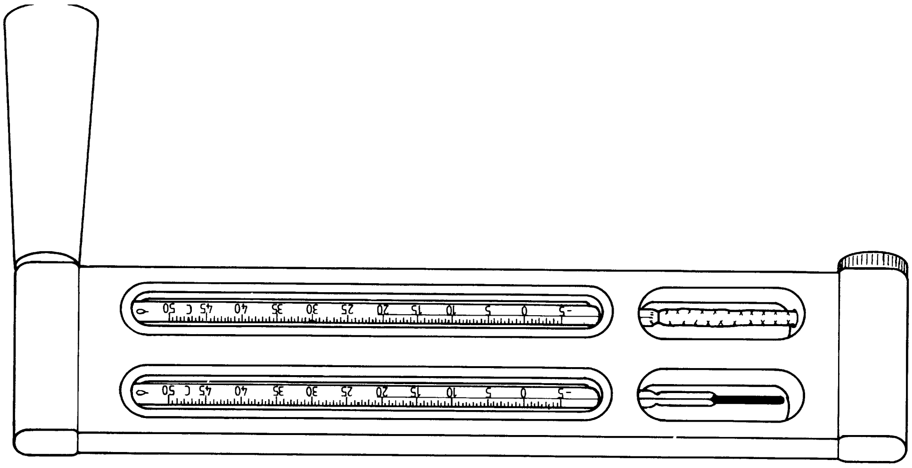
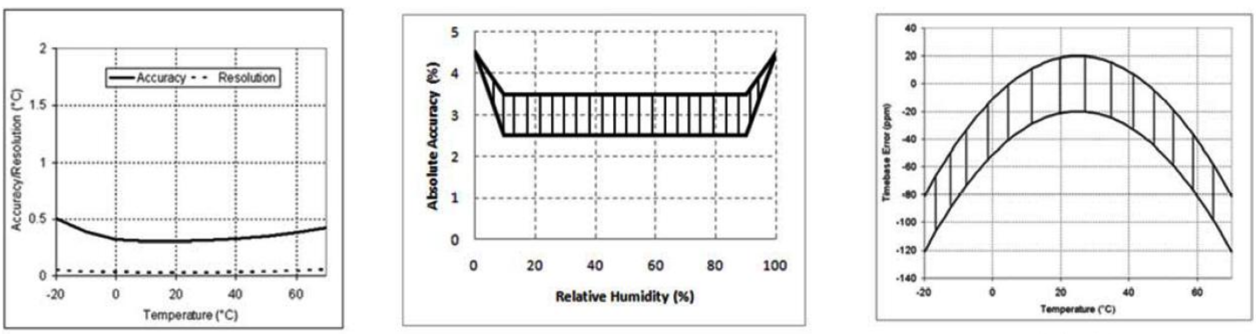


Figure 3-16: An example of sling psychormeter / whirling hygrometer [1]

Measurement range	Temperature: -20° to 70°C (-4° to 158°F) RH: 5% to 95% RH External input channels (see sensor manual): 0 to 2.5 DC Volts
Accuracy	Temperature: ± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F), see Plot A RH: +/- 2.5% from 10% to 90% RH (typical), to a maximum of +/- 3.5%. See Plot B. External input channels (see sensor manual): ± 2 mV ± 2.5% of absolute reading
Resolution	Temperature: 0.03°C at 25°C (0.05°F at 77°F), see Plot A RH: 0.03% RH
Drift	Temperature: 0.1°C/year (0.2°F/year) RH: <1% per year typical; RH hysteresis 1%
Time accuracy	± 1 minute per month at 25°C (77°F), see Plot C
Response time in airflow of 1 m/s (2.2 mph)	Temperature: 6 minutes, typical to 90% RH: 1 minute, typical to 90%
Operating temperature	Logging: -20° to 70°C (-4° to 158°F) Launch/readout: 0° to 50°C (32° to 122°F), per USB specification
Battery life	1 year typical use
Memory	64K bytes (43,000 12-bit measurements)
Weight	46 g (1.6 oz)
Dimensions	58 x 74 x 22 mm (2.3 x 2.9 x 0.9 inches)
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).



Plot A Plot B Plot C

Figure 3-17: HOBO data logger specification used in this trial

3.7.2 HOBO data loggers & globe thermometer

These data loggers were used in the Fixed Indoor Thermal Variables Measurement exercise to measure dry bulb temperature, mean radiant temperature and relative humidity. Three HOBO data loggers type U12 were provided by Mechanical Branch of PWD Malaysia during this trial. Figure 3-17 and Figure 3-18 show the technical specification and the HOBO Data Logger with an external air temperature probe respectively.

Figure 3-18: HOBO data loggers (type U12) and an external air temperature probe used in this trial

The data logger is fitted with build in dry bulb temperature and relative humidity sensors. To measure globe temperature, a compatible external air temperature probe (as shown in Figure 3-18) and a 38 mm diameter table tennis ball painted with matt black were used. The end part of the external probe, which has a thermistor inside was placed inside the painted table tennis ball. Figure 3-19 and Figure 3-20 show an assembled Globe Thermometer and technical specification of the external air temperature probe respectively. To minimize the reading differences error between the data loggers, a calibration using a sling psychrometer was also performed.

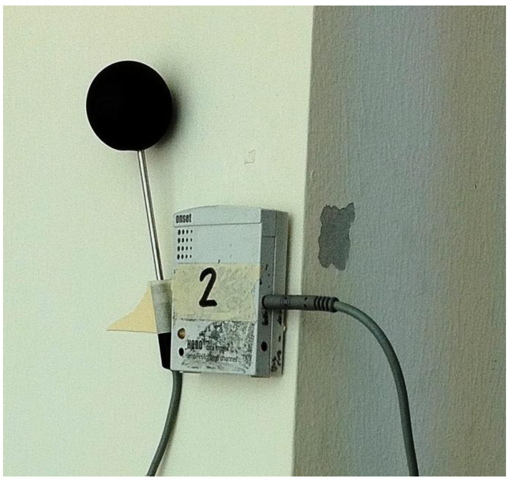


Figure 3-19: An assembled Globe Thermometer with U12 HOBO Data Logger

Measurement range	-40° to 100°C (-40° to 212°F)
Accuracy with U12	±0.25°C from 0° to 50°C (±0.45°F from 32° to 122°F), insert probe 5.08 cm (2 inches) minimum (see plot below)
Accuracy with ZW	±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F), insert probe 5.08 cm (2 inches) minimum
Resolution with U12	0.03° at 20°C (0.05° at 68°F)
Resolution with ZW	0.02°C at 25°C (0.04°F at 77°F)
Response time in air	3 min. typical to 90% in air moving 1 m/sec (2.2 mph)
Response time in stirred water	15 sec typical to 90%.
Probe diameter	3.2mm ±0.25mm (0.12 inches ±0.01)

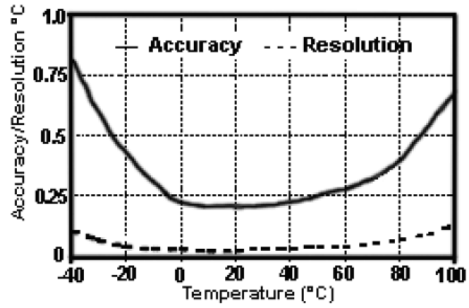


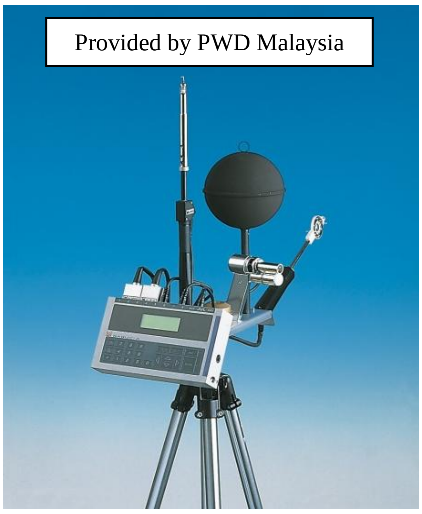
Figure 3-20: HOBO external air temperature probe specification

3.7.3 Thermal comfort monitoring station

The station can be described as a measuring instrument that has three major parts: an intelligent data logger, sensors and an equipment stand. In general, sensors available for this station are not just limited to measure thermal variables. Available sensors include noise sensors, VO2 gas sensors and lux sensors. However, in this trial only four types of sensor were used:

i. Force-ventilation Psychrometer Sensor – RH and Dry Bulb Measurement
ii. Globe Thermometer Sensor – Globe Temperature Measurement
iii. Hot Wire Anemometer Air-Flow Sensor – Low Air Velocity Measurement
iv. CO2 Gas Sensor – CO2 Level Measurement in particles per minute (ppm)

During the transverse survey experiment, two thermal comfort motoring stations were used. One was provided by the Mechanical Engineering Branch and another one by National University of Malaysia (UKM). Except Force-ventilation Psychrometer Sensors which were found not properly functioned at both stations, all the above sensors are complied with ISO 7726 standard. Two Sling Psychrometers were used to replace the Force-ventilation Psychrometer Sensors. Figure 5 below shows the thermal comfort stations provided by the Mechanical Branch of PWD Malaysia (left) and the National University of Malaysia (right).



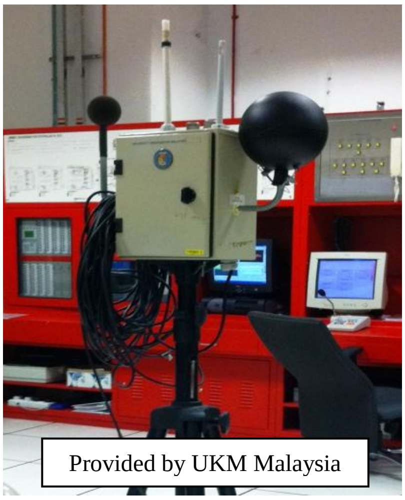


Figure 3-21: shows the assembled thermal comfort monitoring stations used in the transverse survey experiment

3.7.4 Supply and return air temperature sensors

These sensors are readily installed in the building HVAC system and are one of the essential elements of Building Management System (BMS). The supply air temperature sensor for level 6 and 7 of this building is located inside the Air Handling Unit and adjacent to the cooling coil. The return air temperature sensor on the other hand is located inside and at the end of the return air duct. Figure 3-22 below shows typical locations of supply as well as return air temperature sensor in BHEUU. Note that in this figure, supply air temperature is referred as off coil temperature. Temperature signals from these sensors are transmitted to a centralized monitoring system in a control room located in the ground floor and are presented as a readable graphical data.

3.7.5 Supply air flow sensors

Similar to supply and return air temperature sensors, these sensors are also installed as a part of the Intelligent Building Management System. For most buildings, this type of sensor is located in the main supply duct, so can monitor total supply air flowrate for a particular Air Handling Unit. However, these sensors in BHEUU are located inside the VAV Terminals where the flowrate is only a fraction of the total supply air flowrate. Therefore, to get the supply air flowrate of one AHU in this trial, flowrate readings from all related VAV terminals were collected and totalled.

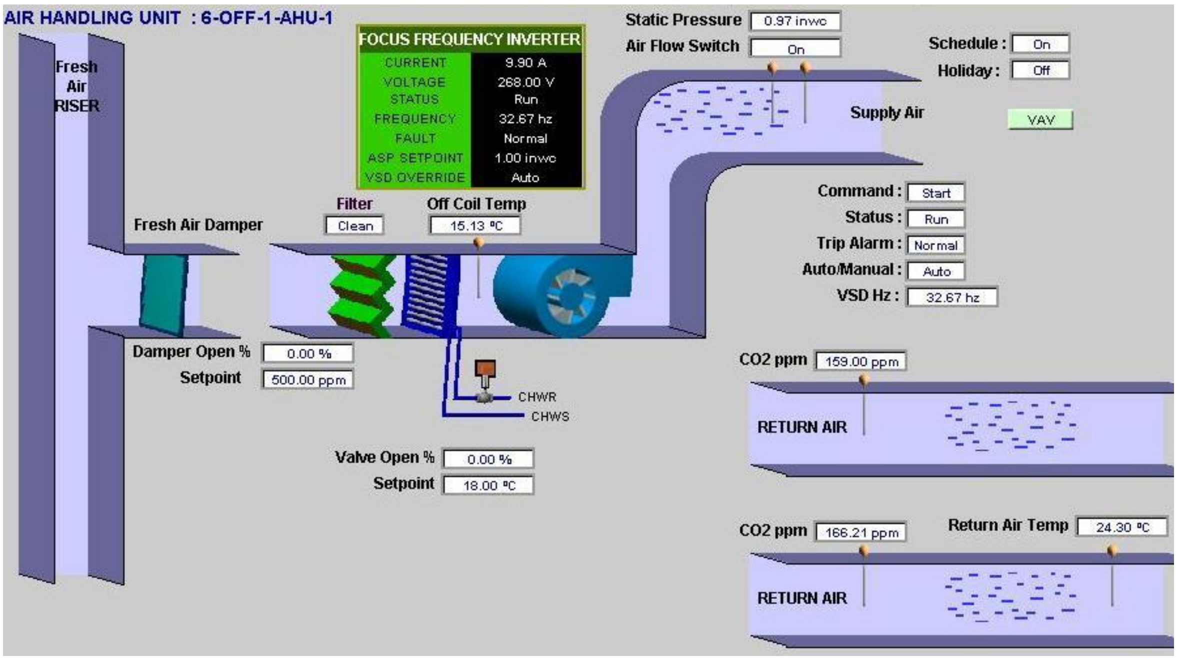


Figure 3-22: Supply and return air temperature sensors positions in BHEUU

CHAPTER 4

FIELD TRIAL EXPERIMENTAL RESULTS AND ANALYSES

4.1 Chapter Introduction

Results for the two field experiments are presented in this chapter. Results from the first field experiment have similar values for the indoor dry bulb temperatures and operative temperatures in level 6, BHEUU when any of the three modes were applied. The results also show the response of the level 6 indoor climate when each of the three modes were implemented. For the second experiment, results are presented to show the thermal comfort votes, percentage of dissatisfied and indoor neutral temperature when each mode of indoor set-point temperature adjustment was implemented. HVAC system energy consumptions of the relevant floor during the experiments are also tabulated.

4.2 Background measurements results

As mentioned in the previous chapter, this experiment was repeated because of errors found when data from the first experiment were analysed. These errors were attributed to the supply air set-point temperature, which was set too low during the experiment. This caused all the VAV room terminal units in level 6 to operate with minimum flowrates, while the indoor air temperature was unintentionally maintained far below the set-point temperature. Since the indoor climate did not respond to any of the indoor set-point temperature adjustment modes, the results from this experiment are used only to show the correlation between the indoor dry bulb temperature, globe temperature and operative temperature.

When the experiment was repeated, only dry bulb temperature and relative humidity were measured. Results from this experiment were analysed to understand the response of the building indoor climate to each of the set-point modes. Tables of results are given as Appendices: table 6-1, table 6-2, table 6-3, table 6-4, table 6-5, table 6-6, table 6-7, table 6-8 and table 6-9 contain the data from the first experiment, and table 6-10, table 6-11, table 6-12, table 6-13, table 6-14 and table 6-15 contain data from the repeated experiment. For the first experiment, the constant mode was applied on 23rd August 2011, the ramp mode on 24th August 2011 and the cyclic mode on 25th August 2011. For the repeated one, the constant mode was applied on 06th December 2011, the ramp mode on 07th December 2011 and the cyclic mode on 08th December 2011.

4.2.1 Building indoor air temperature and operative temperature

Data from the first experiment was analysed to see if there is any significant difference or similarity between indoor air temperature and operative temperature, which cannot be measured experimentally. Theoretically, operative temperature is "*the average of the air temperature and the mean radiant temperature weighted respectively by the convection heat transfer coefficient and the linearized radiation heat transfer coefficient for the occupant*"[3]. In this experiment globe temperature is used as an approximation to the operative temperature. This approximation was also used in [17] by J.F. Nicol et al. Figure 4-1, Figure 4-2 and Figure 4-3 show the changes of space dry bulb temperature and globe temperature for the three set-point temperature modes at placement A. Likewise, Figure 4-4, Figure 4-5, Figure 4-6 for placement B and Figure 4-7, Figure 4-8, Figure 4-9 for placement C.

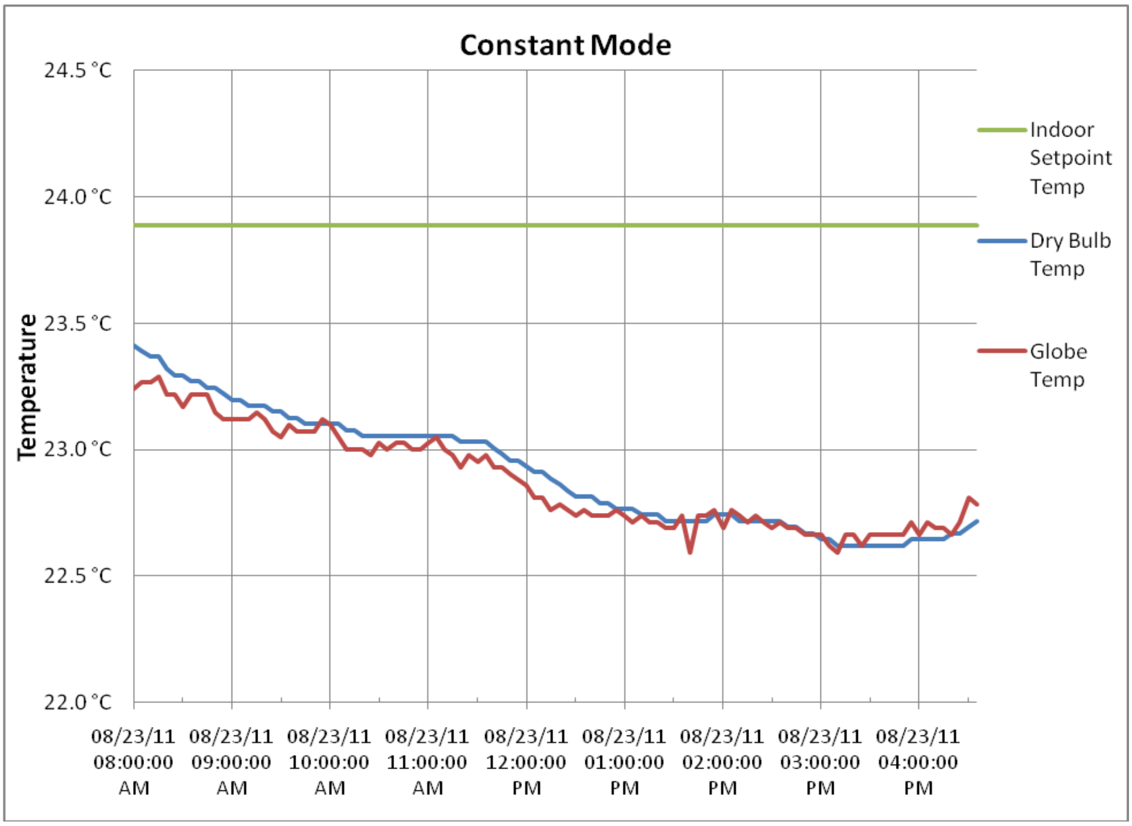


Figure 4-1: The changes of space dry bulb temperature and operative temperature during implementation of constant indoor set-point temperature mode at placement A (23rd August 2011)

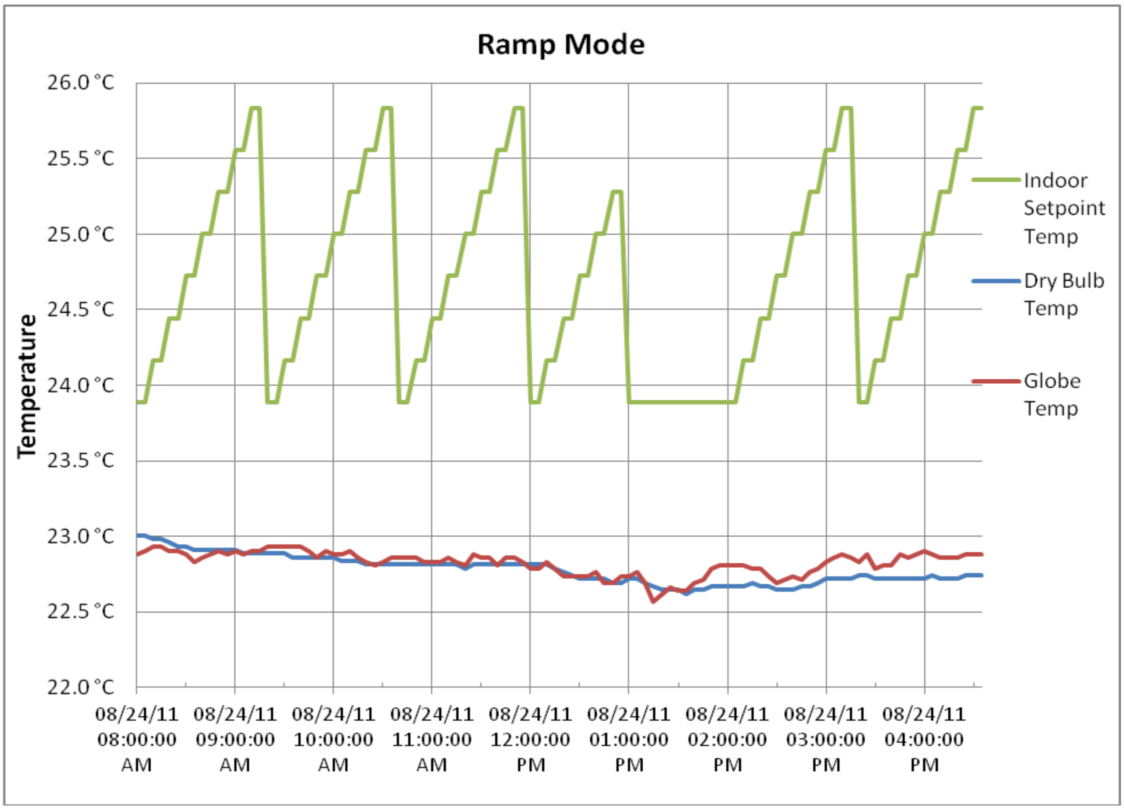


Figure 4-2: The changes of space dry bulb temperature and operative temperature during implementation of ramp indoor set-point temperature mode at placement A (24th August 2011)

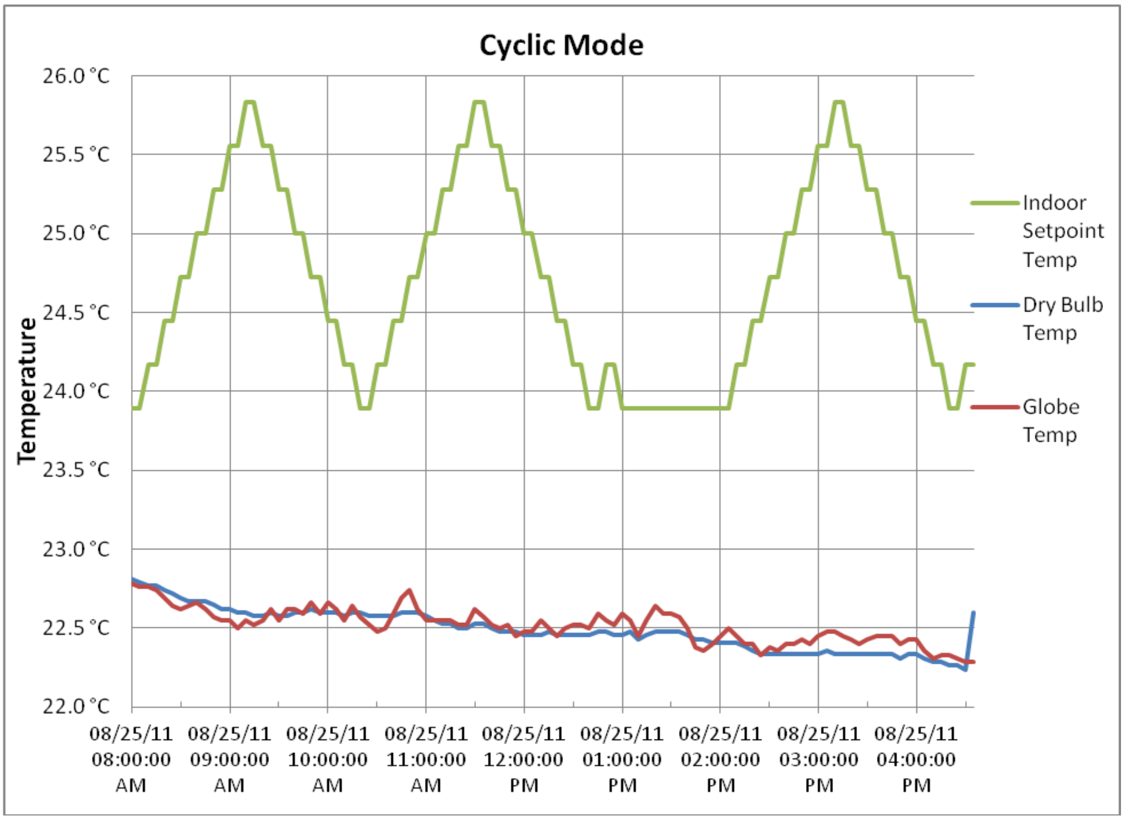


Figure 4-3: The changes of space dry bulb temperature and operative temperature during implementation of cyclic indoor set-point temperature mode at placement A (25th August 2011)

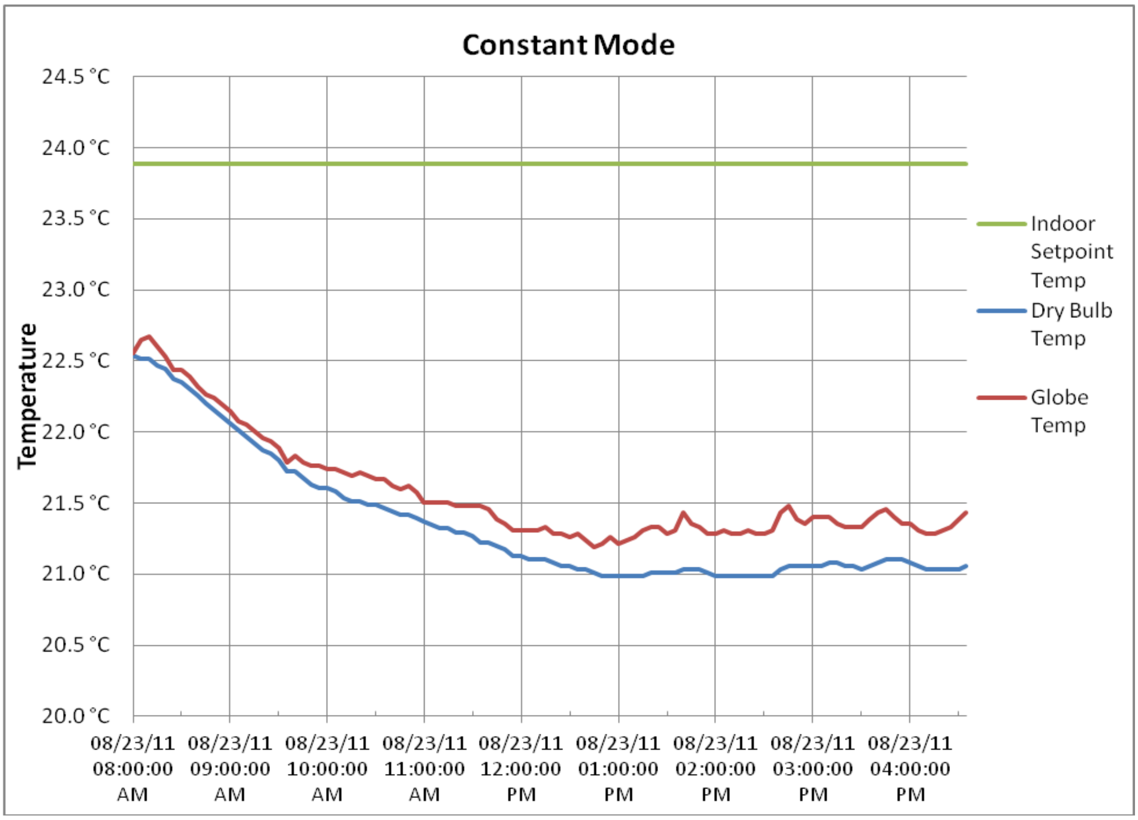


Figure 4-4: The changes of space dry bulb temperature and operative temperature during implementation of constant indoor set-point temperature mode at placement B (23rd August 2011)

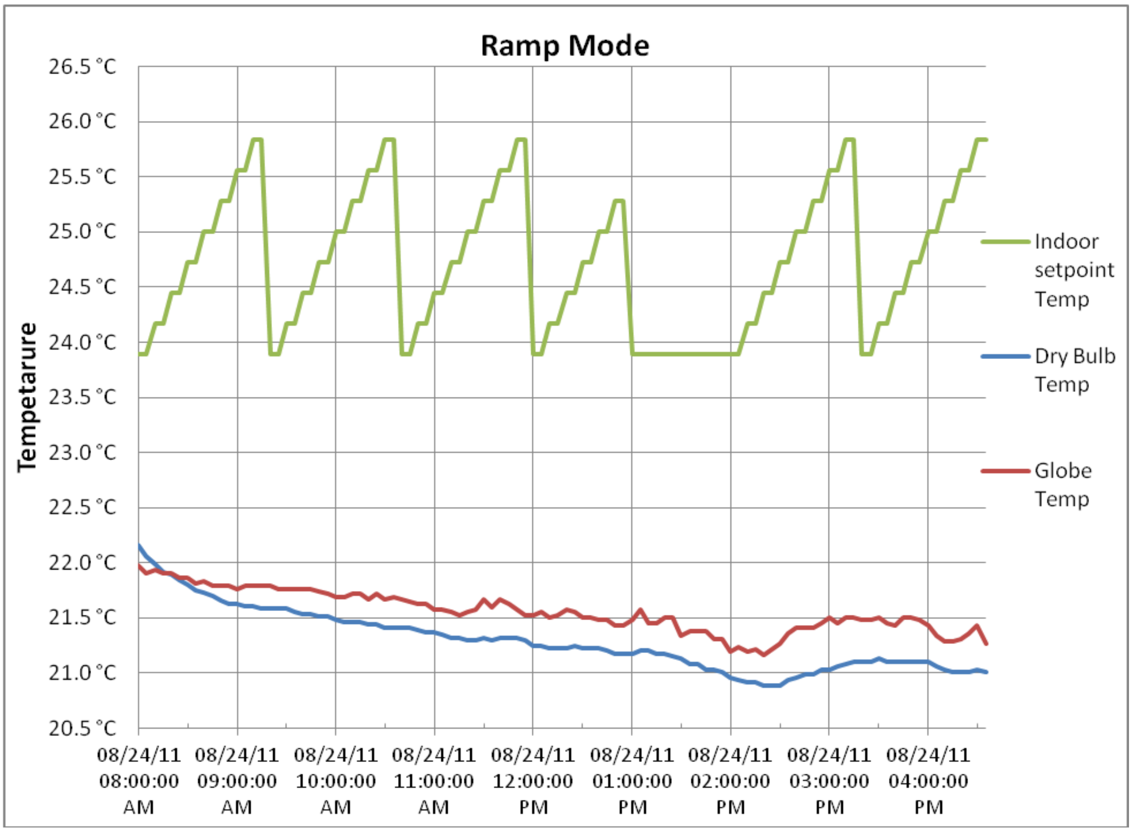


Figure 4-5: The changes of space dry bulb temperature and operative temperature during implementation of ramp indoor set-point temperature mode at placement B (24th August 2011)

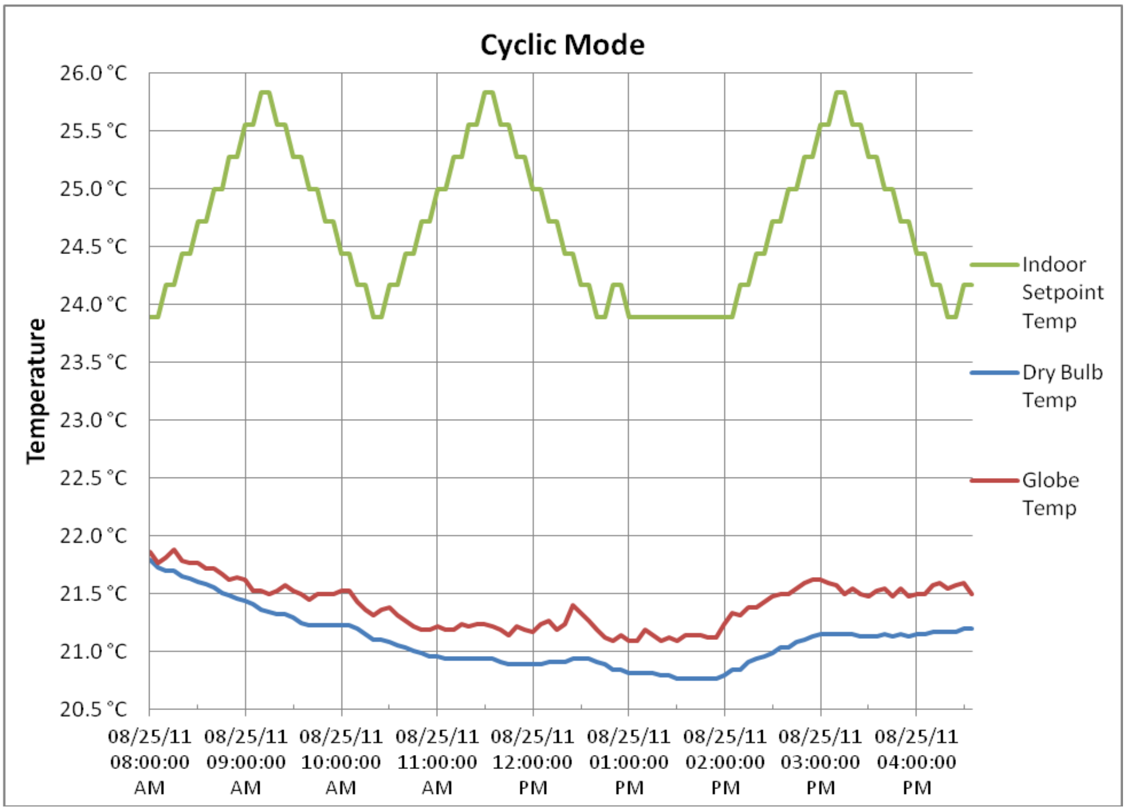


Figure 4-6: The changes of space dry bulb temperature and operative temperature during implementation of cyclic indoor set-point temperature mode at placement B (25th August 2011)

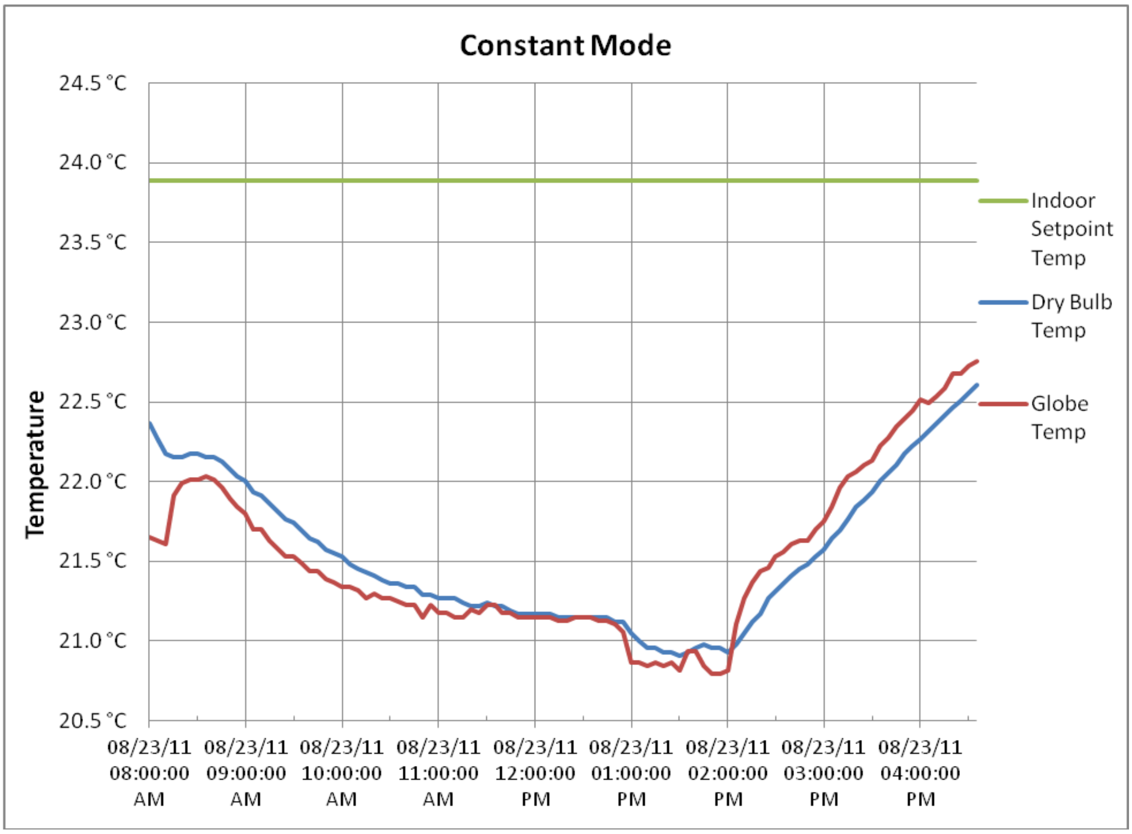


Figure 4-7: The changes of space dry bulb temperature and operative temperature during implementation of constant indoor set-point temperature mode at placement C (23rd August 2011)

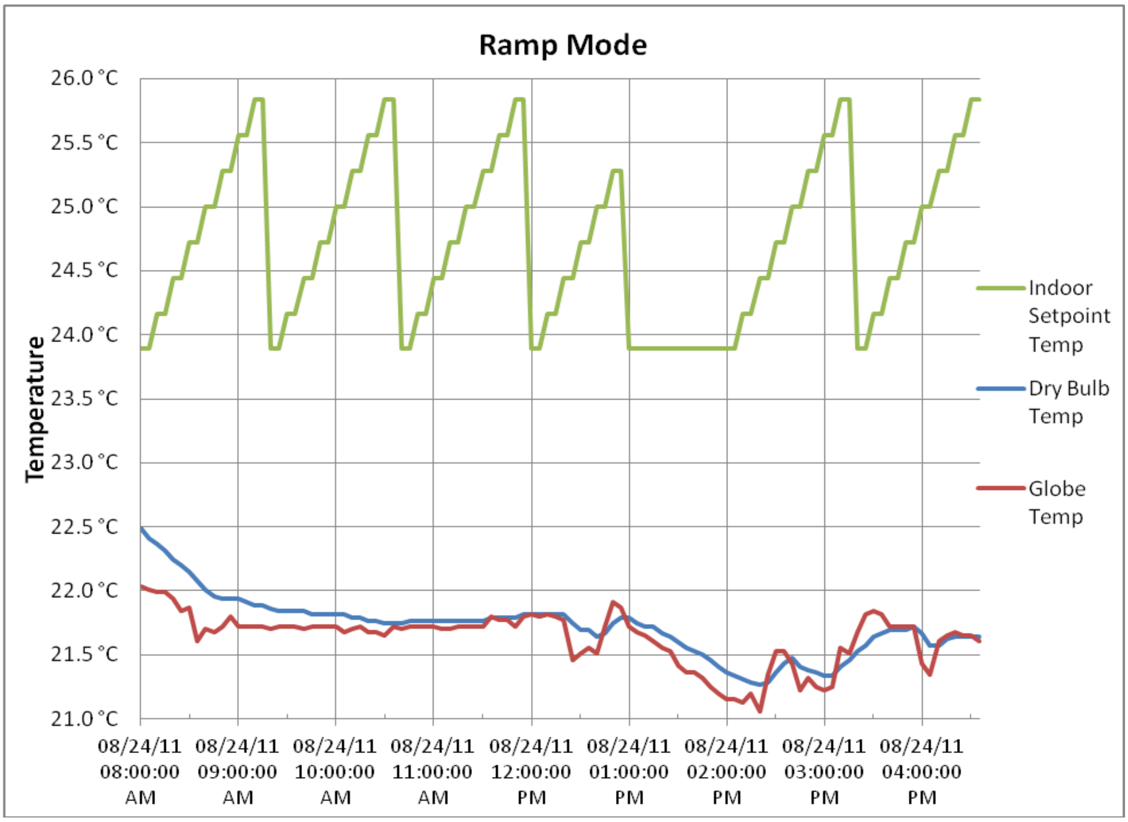


Figure 4-8: The changes of space dry bulb temperature and operative temperature during implementation of ramp indoor set-point temperature mode at placement C (24th August 2011)

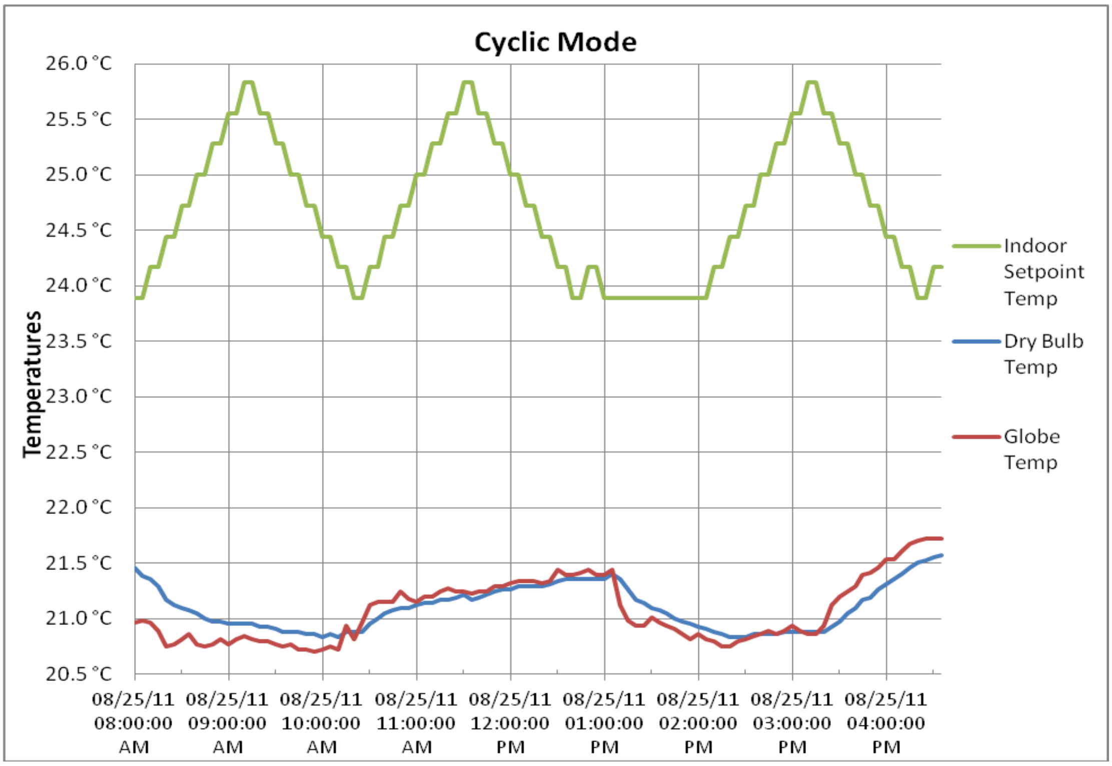


Figure 4-9: The changes of space dry bulb temperature and operative temperature during implementation of cyclic indoor set-point temperature mode at placement C (25th August 2011)

It can be seen from Figure 4-1 – Figure 4-9 that both the dry bulb and operative temperature are always below their relevant indoor set-point temperature. As explained before, this over cooling occurred because the supply air temperature was set too low during the experiments. Furthermore, the indoor set-point temperature modes are also seen to have little impact on both dry bulb and operative temperature changes. However, the trends in the dry bulb and operative temperatures are observed to be fairly similar. There are no significant differences between the dry bulb and operative temperatures during the first set of experiments.

4.2.2 *Building indoor climate response*

Results from the repeated experiment were analysed to understand the space climate response to various set-point adjustment: constant, ramp and cyclic mode of adjustment to indoor set-point temperature. These include the dry bulb temperature and relative humidity for both the space and outside (*denoted as B'*). Figure 4-10 and Figure 4-11 show the space and outside relative humidity changes for the three modes at placements A and C respectively. The space and outside dry bulb temperature changes of the three modes during the experiment for placement A and C are shown in Figure 4-12, Figure 4-13, Figure 4-14 and Figure 4-15, Figure 4-16, Figure 4-17 respectively.

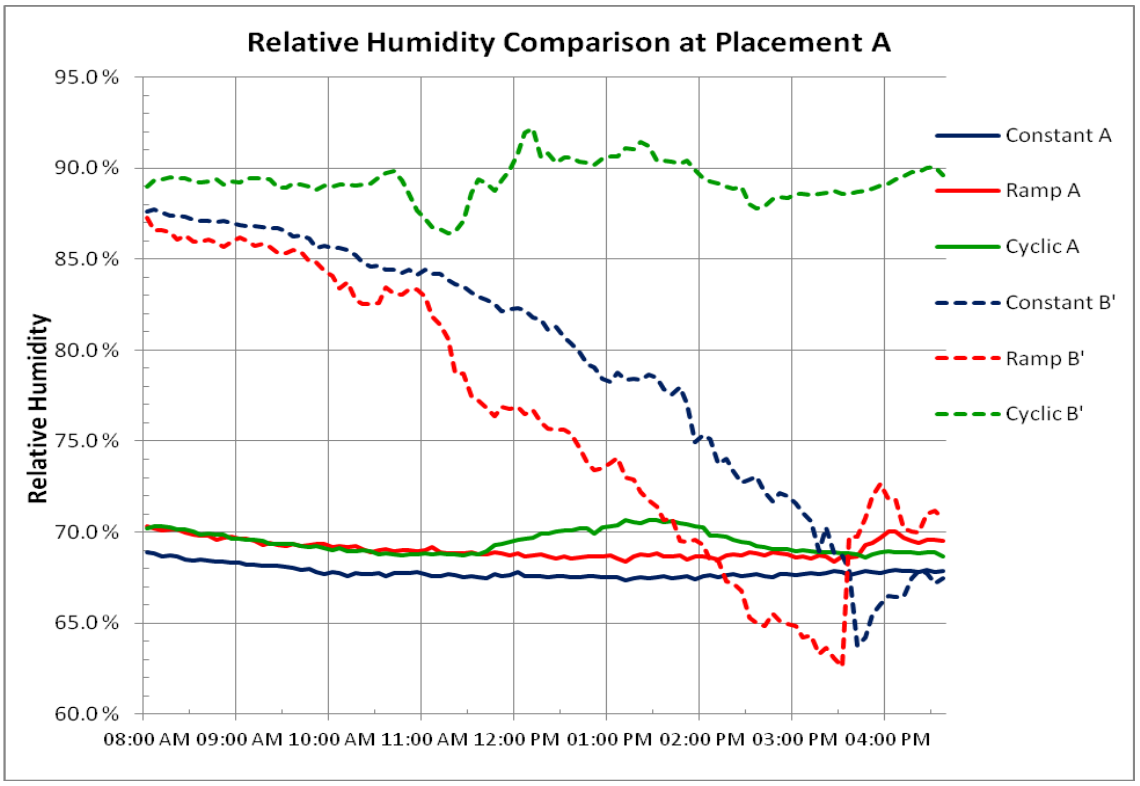


Figure 4-10: The space and outside corresponding relative humidity changes when the three modes are implemented at placement A

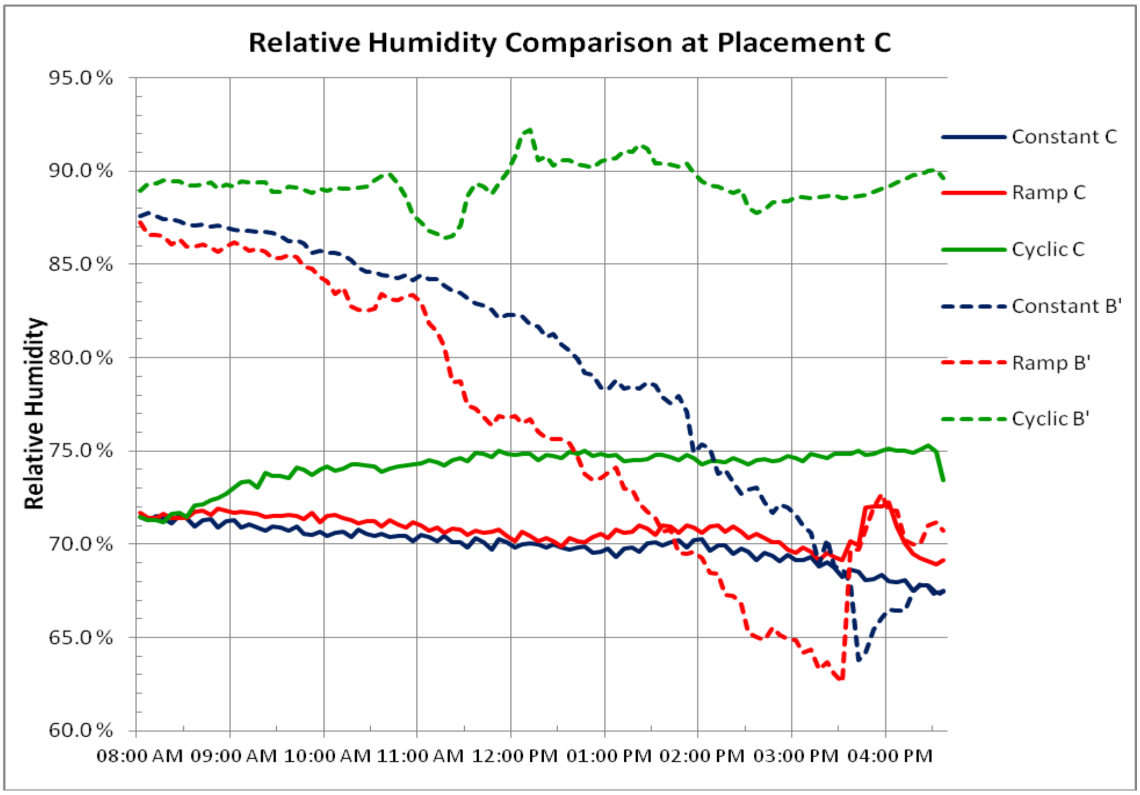


Figure 4-11: The space and outside corresponding relative humidity changes when the three modes are implemented at placement C

In both Figure 4-10 and Figure 4-11, the solid lines represent the relative humidity changes measured in the air-conditioned space, labelled as placement A or C while the dotted lines represent the corresponding changes in the outside conditions, which are labelled as placement B'. Observed from both figures, the corresponding outside relative humidity during the ramp mode implementation day steadily decreased from 87% at 8.00 am to 63% at 3.30pm. It then rose rapidly to 73% at 4.00 pm and ended with 70% at 4.30 pm. On the other hand, the indoor space relative humidity for placements A and C were more or less constant at approximately 68% to 70% for the whole day.

However there was a slight increase in RH for placement C at approximately 4.00 pm to 72.5%. Similarly during the constant mode implementation day, the corresponding outside relative humidity declined gradually from 87% at 8.00 am to 64% 3.40 pm. It then started to rise back to 69% progressively at 4.30pm. The indoor space relative humidity were more or less stable at 68% for placement A while for placement C the space relative humidity decreased gradually from 71.5% at 8.00 am to 67% at 4.30 pm.

As for the cyclic mode implementation day, the corresponding outside relative humidity was more or less steady at 90% from 8.00 am to 4.30 pm with slight fluctuation from 11.00 am to 1.30 pm. The indoor space relative humidity of placement A is also seen to be stably controlled at approximately 70% for the whole day. However, for placement C the space relative humidity increased moderately from 71% at 8.00 am to 75% at 12.00 pm. It then relatively steadied at 75% for the rest of the day. Overall, there is no obvious correlation between the indoor relative humidity and either indoor set-point temperature or outside relative humidity.

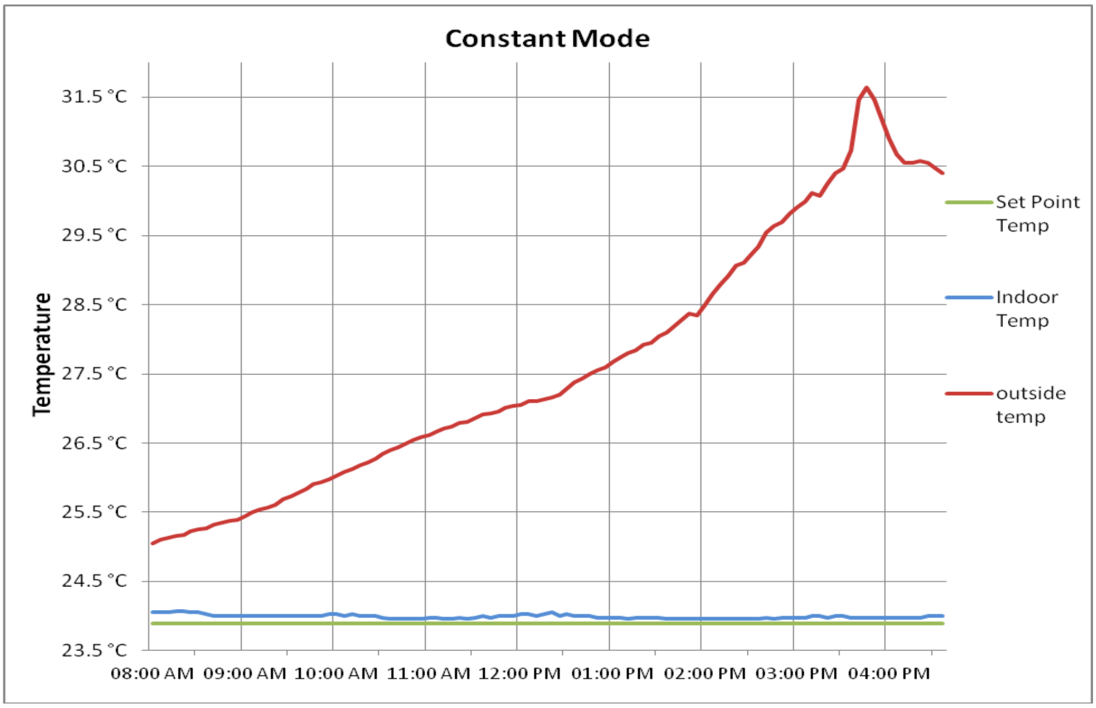


Figure 4-12: The outside and indoor space temperature changes during the constant mode at placement A

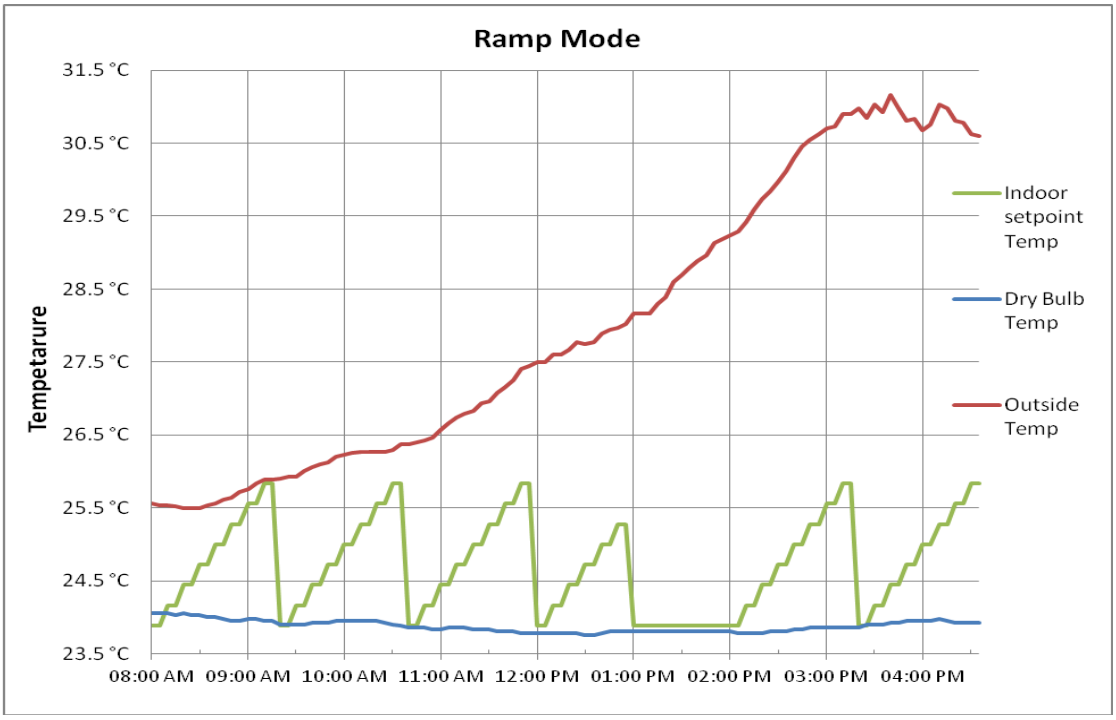


Figure 4-13: The temperature changes during the ramp mode at placement A

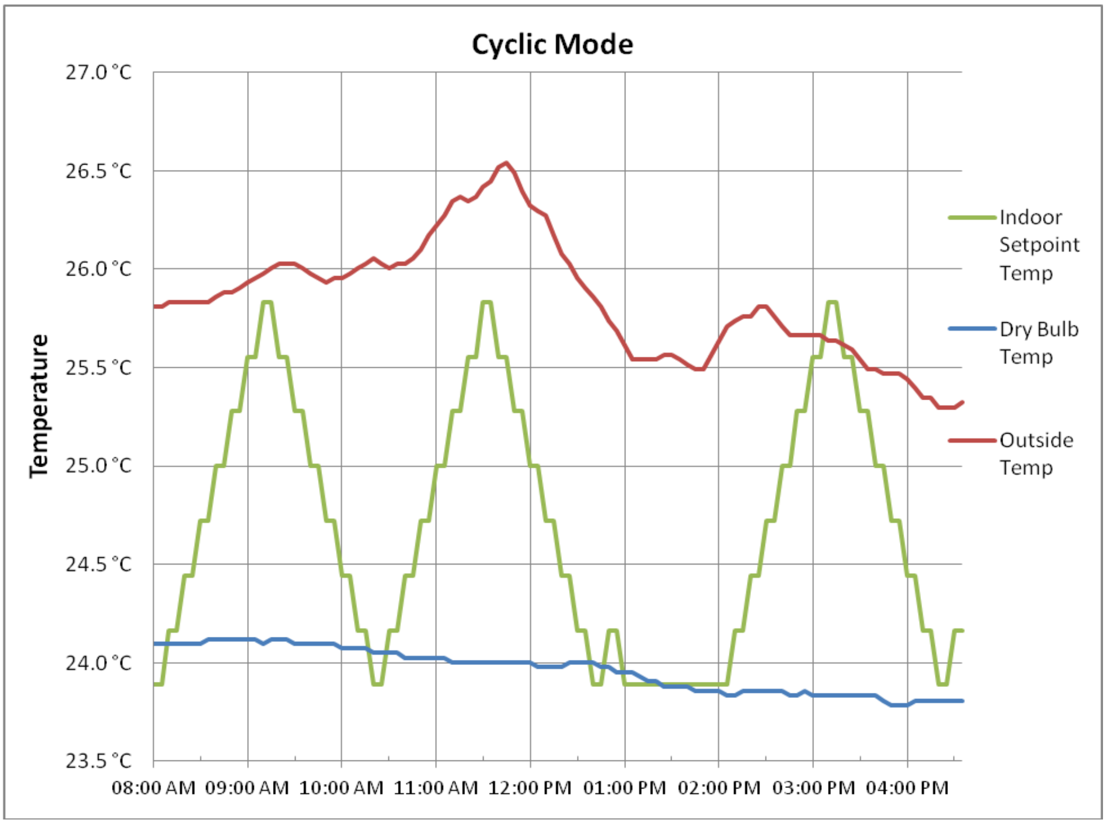


Figure 4-14: The temperature changes during the cyclic mode at placement A

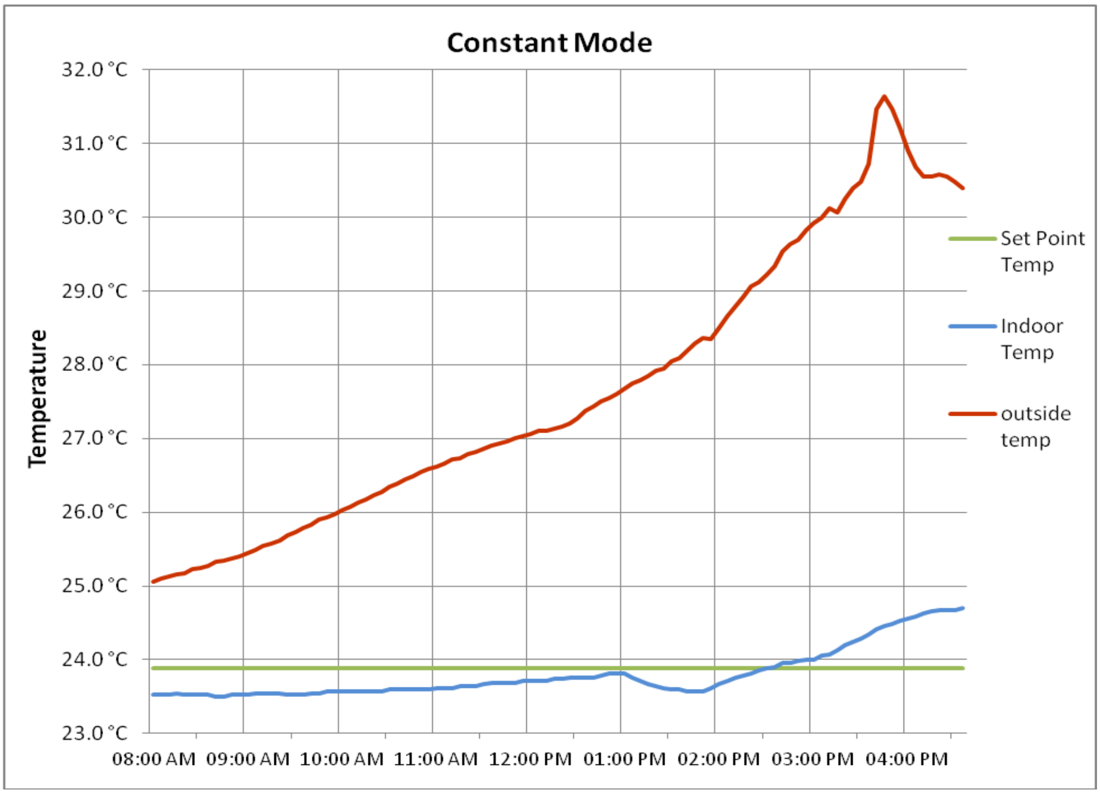


Figure 4-15: The temperature changes during the constant mode at placement B

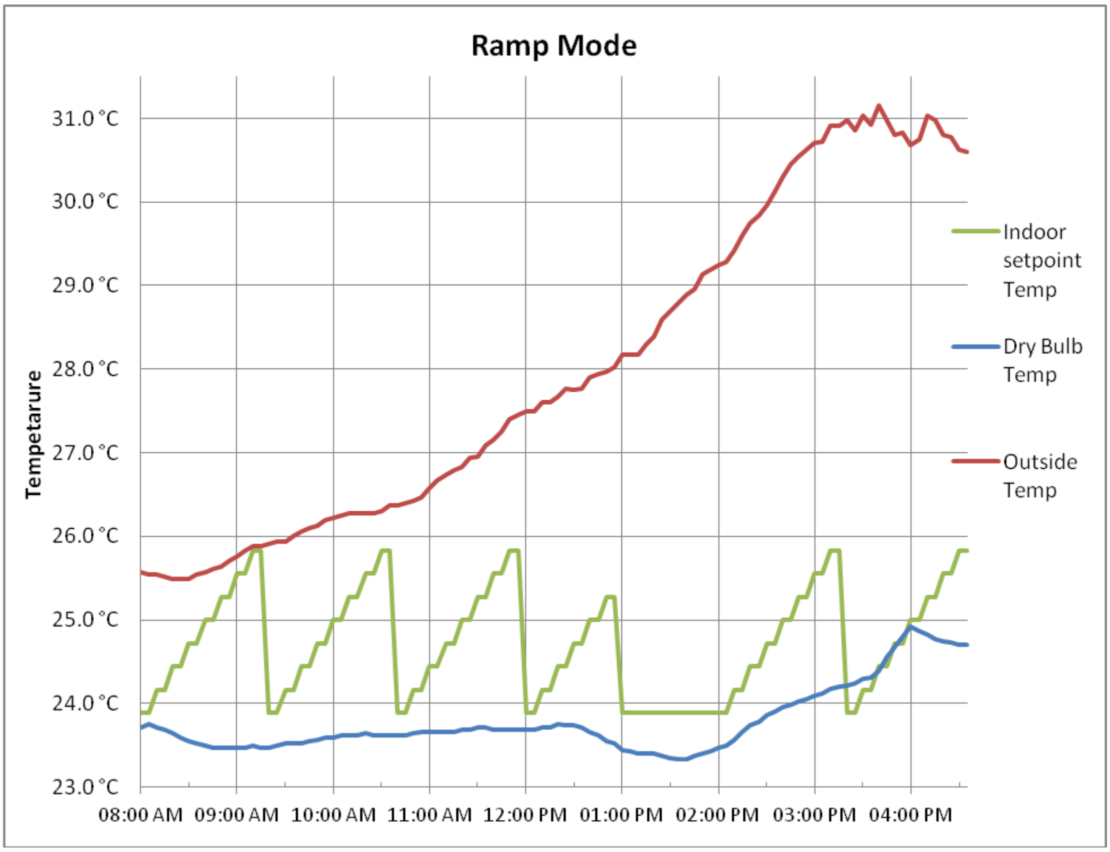


Figure 4-16: The temperature changes during the ramp mode at placement C

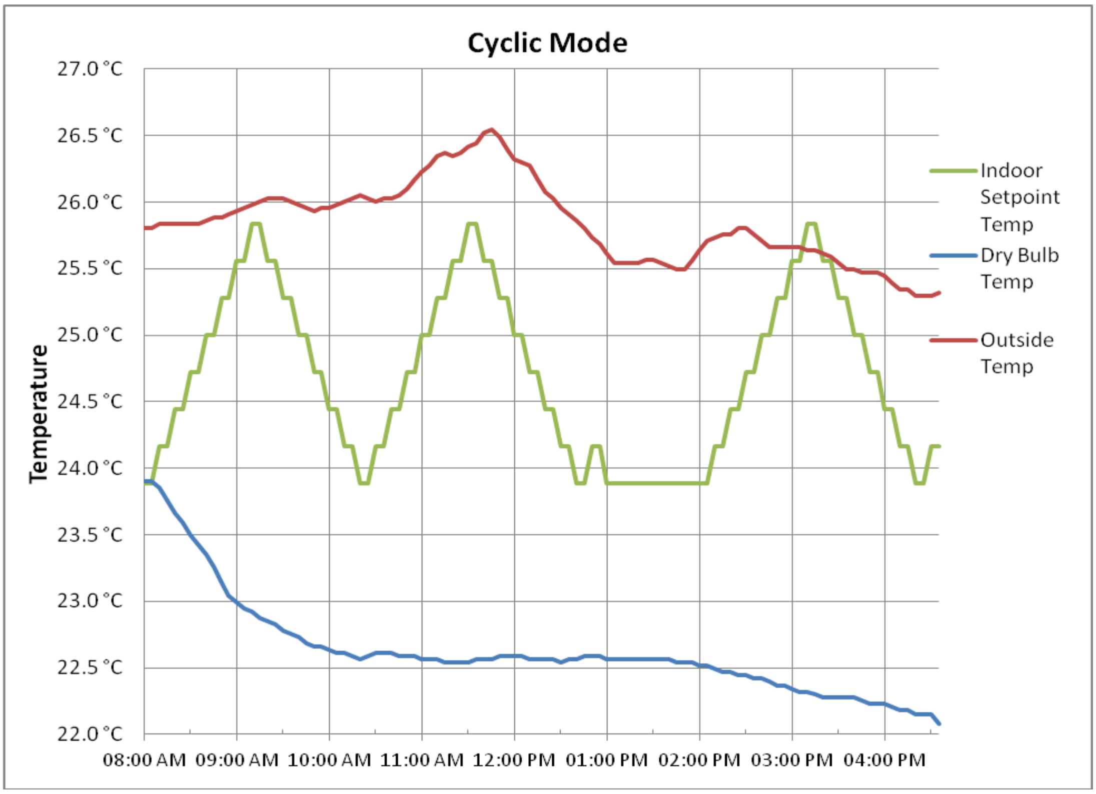


Figure 4-17: The temperature changes during the cyclic mode at placement C

When the constant mode was applied, the corresponding outdoor temperature was seen to steadily increase from 25^{o}C at 8.00 am to 31.5^{o}C at 3.35 pm. It then rapidly dropped back to 30.5^{o}C at 4.30 pm (*Figure 4-12 and Figure 4-15)*. The indoor space dry bulb temperature at placement A was observed to be exactly constant at 24^{o}C from 8.00 am to 4.30 pm *(Figure 4-12)*. Meanwhile, the space dry bulb temperature at placement C was more or less steady at 23.6^{o}C from 8.00 am to 1.50 pm. The temperature then increased gradually to 24.9^{o}C at 4.30 pm *(Figure 4-15).*

The outdoor dry bulb temperature during the ramp mode operation was observed to gradually increase from 25.5^{o}C at 8.00 am to 31^{o}C at 3.30 pm. It then fluctuated between 30.6^{o}C and 31.1^{o}C till 4.30 pm *(Figure 4-13 and Figure 4-16)*. The indoor space dry bulb temperature at placement A was observed to remain reasonably constant at 24^{o}C for the whole day *(Figure 4-13)*. At placement C, the temperature was seen to remain fairly constant at 24^{o}C from 8.00 am to 1.30 pm. It then gradually rose to 25^{o}C at 4.00 pm, then remained relatively stable till 4.30 pm *(Figure 4-16).*

During the cyclic mode operation, the outdoor dry bulb temperature was observed to increase slowly from 25.7^{o}C at 8.00 am to 26.5^{o}C at 11.50 am. It then steeply decreased to 25.5^{o}C at 1.00 pm. The temperature then reached plateau for approximately 50 minutes. It then started to rise again to 25.7^{o}C at 2.30 pm before continue to gradually fall to its nadir of 25.3^{o}C at 4.30 pm *(Figure 4-14 and Figure 4-17).* The corresponding indoor space dry bulb temperature at placement A experienced a gradual, small depreciation from 24.1^{o}C to 23.8^{o}C throughout the day *(Figure 4-14)*. As for placement C, the corresponding indoor space temperature was seen to steeply decline from 23.9^{o}C at 8.00 am to 22.6^{o}C at 10.30 am before reaching a plateau for approximately 3.5 hours. It then decreased steadily to 22.1^{o}C at 4.30 pm *(Figure 4-17).* These show that fluctuations of the building indoor set-point temperature did not have significant impact on the indoor space temperature. Nonetheless, changes of the outside air temperature contributed small but noticeable changes to the space temperature.

4.3 Transverse Survey with Energy Comparison Trial Results

Data collected on the transverse survey forms were examined to calculate the resultant operative temperature and clothing value for each occupant involved. In this experiment, where the occupants were engaged in near sedentary physical activity *(with metabolic rates between 1.0 met and 1.3 met),* the spaces were not in direct sunlight, and the air velocities was not greater than 0.20 m/s (*40 fpm*), equation *(4-i)* [71] together with equation *(4-ii)* [3] below were used to obtain the operative temperature.

$$T_{MR} = T_G(1+2.35v_A^{1/2}) - 2.35T_Av_A^{1/2} \quad (4\text{-}i)$$

$$T_{OP} = (T_A + T_{MR}) / 2 \quad (4\text{-}ii)$$

where:

T_{MR} is Mean Radiant Temperature

T_G is Globe Temperature

T_A is Air Temperature

T_{OP} is Operative Temperature

v_A is Air Velocity

Equation *(3-i)* and *(3-ii)* described in chapter 3 were used to estimate the clothing values. The results of the whole trial are summarized in the appendices section, tables 6-16 to 6-23. Table 6-16 and table 6-20 show the results when the ramp modes were applied in level 6 *(13th September 2011)* and level 7 *(20th September 2011)* respectively. On the other hand, the results for cyclic modes, when applied in level 6 *(15th September 2011)* and level 7 *(22nd September 2011)* are shown in table 6-18 and table 6-22 respectively. The corresponding results when set-points were held constant in the controlled floor are shown in table 6-17, table 6-19, table 6-21 and table 6-23.

A number of measures are used to compare the results between the modes: sensation vote, percentage of dissatisfied and indoor neutral temperature changes. HVAC system energy consumption of the floor during each mode are also tabled and compared.

4.3.1 Sensation vote

In this research, the sensation vote refers to the vote that expresses the thermal or airflow or humidity sensation of the occupant. Results of the sensation votes are tabulated in table 6-16 to table 6-23 *(refer to Appendices section)*. Comparisons between all modes of both levels 6 and 7 are illustrated in Table 4-1 to Table 4-6 and Figure 4-18 to Figure 4-23.

Table 4-1: Thermal sensation votes at level 6 during the three mode implementations

Occupants Response	Thermal Sensation Vote at Level 6							
	Ramp		Cyclic		Constant (i)		Constant (ii)	
Cold	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %
Cool	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %
Slightly Cool	1	6.3 %	6	37.5 %	1	6.3 %	1	6.3 %
Neutral	9	56.3 %	7	43.8 %	13	81.3 %	11	68.8 %
Slightly Warm	5	31.3 %	2	12.5 %	2	12.5 %	3	18.8 %
Warm	1	6.3 %	1	6.3 %	0	0.0 %	1	6.3 %
Hot	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %

* constant (i) is taken from 20/9/11 and (ii) from 22/9/11 data

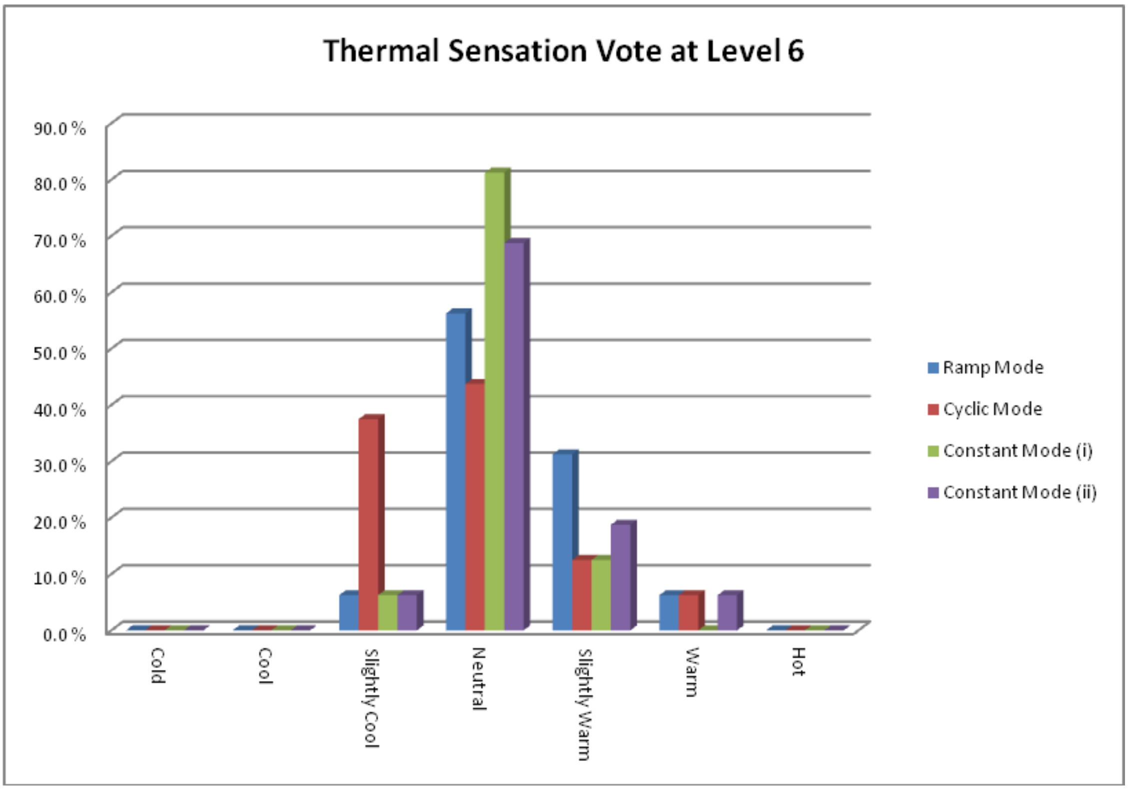


Figure 4-18: Column chart showing the thermal sensation votes at level 6 during the three mode implementations

Table 4-2: Thermal sensation votes at level 7 during the three mode implementations

Occupants Response	Thermal Sensation Vote at Level 7							
	Ramp		Cyclic		Constant (i)		Constant (ii)	
Cold	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %
Cool	1	7.7 %	1	7.1 %	1	7.1 %	0	0.0 %
Slightly Cool	4	30.8 %	3	21.4 %	5	35.7 %	9	64.3 %
Neutral	6	46.2 %	8	57.1 %	4	28.6 %	5	35.7 %
Slightly Warm	1	7.7 %	2	14.3 %	4	28.6 %	0	0.0 %
Warm	1	7.7 %	0	0.0 %	0	0.0 %	0	0.0 %
Hot	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %

* constant (i) is taken from 13/9/11 and (ii) from 15/9/11 data

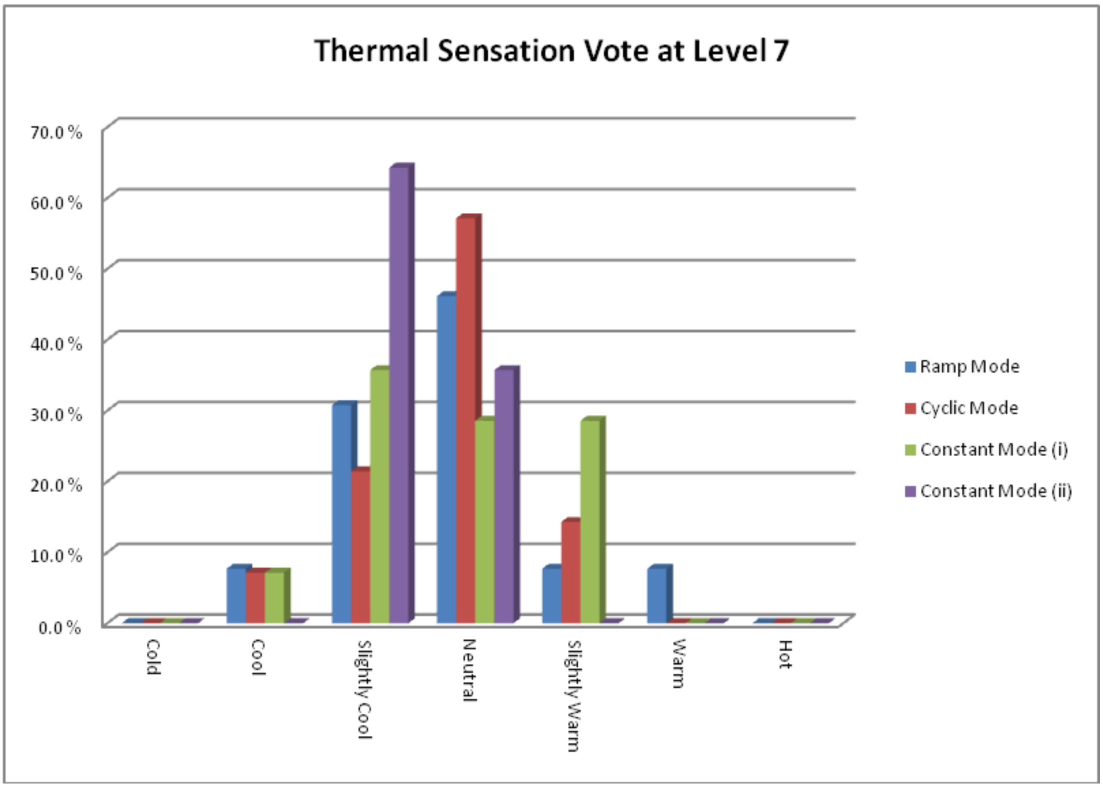


Figure 4-19: Column chart showing the thermal sensation votes at level 7 during the three mode implementations

Table 4-3: Airflow sensation votes at level 6 during the three mode implementations

Occupants Response	Airflow Sensation Vote at Level 6							
	Ramp		Cyclic		Constant (i)		Constant (ii)	
Very low	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %
Low	3	18.8 %	2	12.5 %	1	6.3 %	0	0.0 %
Slightly Slow	7	43.8 %	4	25.0 %	8	50.0 %	6	37.5 %
Neutral	5	31.3 %	7	43.8 %	6	37.5 %	9	56.3 %
Slightly High	1	6.3 %	3	18.8 %	1	6.3 %	0	0.0 %
High	0	0.0 %	0	0.0 %	0	0.0 %	1	6.3 %
Very High	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %

* constant (i) is taken from 20/9/11 and (ii) from 22/9/11 data

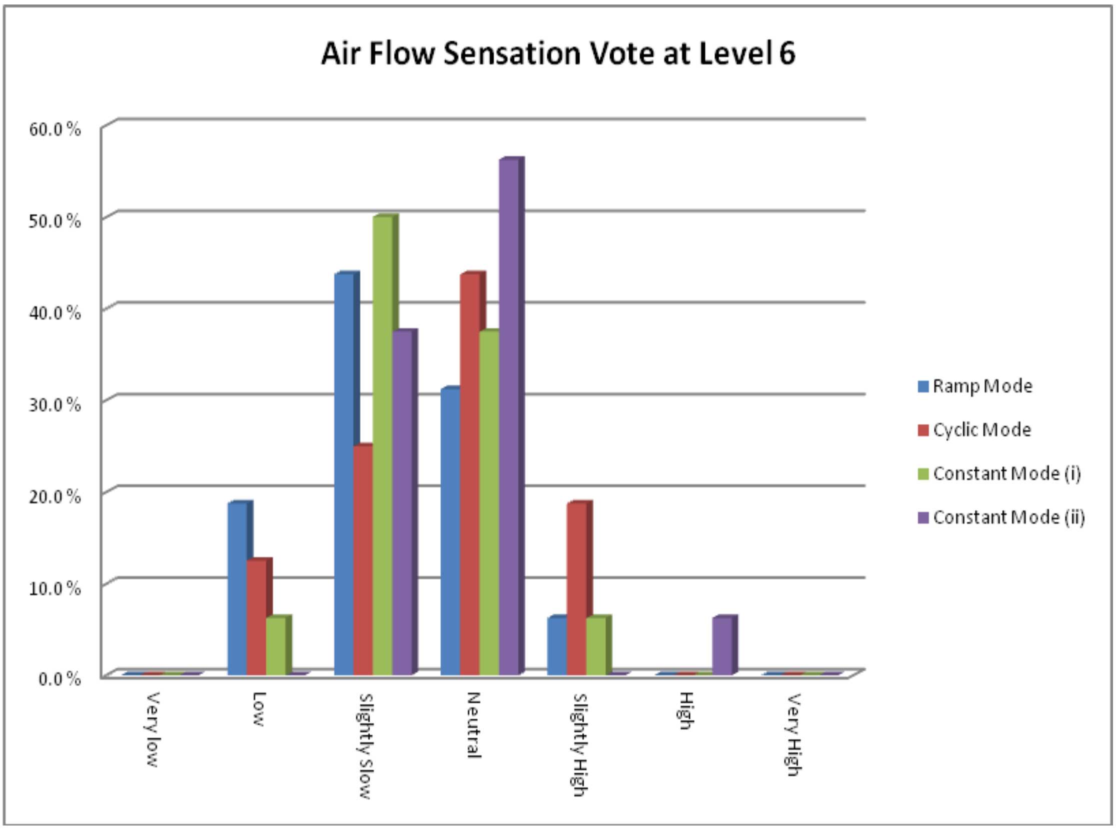


Figure 4-20: Column chart showing the airflow sensation votes at level 6 during the three mode implementations

Table 4-4: Airflow sensation votes at level 7 during the three mode implementations

Occupants Response	Airflow Sensation Vote at Level 7							
	Ramp		Cyclic		Constant (i)		Constant (ii)	
Very low	0	0.0 %	0	0.0 %	0	0.0 %	1	7.1 %
Low	0	0.0 %	0	0.0 %	3	21.4 %	0	0.0 %
Slightly Slow	3	23.1 %	4	28.6 %	3	21.4 %	0	0.0 %
Neutral	10	76.9 %	10	71.4 %	8	57.1 %	13	92.9 %
Slightly High	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %
High	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %
Very High	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %

* constant (i) is taken from 13/9/11 and (ii) from 15/9/11 data

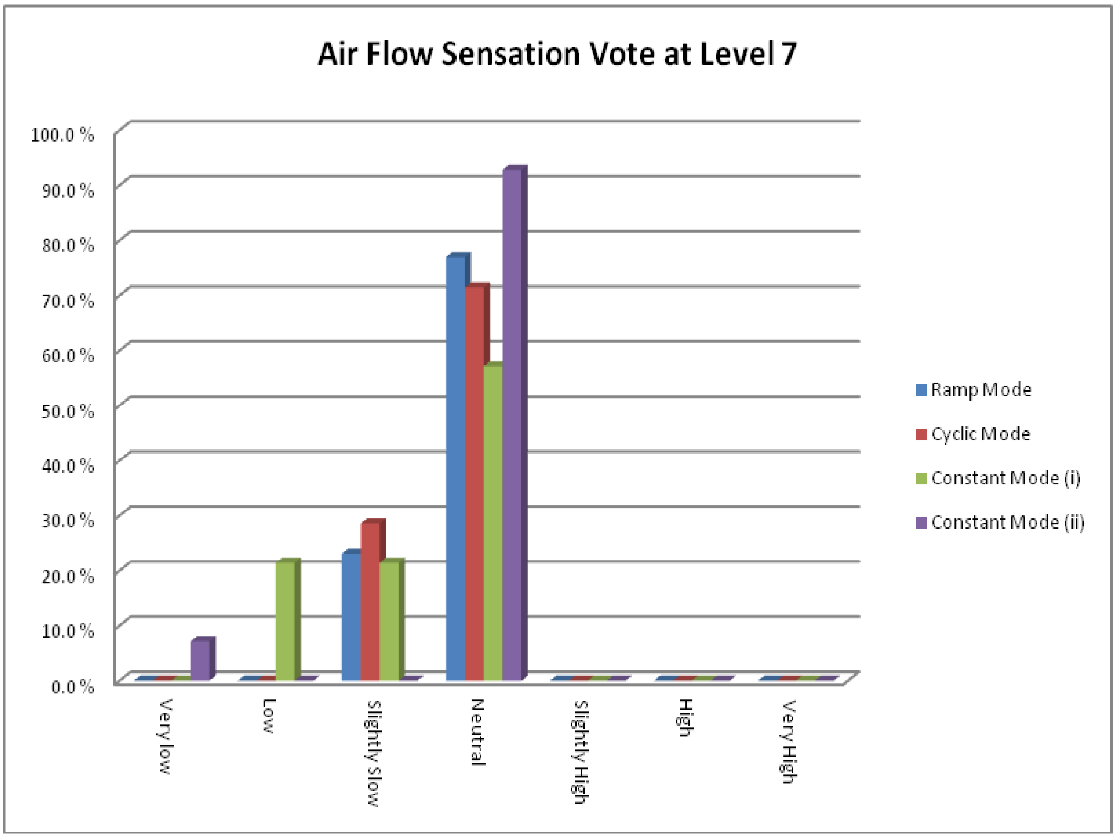


Figure 4-21: Column chart showing the airflow sensation votes at level 7 during the three mode implementations

Table 4-5: Humidity sensation votes at level 6 during the three mode implementations

Occupants Response	Humidity Sensation Vote at Level 6							
	Ramp		Cyclic		Constant (i)		Constant (ii)	
Very Humid	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %
Humid	0	0.0 %	1	6.3 %	0	0.0 %	1	6.3 %
Slightly Humid	4	25.0 %	4	25.0 %	6	37.5 %	3	18.8 %
Neutral	8	50.0 %	6	37.5 %	10	62.5 %	11	68.8 %
Slightly Dry	4	25.0 %	5	31.3 %	0	0.0 %	1	6.3 %
Dry	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %
Very Dry	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %

* constant (i) is taken from 20/9/11 and (ii) from 22/9/11 data

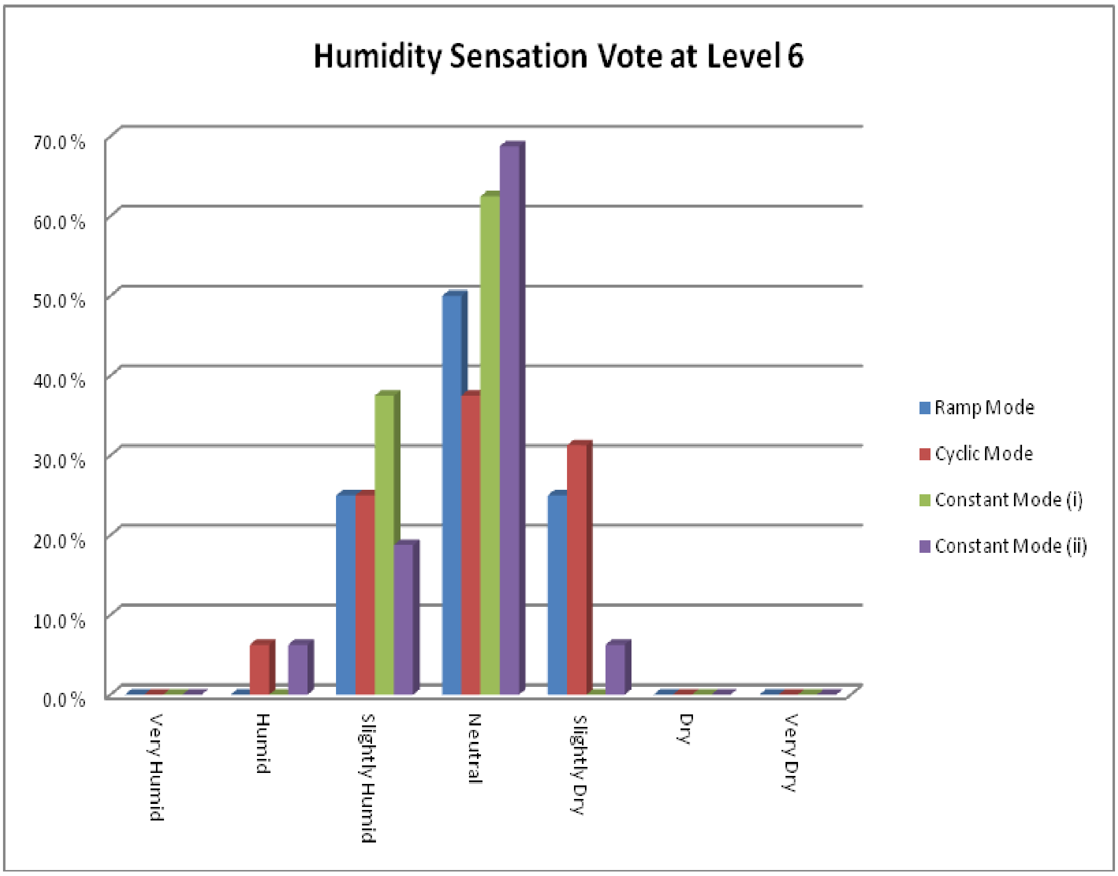


Figure 4-22: Column chart showing the humidity sensation votes at level 6 during the three mode implementations

Table 4-6: Humidity sensation votes at level 7 during the three mode implementations

Occupants Response	Humidity Sensation Vote at Level 7							
	Ramp		Cyclic		Constant (i)		Constant (ii)	
Very Humid	0	0.0 %	0	0.0 %	1	7.1 %	0	0.0 %
Humid	1	7.7 %	0	0.0 %	0	0.0 %	0	0.0 %
Slightly Humid	1	7.7 %	2	14.3 %	3	21.4 %	2	14.3 %
Neutral	8	61.5 %	10	71.4 %	5	35.7 %	9	64.3 %
Slightly Dry	1	7.7 %	2	14.3 %	5	35.7 %	3	21.4 %
Dry	2	15.4 %	0	0.0 %	0	0.0 %	0	0.0 %
Very Dry	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %

* constant (i) is taken from 13/9/11 and (ii) from 15/9/11 data

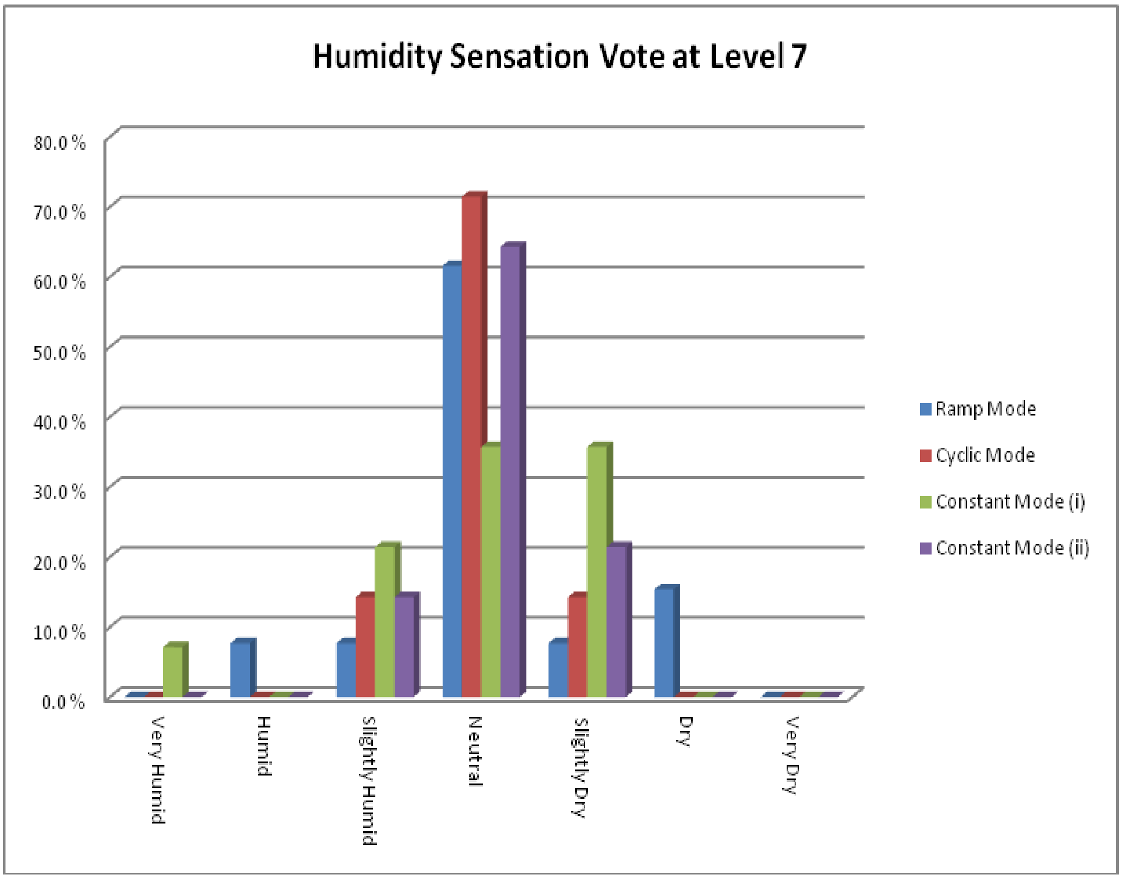


Figure 4-23: Column chart showing the humidity sensation votes at level 7 during the three mode implementations

Results for level 6 from (*Figure 4-18*) show the highest vote is for 'neutral' among the three modes, at 80%, occurred when the constant mode was applied at level 6. 'Neutral' have also the highest values for the ramp and cyclic modes but only with 56.3% and 43.8% respectively. On the other hand, level 7 *(Figure 4-19)* is seen to have the highest 'neutral' vote during cyclic mode implementation *(57.1% votes)*. The highest vote for constant mode is 64.3% of 'slightly cool' while for the ramp mode is 46.2% of 'neutral' response.

For airflow sensation vote, the highest 'neutral' response at level 6 *(Figure 4-20)* is recorded when constant mode was applied *(56.3% votes)*. The highest vote for the ramp and cyclic modes are for 'slightly slow' with 43.8% and 'neutral' with also 43.8%. Similarly, level 7 *(Figure 4-21)* is also seen to have the highest 'neutral' airflow during constant mode implementation *(92.9% votes)*. The highest vote for the ramp and cyclic modes are 76.9% and 71.4% of neutral airflow respectively.

In a similar way, the highest 'neutral' humidity at level 6 *(Figure 4-22)* was recorded when constant the mode was applied *(68.8% votes)*. The highest vote with ramp and cyclic modes are for the 'neutral' humidity *(50% and 37.5% votes respectively)*. Compared with level 6, level 7 *(Figure 4-23)* is seen to have the highest neutral humidity response during the cyclic mode implementation *(71.4% votes)*. Likewise, the highest vote for the constant and ramp modes are also for 'neutral' airflow *(64.3% and 61.5% respectively).*

4.3.2 Actual percentage of dissatisfied

Predicted percentage of dissatisfied (PPD) refers to an index that establishes a predicted percentage of people, who feel too cool or too warm. They indicate this by voting hot, warm, cool or cold on the 7-point thermal sensation scale. During the building design process PPD is estimated from Predicted Mean Values (*PMV*) calculation and usually establishes. An indoor thermal environment is considered to be within the comfort zone when the PPD value is calculated to be lower than 15% [3]. However, as an actual field thermal comfort measurement, this percentage can be determined by analysing the results from the votes of 7-point thermal sensation scale in the questionnaires. The percentage of people who vote for hot, warm, cool or cold over the total number of participants is referred as actual percentage of dissatisfied (APD).

In this research, the same technique is applied to obtain airflow sensation votes and humidity sensation votes. The aim is not to determine the building comfort state, but only to allow possible perspectives related to the thermal APD. Analysed from BHEUU actual thermal comfort survey results, the thermal APD, airflow APD and humidity APD of all modes at level 6 and 7 are identified and compared as illustrated in Figure 4-24 to Figure 4-26.

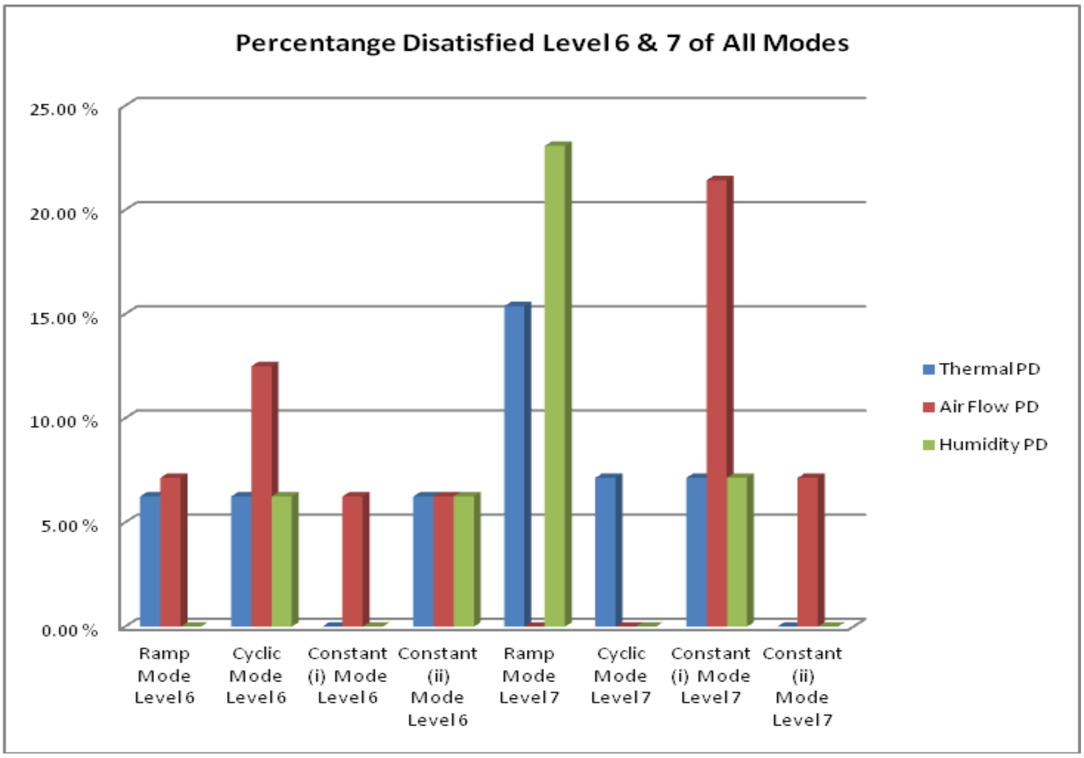


Figure 4-24: Column graph showing the actual percentage of dissatisfied of occupants in level 6 and 7 BHEUU when the constant, ramp and cyclic modes were applied

It can be seen from Figure 4-24 that the highest thermal APD of the occupants in level 6 and 7 BHEUU were recorded during the ramp mode implementation in level 7, which was 15.38%. The thermal APD of level 7 for the constant (i) and the cyclic mode were both recorded at 7.14%, while the constant mode (ii) was at 0%. On the contrary, the highest of airflow APD was recorded at 21.43% during the operation of the constant (i) mode in level 7 and the humidity APD was recorded at its peak of 23.08% when the ramp mode was applied in level 7.

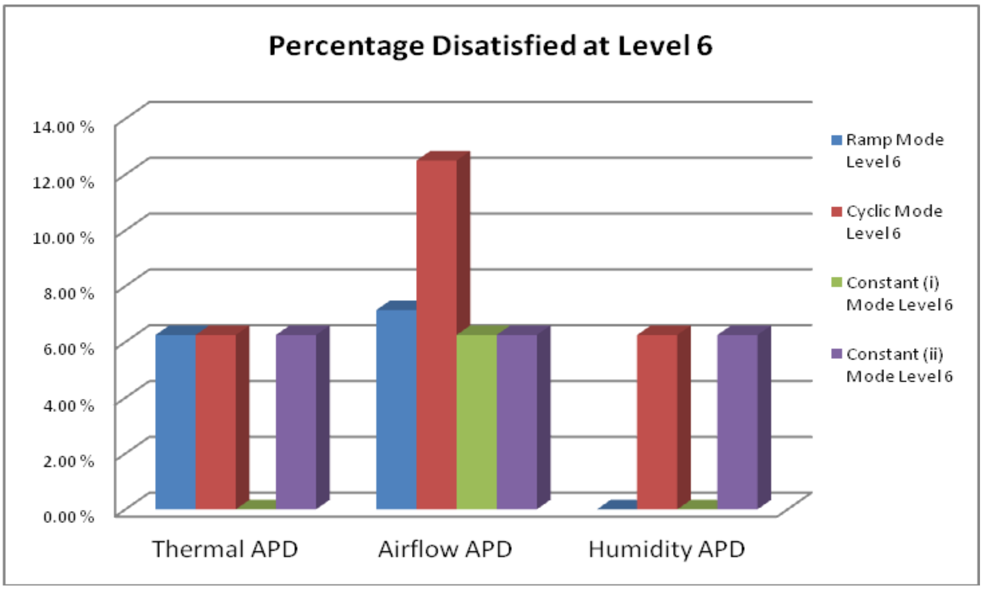


Figure 4-25: Column graph showing the thermal APD, airflow APD and humidity APD of occupant in level 6 BHEUU when the constant, ramp and cyclic modes were applied

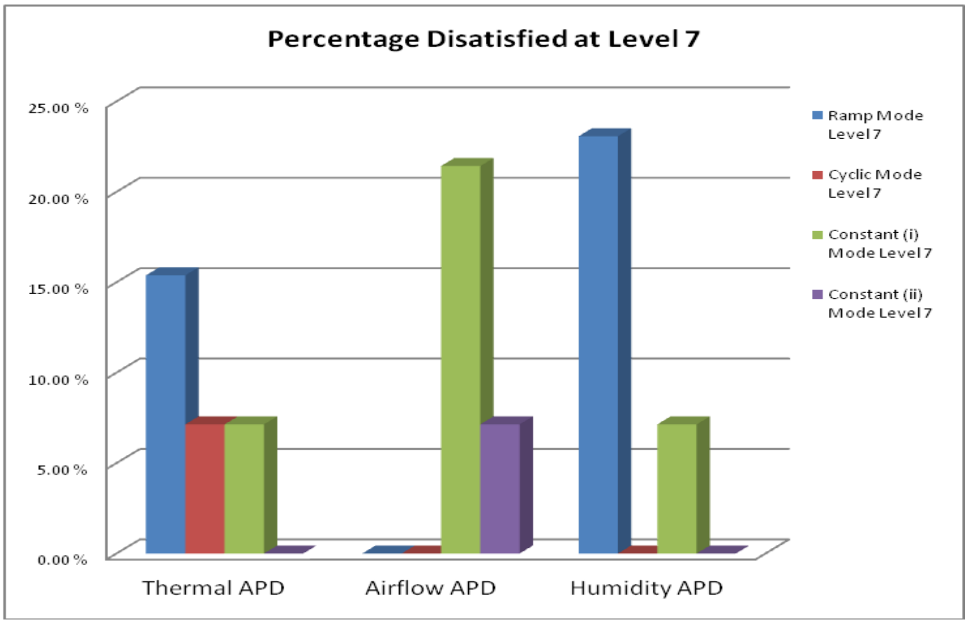


Figure 4-26: Column graph showing the thermal APD, airflow APD and humidity APD of occupant in level 7 BHEUU when the constant, ramp and cyclic modes were applied

The highest thermal APD of level 6 as seen in Figure 4-25 is only 6% which occurred during the constant (ii) mode, the ramp mode and also the cyclic mode. The cyclic mode is also seen to have the highest airflow APD of 12.5%, while the ramp and both the cyclic mode as well as the constant (ii) mode are seen to have the highest humidity APD of only 6%. The thermal APD mean values for the ramp and cyclic modes are 10.8% and 6.7% respectively, while the constant mode is 3.4%. These values, which are below than 15, show that the building indoor thermal environment is within the comfort zone when all indoor set-point temperature modes are applied.

4.3.3 *Indoor neutral temperature*

This technique aims to find the indoor operative temperature of the conditioned space that most closely corresponds to vote zero on 7-point thermal sensation scale and compare them. This temperature is referred as the 'indoor neutral temperature'. A linear regression model of thermal sensation votes and indoor operative temperature is used to determine the neutral temperature of level 6 and 7 during each of the modes. This method is also used in [18] but with more participants. Figure 4-27 to Figure 4-34 show the plots of thermal sensation scale against indoor operative temperature of level 6 and 7 for the constant mode, the ramp mode and the cyclic mode. The square dots on the plots represent occupant thermal sensation votes for corresponding indoor operative temperature when the transverse survey was conducted.

As illustrated in Figure 4-27 and Figure 4-28, the neutral temperature of level 6 during the constant mode in 20th and 22nd of September 2011 is 22.5°C and 23.4°C respectively. The ramp mode *(Figure 4-29)* is observed to have neutral temperature of 22.5°C while the cyclic mode *(Figure 4-30)* is 24.35°C. As for the level 7, neutral temperature during the constant mode in 13th and 15th September 2011 *(Figure 4-31 and Figure 4-32)* is 24.15°C and 24.48°C respectively. The corresponding ramp mode *(Figure 4-33)* and cyclic mode *(Figure 4-34)* are seen to have neutral temperature of 24.1°C and 24.06°C respectively. However as can be seen in all graphs, very little confidence can be attached to these results, because of the small number of votes *(occupants).*

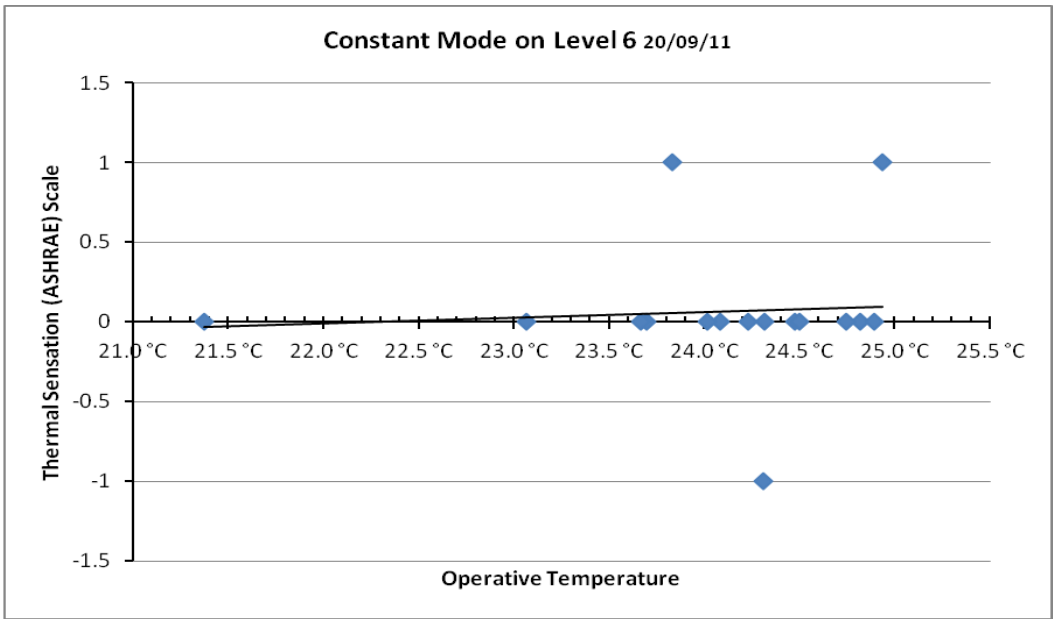


Figure 4-27: The thermal sensation scale against indoor operative temperature in level 6 BHEUU during the constant mode implementation

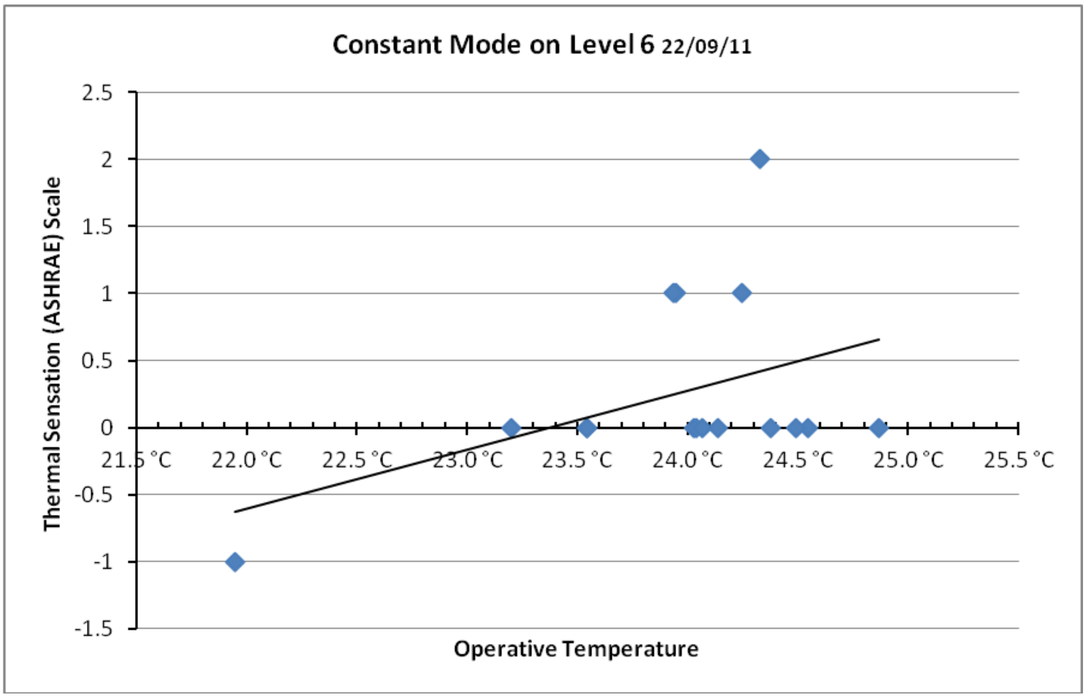


Figure 4-28: The thermal sensation scale against indoor operative temperature in level 6 BHEUU during the constant mode implementation

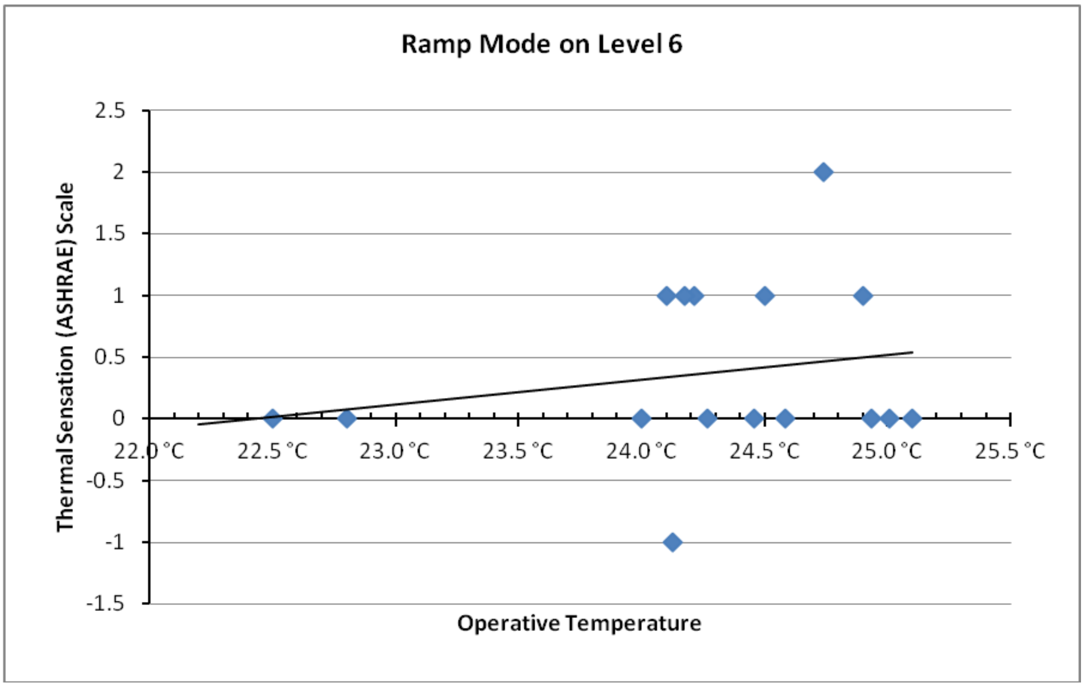


Figure 4-29: The thermal sensation scale against indoor operative temperature in level 6 BHEUU during the ramp mode implementation

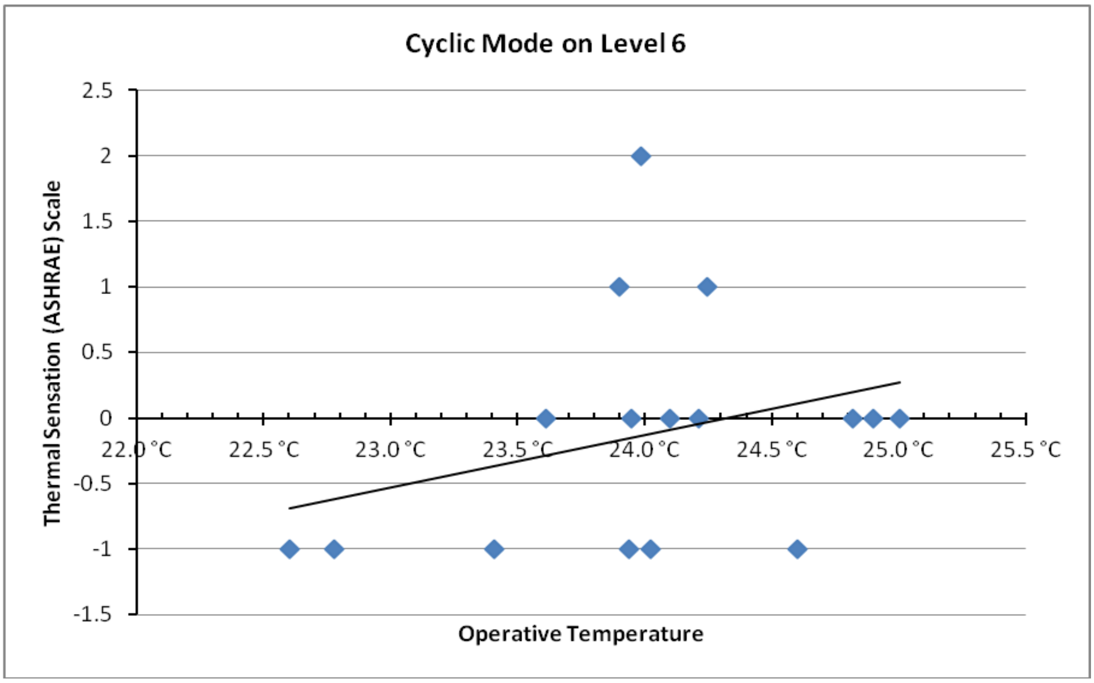


Figure 4-30: The thermal sensation scale against indoor operative temperature in level 6 BHEUU during the cyclic mode implementation

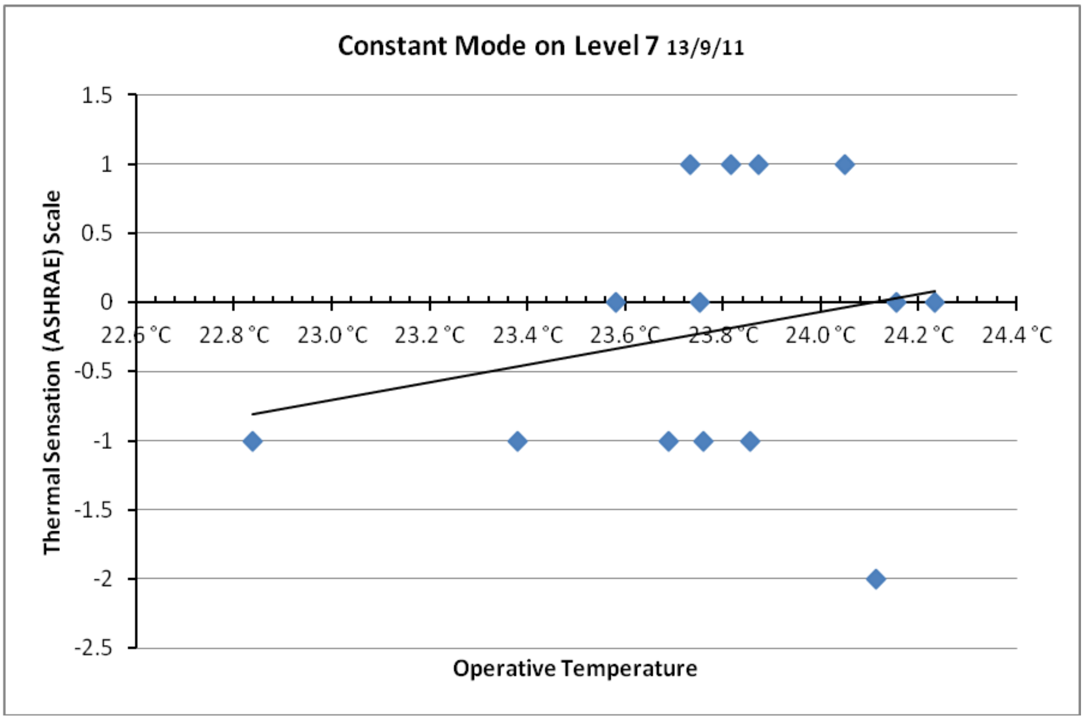


Figure 4-31: The thermal sensation scale against indoor operative temperature in level 7 BHEUU during the constant mode implementation

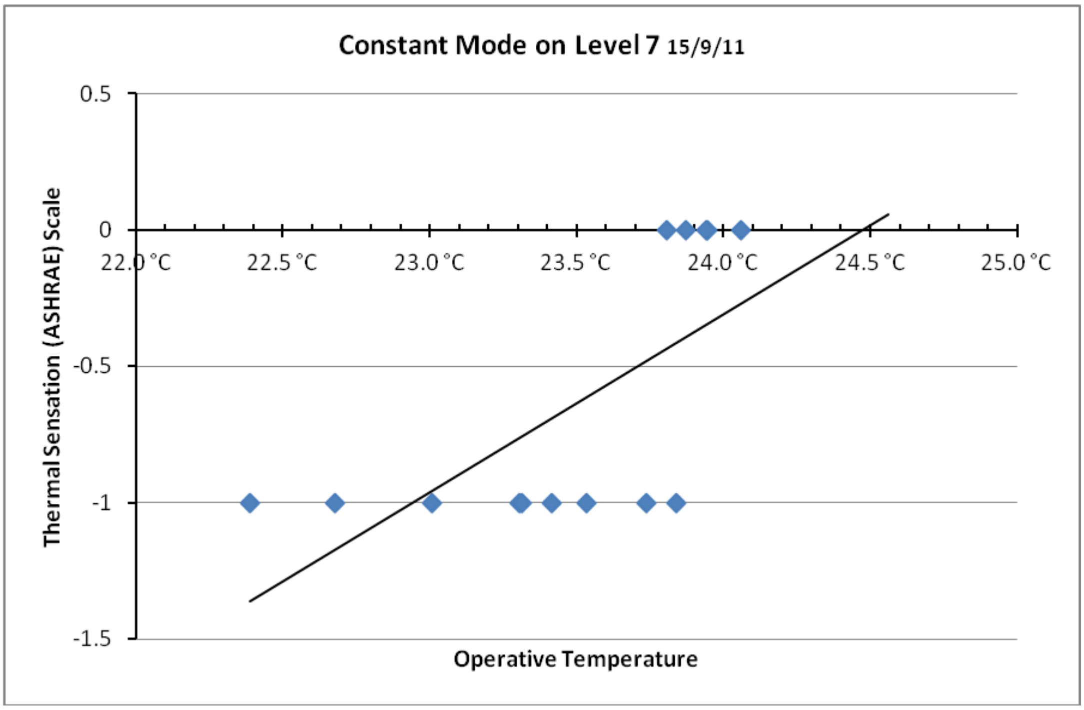


Figure 4-32: The thermal sensation scale against indoor operative temperature in level 7 BHEUU during the constant mode implementation

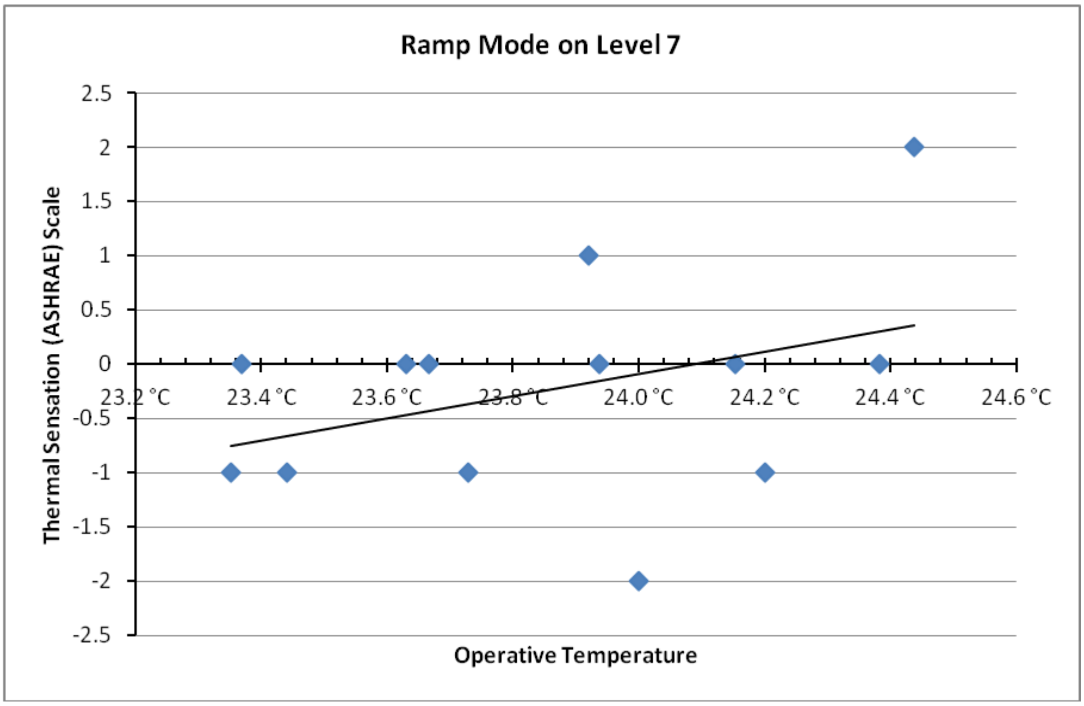


Figure 4-33: The thermal sensation scale against indoor operative temperature in level 7 BHEUU during the ramp mode implementation

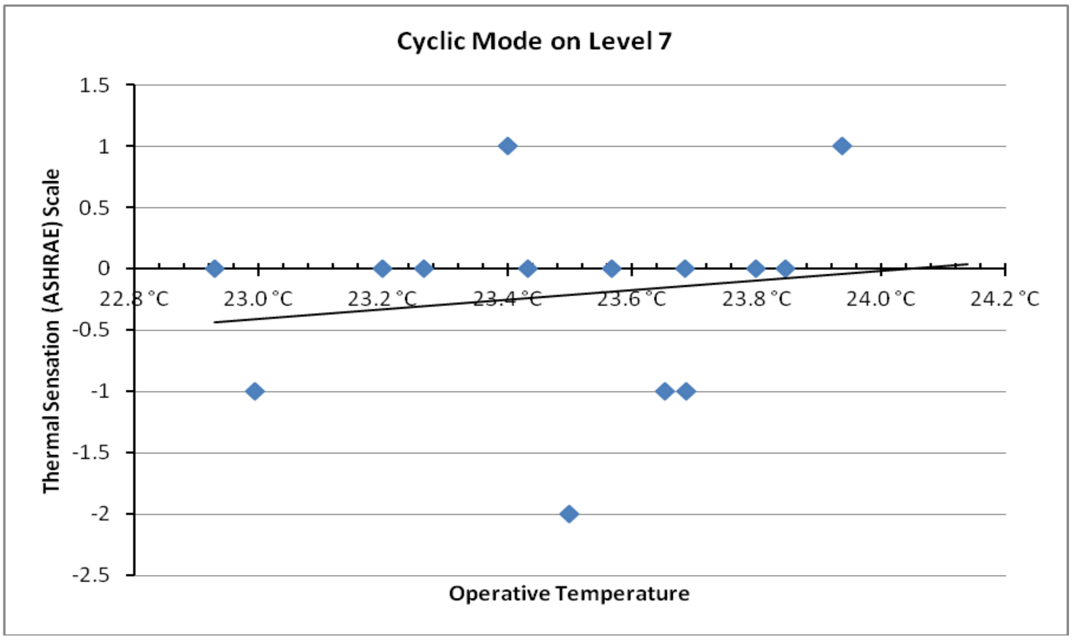


Figure 4-34: The thermal sensation scale against indoor operative temperature in level 7 BHEUU during the cyclic mode implementation

4.3.4 HVAC system energy consumption comparison

HVAC system energy consumptions in levels 6 and 7 were determined from the measured mean airflow rate to the space, off-coil and on-coil temperatures *(chapter 3)*. From the energy comparison between the modes, the energy savings of the dynamic modes *(i.e. ramp and cyclic)* can be obtained. The energy savings can be obtained in two ways.

The first one is to assume that the external load variation of the air-conditioned spaces on the 13th, 15th, 20th, and 22nd of September 2011 is insignificant and negligible. The ramp mode energy saving of level 6, conducted on 13th September 2011 for instance, can then be compared to the energy savings for the constant modes, which were conducted in separate days *(20 and 22 of September 2011)*. The second is to assume that internal load variations of level 6 and 7 are small and negligible. The energy saving of the ramp mode of level 6 for instance is then equal to the difference in energy usage between it and the constant mode on level 7 which was conducted in the same day. The energy comparison between modes when internal load or external load is assumed invariable are summarised in Table 4-7 and Table 4-8 respectively. Figure 4-35 and Figure 4-36 shows the corresponding HVAC system energy improvement of level 6 and 7 in BHEUU.

No	Date	Applied Mode	Experimental Floor (ramp or cyclic mode)			Controlled Floor (constant mode)			Energy Improvement	
1	13/09/2011	Ramp Mode	Level 6	21.4 kWh	73082.5 Btu	Level 7	28.2 kWh	96253.7 Btu	6.8 kWh	23171.2 Btu
2	15/09/2011	Cyclic Mode	Level 6	20.3 kWh	69210.7 Btu	Level 7	27.3 kWh	93194.5 Btu	7.0 kWh	23983.8 Btu
3	20/09/2011	Ramp Mode	Level 7	22.7 kWh	77543.5 Btu	Level 6	24.1 kWh	82380.2 Btu	1.4 kWh	4836.7 Btu
4	22/09/2011	Cyclic Mode	Level 7	22.1 kWh	75267.4 Btu	Level 6	18.6 kWh	63626.8 Btu	-3.4 kWh	-11640.6 Btu

Table 4-7: Energy comparison between modes when internal load variations between level 6 and 7 are assumed negligible

No	Floor Level	Applied Mode	Experimental Floor (ramp or cyclic mode)			Controlled Floor (constant mode)			Energy Improvement	
1	Level 6	Ramp Mode	13/09/2011	21.4 kWh	73082.5 Btu	mean of energy 20 and 22/09/11	21.4 kWh	73003.5 Btu	0.0 kWh	-79.0 Btu
2	Level 6	Cyclic Mode	15/09/2011	20.3 kWh	69210.7 Btu		21.4 kWh	73003.5 Btu	1.1 kWh	3792.7 Btu
3	Level 7	Ramp Mode	20/09/2011	22.7 kWh	77543.5 Btu	mean of energy 13 and 15/09/12	27.8 kWh	94724.1 Btu	5.0 kWh	17180.6 Btu
4	Level 7	Cyclic Mode	22/09/2011	22.1 kWh	75267.4 Btu		27.8 kWh	94724.1 Btu	5.7 kWh	19456.7 Btu

Table 4-8: Energy comparison between modes when external load variations between 13th, 15th, 20th and 22nd September 2011 are assumed negligible

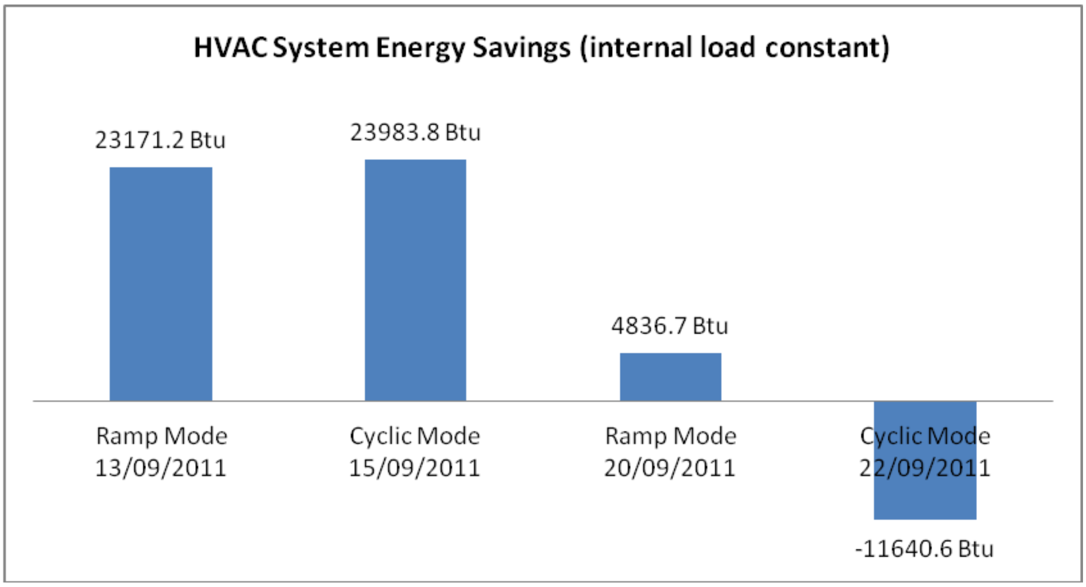


Figure 4-35: HVAC system energy savings when the internal loads between level 6 and 7 are assumed constant

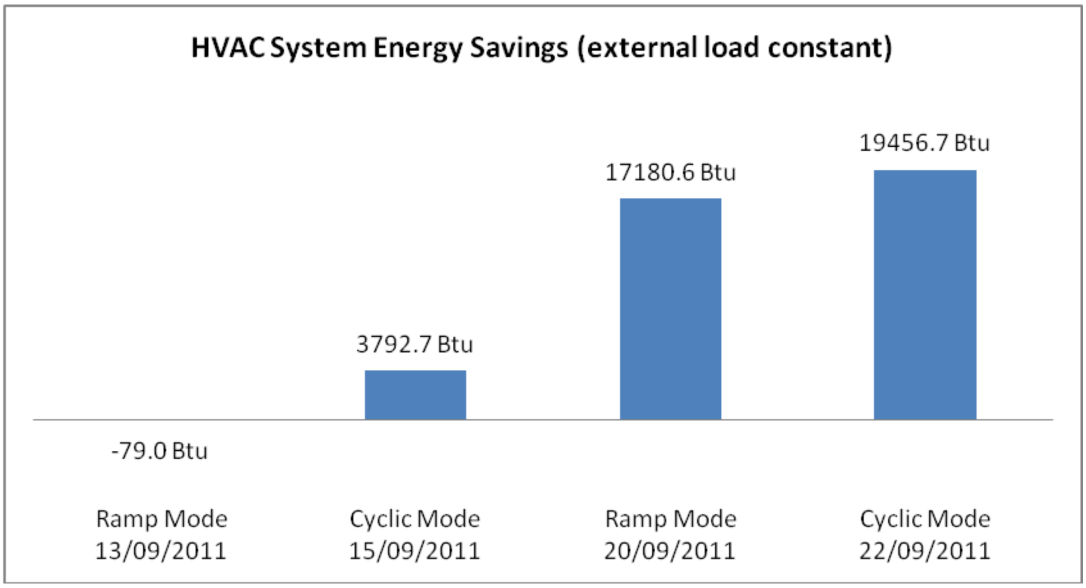


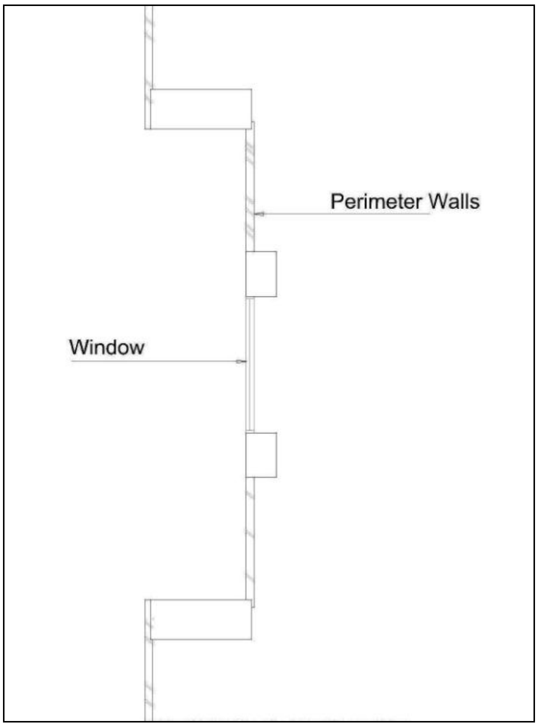
Figure 4-36: HVAC system energy savings when the external loads between 13th, 15th, 20th and 22nd September 2011 are assumed constant

It can be seen from Table 4-7 and Table 4-8 that the highest HVAC energy consumption when the ramp, cyclic and constant mode were applied to the air-conditioned spaces were 22.7 kWh, 22.1 kWh and 28.2 kWh respectively. Observed from Figure 4-35, with 23,983.8 Btu the cyclic mode has the highest energy savings when internal load assumed to be constant. Similarly *(Figure 4-36)*, when external loads are assumed to be constant the cyclic mode is also seen to have the highest energy savings with 19,456.7 Btu.

4.4 Discussion on Background Measurement Results

Similarity between the air temperature *(T_A)* and operative temperature *(T_{OP})* in this experiment show that the mean radiant temperature *(T_{MR}),* which represent the surface temperatures in the conditioned space, were very close to the space air temperature during the measurements. This is simply explained by looking at the definition of operative temperature, which is an average of air temperature and mean radiant temperature [3]. This finding is unusual for buildings located in a country like Malaysia. With very high solar radiant heat transfers to the building walls and windows during day time, the space mean radiant temperature is more often significantly higher than the corresponding air temperature. The architectural design of this building, as compared to other typical office buildings in Malaysia has a very different perimeter wall and building facade. BHEUU was designed mostly with two layers of perimeter wall all around the building whereas a typical design has only one. Figure 4-37 illustrates both designs of perimeter wall. There is an air gap of approximately 715 mm between the outer and the inner wall. The outer wall serves as the building facade as well as a mechanism to reduce the solar heat gain to the building. With a different thickness, the outer wall also acts as a solar shading louver to the windows all around the building. Figure 4-38 shows an example of a window, with solar shading louver, taken at a time when the sun shone directly in to it. The building's unique architectural design provides a good balance between T_A and T_{MR}. However, the explanation above is only base on a surface understanding of the architectural perspective on the subject. A further research related to this is required to understand more regarding the above argument.

In the results, the lack of movement in the indoor relative humidity (RH) suggests that the building has a very minimum and tolerable infiltration and exfiltration rate. It is most likely due to the fine construction of the building envelope and to the specification of the HVAC system equipments, which were sized according to procedures. RH stability also suggests that the indoor set-point temperature control system has no significant relationship to changes indoor RH. This is an expected result knowing that the HVAC system was designed only to control the indoor temperature and just maintain the RH within a scale of human comfort. On the other hand, the changes in outside temperature have a small but noticeable effect on the indoor space temperature changes. Particularly for placement C, the effect is the most obvious among the others, and placement A is the least. Since placement C was also the closest to the building envelope and placement A was the furthest, this could then show that the outside temperature changes has a greater effect to indoor temperature changes that are closer to the building envelope.



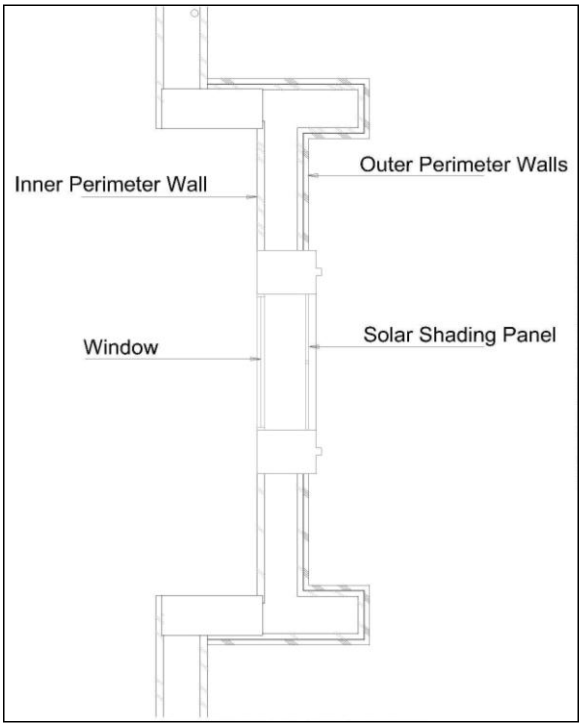


Figure 4-37: Typical design of perimeter wall for office building in Malaysia (left) and the perimeter wall design in BHEUU (right)

Figure 4-38: An example of a window in BHEUU, with its solar shading louver, taken at a time when the sun shone directly shined into it

Nevertheless, the main objective of this experiment is to understand the real response of the space temperature against the set-point temperature variations. The changes of space air temperature *(T_A)*, similar to space operative temperature *(T_{OP})*, are seen to have a poor response to either the ramp or cyclic induced variations. In Chapter 3, the simulation of a simple HVAC system has explained about the chances of getting this sort of result. It is due to insufficient air change of the HVAC system to the spaces. Besides increasing the space air change, another possible approach to achieve the good response is by having a longer interlude between changes to the temperature set-point. For an example, the set-point temperature of the cyclic mode might be increased from 23.9^{o}C to 24.2^{o}C after 20 minutes instead of 10 minutes. However, this would double the cycle time of the set-point temperature variations: from 2 hours 20 minutes to 4 hours 40 minutes for the cyclic mode and 1 hour 20 minutes to 2 hours 40 minutes for the ramp mode. This would also lead to a reduction in the set-point variations cycle in a day. The ramp mode would be reduced from 5 to 3 cycles while the cyclic mode would be from 3 to 1.5 cycles.

Unfortunately time limitations meant that these changes were not performed. A series of similar background experiments would have been required to discover the new interludes period, which would have taken approximately another 4 to 6 weeks. With time limitation given to complete this MSc-by-Research course, the additional weeks to carry out a few more experiments were beyond the author's capability. The transverse survey trials were still carried out even without any adjustment on the interludes. Even though poor space temperature response against the set-point temperature variations was inevitable, there were still many other significant findings that relate to the trials.

4.5 Discussion on Transverse Survey Trial Results

Sensation vote comparisons show that the implementation of both the ramp and cyclic modes did not significantly affect building occupant neutral votes. This is in line with what was learned from the background measurement results. The poor space temperature response did not make the occupants feel the difference between the dynamic modes and the constant mode. However, the analysis also shows that the constant mode was not always voted as the occupants' highest neutral response.

Overall the actual percentage of dissatisfied *(APD)* analysis has shown that implementation of the dynamic indoor set-point temperature modes could slightly induce changes in the APD, but still within the building thermal comfort zone. However, the results also show inconsistencies of the APD when constant modes *(i and ii)* were repeatedly applied at both floors. This illustrates the possibility that changes in APD could also be obtained by repeating the comfort survey.

In the neutral temperature analysis, the results also show that changes in the neutral temperature at level 6 could be obtained by just repeating the same comfort survey regardless of which mode was applied. This suggests that the sample size was too small. However, consistent neutral temperatures were obtained at level 7 even when the constant modes were repeated. With similar neutral temperatures obtained, the implementation of both the ramp and cyclic modes at level 7 did not significantly alter the neutral temperature.

In general, the energy saving analyses have shown significant improvements on energy consumption by applying either the ramp or cyclic mode of indoor set-point temperature. However, there were also increases in energy consumption recorded at each analysis: cyclic mode which was applied on 22/09/11*(analysis when the internal loads were assumed constant)* and ramp mode which was applied on 13/09/11 *(analysis when the external loads were assumed constant)*. These increases could be explored by looking back at figure 4-35 and 4-36 in Chapter 4. In figure 4-35, it is apparent that the energy saving calculated using 'level 7 constant mode energy usages' is far greater than the saving when 'level 6 constant mode energy usage' is used. Similarly, energy saving from figure 4-36 is far greater when the energy usage of constant modes applied on 13th and 15th September 2011 were used in the calculation than the other two. These could show that assumptions made in both analyses: constant internal loads for the first analysis and constant external load for the second analysis, are not applicable for the trials. Based on these perspectives, there is a high chance that the internal heat load in level 7 is greater than what it is in level 6. The external load on the other hand, could also be greater during the trials on 13th and 15th September 2011 than the trials on 20th and 22nd September 2011. If the difference of the internal load between level 6 and 7 is assumed to be 3.4 kWh, which is the energy increase of the cyclic mode trial on 22/09/11, the new energy improvements of the other three trials are:

i. <u>*Energy Improvement of the ramp mode (applied on 13/09/2011)*</u>

Energy Improvement = Energy usage of constant mode (level 7) – Different of internal heat load – Energy usage of ramp mode (level 6)

= 28.2 kWh – 3.4 kWh – 21.4 kWh

= 3.4 kWh

ii. <u>*Energy Improvement of the cyclic mode (applied on 15/09/2011)*</u>

Energy Improvement = Energy usage of constant mode (level 7) – Different of internal heat load – Energy usage of cyclic mode (level 6)

= 27.3 kWh – 3.4 kWh – 20.3 kWh

= 3.6 kWh

iii. <u>*Energy Improvement of the ramp mode (applied on 20/09/2011)*</u>

Energy Improvement = Energy usage of constant mode (level 6) + Different of internal heat load – Energy usage of ramp mode (level 7)

= 24.1 kWh + 3.4 kWh – 22.7 kWh

= 4.8 kWh

Similarly, if the difference of mean external load between the trial days is assumed to be 79 Btu, which is the energy increase of the ramp mode trial on 13/09/2011, the new energy improvements of the other three trials are:

i. <u>*Energy Improvement of the cyclic mode (applied on 15/09/2011)*</u>

Energy Improvement = Mean energy usage of constant modes (level 6) + Mean of external heat load different – Energy usage of cyclic mode (level 6)

= 73,003.5 Btu + 79 Btu – 69,210.7 Btu

= 3,871.8 Btu

ii. <u>*Energy Improvement of the ramp mode (applied on 20/09/2011)*</u>

Energy Improvement = Mean energy usage of constant modes (level 7) – Mean of external heat load different – Energy usage of ramp mode (level 7)

= 94,724.1 Btu – 79 Btu – 77,543.5 Btu

= 17,101.6 Btu

iii. <u>*Energy Improvement of the cyclic (applied on 22/09/2011)*</u>

Energy Improvement = Mean energy usage of constant modes (level 7) –Mean of external heat load different – Energy usage of cyclic mode (level 7)

= 94,724.1 Btu – 79 Btu – 75,267.4 Btu

=19,377.7 Btu

Although the actual differences of internal and external loads between the levels and the trial days could not be identified, the argument is sufficient to show that there is a high probability of improvement in energy consumption when either of the dynamic indoor set-point temperature modes (i.e. ramp and cyclic) is applied.

CHAPTER 5

CONCLUSIONS

5.1 Overall Summary and Conclusion

The overall aim has been to suggest improvements to building air-conditioning control systems, to reduce energy consumption while maintaining occupant comfort level. Recent studies have shown that a more 'adaptive' approach towards temperature control might be favourable both in terms of energy use and in occupant comfort. Conclusive studies have been performed in countries in Western Europe where outside temperature fluctuations are relatively large throughout the year. For these countries, effective energy conservation and occupant comfort can be achieved by varying the indoor set-point temperature with the outside temperature. However, this strategy is not applicable to countries located near the equator like Malaysia, where outside temperature variations throughout the year are relatively small. An alternative form of adaptation is required here. Experiments conducted by Tan and Kosonan [2] in air-conditioned office buildings as described in Chapter 1 suggested that fluctuation of indoor space temperature in a prescribed manner could be one of the alternative forms of adaptation. However, Tan and Kosonan did not describe how they were able to obtain their indoor temperature prescribed patterns in their particular building. Only indoor temperatures were reported, so the performance of the plant was unclear. There was no mention of any indoor temperature set-point changes, or how they found buildings with suitable plants, or about their experimental set-up, or about changes in outside temperature. This knowledge is required before any reasonable assessment can be made. This dissertation has investigated if an approach similar to that recommended by Tan and Kosonan [2] is acceptable to the end user, practicable and financially worthwhile.

User Acceptability

Unfortunately conclusions could not be drawn about user acceptability, because the internal temperature could not be made to follow the prescribed trajectories. This inability must be the key conclusion of this dissertation. However internal temperatures did fluctuate so the occupant surveys still revealed occupant views on temperatures that varied with time. Indeed the temperature history obtained in the transverse survey with energy comparison experiment is close to that prescribed by Tan and Kosonan [2]. In other words, this experiment was valid more by chance than by design. Occupant responses suggest that they would tolerate such a temperature variation. The question then is, would they tolerate faster temperature variations? The transverse survey experiments produced such a variation; again the occupants were tolerant. This is all relatively superficial and many more experiments would be needed before any conclusions could be drawn.

Financially Worthwhile

Three case studies of one building installed with VRF system and two buildings installed with WCCH were carried out in Chapter 2. Using a HVAC computer program, energy analyses and simulations of the three buildings were conducted to estimate potential energy savings that might be obtained if indoor temperature is made to fluctuate in a prescribed manner, i.e. ramp and cyclic mode. Eventually, all three case studies were seen to have significant potential energy savings when they were applied with either the ramp or cyclic modes in the simulation.

Experiment Design

A field trial to verify this potential energy saving is described in Chapter 3. The selection of one of the case studies; Legal Affairs Division Office (BHEUU) for the field trial to be performed was elaborated. There were a few steps taken before the field trial was performed. First, the HVAC detail configuration and control system of BHEUU were studied and understood. Then, the primary thermal comfort variables, which would be measured during the field trial, were further looked into to get a better understanding. Finally, a MATLAB Simulink computer model of a simple HVAC system was developed to gain an understanding of how the system should perform. A key conclusion obtained from this simple model simulation was that a good space temperature response to either the ramp or cyclic induced variations is highly depend on the air-change or supply air flowrate of the HVAC system. The field trial conducted consists of 2 experiments: background measurements and transverse survey with energy comparison. The background measurements experiment aimed to investigate the actual indoor climate behaviour when the constant, ramp and cyclic mode of indoor set-point temperature were applied. The other experiment aimed to compare and understand actual occupants' responses to the constant, cyclic and ramp mode as well as the corresponding HVAC energy savings.

Practicable

The air-conditioning systems installed in a number of buildings in Putrajaya were examined before a suitable test zone could be identified. In other words it is clear that such advanced control strategy could not be identified for any zone in any building. There are a number of limiting factors including poor maintenance, lack of consideration of the building dynamic response in the HVAC system design and poor system set-up, which is likely caused from nonchalant attitude during the system testing and commissioning. These factors will be discussed further in Section 5.2.

Different types of HVAC system have been discussed in Chapter 1. The Variable Refrigerant Flow System (VRF) and the Water Cooled Chiller System (WCCH) were concluded to have better potential in active improvement of energy consumption among other types of air-conditioning system. However, at the very outset it became clear that VRF system would be most compatible with advanced control system. It was on this basis that the Court Complex was considered first. Unfortunately, PWD of Malaysia preferred the field trial to be conducted at Menara Sri Wilayah, which was then substituted with BHEUU due to the system incompatibility. Experimental results were presented in Chapter 4. Results for background measurements experiment suggested that the changes characteristic of the dry bulb and operative temperature were fairly similar during all set-point temperature modes. The dynamic modes of the building indoor set-point temperature also concluded to have insignificant impact to the indoor operative temperature and relative humidity. As for the transverse survey experiment, the results generally suggested that the occupants' comfort response against all modes were fairly similar. This is in line with what was learned from the background measurement results. The poor space temperature response could not make the occupants felt the differences between the dynamic modes and the constant mode. However, it was also concluded that high probability of improvement in energy consumption was taken place when either of the dynamic indoor set-point temperature modes (i.e. ramp and cyclic) was applied.

<u>To Conclude</u>

Although energy reduction was in place and the occupant's comfort were maintained, corresponding conclusive suggestion to improve air-conditioning control system could not been made since the building and HVAC system chosen has failed to accommodate the required response. However, findings in this research project are useful for the government of Malaysia to gauge the actual condition and performance of present HVAC control systems installed in their buildings. Since the selection of BHEUU for the trial building was decided after stages of detail comparison to other similar buildings, the author now could argue whether or not the average performance of building HVAC control system in Malaysia could even meet the initial requirements that they were designed for.

5.2 Lessons Learnt

Many lessons were learnt throughout this project which particularly relate to energy conservation.

Passive improvement of HVAC energy consumption

Architectural design of a building is a major factor in improvement of HVAC energy consumption. Design of building facade, perimeter wall, roof, wall thickness, building orientation and solar shading utilization are elements that contribute to this passive improvement. BHEUU is a building with good architectural design, which has passive energy improvement elements. The building (BHEUU) has a very unique design of facade, which acts not just to improve the side elevation exterior appearance but also reduce the amount of solar and transmission load transfer into the building. The field trial as described in section 4.4 before has shown that globe and air temperature of the conditioned space, which were taken near the perimeter walls and windows are very much alike. Among others, this means that heat transferred through the wall and windows were reduced by the building passive elements.

Maintenance of HVAC system's parts and components

Maintenance is very important for buildings with installed HVAC systems. It is a very popular topic especially in building sustainable industries, but is often considered less by building owners. When choosing the right building for the field trial at Putrajaya, the author encountered that most of the buildings suffered from poor maintenance. This included buildings that were installed with expensive HVAC systems, which were designed to operate with improved system efficiencies and energy savings. Unfortunately, poor maintenance of the system has introduced inefficient operation. Building owners pay more for energy consumed even compared to much cheaper HVAC system applications.

Knowledge in Building Management System (BMS) operation

Building facilities maintenance teams should have sufficient knowledge about BMS operation especially relating to HVAC systems. The slow development of a fault could be detected earlier before it goes severe, effecting occupant comfort as well as system efficiency. During the visits to the government buildings at Putrajaya, the BMS control room was often left with incompetent personnel, who failed to even recognise the symptoms from the BMS relating to major functionality errors.

Building end users involvement during design stage

Building end user involvement during the design stage is crucial. The field visits showed that building partitions are likely to be rearranged and reconstructed to suit the end users requirements or needs. As far as the HVAC system is concern, this could cause serious damage to the air side of the HVAC system, degrading system performance to a point where it is unable to satisfy occupant comfort needs. The HVAC system will then consume more energy for less comfort satisfaction.

Building occupants' work station

Occupant workspaces should be placed according to their norms of work. Active office workers, i.e. those who move around during office hours delivering letters, attend outside meetings, and so on should be placed together, while occupants who are not, should be grouped in a different place. In this way, the occupant satisfaction is likely to be more achievable. Chances to achieve required comfort and to save energy will be much higher.

Involvement of mechanical consultant

A certified mechanical consultant firm should be engaged when partitions are rearranged in buildings installed with VAV system. This is to ensure that the system air-duct and room temperature sensors are also redesigned and relocated to avoid future HVAC control system failure. It was apparent during the visits that all the buildings including BHEUU suffer from either minor or major control errors due to partition rearrangement and reconstruction. This repartitioning works were done without involvement of a certified mechanical consultant.

HVAC system specification to track dynamic indoor temperature set-point changes

The specification of HVAC system equipment, particularly their capacity, is an important factor in achieving the required conditioned space temperature response of when a dynamic indoor set-point temperature mode is applied. Learned from the background experiment, the capacity of HVAC system equipment that is able to maintain a fixed indoor set-point temperature is unlikely to be sufficient to track dynamic changes in the indoor temperature set-point.

Centralised HVAC system with individual fan-coil and local climate control

A centralised HVAC system with individual fan-coil and local climate control such as Variable Refrigerant Flow (VRF) system is likely to more suitable to indoor temperature set-point tracking. This is due the fact that the conditioned space temperature and the air-change could be controlled and adjusted locally, while for the other centralised systems, more global dynamics are involved.

Building occupant tolerance

Learnt from the first background experiment, the occupants in BHEUU were more tolerant when the conditioned spaces were overcooled and less forgiving when they were under-cooled. This could be observed when the off-coil set-point temperature was accidentally set to be too low and resulted in the lowest dry bulb temperature recorded of 20.8 ^{o}C. Even though the comfort survey was not conducted during that experiment, there were no complaints reported to the maintenance team on that day. The indoor set-point temperature is typically 24 ^{o}C. However, the occupants warm votes started to be recorded when the space air temperature reached only 25 ^{o}C.

Improvement of HVAC system energy consumption

Even with poor indoor space temperature response in levels 6 and 7 in BHEUU, both dynamic modes (ramp and cyclic) of indoor set-point temperature application have improved the energy consumption of the building HVAC system while maintaining occupant thermal experience within the comfort zone.

Supply air temperature control system

The HVAC supply air temperature control system in BHEUU could be improved to potentially save significant amounts of energy. The current system requires the user to manually set one fixed desired supply air temperature via the BMS. The control system then modulates the chilled water flowrate going through the cooling coil to maintain the desired off-coil temperature. This fixed supply temperature set-point could cause the conditioned space to be overcooled especially when outside temperature is at its minimum.

Improvements in HVAC system energy simulation computer program

The HVAC system energy simulation computer program used in this project could give an accurate simulation result, provided that the building model and required HVAC system data are correct. However, the computer program has certain restrictions that could be improved for more compatibility in studies related to dynamic operation of the HVAC system. Instead of completely relying on the weather data from the ASHRAE database for the simulation, the program should allow the user to manually alter the data when required. The program should also allow multiple changes of indoor set-point temperature in one simulation (*the program has a fixed indoor set-point temperature input*). Energy simulations driven by dynamic indoor temperature set-point changes could be run only one time without having to manually calculate the multiple energy simulation results when the dynamic set-point is applied. Furthermore, results generated from the simulation should also include hourly temperature changes of the conditioned space. This feature could be used to determine the suitability of a building and its HVAC system for dynamic indoor temperature set-point variation.

5.3 What Might Be Done Next

The most important contribution of this dissertation is in the provision of experimental findings that show energy savings in a HVAC system by simply having the indoor set-point temperature fluctuate in a prescribed manner. However, the air-conditioned space climate of the building chosen for the field trial failed to respond accordingly due to limitations in its HVAC system specification. In the author’s opinion, there are more significant findings related to energy conservation and human comfort that could be achieved if the required indoor temperature responses were obtained.

Therefore, the author would like to propose that the current research should be continued by first finding a more suitable plant for the field trial and experimentation. When the right response is obtained, the research can be extended to investigate the prescribed changes in conditioned space temperature, during a normal working day that could save the most energy while maintaining comfort. Obtaining this pattern could potentially suggest a control algorithm of indoor set-point temperature that could be used in buildings with similar functionality, in countries with similar climate, to improve energy consumption of building a HVAC system.

The research could also be extended to study the impact of rapid changes in the indoor temperature set-point on the deterioration and life span of HVAC system parts and equipment.

APPENDICES

A : Background Measurements Results

Table 6-1: Constant indoor set-point temperature mode of BHEUU Background Measurements at placement A (performed on 23rd August 2011)

No	Date Time, GMT+08:00	Indoor Set-Point Temperature	Indoor Set-Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)*	Operative/ Globe Temperature (corrected)*	Operative/ Globe Temperature (corrected)*
1	08/23/11 08:00:00 AM	75.0 °F	23.9 °C	75.2 °F	74.1 °F	23.4 °C	64.8 %	65.3 %	74.0 °F	73.8 °F	23.2 °C
2	08/23/11 08:10:00 AM	75.0 °F	23.9 °C	75.2 °F	74.1 °F	23.4 °C	65.0 %	65.5 %	74.1 °F	73.9 °F	23.3 °C
3	08/23/11 08:20:00 AM	75.0 °F	23.9 °C	75.1 °F	74.0 °F	23.3 °C	64.6 %	65.1 %	74.0 °F	73.8 °F	23.2 °C
4	08/23/11 08:30:00 AM	75.0 °F	23.9 °C	75.0 °F	73.9 °F	23.3 °C	64.6 %	65.1 %	73.9 °F	73.7 °F	23.2 °C
5	08/23/11 08:40:00 AM	75.0 °F	23.9 °C	75.0 °F	73.9 °F	23.3 °C	64.4 %	64.9 %	74.0 °F	73.8 °F	23.2 °C
6	08/23/11 08:50:00 AM	75.0 °F	23.9 °C	74.9 °F	73.8 °F	23.2 °C	64.2 %	64.7 %	73.9 °F	73.7 °F	23.1 °C
7	08/23/11 09:00:00 AM	75.0 °F	23.9 °C	74.9 °F	73.8 °F	23.2 °C	64.0 %	64.5 %	73.8 °F	73.6 °F	23.1 °C
8	08/23/11 09:10:00 AM	75.0 °F	23.9 °C	74.8 °F	73.7 °F	23.2 °C	63.7 %	64.2 %	73.8 °F	73.6 °F	23.1 °C
9	08/23/11 09:20:00 AM	75.0 °F	23.9 °C	74.8 °F	73.7 °F	23.2 °C	63.6 %	64.1 %	73.8 °F	73.6 °F	23.1 °C
10	08/23/11 09:30:00 AM	75.0 °F	23.9 °C	74.8 °F	73.7 °F	23.2 °C	63.5 %	64.0 %	73.7 °F	73.5 °F	23.0 °C
11	08/23/11 09:40:00 AM	75.0 °F	23.9 °C	74.7 °F	73.6 °F	23.1 °C	63.1 %	63.6 %	73.7 °F	73.5 °F	23.1 °C
12	08/23/11 09:50:00 AM	75.0 °F	23.9 °C	74.7 °F	73.6 °F	23.1 °C	63.1 %	63.6 %	73.7 °F	73.5 °F	23.1 °C
13	08/23/11 10:00:00 AM	75.0 °F	23.9 °C	74.7 °F	73.6 °F	23.1 °C	62.9 %	63.4 %	73.8 °F	73.6 °F	23.1 °C
14	08/23/11 10:10:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.1 °C	63.1 %	63.6 %	73.6 °F	73.4 °F	23.0 °C
15	08/23/11 10:20:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.1 °C	63.0 %	63.5 %	73.6 °F	73.4 °F	23.0 °C
16	08/23/11 10:30:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.1 °C	63.0 %	63.5 %	73.6 °F	73.4 °F	23.0 °C
17	08/23/11 10:40:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.1 °C	62.9 %	63.4 %	73.6 °F	73.4 °F	23.0 °C
18	08/23/11 10:50:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.1 °C	62.7 %	63.2 %	73.6 °F	73.4 °F	23.0 °C
19	08/23/11 11:00:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.1 °C	62.8 %	63.3 %	73.6 °F	73.4 °F	23.0 °C
20	08/23/11 11:10:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.1 °C	62.8 %	63.3 %	73.6 °F	73.4 °F	23.0 °C
21	08/23/11 11:20:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.0 °C	62.8 %	63.3 %	73.5 °F	73.3 °F	22.9 °C
22	08/23/11 11:30:00 AM	75.0 °F	23.9 °C	74.6 °F	73.5 °F	23.0 °C	62.8 %	63.3 %	73.5 °F	73.3 °F	23.0 °C
23	08/23/11 11:40:00 AM	75.0 °F	23.9 °C	74.5 °F	73.4 °F	23.0 °C	62.8 %	63.3 %	73.5 °F	73.3 °F	22.9 °C
24	08/23/11 11:50:00 AM	75.0 °F	23.9 °C	74.4 °F	73.3 °F	23.0 °C	62.8 %	63.3 %	73.4 °F	73.2 °F	22.9 °C
25	08/23/11 12:00:00 PM	75.0 °F	23.9 °C	74.4 °F	73.3 °F	22.9 °C	62.7 %	63.2 %	73.3 °F	73.1 °F	22.9 °C
26	08/23/11 12:10:00 PM	75.0 °F	23.9 °C	74.3 °F	73.2 °F	22.9 °C	62.8 %	63.3 %	73.3 °F	73.1 °F	22.8 °C
27	08/23/11 12:20:00 PM	75.0 °F	23.9 °C	74.3 °F	73.2 °F	22.9 °C	62.7 %	63.2 %	73.2 °F	73.0 °F	22.8 °C
28	08/23/11 12:30:00 PM	75.0 °F	23.9 °C	74.2 °F	73.1 °F	22.8 °C	62.8 %	63.3 %	73.1 °F	72.9 °F	22.7 °C
29	08/23/11 12:40:00 PM	75.0 °F	23.9 °C	74.2 °F	73.1 °F	22.8 °C	62.8 %	63.3 %	73.1 °F	72.9 °F	22.7 °C
30	08/23/11 12:50:00 PM	75.0 °F	23.9 °C	74.1 °F	73.0 °F	22.8 °C	62.6 %	63.1 %	73.1 °F	72.9 °F	22.7 °C
31	08/23/11 01:00:00 PM	75.0 °F	23.9 °C	74.1 °F	73.0 °F	22.8 °C	62.5 %	63.0 %	73.1 °F	72.9 °F	22.7 °C
32	08/23/11 01:10:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	62.4 %	62.9 %	73.1 °F	72.9 °F	22.7 °C
33	08/23/11 01:20:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	62.4 %	62.9 %	73.1 °F	72.9 °F	22.7 °C
34	08/23/11 01:30:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	62.7 %	63.2 %	73.0 °F	72.8 °F	22.7 °C
35	08/23/11 01:40:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	62.7 %	63.2 %	72.9 °F	72.7 °F	22.6 °C
36	08/23/11 01:50:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	63.0 %	63.5 %	73.1 °F	72.9 °F	22.7 °C
37	08/23/11 02:00:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	63.1 %	63.6 %	73.0 °F	72.8 °F	22.7 °C
38	08/23/11 02:10:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	63.0 %	63.5 %	73.1 °F	72.9 °F	22.7 °C
39	08/23/11 02:20:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	63.3 %	63.8 %	73.1 °F	72.9 °F	22.7 °C
40	08/23/11 02:30:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	63.4 %	63.9 %	73.0 °F	72.8 °F	22.7 °C
41	08/23/11 02:40:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.7 °C	63.5 %	64.0 %	73.0 °F	72.8 °F	22.7 °C
42	08/23/11 02:50:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.7 °C	63.4 %	63.9 %	73.0 °F	72.8 °F	22.7 °C
43	08/23/11 03:00:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.6 °C	63.3 %	63.8 %	73.0 °F	72.8 °F	22.7 °C
44	08/23/11 03:10:00 PM	75.0 °F	23.9 °C	73.8 °F	72.7 °F	22.6 °C	63.9 %	64.4 %	72.9 °F	72.7 °F	22.6 °C
45	08/23/11 03:20:00 PM	75.0 °F	23.9 °C	73.8 °F	72.7 °F	22.6 °C	63.7 %	64.2 %	73.0 °F	72.8 °F	22.7 °C
46	08/23/11 03:30:00 PM	75.0 °F	23.9 °C	73.8 °F	72.7 °F	22.6 °C	63.8 %	64.3 %	73.0 °F	72.8 °F	22.7 °C
47	08/23/11 03:40:00 PM	75.0 °F	23.9 °C	73.8 °F	72.7 °F	22.6 °C	63.7 %	64.2 %	73.0 °F	72.8 °F	22.7 °C
48	08/23/11 03:50:00 PM	75.0 °F	23.9 °C	73.8 °F	72.7 °F	22.6 °C	63.6 %	64.1 %	73.0 °F	72.8 °F	22.7 °C
49	08/23/11 04:00:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.6 °C	63.6 %	64.1 %	73.0 °F	72.8 °F	22.7 °C
50	08/23/11 04:10:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.6 °C	63.4 %	63.9 %	73.0 °F	72.8 °F	22.7 °C
51	08/23/11 04:20:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.7 °C	63.2 %	63.7 %	73.0 °F	72.8 °F	22.7 °C
52	08/23/11 04:30:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.7 °C	63.4 %	63.9 %	73.3 °F	73.1 °F	22.8 °C
53	08/23/11 04:35:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	63.4 %	63.9 %	73.2 °F	73.0 °F	22.8 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-2: Ramp indoor set-point temperature mode of BHEUU Background Measurements at placement A (performed on 24th August 2011)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)*	Operative/ Globe Temperature (corrected)*	Operative/ Globe Temperature (corrected)*
1	08/24/11 08:00:00 AM	75.0 °F	23.9 °C	74.5 °F	73.4 °F	23.0 °C	65.1 %	65.6 %	73.4 °F	73.2 °F	22.9 °C
2	08/24/11 08:10:00 AM	75.5 °F	24.2 °C	74.5 °F	73.4 °F	23.0 °C	64.8 %	65.3 %	73.5 °F	73.3 °F	22.9 °C
3	08/24/11 08:20:00 AM	76.0 °F	24.4 °C	74.4 °F	73.3 °F	23.0 °C	64.6 %	65.1 %	73.4 °F	73.2 °F	22.9 °C
4	08/24/11 08:30:00 AM	76.5 °F	24.7 °C	74.4 °F	73.3 °F	22.9 °C	64.5 %	65.0 %	73.4 °F	73.2 °F	22.9 °C
5	08/24/11 08:40:00 AM	77.0 °F	25.0 °C	74.3 °F	73.2 °F	22.9 °C	64.5 %	65.0 %	73.3 °F	73.1 °F	22.9 °C
6	08/24/11 08:50:00 AM	77.5 °F	25.3 °C	74.3 °F	73.2 °F	22.9 °C	64.4 %	64.9 %	73.4 °F	73.2 °F	22.9 °C
7	08/24/11 09:00:00 AM	78.0 °F	25.6 °C	74.3 °F	73.2 °F	22.9 °C	64.4 %	64.9 %	73.4 °F	73.2 °F	22.9 °C
8	08/24/11 09:10:00 AM	78.5 °F	25.8 °C	74.3 °F	73.2 °F	22.9 °C	64.2 %	64.7 %	73.4 °F	73.2 °F	22.9 °C
9	08/24/11 09:20:00 AM	75.0 °F	23.9 °C	74.3 °F	73.2 °F	22.9 °C	64.1 %	64.6 %	73.5 °F	73.3 °F	22.9 °C
10	08/24/11 09:30:00 AM	75.5 °F	24.2 °C	74.3 °F	73.2 °F	22.9 °C	63.8 %	64.3 %	73.5 °F	73.3 °F	22.9 °C
11	08/24/11 09:40:00 AM	76.0 °F	24.4 °C	74.3 °F	73.2 °F	22.9 °C	63.7 %	64.2 %	73.5 °F	73.3 °F	22.9 °C
12	08/24/11 09:50:00 AM	76.5 °F	24.7 °C	74.3 °F	73.2 °F	22.9 °C	63.9 %	64.4 %	73.3 °F	73.1 °F	22.9 °C
13	08/24/11 10:00:00 AM	77.0 °F	25.0 °C	74.3 °F	73.2 °F	22.9 °C	63.9 %	64.4 %	73.4 °F	73.2 °F	22.9 °C
14	08/24/11 10:10:00 AM	77.5 °F	25.3 °C	74.2 °F	73.1 °F	22.8 °C	63.7 %	64.2 %	73.4 °F	73.2 °F	22.9 °C
15	08/24/11 10:20:00 AM	78.0 °F	25.6 °C	74.2 °F	73.1 °F	22.8 °C	63.5 %	64.0 %	73.3 °F	73.1 °F	22.8 °C
16	08/24/11 10:30:00 AM	78.5 °F	25.8 °C	74.2 °F	73.1 °F	22.8 °C	63.4 %	63.9 %	73.3 °F	73.1 °F	22.8 °C
17	08/24/11 10:40:00 AM	75.0 °F	23.9 °C	74.2 °F	73.1 °F	22.8 °C	63.7 %	64.2 %	73.3 °F	73.1 °F	22.9 °C
18	08/24/11 10:50:00 AM	75.5 °F	24.2 °C	74.2 °F	73.1 °F	22.8 °C	63.5 %	64.0 %	73.3 °F	73.1 °F	22.9 °C
19	08/24/11 11:00:00 AM	76.0 °F	24.4 °C	74.2 °F	73.1 °F	22.8 °C	63.5 %	64.0 %	73.3 °F	73.1 °F	22.8 °C
20	08/24/11 11:10:00 AM	76.5 °F	24.7 °C	74.2 °F	73.1 °F	22.8 °C	63.5 %	64.0 %	73.3 °F	73.1 °F	22.9 °C
21	08/24/11 11:20:00 AM	77.0 °F	25.0 °C	74.1 °F	73.0 °F	22.8 °C	63.4 %	63.9 %	73.3 °F	73.1 °F	22.8 °C
22	08/24/11 11:30:00 AM	77.5 °F	25.3 °C	74.2 °F	73.1 °F	22.8 °C	63.3 %	63.8 %	73.3 °F	73.1 °F	22.9 °C
23	08/24/11 11:40:00 AM	78.0 °F	25.6 °C	74.2 °F	73.1 °F	22.8 °C	63.4 %	63.9 %	73.3 °F	73.1 °F	22.8 °C
24	08/24/11 11:50:00 AM	78.5 °F	25.8 °C	74.2 °F	73.1 °F	22.8 °C	63.4 %	63.9 %	73.3 °F	73.1 °F	22.9 °C
25	08/24/11 12:00:00 PM	75.0 °F	23.9 °C	74.2 °F	73.1 °F	22.8 °C	63.3 %	63.8 %	73.2 °F	73.0 °F	22.8 °C
26	08/24/11 12:10:00 PM	75.5 °F	24.2 °C	74.2 °F	73.1 °F	22.8 °C	63.4 %	63.9 %	73.3 °F	73.1 °F	22.8 °C
27	08/24/11 12:20:00 PM	76.0 °F	24.4 °C	74.1 °F	73.0 °F	22.8 °C	63.3 %	63.8 %	73.1 °F	72.9 °F	22.7 °C
28	08/24/11 12:30:00 PM	76.5 °F	24.7 °C	74.0 °F	72.9 °F	22.7 °C	63.4 %	63.9 %	73.1 °F	72.9 °F	22.7 °C
29	08/24/11 12:40:00 PM	77.0 °F	25.0 °C	74.0 °F	72.9 °F	22.7 °C	63.5 %	64.0 %	73.2 °F	73.0 °F	22.8 °C
30	08/24/11 12:50:00 PM	77.5 °F	25.3 °C	73.9 °F	72.8 °F	22.7 °C	63.8 %	64.3 %	73.0 °F	72.8 °F	22.7 °C
31	08/24/11 01:00:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	64.4 %	64.9 %	73.1 °F	72.9 °F	22.7 °C
32	08/24/11 01:10:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.7 °C	64.5 %	65.0 %	73.0 °F	72.8 °F	22.7 °C
33	08/24/11 01:20:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.6 °C	65.0 %	65.5 %	72.9 °F	72.7 °F	22.6 °C
34	08/24/11 01:30:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.6 °C	65.5 %	66.0 %	73.0 °F	72.8 °F	22.6 °C
35	08/24/11 01:40:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.6 °C	65.4 %	65.9 %	73.0 °F	72.8 °F	22.7 °C
36	08/24/11 01:50:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.7 °C	65.3 %	65.8 %	73.2 °F	73.0 °F	22.8 °C
37	08/24/11 02:00:00 PM	75.0 °F	23.9 °C	73.9 °F	72.8 °F	22.7 °C	65.0 %	65.5 %	73.3 °F	73.1 °F	22.8 °C
38	08/24/11 02:10:00 PM	75.5 °F	24.2 °C	73.9 °F	72.8 °F	22.7 °C	64.7 %	65.2 %	73.3 °F	73.1 °F	22.8 °C
39	08/24/11 02:20:00 PM	76.0 °F	24.4 °C	73.9 °F	72.8 °F	22.7 °C	64.4 %	64.9 %	73.2 °F	73.0 °F	22.8 °C
40	08/24/11 02:30:00 PM	76.5 °F	24.7 °C	73.9 °F	72.8 °F	22.6 °C	64.6 %	65.1 %	73.0 °F	72.8 °F	22.7 °C
41	08/24/11 02:40:00 PM	77.0 °F	25.0 °C	73.9 °F	72.8 °F	22.6 °C	64.9 %	65.4 %	73.1 °F	72.9 °F	22.7 °C
42	08/24/11 02:50:00 PM	77.5 °F	25.3 °C	73.9 °F	72.8 °F	22.7 °C	66.4 %	66.9 %	73.2 °F	73.0 °F	22.8 °C
43	08/24/11 03:00:00 PM	78.0 °F	25.6 °C	74.0 °F	72.9 °F	22.7 °C	66.9 %	67.4 %	73.3 °F	73.1 °F	22.8 °C
44	08/24/11 03:10:00 PM	78.5 °F	25.8 °C	74.0 °F	72.9 °F	22.7 °C	67.5 %	68.0 %	73.4 °F	73.2 °F	22.9 °C
45	08/24/11 03:20:00 PM	75.0 °F	23.9 °C	74.0 °F	72.9 °F	22.7 °C	67.3 %	67.8 %	73.3 °F	73.1 °F	22.8 °C
46	08/24/11 03:30:00 PM	75.5 °F	24.2 °C	74.0 °F	72.9 °F	22.7 °C	66.6 %	67.1 %	73.2 °F	73.0 °F	22.8 °C
47	08/24/11 03:40:00 PM	76.0 °F	24.4 °C	74.0 °F	72.9 °F	22.7 °C	66.2 %	66.7 %	73.3 °F	73.1 °F	22.8 °C
48	08/24/11 03:50:00 PM	76.5 °F	24.7 °C	74.0 °F	72.9 °F	22.7 °C	66.0 %	66.5 %	73.3 °F	73.1 °F	22.9 °C
49	08/24/11 04:00:00 PM	77.0 °F	25.0 °C	74.0 °F	72.9 °F	22.7 °C	65.9 %	66.4 %	73.4 °F	73.2 °F	22.9 °C
50	08/24/11 04:10:00 PM	77.5 °F	25.3 °C	74.0 °F	72.9 °F	22.7 °C	65.8 %	66.3 %	73.3 °F	73.1 °F	22.9 °C
51	08/24/11 04:20:00 PM	78.0 °F	25.6 °C	74.0 °F	72.9 °F	22.7 °C	65.6 %	66.1 %	73.3 °F	73.1 °F	22.9 °C
52	08/24/11 04:30:00 PM	78.5 °F	25.8 °C	74.0 °F	72.9 °F	22.7 °C	65.7 %	66.2 %	73.4 °F	73.2 °F	22.9 °C
53	08/24/11 04:35:00 PM	78.5 °F	25.8 °C	74.0 °F	72.9 °F	22.7 °C	65.7 %	66.2 %	73.4 °F	73.2 °F	22.9 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-3: Cyclic indoor set-point temperature mode of BHEUU Background Measurements at placement A (performed on 25th August 2011)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)*	Operative/ Globe Temperature (corrected)*	Operative/ Globe Temperature (corrected)*
1	08/25/11 08:00:00 AM	75.0 °F	23.9 °C	74.2 °F	73.1 °F	22.8 °C	64.7 %	65.2 %	73.2 °F	73.0 °F	22.8 °C
2	08/25/11 08:10:00 AM	75.5 °F	24.2 °C	74.1 °F	73.0 °F	22.8 °C	64.6 %	65.1 %	73.2 °F	73.0 °F	22.8 °C
3	08/25/11 08:20:00 AM	76.0 °F	24.4 °C	74.0 °F	72.9 °F	22.7 °C	64.5 %	65.0 %	73.0 °F	72.8 °F	22.7 °C
4	08/25/11 08:30:00 AM	76.5 °F	24.7 °C	73.9 °F	72.8 °F	22.7 °C	64.5 %	65.0 %	72.9 °F	72.7 °F	22.6 °C
5	08/25/11 08:40:00 AM	77.0 °F	25.0 °C	73.9 °F	72.8 °F	22.7 °C	64.6 %	65.1 %	73.0 °F	72.8 °F	22.7 °C
6	08/25/11 08:50:00 AM	77.5 °F	25.3 °C	73.9 °F	72.8 °F	22.6 °C	64.5 %	65.0 %	72.8 °F	72.6 °F	22.6 °C
7	08/25/11 09:00:00 AM	78.0 °F	25.6 °C	73.8 °F	72.7 °F	22.6 °C	64.4 %	64.9 %	72.8 °F	72.6 °F	22.5 °C
8	08/25/11 09:10:00 AM	78.5 °F	25.8 °C	73.8 °F	72.7 °F	22.6 °C	64.5 %	65.0 %	72.8 °F	72.6 °F	22.5 °C
9	08/25/11 09:20:00 AM	78.0 °F	25.6 °C	73.7 °F	72.6 °F	22.6 °C	64.7 %	65.2 %	72.8 °F	72.6 °F	22.5 °C
10	08/25/11 09:30:00 AM	77.5 °F	25.3 °C	73.7 °F	72.6 °F	22.6 °C	64.7 %	65.2 %	72.8 °F	72.6 °F	22.5 °C
11	08/25/11 09:40:00 AM	77.0 °F	25.0 °C	73.8 °F	72.7 °F	22.6 °C	64.6 %	65.1 %	72.9 °F	72.7 °F	22.6 °C
12	08/25/11 09:50:00 AM	76.5 °F	24.7 °C	73.8 °F	72.7 °F	22.6 °C	64.4 %	64.9 %	73.0 °F	72.8 °F	22.7 °C
13	08/25/11 10:00:00 AM	76.0 °F	24.4 °C	73.8 °F	72.7 °F	22.6 °C	64.3 %	64.8 %	73.0 °F	72.8 °F	22.7 °C
14	08/25/11 10:10:00 AM	75.5 °F	24.2 °C	73.7 °F	72.6 °F	22.6 °C	64.3 %	64.8 %	72.8 °F	72.6 °F	22.5 °C
15	08/25/11 10:20:00 AM	75.0 °F	23.9 °C	73.8 °F	72.7 °F	22.6 °C	64.2 %	64.7 %	72.8 °F	72.6 °F	22.6 °C
16	08/25/11 10:30:00 AM	75.5 °F	24.2 °C	73.7 °F	72.6 °F	22.6 °C	64.2 %	64.7 %	72.7 °F	72.5 °F	22.5 °C
17	08/25/11 10:40:00 AM	76.0 °F	24.4 °C	73.7 °F	72.6 °F	22.6 °C	64.2 %	64.7 %	72.9 °F	72.7 °F	22.6 °C
18	08/25/11 10:50:00 AM	76.5 °F	24.7 °C	73.8 °F	72.7 °F	22.6 °C	64.3 %	64.8 %	73.1 °F	72.9 °F	22.7 °C
19	08/25/11 11:00:00 AM	77.0 °F	25.0 °C	73.7 °F	72.6 °F	22.6 °C	64.2 %	64.7 %	72.8 °F	72.6 °F	22.5 °C
20	08/25/11 11:10:00 AM	77.5 °F	25.3 °C	73.6 °F	72.5 °F	22.5 °C	64.2 %	64.7 %	72.8 °F	72.6 °F	22.5 °C
21	08/25/11 11:20:00 AM	78.0 °F	25.6 °C	73.6 °F	72.5 °F	22.5 °C	64.3 %	64.8 %	72.7 °F	72.5 °F	22.5 °C
22	08/25/11 11:30:00 AM	78.5 °F	25.8 °C	73.6 °F	72.5 °F	22.5 °C	64.4 %	64.9 %	72.9 °F	72.7 °F	22.6 °C
23	08/25/11 11:40:00 AM	78.0 °F	25.6 °C	73.6 °F	72.5 °F	22.5 °C	64.4 %	64.9 %	72.7 °F	72.5 °F	22.5 °C
24	08/25/11 11:50:00 AM	77.5 °F	25.3 °C	73.6 °F	72.5 °F	22.5 °C	64.2 %	64.7 %	72.7 °F	72.5 °F	22.5 °C
25	08/25/11 12:00:00 PM	77.0 °F	25.0 °C	73.5 °F	72.4 °F	22.5 °C	64.4 %	64.9 %	72.7 °F	72.5 °F	22.5 °C
26	08/25/11 12:10:00 PM	76.5 °F	24.7 °C	73.5 °F	72.4 °F	22.5 °C	64.4 %	64.9 %	72.8 °F	72.6 °F	22.5 °C
27	08/25/11 12:20:00 PM	76.0 °F	24.4 °C	73.5 °F	72.4 °F	22.5 °C	64.1 %	64.6 %	72.6 °F	72.4 °F	22.5 °C
28	08/25/11 12:30:00 PM	75.5 °F	24.2 °C	73.5 °F	72.4 °F	22.5 °C	64.4 %	64.9 %	72.7 °F	72.5 °F	22.5 °C
29	08/25/11 12:40:00 PM	75.0 °F	23.9 °C	73.5 °F	72.4 °F	22.5 °C	64.5 %	65.0 %	72.7 °F	72.5 °F	22.5 °C
30	08/25/11 12:50:00 PM	75.5 °F	24.2 °C	73.6 °F	72.5 °F	22.5 °C	64.4 %	64.9 %	72.8 °F	72.6 °F	22.5 °C
31	08/25/11 01:00:00 PM	75.0 °F	23.9 °C	73.5 °F	72.4 °F	22.5 °C	64.9 %	65.4 %	72.9 °F	72.7 °F	22.6 °C
32	08/25/11 01:10:00 PM	75.0 °F	23.9 °C	73.5 °F	72.4 °F	22.4 °C	65.9 %	66.4 %	72.6 °F	72.4 °F	22.5 °C
33	08/25/11 01:20:00 PM	75.0 °F	23.9 °C	73.6 °F	72.5 °F	22.5 °C	66.9 %	67.4 %	73.0 °F	72.8 °F	22.6 °C
34	08/25/11 01:30:00 PM	75.0 °F	23.9 °C	73.6 °F	72.5 °F	22.5 °C	66.9 %	67.4 %	72.9 °F	72.7 °F	22.6 °C
35	08/25/11 01:40:00 PM	75.0 °F	23.9 °C	73.5 °F	72.4 °F	22.5 °C	66.2 %	66.7 %	72.7 °F	72.5 °F	22.5 °C
36	08/25/11 01:50:00 PM	75.0 °F	23.9 °C	73.5 °F	72.4 °F	22.4 °C	65.6 %	66.1 %	72.4 °F	72.2 °F	22.4 °C
37	08/25/11 02:00:00 PM	75.0 °F	23.9 °C	73.4 °F	72.3 °F	22.4 °C	65.3 %	65.8 %	72.6 °F	72.4 °F	22.5 °C
38	08/25/11 02:10:00 PM	75.5 °F	24.2 °C	73.4 °F	72.3 °F	22.4 °C	64.7 %	65.2 %	72.6 °F	72.4 °F	22.5 °C
39	08/25/11 02:20:00 PM	76.0 °F	24.4 °C	73.3 °F	72.2 °F	22.4 °C	64.6 %	65.1 %	72.5 °F	72.3 °F	22.4 °C
40	08/25/11 02:30:00 PM	76.5 °F	24.7 °C	73.3 °F	72.2 °F	22.3 °C	64.8 %	65.3 %	72.5 °F	72.3 °F	22.4 °C
41	08/25/11 02:40:00 PM	77.0 °F	25.0 °C	73.3 °F	72.2 °F	22.3 °C	65.1 %	65.6 %	72.5 °F	72.3 °F	22.4 °C
42	08/25/11 02:50:00 PM	77.5 °F	25.3 °C	73.3 °F	72.2 °F	22.3 °C	65.4 %	65.9 %	72.6 °F	72.4 °F	22.4 °C
43	08/25/11 03:00:00 PM	78.0 °F	25.6 °C	73.3 °F	72.2 °F	22.3 °C	65.4 %	65.9 %	72.6 °F	72.4 °F	22.5 °C
44	08/25/11 03:10:00 PM	78.5 °F	25.8 °C	73.3 °F	72.2 °F	22.3 °C	65.2 %	65.7 %	72.7 °F	72.5 °F	22.5 °C
45	08/25/11 03:20:00 PM	78.0 °F	25.6 °C	73.3 °F	72.2 °F	22.3 °C	64.9 %	65.4 %	72.6 °F	72.4 °F	22.4 °C
46	08/25/11 03:30:00 PM	77.5 °F	25.3 °C	73.3 °F	72.2 °F	22.3 °C	65.1 %	65.6 %	72.6 °F	72.4 °F	22.4 °C
47	08/25/11 03:40:00 PM	77.0 °F	25.0 °C	73.3 °F	72.2 °F	22.3 °C	64.9 %	65.4 %	72.6 °F	72.4 °F	22.5 °C
48	08/25/11 03:50:00 PM	76.5 °F	24.7 °C	73.3 °F	72.2 °F	22.3 °C	64.9 %	65.4 %	72.5 °F	72.3 °F	22.4 °C
49	08/25/11 04:00:00 PM	76.0 °F	24.4 °C	73.3 °F	72.2 °F	22.3 °C	64.9 %	65.4 %	72.6 °F	72.4 °F	22.4 °C
50	08/25/11 04:10:00 PM	75.5 °F	24.2 °C	73.2 °F	72.1 °F	22.3 °C	65.0 %	65.5 %	72.4 °F	72.2 °F	22.3 °C
51	08/25/11 04:20:00 PM	75.0 °F	23.9 °C	73.2 °F	72.1 °F	22.3 °C	65.2 %	65.7 %	72.4 °F	72.2 °F	22.3 °C
52	08/25/11 04:30:00 PM	75.5 °F	24.2 °C	73.1 °F	72.0 °F	22.2 °C	65.6 %	66.1 %	72.3 °F	72.1 °F	22.3 °C
53	08/25/11 04:35:00 PM	75.5 °F	24.2 °C	73.8 °F	72.7 °F	22.6 °C	65.4 %	65.9 %	72.3 °F	72.1 °F	22.3 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-4: Constant indoor set-point temperature mode of BHEUU Background Measurements at placement B (performed on 23rd August 2011)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)*	Operative/ Globe Temperature (corrected)*	Operative/ Globe Temperature (corrected)*
1	08/23/11 08:00:00 AM	75.0 °F	23.9 °C	73.8 °F	72.6 °F	22.5 °C	68.6 %	69.1 %	73.3 °F	72.6 °F	22.6 °C
2	08/23/11 08:10:00 AM	75.0 °F	23.9 °C	73.7 °F	72.5 °F	22.5 °C	68.7 %	69.2 %	73.5 °F	72.8 °F	22.7 °C
3	08/23/11 08:20:00 AM	75.0 °F	23.9 °C	73.6 °F	72.4 °F	22.4 °C	68.5 %	69.0 %	73.3 °F	72.6 °F	22.5 °C
4	08/23/11 08:30:00 AM	75.0 °F	23.9 °C	73.4 °F	72.2 °F	22.3 °C	68.5 %	69.0 %	73.1 °F	72.4 °F	22.4 °C
5	08/23/11 08:40:00 AM	75.0 °F	23.9 °C	73.3 °F	72.1 °F	22.3 °C	68.4 %	68.9 %	72.9 °F	72.2 °F	22.3 °C
6	08/23/11 08:50:00 AM	75.0 °F	23.9 °C	73.1 °F	71.9 °F	22.2 °C	68.5 %	69.0 %	72.7 °F	72.0 °F	22.2 °C
7	08/23/11 09:00:00 AM	75.0 °F	23.9 °C	72.9 °F	71.7 °F	22.1 °C	68.3 %	68.8 %	72.6 °F	71.9 °F	22.1 °C
8	08/23/11 09:10:00 AM	75.0 °F	23.9 °C	72.7 °F	71.5 °F	22.0 °C	68.3 %	68.8 %	72.4 °F	71.7 °F	22.1 °C
9	08/23/11 09:20:00 AM	75.0 °F	23.9 °C	72.6 °F	71.4 °F	21.9 °C	68.4 %	68.9 %	72.2 °F	71.5 °F	22.0 °C
10	08/23/11 09:30:00 AM	75.0 °F	23.9 °C	72.4 °F	71.2 °F	21.8 °C	68.3 %	68.8 %	72.1 °F	71.4 °F	21.9 °C
11	08/23/11 09:40:00 AM	75.0 °F	23.9 °C	72.3 °F	71.1 °F	21.7 °C	68.1 %	68.6 %	72.0 °F	71.3 °F	21.8 °C
12	08/23/11 09:50:00 AM	75.0 °F	23.9 °C	72.1 °F	70.9 °F	21.6 °C	68.2 %	68.7 %	71.9 °F	71.2 °F	21.8 °C
13	08/23/11 10:00:00 AM	75.0 °F	23.9 °C	72.1 °F	70.9 °F	21.6 °C	68.3 %	68.8 %	71.8 °F	71.1 °F	21.7 °C
14	08/23/11 10:10:00 AM	75.0 °F	23.9 °C	72.0 °F	70.8 °F	21.5 °C	68.5 %	69.0 %	71.8 °F	71.1 °F	21.7 °C
15	08/23/11 10:20:00 AM	75.0 °F	23.9 °C	71.9 °F	70.7 °F	21.5 °C	68.5 %	69.0 %	71.8 °F	71.1 °F	21.7 °C
16	08/23/11 10:30:00 AM	75.0 °F	23.9 °C	71.9 °F	70.7 °F	21.5 °C	68.5 %	69.0 %	71.7 °F	71.0 °F	21.7 °C
17	08/23/11 10:40:00 AM	75.0 °F	23.9 °C	71.8 °F	70.6 °F	21.4 °C	68.6 %	69.1 %	71.6 °F	70.9 °F	21.6 °C
18	08/23/11 10:50:00 AM	75.0 °F	23.9 °C	71.7 °F	70.5 °F	21.4 °C	68.6 %	69.1 %	71.6 °F	70.9 °F	21.6 °C
19	08/23/11 11:00:00 AM	75.0 °F	23.9 °C	71.7 °F	70.5 °F	21.4 °C	68.7 %	69.2 %	71.4 °F	70.7 °F	21.5 °C
20	08/23/11 11:10:00 AM	75.0 °F	23.9 °C	71.6 °F	70.4 °F	21.3 °C	68.5 %	69.0 %	71.4 °F	70.7 °F	21.5 °C
21	08/23/11 11:20:00 AM	75.0 °F	23.9 °C	71.5 °F	70.3 °F	21.3 °C	68.6 %	69.1 %	71.4 °F	70.7 °F	21.5 °C
22	08/23/11 11:30:00 AM	75.0 °F	23.9 °C	71.5 °F	70.3 °F	21.3 °C	68.9 %	69.4 %	71.4 °F	70.7 °F	21.5 °C
23	08/23/11 11:40:00 AM	75.0 °F	23.9 °C	71.4 °F	70.2 °F	21.2 °C	69.0 %	69.5 %	71.3 °F	70.6 °F	21.5 °C
24	08/23/11 11:50:00 AM	75.0 °F	23.9 °C	71.3 °F	70.1 °F	21.2 °C	68.8 %	69.3 %	71.1 °F	70.4 °F	21.4 °C
25	08/23/11 12:00:00 PM	75.0 °F	23.9 °C	71.2 °F	70.0 °F	21.1 °C	68.8 %	69.3 %	71.1 °F	70.4 °F	21.3 °C
26	08/23/11 12:10:00 PM	75.0 °F	23.9 °C	71.2 °F	70.0 °F	21.1 °C	69.0 %	69.5 %	71.1 °F	70.4 °F	21.3 °C
27	08/23/11 12:20:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	68.8 %	69.3 %	71.0 °F	70.3 °F	21.3 °C
28	08/23/11 12:30:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	69.0 %	69.5 %	71.0 °F	70.3 °F	21.3 °C
29	08/23/11 12:40:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	69.1 %	69.6 %	70.9 °F	70.2 °F	21.2 °C
30	08/23/11 12:50:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	68.9 %	69.4 %	70.9 °F	70.2 °F	21.2 °C
31	08/23/11 01:00:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	68.8 %	69.3 %	70.9 °F	70.2 °F	21.2 °C
32	08/23/11 01:10:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	68.7 %	69.2 %	71.0 °F	70.3 °F	21.3 °C
33	08/23/11 01:20:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	68.7 %	69.2 %	71.1 °F	70.4 °F	21.3 °C
34	08/23/11 01:30:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	68.9 %	69.4 %	71.0 °F	70.3 °F	21.3 °C
35	08/23/11 01:40:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	68.9 %	69.4 %	71.3 °F	70.6 °F	21.4 °C
36	08/23/11 01:50:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	68.9 %	69.4 %	71.1 °F	70.4 °F	21.3 °C
37	08/23/11 02:00:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	69.1 %	69.6 %	71.0 °F	70.3 °F	21.3 °C
38	08/23/11 02:10:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	69.2 %	69.7 %	71.0 °F	70.3 °F	21.3 °C
39	08/23/11 02:20:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	69.4 %	69.9 %	71.1 °F	70.4 °F	21.3 °C
40	08/23/11 02:30:00 PM	75.0 °F	23.9 °C	71.0 °F	69.8 °F	21.0 °C	69.6 %	70.1 %	71.0 °F	70.3 °F	21.3 °C
41	08/23/11 02:40:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	69.5 %	70.0 %	71.3 °F	70.6 °F	21.4 °C
42	08/23/11 02:50:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	69.3 %	69.8 %	71.2 °F	70.5 °F	21.4 °C
43	08/23/11 03:00:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	69.1 %	69.6 %	71.2 °F	70.5 °F	21.4 °C
44	08/23/11 03:10:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	69.1 %	69.6 %	71.2 °F	70.5 °F	21.4 °C
45	08/23/11 03:20:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	69.1 %	69.6 %	71.1 °F	70.4 °F	21.3 °C
46	08/23/11 03:30:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	69.1 %	69.6 %	71.1 °F	70.4 °F	21.3 °C
47	08/23/11 03:40:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	69.1 %	69.6 %	71.3 °F	70.6 °F	21.4 °C
48	08/23/11 03:50:00 PM	75.0 °F	23.9 °C	71.2 °F	70.0 °F	21.1 °C	69.2 %	69.7 %	71.2 °F	70.5 °F	21.4 °C
49	08/23/11 04:00:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	69.1 %	69.6 %	71.1 °F	70.4 °F	21.4 °C
50	08/23/11 04:10:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	68.9 %	69.4 %	71.0 °F	70.3 °F	21.3 °C
51	08/23/11 04:20:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	68.9 %	69.4 %	71.1 °F	70.4 °F	21.3 °C
52	08/23/11 04:30:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	69.1 %	69.6 %	71.2 °F	70.5 °F	21.4 °C
53	08/23/11 04:35:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	69.1 %	69.6 %	71.3 °F	70.6 °F	21.4 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-5: Ramp indoor set-point temperature mode of BHEUU Background Measurements at placement B (performed on 24th August 2011)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)*	Operative/ Globe Temperature (corrected)*	Operative/ Globe Temperature (corrected)*
1	08/24/11 08:00:00 AM	75.0 °F	23.9 °C	73.1 °F	71.9 °F	22.2 °C	67.8 %	68.3 %	72.3 °F	71.6 °F	22.0 °C
2	08/24/11 08:10:00 AM	75.5 °F	24.2 °C	72.8 °F	71.6 °F	22.0 °C	68.2 %	68.7 %	72.2 °F	71.5 °F	21.9 °C
3	08/24/11 08:20:00 AM	76.0 °F	24.4 °C	72.6 °F	71.4 °F	21.9 °C	68.4 %	68.9 %	72.1 °F	71.4 °F	21.9 °C
4	08/24/11 08:30:00 AM	76.5 °F	24.7 °C	72.4 °F	71.2 °F	21.8 °C	68.4 %	68.9 %	72.1 °F	71.4 °F	21.9 °C
5	08/24/11 08:40:00 AM	77.0 °F	25.0 °C	72.3 °F	71.1 °F	21.7 °C	68.3 %	68.8 %	72.0 °F	71.3 °F	21.8 °C
6	08/24/11 08:50:00 AM	77.5 °F	25.3 °C	72.2 °F	71.0 °F	21.7 °C	68.5 %	69.0 %	71.9 °F	71.2 °F	21.8 °C
7	08/24/11 09:00:00 AM	78.0 °F	25.6 °C	72.1 °F	70.9 °F	21.6 °C	68.6 %	69.1 %	71.9 °F	71.2 °F	21.8 °C
8	08/24/11 09:10:00 AM	78.5 °F	25.8 °C	72.1 °F	70.9 °F	21.6 °C	68.7 %	69.2 %	71.9 °F	71.2 °F	21.8 °C
9	08/24/11 09:20:00 AM	75.0 °F	23.9 °C	72.1 °F	70.9 °F	21.6 °C	68.6 %	69.1 %	71.9 °F	71.2 °F	21.8 °C
10	08/24/11 09:30:00 AM	75.5 °F	24.2 °C	72.1 °F	70.9 °F	21.6 °C	68.5 %	69.0 %	71.9 °F	71.2 °F	21.8 °C
11	08/24/11 09:40:00 AM	76.0 °F	24.4 °C	72.0 °F	70.8 °F	21.5 °C	68.5 %	69.0 %	71.9 °F	71.2 °F	21.8 °C
12	08/24/11 09:50:00 AM	76.5 °F	24.7 °C	71.9 °F	70.7 °F	21.5 °C	68.5 %	69.0 %	71.8 °F	71.1 °F	21.7 °C
13	08/24/11 10:00:00 AM	77.0 °F	25.0 °C	71.9 °F	70.7 °F	21.5 °C	68.5 %	69.0 %	71.7 °F	71.0 °F	21.7 °C
14	08/24/11 10:10:00 AM	77.5 °F	25.3 °C	71.8 °F	70.6 °F	21.5 °C	68.6 %	69.1 %	71.8 °F	71.1 °F	21.7 °C
15	08/24/11 10:20:00 AM	78.0 °F	25.6 °C	71.8 °F	70.6 °F	21.4 °C	68.5 %	69.0 %	71.7 °F	71.0 °F	21.7 °C
16	08/24/11 10:30:00 AM	78.5 °F	25.8 °C	71.7 °F	70.5 °F	21.4 °C	68.5 %	69.0 %	71.7 °F	71.0 °F	21.7 °C
17	08/24/11 10:40:00 AM	75.0 °F	23.9 °C	71.7 °F	70.5 °F	21.4 °C	68.7 %	69.2 %	71.7 °F	71.0 °F	21.7 °C
18	08/24/11 10:50:00 AM	75.5 °F	24.2 °C	71.7 °F	70.5 °F	21.4 °C	68.5 %	69.0 %	71.6 °F	70.9 °F	21.6 °C
19	08/24/11 11:00:00 AM	76.0 °F	24.4 °C	71.7 °F	70.5 °F	21.4 °C	68.6 %	69.1 %	71.5 °F	70.8 °F	21.6 °C
20	08/24/11 11:10:00 AM	76.5 °F	24.7 °C	71.6 °F	70.4 °F	21.3 °C	68.6 %	69.1 %	71.5 °F	70.8 °F	21.6 °C
21	08/24/11 11:20:00 AM	77.0 °F	25.0 °C	71.5 °F	70.3 °F	21.3 °C	68.8 %	69.3 %	71.5 °F	70.8 °F	21.6 °C
22	08/24/11 11:30:00 AM	77.5 °F	25.3 °C	71.6 °F	70.4 °F	21.3 °C	68.6 %	69.1 %	71.7 °F	71.0 °F	21.7 °C
23	08/24/11 11:40:00 AM	78.0 °F	25.6 °C	71.6 °F	70.4 °F	21.3 °C	68.6 %	69.1 %	71.7 °F	71.0 °F	21.7 °C
24	08/24/11 11:50:00 AM	78.5 °F	25.8 °C	71.6 °F	70.4 °F	21.3 °C	68.7 %	69.2 %	71.5 °F	70.8 °F	21.6 °C
25	08/24/11 12:00:00 PM	75.0 °F	23.9 °C	71.4 °F	70.2 °F	21.2 °C	68.9 %	69.4 %	71.4 °F	70.7 °F	21.5 °C
26	08/24/11 12:10:00 PM	75.5 °F	24.2 °C	71.4 °F	70.2 °F	21.2 °C	68.9 %	69.4 %	71.4 °F	70.7 °F	21.5 °C
27	08/24/11 12:20:00 PM	76.0 °F	24.4 °C	71.4 °F	70.2 °F	21.2 °C	68.7 %	69.2 %	71.5 °F	70.8 °F	21.6 °C
28	08/24/11 12:30:00 PM	76.5 °F	24.7 °C	71.4 °F	70.2 °F	21.2 °C	68.7 %	69.2 %	71.4 °F	70.7 °F	21.5 °C
29	08/24/11 12:40:00 PM	77.0 °F	25.0 °C	71.4 °F	70.2 °F	21.2 °C	68.8 %	69.3 %	71.4 °F	70.7 °F	21.5 °C
30	08/24/11 12:50:00 PM	77.5 °F	25.3 °C	71.3 °F	70.1 °F	21.2 °C	69.0 %	69.5 %	71.3 °F	70.6 °F	21.4 °C
31	08/24/11 01:00:00 PM	75.0 °F	23.9 °C	71.3 °F	70.1 °F	21.2 °C	70.0 %	70.5 %	71.4 °F	70.7 °F	21.5 °C
32	08/24/11 01:10:00 PM	75.0 °F	23.9 °C	71.4 °F	70.2 °F	21.2 °C	69.8 %	70.3 %	71.3 °F	70.6 °F	21.5 °C
33	08/24/11 01:20:00 PM	75.0 °F	23.9 °C	71.3 °F	70.1 °F	21.2 °C	70.5 %	71.0 %	71.4 °F	70.7 °F	21.5 °C
34	08/24/11 01:30:00 PM	75.0 °F	23.9 °C	71.2 °F	70.0 °F	21.1 °C	70.9 %	71.4 %	71.1 °F	70.4 °F	21.3 °C
35	08/24/11 01:40:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.1 °C	70.6 %	71.1 %	71.2 °F	70.5 °F	21.4 °C
36	08/24/11 01:50:00 PM	75.0 °F	23.9 °C	71.1 °F	69.9 °F	21.0 °C	70.6 %	71.1 %	71.1 °F	70.4 °F	21.3 °C
37	08/24/11 02:00:00 PM	75.0 °F	23.9 °C	70.9 °F	69.7 °F	21.0 °C	70.4 %	70.9 %	70.8 °F	70.1 °F	21.2 °C
38	08/24/11 02:10:00 PM	75.5 °F	24.2 °C	70.8 °F	69.6 °F	20.9 °C	70.3 %	70.8 %	70.8 °F	70.1 °F	21.2 °C
39	08/24/11 02:20:00 PM	76.0 °F	24.4 °C	70.8 °F	69.6 °F	20.9 °C	70.2 %	70.7 %	70.8 °F	70.1 °F	21.2 °C
40	08/24/11 02:30:00 PM	76.5 °F	24.7 °C	70.8 °F	69.6 °F	20.9 °C	70.6 %	71.1 %	71.0 °F	70.3 °F	21.3 °C
41	08/24/11 02:40:00 PM	77.0 °F	25.0 °C	70.9 °F	69.7 °F	21.0 °C	70.8 %	71.3 %	71.2 °F	70.5 °F	21.4 °C
42	08/24/11 02:50:00 PM	77.5 °F	25.3 °C	71.0 °F	69.8 °F	21.0 °C	71.3 %	71.8 %	71.2 °F	70.5 °F	21.4 °C
43	08/24/11 03:00:00 PM	78.0 °F	25.6 °C	71.1 °F	69.9 °F	21.0 °C	71.9 %	72.4 %	71.4 °F	70.7 °F	21.5 °C
44	08/24/11 03:10:00 PM	78.5 °F	25.8 °C	71.1 °F	69.9 °F	21.1 °C	72.0 %	72.5 %	71.4 °F	70.7 °F	21.5 °C
45	08/24/11 03:20:00 PM	75.0 °F	23.9 °C	71.2 °F	70.0 °F	21.1 °C	71.6 %	72.1 %	71.4 °F	70.7 °F	21.5 °C
46	08/24/11 03:30:00 PM	75.5 °F	24.2 °C	71.2 °F	70.0 °F	21.1 °C	71.5 %	72.0 %	71.4 °F	70.7 °F	21.5 °C
47	08/24/11 03:40:00 PM	76.0 °F	24.4 °C	71.2 °F	70.0 °F	21.1 °C	71.1 %	71.6 %	71.3 °F	70.6 °F	21.4 °C
48	08/24/11 03:50:00 PM	76.5 °F	24.7 °C	71.2 °F	70.0 °F	21.1 °C	70.7 %	71.2 %	71.4 °F	70.7 °F	21.5 °C
49	08/24/11 04:00:00 PM	77.0 °F	25.0 °C	71.2 °F	70.0 °F	21.1 °C	70.5 %	71.0 %	71.3 °F	70.6 °F	21.4 °C
50	08/24/11 04:10:00 PM	77.5 °F	25.3 °C	71.1 °F	69.9 °F	21.0 °C	70.7 %	71.2 %	71.0 °F	70.3 °F	21.3 °C
51	08/24/11 04:20:00 PM	78.0 °F	25.6 °C	71.0 °F	69.8 °F	21.0 °C	70.7 %	71.2 %	71.1 °F	70.4 °F	21.3 °C
52	08/24/11 04:30:00 PM	78.5 °F	25.8 °C	71.1 °F	69.9 °F	21.0 °C	70.9 %	71.4 %	71.3 °F	70.6 °F	21.4 °C
53	08/24/11 04:35:00 PM	78.5 °F	25.8 °C	71.0 °F	69.8 °F	21.0 °C	70.7 %	71.2 %	71.0 °F	70.3 °F	21.3 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-6: Cyclic indoor set-point temperature mode of BHEUU Background Measurements at placement B (performed on 25th August 2011)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)*	Operative/ Globe Temperature (corrected)*	Operative/ Globe Temperature (corrected)*
1	08/25/11 08:00:00 AM	75.0 °F	23.9 °C	72.4 °F	71.2 °F	21.8 °C	68.8 %	69.3 %	72.1 °F	71.4 °F	21.9 °C
2	08/25/11 08:10:00 AM	75.5 °F	24.2 °C	72.3 °F	71.1 °F	21.7 °C	69.2 %	69.7 %	72.0 °F	71.3 °F	21.8 °C
3	08/25/11 08:20:00 AM	76.0 °F	24.4 °C	72.2 °F	71.0 °F	21.7 °C	69.0 %	69.5 %	71.9 °F	71.2 °F	21.8 °C
4	08/25/11 08:30:00 AM	76.5 °F	24.7 °C	72.1 °F	70.9 °F	21.6 °C	69.0 %	69.5 %	71.9 °F	71.2 °F	21.8 °C
5	08/25/11 08:40:00 AM	77.0 °F	25.0 °C	72.0 °F	70.8 °F	21.6 °C	68.9 %	69.4 %	71.8 °F	71.1 °F	21.7 °C
6	08/25/11 08:50:00 AM	77.5 °F	25.3 °C	71.9 °F	70.7 °F	21.5 °C	68.9 %	69.4 %	71.6 °F	70.9 °F	21.6 °C
7	08/25/11 09:00:00 AM	78.0 °F	25.6 °C	71.8 °F	70.6 °F	21.4 °C	69.0 %	69.5 %	71.6 °F	70.9 °F	21.6 °C
8	08/25/11 09:10:00 AM	78.5 °F	25.8 °C	71.7 °F	70.5 °F	21.4 °C	69.3 %	69.8 %	71.4 °F	70.7 °F	21.5 °C
9	08/25/11 09:20:00 AM	78.0 °F	25.6 °C	71.6 °F	70.4 °F	21.3 °C	69.4 %	69.9 %	71.4 °F	70.7 °F	21.5 °C
10	08/25/11 09:30:00 AM	77.5 °F	25.3 °C	71.5 °F	70.3 °F	21.3 °C	69.2 %	69.7 %	71.4 °F	70.7 °F	21.5 °C
11	08/25/11 09:40:00 AM	77.0 °F	25.0 °C	71.4 °F	70.2 °F	21.2 °C	69.2 %	69.7 %	71.3 °F	70.6 °F	21.5 °C
12	08/25/11 09:50:00 AM	76.5 °F	24.7 °C	71.4 °F	70.2 °F	21.2 °C	69.1 %	69.6 %	71.4 °F	70.7 °F	21.5 °C
13	08/25/11 10:00:00 AM	76.0 °F	24.4 °C	71.4 °F	70.2 °F	21.2 °C	69.2 %	69.7 %	71.4 °F	70.7 °F	21.5 °C
14	08/25/11 10:10:00 AM	75.5 °F	24.2 °C	71.4 °F	70.2 °F	21.2 °C	69.0 %	69.5 %	71.3 °F	70.6 °F	21.4 °C
15	08/25/11 10:20:00 AM	75.0 °F	23.9 °C	71.2 °F	70.0 °F	21.1 °C	69.2 %	69.7 %	71.1 °F	70.4 °F	21.3 °C
16	08/25/11 10:30:00 AM	75.5 °F	24.2 °C	71.1 °F	69.9 °F	21.1 °C	69.5 %	70.0 %	71.2 °F	70.5 °F	21.4 °C
17	08/25/11 10:40:00 AM	76.0 °F	24.4 °C	71.1 °F	69.9 °F	21.0 °C	69.5 %	70.0 %	71.0 °F	70.3 °F	21.3 °C
18	08/25/11 10:50:00 AM	76.5 °F	24.7 °C	71.0 °F	69.8 °F	21.0 °C	69.6 %	70.1 %	70.8 °F	70.1 °F	21.2 °C
19	08/25/11 11:00:00 AM	77.0 °F	25.0 °C	70.9 °F	69.7 °F	21.0 °C	69.7 %	70.2 %	70.9 °F	70.2 °F	21.2 °C
20	08/25/11 11:10:00 AM	77.5 °F	25.3 °C	70.9 °F	69.7 °F	20.9 °C	69.8 %	70.3 %	70.8 °F	70.1 °F	21.2 °C
21	08/25/11 11:20:00 AM	78.0 °F	25.6 °C	70.9 °F	69.7 °F	20.9 °C	69.8 %	70.3 %	70.9 °F	70.2 °F	21.2 °C
22	08/25/11 11:30:00 AM	78.5 °F	25.8 °C	70.9 °F	69.7 °F	20.9 °C	69.9 %	70.4 %	70.9 °F	70.2 °F	21.2 °C
23	08/25/11 11:40:00 AM	78.0 °F	25.6 °C	70.8 °F	69.6 °F	20.9 °C	70.0 %	70.5 %	70.8 °F	70.1 °F	21.2 °C
24	08/25/11 11:50:00 AM	77.5 °F	25.3 °C	70.8 °F	69.6 °F	20.9 °C	69.9 %	70.4 %	70.9 °F	70.2 °F	21.2 °C
25	08/25/11 12:00:00 PM	77.0 °F	25.0 °C	70.8 °F	69.6 °F	20.9 °C	69.7 %	70.2 %	70.8 °F	70.1 °F	21.2 °C
26	08/25/11 12:10:00 PM	76.5 °F	24.7 °C	70.8 °F	69.6 °F	20.9 °C	69.8 %	70.3 %	71.0 °F	70.3 °F	21.3 °C
27	08/25/11 12:20:00 PM	76.0 °F	24.4 °C	70.8 °F	69.6 °F	20.9 °C	69.9 %	70.4 %	70.9 °F	70.2 °F	21.2 °C
28	08/25/11 12:30:00 PM	75.5 °F	24.2 °C	70.9 °F	69.7 °F	20.9 °C	69.7 %	70.2 %	71.1 °F	70.4 °F	21.3 °C
29	08/25/11 12:40:00 PM	75.0 °F	23.9 °C	70.8 °F	69.6 °F	20.9 °C	69.6 %	70.1 %	70.8 °F	70.1 °F	21.2 °C
30	08/25/11 12:50:00 PM	75.5 °F	24.2 °C	70.7 °F	69.5 °F	20.8 °C	69.8 %	70.3 %	70.7 °F	70.0 °F	21.1 °C
31	08/25/11 01:00:00 PM	75.0 °F	23.9 °C	70.7 °F	69.5 °F	20.8 °C	70.3 %	70.8 %	70.7 °F	70.0 °F	21.1 °C
32	08/25/11 01:10:00 PM	75.0 °F	23.9 °C	70.7 °F	69.5 °F	20.8 °C	71.4 %	71.9 %	70.8 °F	70.1 °F	21.2 °C
33	08/25/11 01:20:00 PM	75.0 °F	23.9 °C	70.6 °F	69.4 °F	20.8 °C	71.3 %	71.8 %	70.7 °F	70.0 °F	21.1 °C
34	08/25/11 01:30:00 PM	75.0 °F	23.9 °C	70.6 °F	69.4 °F	20.8 °C	71.4 %	71.9 %	70.7 °F	70.0 °F	21.1 °C
35	08/25/11 01:40:00 PM	75.0 °F	23.9 °C	70.6 °F	69.4 °F	20.8 °C	71.4 %	71.9 %	70.8 °F	70.1 °F	21.1 °C
36	08/25/11 01:50:00 PM	75.0 °F	23.9 °C	70.6 °F	69.4 °F	20.8 °C	70.9 %	71.4 %	70.7 °F	70.0 °F	21.1 °C
37	08/25/11 02:00:00 PM	75.0 °F	23.9 °C	70.6 °F	69.4 °F	20.8 °C	70.5 %	71.0 %	70.9 °F	70.2 °F	21.2 °C
38	08/25/11 02:10:00 PM	75.5 °F	24.2 °C	70.7 °F	69.5 °F	20.8 °C	70.3 %	70.8 %	71.1 °F	70.4 °F	21.3 °C
39	08/25/11 02:20:00 PM	76.0 °F	24.4 °C	70.9 °F	69.7 °F	20.9 °C	70.1 %	70.6 %	71.2 °F	70.5 °F	21.4 °C
40	08/25/11 02:30:00 PM	76.5 °F	24.7 °C	71.0 °F	69.8 °F	21.0 °C	70.1 %	70.6 %	71.4 °F	70.7 °F	21.5 °C
41	08/25/11 02:40:00 PM	77.0 °F	25.0 °C	71.1 °F	69.9 °F	21.0 °C	70.1 %	70.6 %	71.4 °F	70.7 °F	21.5 °C
42	08/25/11 02:50:00 PM	77.5 °F	25.3 °C	71.2 °F	70.0 °F	21.1 °C	70.4 %	70.9 %	71.6 °F	70.9 °F	21.6 °C
43	08/25/11 03:00:00 PM	78.0 °F	25.6 °C	71.3 °F	70.1 °F	21.2 °C	70.2 %	70.7 %	71.6 °F	70.9 °F	21.6 °C
44	08/25/11 03:10:00 PM	78.5 °F	25.8 °C	71.3 °F	70.1 °F	21.2 °C	69.9 %	70.4 %	71.5 °F	70.8 °F	21.6 °C
45	08/25/11 03:20:00 PM	78.0 °F	25.6 °C	71.3 °F	70.1 °F	21.2 °C	69.7 %	70.2 %	71.5 °F	70.8 °F	21.6 °C
46	08/25/11 03:30:00 PM	77.5 °F	25.3 °C	71.2 °F	70.0 °F	21.1 °C	69.8 %	70.3 %	71.4 °F	70.7 °F	21.5 °C
47	08/25/11 03:40:00 PM	77.0 °F	25.0 °C	71.3 °F	70.1 °F	21.2 °C	69.9 %	70.4 %	71.5 °F	70.8 °F	21.6 °C
48	08/25/11 03:50:00 PM	76.5 °F	24.7 °C	71.3 °F	70.1 °F	21.2 °C	69.8 %	70.3 %	71.5 °F	70.8 °F	21.6 °C
49	08/25/11 04:00:00 PM	76.0 °F	24.4 °C	71.3 °F	70.1 °F	21.2 °C	69.7 %	70.2 %	71.4 °F	70.7 °F	21.5 °C
50	08/25/11 04:10:00 PM	75.5 °F	24.2 °C	71.3 °F	70.1 °F	21.2 °C	69.6 %	70.1 %	71.5 °F	70.8 °F	21.6 °C
51	08/25/11 04:20:00 PM	75.0 °F	23.9 °C	71.3 °F	70.1 °F	21.2 °C	69.6 %	70.1 %	71.5 °F	70.8 °F	21.6 °C
52	08/25/11 04:30:00 PM	75.5 °F	24.2 °C	71.4 °F	70.2 °F	21.2 °C	69.8 %	70.3 %	71.6 °F	70.9 °F	21.6 °C
53	08/25/11 04:35:00 PM	75.5 °F	24.2 °C	71.4 °F	70.2 °F	21.2 °C	70.4 %	70.9 %	71.4 °F	70.7 °F	21.5 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-7: Constant indoor set-point temperature mode of BHEUU Background Measurements at placement C (performed on 23rd August 2011)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)	Operative/ Globe Temperature (corrected)	Operative/ Globe Temperature (corrected)
1	08/23/11 08:00:00 AM	75.0 °F	23.9 °C	73.6 °F	72.3 °F	22.4 °C	64.8 %	66.3 %	71.3 °F	71.0 °F	21.7 °C
2	08/23/11 08:10:00 AM	75.0 °F	23.9 °C	73.2 °F	71.9 °F	22.2 °C	65.3 %	66.8 %	71.2 °F	70.9 °F	21.6 °C
3	08/23/11 08:20:00 AM	75.0 °F	23.9 °C	73.2 °F	71.9 °F	22.2 °C	65.6 %	67.1 %	71.9 °F	71.6 °F	22.0 °C
4	08/23/11 08:30:00 AM	75.0 °F	23.9 °C	73.2 °F	71.9 °F	22.2 °C	65.6 %	67.1 %	71.9 °F	71.6 °F	22.0 °C
5	08/23/11 08:40:00 AM	75.0 °F	23.9 °C	73.2 °F	71.9 °F	22.2 °C	65.5 %	67.0 %	71.9 °F	71.6 °F	22.0 °C
6	08/23/11 08:50:00 AM	75.0 °F	23.9 °C	73.0 °F	71.7 °F	22.1 °C	65.7 %	67.2 %	71.7 °F	71.4 °F	21.9 °C
7	08/23/11 09:00:00 AM	75.0 °F	23.9 °C	72.9 °F	71.6 °F	22.0 °C	65.4 %	66.9 %	71.5 °F	71.2 °F	21.8 °C
8	08/23/11 09:10:00 AM	75.0 °F	23.9 °C	72.7 °F	71.4 °F	21.9 °C	65.5 %	67.0 %	71.4 °F	71.1 °F	21.7 °C
9	08/23/11 09:20:00 AM	75.0 °F	23.9 °C	72.6 °F	71.3 °F	21.8 °C	65.7 %	67.2 %	71.1 °F	70.8 °F	21.6 °C
10	08/23/11 09:30:00 AM	75.0 °F	23.9 °C	72.4 °F	71.1 °F	21.7 °C	65.8 %	67.3 %	71.1 °F	70.8 °F	21.5 °C
11	08/23/11 09:40:00 AM	75.0 °F	23.9 °C	72.3 °F	71.0 °F	21.6 °C	65.6 %	67.1 %	70.9 °F	70.6 °F	21.4 °C
12	08/23/11 09:50:00 AM	75.0 °F	23.9 °C	72.1 °F	70.8 °F	21.6 °C	65.6 %	67.1 %	70.8 °F	70.5 °F	21.4 °C
13	08/23/11 10:00:00 AM	75.0 °F	23.9 °C	72.1 °F	70.8 °F	21.5 °C	65.8 %	67.3 %	70.7 °F	70.4 °F	21.3 °C
14	08/23/11 10:10:00 AM	75.0 °F	23.9 °C	71.9 °F	70.6 °F	21.5 °C	66.2 %	67.7 %	70.7 °F	70.4 °F	21.3 °C
15	08/23/11 10:20:00 AM	75.0 °F	23.9 °C	71.8 °F	70.5 °F	21.4 °C	66.5 %	68.0 %	70.6 °F	70.3 °F	21.3 °C
16	08/23/11 10:30:00 AM	75.0 °F	23.9 °C	71.7 °F	70.4 °F	21.4 °C	66.2 %	67.7 %	70.6 °F	70.3 °F	21.3 °C
17	08/23/11 10:40:00 AM	75.0 °F	23.9 °C	71.7 °F	70.4 °F	21.3 °C	66.4 %	67.9 %	70.5 °F	70.2 °F	21.2 °C
18	08/23/11 10:50:00 AM	75.0 °F	23.9 °C	71.6 °F	70.3 °F	21.3 °C	66.5 %	68.0 %	70.4 °F	70.1 °F	21.2 °C
19	08/23/11 11:00:00 AM	75.0 °F	23.9 °C	71.6 °F	70.3 °F	21.3 °C	66.7 %	68.2 %	70.4 °F	70.1 °F	21.2 °C
20	08/23/11 11:10:00 AM	75.0 °F	23.9 °C	71.6 °F	70.3 °F	21.3 °C	66.7 %	68.2 %	70.4 °F	70.1 °F	21.2 °C
21	08/23/11 11:20:00 AM	75.0 °F	23.9 °C	71.5 °F	70.2 °F	21.2 °C	66.6 %	68.1 %	70.5 °F	70.2 °F	21.2 °C
22	08/23/11 11:30:00 AM	75.0 °F	23.9 °C	71.5 °F	70.2 °F	21.2 °C	66.7 %	68.2 %	70.5 °F	70.2 °F	21.2 °C
23	08/23/11 11:40:00 AM	75.0 °F	23.9 °C	71.5 °F	70.2 °F	21.2 °C	66.9 %	68.4 %	70.4 °F	70.1 °F	21.2 °C
24	08/23/11 11:50:00 AM	75.0 °F	23.9 °C	71.4 °F	70.1 °F	21.2 °C	66.7 %	68.2 %	70.4 °F	70.1 °F	21.2 °C
25	08/23/11 12:00:00 PM	75.0 °F	23.9 °C	71.4 °F	70.1 °F	21.2 °C	66.4 %	67.9 %	70.4 °F	70.1 °F	21.2 °C
26	08/23/11 12:10:00 PM	75.0 °F	23.9 °C	71.4 °F	70.1 °F	21.2 °C	66.7 %	68.2 %	70.4 °F	70.1 °F	21.2 °C
27	08/23/11 12:20:00 PM	75.0 °F	23.9 °C	71.4 °F	70.1 °F	21.1 °C	66.6 %	68.1 %	70.3 °F	70.0 °F	21.1 °C
28	08/23/11 12:30:00 PM	75.0 °F	23.9 °C	71.4 °F	70.1 °F	21.1 °C	66.7 %	68.2 %	70.4 °F	70.1 °F	21.2 °C
29	08/23/11 12:40:00 PM	75.0 °F	23.9 °C	71.4 °F	70.1 °F	21.1 °C	66.8 %	68.3 %	70.3 °F	70.0 °F	21.1 °C
30	08/23/11 12:50:00 PM	75.0 °F	23.9 °C	71.3 °F	70.0 °F	21.1 °C	66.7 %	68.2 %	70.3 °F	70.0 °F	21.1 °C
31	08/23/11 01:00:00 PM	75.0 °F	23.9 °C	71.2 °F	69.9 °F	21.1 °C	66.6 %	68.1 %	69.9 °F	69.6 °F	20.9 °C
32	08/23/11 01:10:00 PM	75.0 °F	23.9 °C	71.0 °F	69.7 °F	21.0 °C	66.6 %	68.1 %	69.8 °F	69.5 °F	20.8 °C
33	08/23/11 01:20:00 PM	75.0 °F	23.9 °C	71.0 °F	69.7 °F	20.9 °C	66.6 %	68.1 %	69.8 °F	69.5 °F	20.8 °C
34	08/23/11 01:30:00 PM	75.0 °F	23.9 °C	70.9 °F	69.6 °F	20.9 °C	67.3 %	68.8 %	69.8 °F	69.5 °F	20.8 °C
35	08/23/11 01:40:00 PM	75.0 °F	23.9 °C	71.0 °F	69.7 °F	21.0 °C	67.2 %	68.7 %	70.0 °F	69.7 °F	20.9 °C
36	08/23/11 01:50:00 PM	75.0 °F	23.9 °C	71.0 °F	69.7 °F	21.0 °C	67.4 %	68.9 %	69.7 °F	69.4 °F	20.8 °C
37	08/23/11 02:00:00 PM	75.0 °F	23.9 °C	71.0 °F	69.7 °F	20.9 °C	67.3 %	68.8 %	69.8 °F	69.5 °F	20.8 °C
38	08/23/11 02:10:00 PM	75.0 °F	23.9 °C	71.2 °F	69.9 °F	21.1 °C	67.2 %	68.7 %	70.6 °F	70.3 °F	21.3 °C
39	08/23/11 02:20:00 PM	75.0 °F	23.9 °C	71.4 °F	70.1 °F	21.2 °C	67.0 %	68.5 %	70.9 °F	70.6 °F	21.4 °C
40	08/23/11 02:30:00 PM	75.0 °F	23.9 °C	71.7 °F	70.4 °F	21.3 °C	67.0 %	68.5 %	71.1 °F	70.8 °F	21.5 °C
41	08/23/11 02:40:00 PM	75.0 °F	23.9 °C	71.8 °F	70.5 °F	21.4 °C	66.7 %	68.2 %	71.2 °F	70.9 °F	21.6 °C
42	08/23/11 02:50:00 PM	75.0 °F	23.9 °C	72.0 °F	70.7 °F	21.5 °C	66.5 %	68.0 %	71.2 °F	70.9 °F	21.6 °C
43	08/23/11 03:00:00 PM	75.0 °F	23.9 °C	72.1 °F	70.8 °F	21.6 °C	66.2 %	67.7 %	71.4 °F	71.1 °F	21.7 °C
44	08/23/11 03:10:00 PM	75.0 °F	23.9 °C	72.4 °F	71.1 °F	21.7 °C	65.8 %	67.3 %	71.8 °F	71.5 °F	22.0 °C
45	08/23/11 03:20:00 PM	75.0 °F	23.9 °C	72.6 °F	71.3 °F	21.8 °C	65.3 %	66.8 %	72.0 °F	71.7 °F	22.1 °C
46	08/23/11 03:30:00 PM	75.0 °F	23.9 °C	72.8 °F	71.5 °F	21.9 °C	65.0 %	66.5 %	72.1 °F	71.8 °F	22.1 °C
47	08/23/11 03:40:00 PM	75.0 °F	23.9 °C	73.0 °F	71.7 °F	22.1 °C	64.8 %	66.3 %	72.4 °F	72.1 °F	22.3 °C
48	08/23/11 03:50:00 PM	75.0 °F	23.9 °C	73.2 °F	71.9 °F	22.2 °C	64.9 %	66.4 %	72.6 °F	72.3 °F	22.4 °C
49	08/23/11 04:00:00 PM	75.0 °F	23.9 °C	73.4 °F	72.1 °F	22.3 °C	64.3 %	65.8 %	72.8 °F	72.5 °F	22.5 °C
50	08/23/11 04:10:00 PM	75.0 °F	23.9 °C	73.6 °F	72.3 °F	22.4 °C	63.8 %	65.3 %	72.9 °F	72.6 °F	22.5 °C
51	08/23/11 04:20:00 PM	75.0 °F	23.9 °C	73.7 °F	72.4 °F	22.5 °C	63.2 %	64.7 %	73.1 °F	72.8 °F	22.7 °C
52	08/23/11 04:30:00 PM	75.0 °F	23.9 °C	73.9 °F	72.6 °F	22.6 °C	63.1 %	64.6 %	73.2 °F	72.9 °F	22.7 °C
53	08/23/11 04:35:00 PM	75.0 °F	23.9 °C	74.0 °F	72.7 °F	22.6 °C	63.2 %	64.7 %	73.3 °F	73.0 °F	22.8 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-8: Ramp indoor set-point temperature mode of BHEUU Background Measurements at placement C (performed on 24th August 2011)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)	Operative/ Globe Temperature (corrected)	Operative/ Globe Temperature (corrected)
1	08/24/11 08:00:00 AM	75.0 °F	23.9 °C	73.8 °F	72.5 °F	22.5 °C	63.6 %	65.1 %	72.0 °F	71.7 °F	22.0 °C
2	08/24/11 08:10:00 AM	75.5 °F	24.2 °C	73.6 °F	72.3 °F	22.4 °C	63.8 %	65.3 %	71.9 °F	71.6 °F	22.0 °C
3	08/24/11 08:20:00 AM	76.0 °F	24.4 °C	73.3 °F	72.0 °F	22.2 °C	64.2 %	65.7 %	71.8 °F	71.5 °F	21.9 °C
4	08/24/11 08:30:00 AM	76.5 °F	24.7 °C	73.2 °F	71.9 °F	22.2 °C	64.7 %	66.2 %	71.7 °F	71.4 °F	21.9 °C
5	08/24/11 08:40:00 AM	77.0 °F	25.0 °C	72.9 °F	71.6 °F	22.0 °C	64.9 %	66.4 %	71.4 °F	71.1 °F	21.7 °C
6	08/24/11 08:50:00 AM	77.5 °F	25.3 °C	72.8 °F	71.5 °F	21.9 °C	65.0 %	66.5 %	71.4 °F	71.1 °F	21.7 °C
7	08/24/11 09:00:00 AM	78.0 °F	25.6 °C	72.8 °F	71.5 °F	21.9 °C	65.1 %	66.6 %	71.4 °F	71.1 °F	21.7 °C
8	08/24/11 09:10:00 AM	78.5 °F	25.8 °C	72.7 °F	71.4 °F	21.9 °C	65.3 %	66.8 %	71.4 °F	71.1 °F	21.7 °C
9	08/24/11 09:20:00 AM	75.0 °F	23.9 °C	72.7 °F	71.4 °F	21.9 °C	65.2 %	66.7 %	71.4 °F	71.1 °F	21.7 °C
10	08/24/11 09:30:00 AM	75.5 °F	24.2 °C	72.6 °F	71.3 °F	21.8 °C	65.1 %	66.6 %	71.4 °F	71.1 °F	21.7 °C
11	08/24/11 09:40:00 AM	76.0 °F	24.4 °C	72.6 °F	71.3 °F	21.8 °C	65.2 %	66.7 %	71.4 °F	71.1 °F	21.7 °C
12	08/24/11 09:50:00 AM	76.5 °F	24.7 °C	72.6 °F	71.3 °F	21.8 °C	65.5 %	67.0 %	71.4 °F	71.1 °F	21.7 °C
13	08/24/11 10:00:00 AM	77.0 °F	25.0 °C	72.6 °F	71.3 °F	21.8 °C	65.4 %	66.9 %	71.4 °F	71.1 °F	21.7 °C
14	08/24/11 10:10:00 AM	77.5 °F	25.3 °C	72.5 °F	71.2 °F	21.8 °C	65.3 %	66.8 %	71.4 °F	71.1 °F	21.7 °C
15	08/24/11 10:20:00 AM	78.0 °F	25.6 °C	72.5 °F	71.2 °F	21.8 °C	65.1 %	66.6 %	71.3 °F	71.0 °F	21.7 °C
16	08/24/11 10:30:00 AM	78.5 °F	25.8 °C	72.4 °F	71.1 °F	21.7 °C	65.2 %	66.7 %	71.3 °F	71.0 °F	21.7 °C
17	08/24/11 10:40:00 AM	75.0 °F	23.9 °C	72.4 °F	71.1 °F	21.7 °C	65.5 %	67.0 %	71.4 °F	71.1 °F	21.7 °C
18	08/24/11 10:50:00 AM	75.5 °F	24.2 °C	72.5 °F	71.2 °F	21.8 °C	65.2 %	66.7 %	71.4 °F	71.1 °F	21.7 °C
19	08/24/11 11:00:00 AM	76.0 °F	24.4 °C	72.5 °F	71.2 °F	21.8 °C	65.2 %	66.7 %	71.4 °F	71.1 °F	21.7 °C
20	08/24/11 11:10:00 AM	76.5 °F	24.7 °C	72.5 °F	71.2 °F	21.8 °C	65.2 %	66.7 %	71.4 °F	71.1 °F	21.7 °C
21	08/24/11 11:20:00 AM	77.0 °F	25.0 °C	72.5 °F	71.2 °F	21.8 °C	65.5 %	67.0 %	71.4 °F	71.1 °F	21.7 °C
22	08/24/11 11:30:00 AM	77.5 °F	25.3 °C	72.5 °F	71.2 °F	21.8 °C	65.3 %	66.8 %	71.4 °F	71.1 °F	21.7 °C
23	08/24/11 11:40:00 AM	78.0 °F	25.6 °C	72.5 °F	71.2 °F	21.8 °C	65.1 %	66.6 %	71.5 °F	71.2 °F	21.8 °C
24	08/24/11 11:50:00 AM	78.5 °F	25.8 °C	72.5 °F	71.2 °F	21.8 °C	65.2 %	66.7 %	71.4 °F	71.1 °F	21.7 °C
25	08/24/11 12:00:00 PM	75.0 °F	23.9 °C	72.6 °F	71.3 °F	21.8 °C	65.3 %	66.8 %	71.6 °F	71.3 °F	21.8 °C
26	08/24/11 12:10:00 PM	75.5 °F	24.2 °C	72.6 °F	71.3 °F	21.8 °C	65.3 %	66.8 %	71.6 °F	71.3 °F	21.8 °C
27	08/24/11 12:20:00 PM	76.0 °F	24.4 °C	72.6 °F	71.3 °F	21.8 °C	65.2 %	66.7 %	71.5 °F	71.2 °F	21.8 °C
28	08/24/11 12:30:00 PM	76.5 °F	24.7 °C	72.4 °F	71.1 °F	21.7 °C	65.2 %	66.7 %	71.0 °F	70.7 °F	21.5 °C
29	08/24/11 12:40:00 PM	77.0 °F	25.0 °C	72.3 °F	71.0 °F	21.6 °C	65.3 %	66.8 %	71.0 °F	70.7 °F	21.5 °C
30	08/24/11 12:50:00 PM	77.5 °F	25.3 °C	72.4 °F	71.1 °F	21.7 °C	65.5 %	67.0 %	71.7 °F	71.4 °F	21.9 °C
31	08/24/11 01:00:00 PM	75.0 °F	23.9 °C	72.5 °F	71.2 °F	21.8 °C	65.7 %	67.2 %	71.4 °F	71.1 °F	21.7 °C
32	08/24/11 01:10:00 PM	75.0 °F	23.9 °C	72.4 °F	71.1 °F	21.7 °C	65.6 %	67.1 %	71.3 °F	71.0 °F	21.7 °C
33	08/24/11 01:20:00 PM	75.0 °F	23.9 °C	72.3 °F	71.0 °F	21.7 °C	65.9 %	67.4 %	71.1 °F	70.8 °F	21.6 °C
34	08/24/11 01:30:00 PM	75.0 °F	23.9 °C	72.2 °F	70.9 °F	21.6 °C	66.4 %	67.9 %	70.8 °F	70.5 °F	21.4 °C
35	08/24/11 01:40:00 PM	75.0 °F	23.9 °C	72.1 °F	70.8 °F	21.5 °C	66.3 %	67.8 %	70.8 °F	70.5 °F	21.4 °C
36	08/24/11 01:50:00 PM	75.0 °F	23.9 °C	71.9 °F	70.6 °F	21.5 °C	66.7 %	68.2 %	70.5 °F	70.2 °F	21.2 °C
37	08/24/11 02:00:00 PM	75.0 °F	23.9 °C	71.7 °F	70.4 °F	21.4 °C	66.7 %	68.2 %	70.4 °F	70.1 °F	21.2 °C
38	08/24/11 02:10:00 PM	75.5 °F	24.2 °C	71.7 °F	70.4 °F	21.3 °C	66.7 %	68.2 %	70.3 °F	70.0 °F	21.1 °C
39	08/24/11 02:20:00 PM	76.0 °F	24.4 °C	71.6 °F	70.3 °F	21.3 °C	66.7 %	68.2 %	70.2 °F	69.9 °F	21.1 °C
40	08/24/11 02:30:00 PM	76.5 °F	24.7 °C	71.7 °F	70.4 °F	21.4 °C	67.5 %	69.0 %	71.1 °F	70.8 °F	21.5 °C
41	08/24/11 02:40:00 PM	77.0 °F	25.0 °C	72.0 °F	70.7 °F	21.5 °C	67.7 %	69.2 %	70.9 °F	70.6 °F	21.4 °C
42	08/24/11 02:50:00 PM	77.5 °F	25.3 °C	71.8 °F	70.5 °F	21.4 °C	68.3 %	69.8 %	70.7 °F	70.4 °F	21.3 °C
43	08/24/11 03:00:00 PM	78.0 °F	25.6 °C	71.7 °F	70.4 °F	21.3 °C	70.4 %	71.9 %	70.5 °F	70.2 °F	21.2 °C
44	08/24/11 03:10:00 PM	78.5 °F	25.8 °C	71.8 °F	70.5 °F	21.4 °C	70.0 %	71.5 %	71.1 °F	70.8 °F	21.6 °C
45	08/24/11 03:20:00 PM	75.0 °F	23.9 °C	72.1 °F	70.8 °F	21.5 °C	69.4 %	70.9 %	71.3 °F	71.0 °F	21.7 °C
46	08/24/11 03:30:00 PM	75.5 °F	24.2 °C	72.3 °F	71.0 °F	21.6 °C	69.3 %	70.8 %	71.6 °F	71.3 °F	21.8 °C
47	08/24/11 03:40:00 PM	76.0 °F	24.4 °C	72.4 °F	71.1 °F	21.7 °C	68.8 %	70.3 %	71.4 °F	71.1 °F	21.7 °C
48	08/24/11 03:50:00 PM	76.5 °F	24.7 °C	72.4 °F	71.1 °F	21.7 °C	68.4 %	69.9 %	71.4 °F	71.1 °F	21.7 °C
49	08/24/11 04:00:00 PM	77.0 °F	25.0 °C	72.3 °F	71.0 °F	21.7 °C	67.5 %	69.0 %	70.9 °F	70.6 °F	21.4 °C
50	08/24/11 04:10:00 PM	77.5 °F	25.3 °C	72.1 °F	70.8 °F	21.6 °C	68.2 %	69.7 %	71.2 °F	70.9 °F	21.6 °C
51	08/24/11 04:20:00 PM	78.0 °F	25.6 °C	72.3 °F	71.0 °F	21.6 °C	68.0 %	69.5 %	71.3 °F	71.0 °F	21.7 °C
52	08/24/11 04:30:00 PM	78.5 °F	25.8 °C	72.3 °F	71.0 °F	21.6 °C	68.1 %	69.6 %	71.3 °F	71.0 °F	21.7 °C
53	08/24/11 04:35:00 PM	78.5 °F	25.8 °C	72.3 °F	71.0 °F	21.6 °C	67.9 %	69.4 %	71.2 °F	70.9 °F	21.6 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-9: Cyclic indoor set-point temperature mode of BHEUU Background Measurements at placement C (performed on 25th August 2011)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Operative/ Globe Temperature (raw)	Operative/ Globe Temperature (corrected)	Operative/ Globe Temperature (corrected)
1	08/25/11 08:00:00 AM	75.0 °F	23.9 °C	71.9 °F	70.6 °F	21.5 °C	66.3 %	67.8 %	70.0 °F	69.7 °F	21.0 °C
2	08/25/11 08:10:00 AM	75.5 °F	24.2 °C	71.7 °F	70.4 °F	21.4 °C	66.8 %	68.3 %	70.0 °F	69.7 °F	21.0 °C
3	08/25/11 08:20:00 AM	76.0 °F	24.4 °C	71.4 °F	70.1 °F	21.2 °C	67.2 %	68.7 %	69.6 °F	69.3 °F	20.7 °C
4	08/25/11 08:30:00 AM	76.5 °F	24.7 °C	71.3 °F	70.0 °F	21.1 °C	67.7 %	69.2 %	69.8 °F	69.5 °F	20.8 °C
5	08/25/11 08:40:00 AM	77.0 °F	25.0 °C	71.2 °F	69.9 °F	21.1 °C	67.9 %	69.4 %	69.7 °F	69.4 °F	20.8 °C
6	08/25/11 08:50:00 AM	77.5 °F	25.3 °C	71.1 °F	69.8 °F	21.0 °C	67.7 %	69.2 %	69.7 °F	69.4 °F	20.8 °C
7	08/25/11 09:00:00 AM	78.0 °F	25.6 °C	71.0 °F	69.7 °F	21.0 °C	67.7 %	69.2 %	69.7 °F	69.4 °F	20.8 °C
8	08/25/11 09:10:00 AM	78.5 °F	25.8 °C	71.0 °F	69.7 °F	21.0 °C	68.3 %	69.8 %	69.8 °F	69.5 °F	20.8 °C
9	08/25/11 09:20:00 AM	78.0 °F	25.6 °C	71.0 °F	69.7 °F	20.9 °C	68.8 %	70.3 %	69.7 °F	69.4 °F	20.8 °C
10	08/25/11 09:30:00 AM	77.5 °F	25.3 °C	70.9 °F	69.6 °F	20.9 °C	68.2 %	69.7 %	69.7 °F	69.4 °F	20.8 °C
11	08/25/11 09:40:00 AM	77.0 °F	25.0 °C	70.9 °F	69.6 °F	20.9 °C	68.0 %	69.5 %	69.7 °F	69.4 °F	20.8 °C
12	08/25/11 09:50:00 AM	76.5 °F	24.7 °C	70.8 °F	69.5 °F	20.9 °C	68.1 %	69.6 %	69.6 °F	69.3 °F	20.7 °C
13	08/25/11 10:00:00 AM	76.0 °F	24.4 °C	70.8 °F	69.5 °F	20.8 °C	68.2 %	69.7 %	69.6 °F	69.3 °F	20.7 °C
14	08/25/11 10:10:00 AM	75.5 °F	24.2 °C	70.8 °F	69.5 °F	20.8 °C	68.2 %	69.7 %	69.6 °F	69.3 °F	20.7 °C
15	08/25/11 10:20:00 AM	75.0 °F	23.9 °C	70.9 °F	69.6 °F	20.9 °C	68.2 %	69.7 %	69.8 °F	69.5 °F	20.8 °C
16	08/25/11 10:30:00 AM	75.5 °F	24.2 °C	71.0 °F	69.7 °F	21.0 °C	68.4 %	69.9 %	70.3 °F	70.0 °F	21.1 °C
17	08/25/11 10:40:00 AM	76.0 °F	24.4 °C	71.2 °F	69.9 °F	21.1 °C	68.2 %	69.7 %	70.4 °F	70.1 °F	21.2 °C
18	08/25/11 10:50:00 AM	76.5 °F	24.7 °C	71.3 °F	70.0 °F	21.1 °C	67.9 %	69.4 %	70.5 °F	70.2 °F	21.2 °C
19	08/25/11 11:00:00 AM	77.0 °F	25.0 °C	71.3 °F	70.0 °F	21.1 °C	67.3 %	68.8 %	70.4 °F	70.1 °F	21.2 °C
20	08/25/11 11:10:00 AM	77.5 °F	25.3 °C	71.4 °F	70.1 °F	21.1 °C	67.4 %	68.9 %	70.5 °F	70.2 °F	21.2 °C
21	08/25/11 11:20:00 AM	78.0 °F	25.6 °C	71.4 °F	70.1 °F	21.2 °C	67.4 %	68.9 %	70.6 °F	70.3 °F	21.3 °C
22	08/25/11 11:30:00 AM	78.5 °F	25.8 °C	71.5 °F	70.2 °F	21.2 °C	67.6 %	69.1 %	70.5 °F	70.2 °F	21.2 °C
23	08/25/11 11:40:00 AM	78.0 °F	25.6 °C	71.4 °F	70.1 °F	21.2 °C	67.7 %	69.2 %	70.5 °F	70.2 °F	21.2 °C
24	08/25/11 11:50:00 AM	77.5 °F	25.3 °C	71.5 °F	70.2 °F	21.2 °C	67.4 %	68.9 %	70.6 °F	70.3 °F	21.3 °C
25	08/25/11 12:00:00 PM	77.0 °F	25.0 °C	71.6 °F	70.3 °F	21.3 °C	67.0 %	68.5 %	70.7 °F	70.4 °F	21.3 °C
26	08/25/11 12:10:00 PM	76.5 °F	24.7 °C	71.6 °F	70.3 °F	21.3 °C	66.7 %	68.2 %	70.7 °F	70.4 °F	21.3 °C
27	08/25/11 12:20:00 PM	76.0 °F	24.4 °C	71.6 °F	70.3 °F	21.3 °C	66.7 %	68.2 %	70.7 °F	70.4 °F	21.3 °C
28	08/25/11 12:30:00 PM	75.5 °F	24.2 °C	71.7 °F	70.4 °F	21.3 °C	66.7 %	68.2 %	70.9 °F	70.6 °F	21.4 °C
29	08/25/11 12:40:00 PM	75.0 °F	23.9 °C	71.7 °F	70.4 °F	21.4 °C	66.8 %	68.3 %	70.8 °F	70.5 °F	21.4 °C
30	08/25/11 12:50:00 PM	75.5 °F	24.2 °C	71.7 °F	70.4 °F	21.4 °C	67.1 %	68.6 %	70.9 °F	70.6 °F	21.4 °C
31	08/25/11 01:00:00 PM	75.0 °F	23.9 °C	71.7 °F	70.4 °F	21.4 °C	68.2 %	69.7 %	70.8 °F	70.5 °F	21.4 °C
32	08/25/11 01:10:00 PM	75.0 °F	23.9 °C	71.7 °F	70.4 °F	21.4 °C	67.7 %	69.2 %	70.3 °F	70.0 °F	21.1 °C
33	08/25/11 01:20:00 PM	75.0 °F	23.9 °C	71.4 °F	70.1 °F	21.2 °C	67.3 %	68.8 %	70.0 °F	69.7 °F	20.9 °C
34	08/25/11 01:30:00 PM	75.0 °F	23.9 °C	71.3 °F	70.0 °F	21.1 °C	67.3 %	68.8 %	70.1 °F	69.8 °F	21.0 °C
35	08/25/11 01:40:00 PM	75.0 °F	23.9 °C	71.2 °F	69.9 °F	21.1 °C	68.0 %	69.5 %	70.0 °F	69.7 °F	20.9 °C
36	08/25/11 01:50:00 PM	75.0 °F	23.9 °C	71.1 °F	69.8 °F	21.0 °C	67.9 %	69.4 %	69.9 °F	69.6 °F	20.9 °C
37	08/25/11 02:00:00 PM	75.0 °F	23.9 °C	71.0 °F	69.7 °F	20.9 °C	67.7 %	69.2 %	69.9 °F	69.6 °F	20.9 °C
38	08/25/11 02:10:00 PM	75.5 °F	24.2 °C	70.9 °F	69.6 °F	20.9 °C	67.6 %	69.1 %	69.7 °F	69.4 °F	20.8 °C
39	08/25/11 02:20:00 PM	76.0 °F	24.4 °C	70.8 °F	69.5 °F	20.8 °C	67.8 %	69.3 %	69.6 °F	69.3 °F	20.7 °C
40	08/25/11 02:30:00 PM	76.5 °F	24.7 °C	70.8 °F	69.5 °F	20.8 °C	67.9 %	69.4 %	69.8 °F	69.5 °F	20.8 °C
41	08/25/11 02:40:00 PM	77.0 °F	25.0 °C	70.8 °F	69.5 °F	20.9 °C	68.0 %	69.5 %	69.9 °F	69.6 °F	20.9 °C
42	08/25/11 02:50:00 PM	77.5 °F	25.3 °C	70.8 °F	69.5 °F	20.9 °C	68.6 %	70.1 %	69.9 °F	69.6 °F	20.9 °C
43	08/25/11 03:00:00 PM	78.0 °F	25.6 °C	70.9 °F	69.6 °F	20.9 °C	68.4 %	69.9 %	70.0 °F	69.7 °F	20.9 °C
44	08/25/11 03:10:00 PM	78.5 °F	25.8 °C	70.9 °F	69.6 °F	20.9 °C	67.9 %	69.4 %	69.9 °F	69.6 °F	20.9 °C
45	08/25/11 03:20:00 PM	78.0 °F	25.6 °C	70.9 °F	69.6 °F	20.9 °C	67.7 %	69.2 %	70.0 °F	69.7 °F	20.9 °C
46	08/25/11 03:30:00 PM	77.5 °F	25.3 °C	71.1 °F	69.8 °F	21.0 °C	68.0 %	69.5 %	70.5 °F	70.2 °F	21.2 °C
47	08/25/11 03:40:00 PM	77.0 °F	25.0 °C	71.3 °F	70.0 °F	21.1 °C	67.9 %	69.4 %	70.6 °F	70.3 °F	21.3 °C
48	08/25/11 03:50:00 PM	76.5 °F	24.7 °C	71.4 °F	70.1 °F	21.2 °C	67.6 %	69.1 %	70.8 °F	70.5 °F	21.4 °C
49	08/25/11 04:00:00 PM	76.0 °F	24.4 °C	71.7 °F	70.4 °F	21.3 °C	67.6 %	69.1 %	71.1 °F	70.8 °F	21.5 °C
50	08/25/11 04:10:00 PM	75.5 °F	24.2 °C	71.8 °F	70.5 °F	21.4 °C	67.1 %	68.6 %	71.2 °F	70.9 °F	21.6 °C
51	08/25/11 04:20:00 PM	75.0 °F	23.9 °C	72.0 °F	70.7 °F	21.5 °C	67.0 %	68.5 %	71.4 °F	71.1 °F	21.7 °C
52	08/25/11 04:30:00 PM	75.5 °F	24.2 °C	72.1 °F	70.8 °F	21.6 °C	67.0 %	68.5 %	71.4 °F	71.1 °F	21.7 °C
53	08/25/11 04:35:00 PM	75.5 °F	24.2 °C	72.1 °F	70.8 °F	21.6 °C	67.1 %	68.6 %	71.4 °F	71.1 °F	21.7 °C

*globe temperature is used as an approximation of the operative temperature

Table 6-10: Constant indoor set-point temperature mode of BHEUU Background Measurements at placement A (performed on 06th December 2011 as the repeated experiment)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Outside Temperature (raw)*	Outside Temperature (corrected)	Outside Relative Humidity (raw)	Outside Relative Humidity (corrected)
1	08:00 AM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	70.9 %	68.9 %	25.4 °C	25.1 °C	80.6 %	87.6 %
2	08:10 AM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	70.7 %	68.7 %	25.4 °C	25.1 °C	80.6 %	87.6 %
3	08:20 AM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	70.6 %	68.6 %	25.5 °C	25.2 °C	80.4 %	87.4 %
4	08:30 AM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	70.4 %	68.4 %	25.6 °C	25.3 °C	80.2 %	87.2 %
5	08:40 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	70.4 %	68.4 %	25.6 °C	25.3 °C	80.1 %	87.1 %
6	08:50 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	70.4 %	68.4 %	25.7 °C	25.4 °C	80.1 %	87.1 %
7	09:00 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	70.3 %	68.3 %	25.7 °C	25.4 °C	79.9 %	86.9 %
8	09:10 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	70.2 %	68.2 %	25.8 °C	25.5 °C	79.8 %	86.8 %
9	09:20 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	70.1 %	68.1 %	25.9 °C	25.6 °C	79.7 %	86.7 %
10	09:30 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	70.1 %	68.1 %	26.0 °C	25.7 °C	79.5 %	86.5 %
11	09:40 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.9 %	67.9 %	26.1 °C	25.8 °C	79.3 %	86.3 %
12	09:50 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	26.2 °C	25.9 °C	78.6 %	85.6 %
13	10:00 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	26.3 °C	26.0 °C	78.6 %	85.6 %
14	10:10 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	26.4 °C	26.1 °C	78.5 %	85.5 %
15	10:20 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	26.5 °C	26.2 °C	77.8 %	84.8 %
16	10:30 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	26.6 °C	26.3 °C	77.6 %	84.6 %
17	10:40 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	26.7 °C	26.4 °C	77.4 %	84.4 %
18	10:50 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	26.8 °C	26.5 °C	77.4 %	84.4 %
19	11:00 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	26.9 °C	26.6 °C	77.4 %	84.4 %
20	11:10 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	27.0 °C	26.7 °C	77.2 %	84.2 %
21	11:20 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	27.1 °C	26.8 °C	76.6 %	83.6 %
22	11:30 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	27.2 °C	26.9 °C	76.2 %	83.2 %
23	11:40 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.5 %	67.5 %	27.2 °C	26.9 °C	75.8 %	82.8 %
24	11:50 AM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	27.3 °C	27.0 °C	75.1 %	82.1 %
25	12:00 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	27.4 °C	27.1 °C	75.3 %	82.3 %
26	12:10 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	27.4 °C	27.1 °C	74.8 %	81.8 %
27	12:20 PM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	69.5 %	67.5 %	27.5 °C	27.2 °C	74.1 %	81.1 %
28	12:30 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	27.6 °C	27.3 °C	73.7 %	80.7 %
29	12:40 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.5 %	67.5 %	27.7 °C	27.4 °C	72.9 %	79.9 %
30	12:50 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	27.9 °C	27.6 °C	72.1 %	79.1 %
31	01:00 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.5 %	67.5 %	28.0 °C	27.7 °C	71.3 %	78.3 %
32	01:10 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.4 %	67.4 %	28.1 °C	27.8 °C	71.4 %	78.4 %
33	01:20 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.5 %	67.5 %	28.2 °C	27.9 °C	71.3 %	78.3 %
34	01:30 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.5 %	67.5 %	28.3 °C	28.0 °C	71.5 %	78.5 %
35	01:40 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.5 %	67.5 %	28.5 °C	28.2 °C	70.6 %	77.6 %
36	01:50 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	28.7 °C	28.4 °C	70.1 %	77.1 %
37	02:00 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	28.8 °C	28.5 °C	68.4 %	75.4 %
38	02:10 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.5 %	67.5 %	29.1 °C	28.8 °C	66.8 %	73.8 %
39	02:20 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	29.4 °C	29.1 °C	66.3 %	73.3 %
40	02:30 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	29.5 °C	29.2 °C	65.9 %	72.9 %
41	02:40 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.6 %	67.6 %	29.8 °C	29.5 °C	65.2 %	72.2 %
42	02:50 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	30.0 °C	29.7 °C	65.2 %	72.2 %
43	03:00 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	30.2 °C	29.9 °C	64.6 %	71.6 %
44	03:10 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	30.4 °C	30.1 °C	63.6 %	70.6 %
45	03:20 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	30.5 °C	30.2 °C	63.3 %	70.3 %
46	03:30 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	30.8 °C	30.5 °C	61.7 %	68.7 %
47	03:40 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.7 %	67.7 %	31.8 °C	31.5 °C	56.8 %	63.8 %
48	03:50 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	31.8 °C	31.5 °C	58.4 %	65.4 %
49	04:00 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.9 %	67.9 %	31.2 °C	30.9 °C	59.5 %	66.5 %
50	04:10 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.9 %	67.9 %	30.8 °C	30.5 °C	59.5 %	66.5 %
51	04:20 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	30.9 °C	30.6 °C	60.9 %	67.9 %
52	04:30 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.8 %	67.8 %	30.8 °C	30.5 °C	60.2 %	67.2 %
53	04:35 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	69.9 %	67.9 %	30.7 °C	30.4 °C	60.5 %	67.5 %

* outside air temperatures and relative humidity are obtained from Data Logger at placement B'

Table 6-11: Ramp indoor set-point temperature mode of BHEUU Background Measurements at placement A (performed on 07th December 2011 as the repeated experiment)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Outside Temperature (raw)*	Outside Temperature (corrected)	Outside Relative Humidity (raw)	Outside Relative Humidity (corrected)
1	08:00 AM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	72.3 %	70.3 %	25.9 °C	25.6 °C	80.3 %	87.3 %
2	08:10 AM	75.5 °F	24.2 °C	24.1 °C	24.1 °C	72.1 %	70.1 %	25.8 °C	25.5 °C	79.6 %	86.6 %
3	08:20 AM	76.0 °F	24.4 °C	24.1 °C	24.1 °C	72.1 %	70.1 %	25.8 °C	25.5 °C	79.1 %	86.1 %
4	08:30 AM	76.5 °F	24.7 °C	24.0 °C	24.0 °C	71.8 %	69.8 %	25.8 °C	25.5 °C	79.0 %	86.0 %
5	08:40 AM	77.0 °F	25.0 °C	24.0 °C	24.0 °C	71.8 %	69.8 %	25.9 °C	25.6 °C	79.1 %	86.1 %
6	08:50 AM	77.5 °F	25.3 °C	24.0 °C	24.0 °C	71.7 %	69.7 %	25.9 °C	25.6 °C	78.7 %	85.7 %
7	09:00 AM	78.0 °F	25.6 °C	24.0 °C	24.0 °C	71.6 %	69.6 %	26.1 °C	25.8 °C	79.2 %	86.2 %
8	09:10 AM	78.5 °F	25.8 °C	24.0 °C	24.0 °C	71.5 %	69.5 %	26.2 °C	25.9 °C	78.7 %	85.7 %
9	09:20 AM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	71.4 %	69.4 %	26.2 °C	25.9 °C	78.7 %	85.7 %
10	09:30 AM	75.5 °F	24.2 °C	23.9 °C	23.9 °C	71.3 %	69.3 %	26.2 °C	25.9 °C	78.3 %	85.3 %
11	09:40 AM	76.0 °F	24.4 °C	23.9 °C	23.9 °C	71.2 %	69.2 %	26.4 °C	26.1 °C	78.4 %	85.4 %
12	09:50 AM	76.5 °F	24.7 °C	23.9 °C	23.9 °C	71.3 %	69.3 %	26.4 °C	26.1 °C	77.8 %	84.8 %
13	10:00 AM	77.0 °F	25.0 °C	24.0 °C	24.0 °C	71.2 %	69.2 %	26.5 °C	26.2 °C	77.1 %	84.1 %
14	10:10 AM	77.5 °F	25.3 °C	24.0 °C	24.0 °C	71.2 %	69.2 %	26.6 °C	26.3 °C	76.8 %	83.8 %
15	10:20 AM	78.0 °F	25.6 °C	24.0 °C	24.0 °C	71.0 %	69.0 %	26.6 °C	26.3 °C	75.6 %	82.6 %
16	10:30 AM	78.5 °F	25.8 °C	23.9 °C	23.9 °C	71.0 %	69.0 %	26.6 °C	26.3 °C	75.6 %	82.6 %
17	10:40 AM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	71.0 %	69.0 %	26.7 °C	26.4 °C	76.1 %	83.1 %
18	10:50 AM	75.5 °F	24.2 °C	23.9 °C	23.9 °C	71.0 %	69.0 %	26.7 °C	26.4 °C	76.3 %	83.3 %
19	11:00 AM	76.0 °F	24.4 °C	23.8 °C	23.8 °C	71.0 %	69.0 %	26.9 °C	26.6 °C	75.9 %	82.9 %
20	11:10 AM	76.5 °F	24.7 °C	23.9 °C	23.9 °C	70.9 %	68.9 %	27.0 °C	26.7 °C	74.4 %	81.4 %
21	11:20 AM	77.0 °F	25.0 °C	23.8 °C	23.8 °C	70.9 %	68.9 %	27.1 °C	26.8 °C	71.7 %	78.7 %
22	11:30 AM	77.5 °F	25.3 °C	23.8 °C	23.8 °C	70.9 %	68.9 %	27.3 °C	27.0 °C	70.5 %	77.5 %
23	11:40 AM	78.0 °F	25.6 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	27.5 °C	27.2 °C	69.8 %	76.8 %
24	11:50 AM	78.5 °F	25.8 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	27.7 °C	27.4 °C	69.9 %	76.9 %
25	12:00 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	27.8 °C	27.5 °C	69.9 %	76.9 %
26	12:10 PM	75.5 °F	24.2 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	27.9 °C	27.6 °C	69.7 %	76.7 %
27	12:20 PM	76.0 °F	24.4 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	28.0 °C	27.7 °C	68.7 %	75.7 %
28	12:30 PM	76.5 °F	24.7 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	28.0 °C	27.7 °C	68.6 %	75.6 %
29	12:40 PM	77.0 °F	25.0 °C	23.8 °C	23.8 °C	70.6 %	68.6 %	28.2 °C	27.9 °C	67.7 %	74.7 %
30	12:50 PM	77.5 °F	25.3 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	28.3 °C	28.0 °C	66.4 %	73.4 %
31	01:00 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	28.5 °C	28.2 °C	66.8 %	73.8 %
32	01:10 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.4 %	68.4 %	28.5 °C	28.2 °C	66.0 %	73.0 %
33	01:20 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	28.7 °C	28.4 °C	65.2 %	72.2 %
34	01:30 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	29.0 °C	28.7 °C	64.4 %	71.4 %
35	01:40 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	29.2 °C	28.9 °C	63.8 %	70.8 %
36	01:50 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.5 %	68.5 %	29.4 °C	29.1 °C	62.5 %	69.5 %
37	02:00 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	29.5 °C	29.2 °C	62.3 %	69.3 %
38	02:10 PM	75.5 °F	24.2 °C	23.8 °C	23.8 °C	70.5 %	68.5 %	29.7 °C	29.4 °C	61.4 %	68.4 %
39	02:20 PM	76.0 °F	24.4 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	30.0 °C	29.7 °C	60.2 %	67.2 %
40	02:30 PM	76.5 °F	24.7 °C	23.8 °C	23.8 °C	70.9 %	68.9 %	30.3 °C	30.0 °C	58.3 %	65.3 %
41	02:40 PM	77.0 °F	25.0 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	30.6 °C	30.3 °C	57.9 %	64.9 %
42	02:50 PM	77.5 °F	25.3 °C	23.9 °C	23.9 °C	70.9 %	68.9 %	30.8 °C	30.5 °C	58.1 %	65.1 %
43	03:00 PM	78.0 °F	25.6 °C	23.9 °C	23.9 °C	70.6 %	68.6 %	31.0 °C	30.7 °C	57.9 %	64.9 %
44	03:10 PM	78.5 °F	25.8 °C	23.9 °C	23.9 °C	70.5 %	68.5 %	31.2 °C	30.9 °C	57.3 %	64.3 %
45	03:20 PM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	70.7 %	68.7 %	31.3 °C	31.0 °C	56.7 %	63.7 %
46	03:30 PM	75.5 °F	24.2 °C	23.9 °C	23.9 °C	70.6 %	68.6 %	31.3 °C	31.0 °C	55.6 %	62.6 %
47	03:40 PM	76.0 °F	24.4 °C	23.9 °C	23.9 °C	70.7 %	68.7 %	31.5 °C	31.2 °C	62.7 %	69.7 %
48	03:50 PM	76.5 °F	24.7 °C	24.0 °C	24.0 °C	71.4 %	69.4 %	31.1 °C	30.8 °C	65.0 %	72.0 %
49	04:00 PM	77.0 °F	25.0 °C	24.0 °C	24.0 °C	72.1 %	70.1 %	31.0 °C	30.7 °C	64.8 %	71.8 %
50	04:10 PM	77.5 °F	25.3 °C	24.0 °C	24.0 °C	71.7 %	69.7 %	31.3 °C	31.0 °C	63.2 %	70.2 %
51	04:20 PM	78.0 °F	25.6 °C	23.9 °C	23.9 °C	71.4 %	69.4 %	31.1 °C	30.8 °C	63.0 %	70.0 %
52	04:30 PM	78.5 °F	25.8 °C	23.9 °C	23.9 °C	71.6 %	69.6 %	30.9 °C	30.6 °C	64.2 %	71.2 %
53	04:35 PM	78.5 °F	25.8 °C	23.9 °C	23.9 °C	71.5 %	69.5 %	30.9 °C	30.6 °C	63.7 %	70.7 %

* outside air temperatures and relative humidity are obtained from Data Logger at placement B'

Table 6-12: Cyclic indoor set-point temperature mode of BHEUU Background Measurements at placement A (performed on 08th December 2011 as the repeated experiment)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Outside Temperature (raw)*	Outside Temperature (corrected)	Outside Relative Humidity (raw) *	Outside Relative Humidity (corrected)
1	08:00 AM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	72.2 %	70.2 %	26.1 °C	25.8 °C	82.0 %	89.0 %
2	08:10 AM	75.5 °F	24.2 °C	24.1 °C	24.1 °C	72.3 %	70.3 %	26.1 °C	25.8 °C	82.4 %	89.4 %
3	08:20 AM	76.0 °F	24.4 °C	24.1 °C	24.1 °C	72.2 %	70.2 %	26.1 °C	25.8 °C	82.4 %	89.4 %
4	08:30 AM	76.5 °F	24.7 °C	24.1 °C	24.1 °C	72.0 %	70.0 %	26.1 °C	25.8 °C	82.3 %	89.3 %
5	08:40 AM	77.0 °F	25.0 °C	24.1 °C	24.1 °C	71.9 %	69.9 %	26.2 °C	25.9 °C	82.3 %	89.3 %
6	08:50 AM	77.5 °F	25.3 °C	24.1 °C	24.1 °C	71.8 %	69.8 %	26.2 °C	25.9 °C	82.1 %	89.1 %
7	09:00 AM	78.0 °F	25.6 °C	24.1 °C	24.1 °C	71.6 %	69.6 %	26.2 °C	25.9 °C	82.2 %	89.2 %
8	09:10 AM	78.5 °F	25.8 °C	24.1 °C	24.1 °C	71.6 %	69.6 %	26.3 °C	26.0 °C	82.4 %	89.4 %
9	09:20 AM	78.0 °F	25.6 °C	24.1 °C	24.1 °C	71.3 %	69.3 %	26.3 °C	26.0 °C	82.4 %	89.4 %
10	09:30 AM	77.5 °F	25.3 °C	24.1 °C	24.1 °C	71.4 %	69.4 %	26.3 °C	26.0 °C	81.9 %	88.9 %
11	09:40 AM	77.0 °F	25.0 °C	24.1 °C	24.1 °C	71.2 %	69.2 %	26.3 °C	26.0 °C	82.1 %	89.1 %
12	09:50 AM	76.5 °F	24.7 °C	24.1 °C	24.1 °C	71.2 %	69.2 %	26.2 °C	25.9 °C	81.8 %	88.8 %
13	10:00 AM	76.0 °F	24.4 °C	24.1 °C	24.1 °C	71.0 %	69.0 %	26.3 °C	26.0 °C	82.0 %	89.0 %
14	10:10 AM	75.5 °F	24.2 °C	24.1 °C	24.1 °C	71.0 %	69.0 %	26.3 °C	26.0 °C	82.1 %	89.1 %
15	10:20 AM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	71.0 %	69.0 %	26.4 °C	26.1 °C	82.1 %	89.1 %
16	10:30 AM	75.5 °F	24.2 °C	24.1 °C	24.1 °C	70.8 %	68.8 %	26.3 °C	26.0 °C	82.5 %	89.5 %
17	10:40 AM	76.0 °F	24.4 °C	24.0 °C	24.0 °C	70.8 %	68.8 %	26.3 °C	26.0 °C	82.9 %	89.9 %
18	10:50 AM	76.5 °F	24.7 °C	24.0 °C	24.0 °C	70.8 %	68.8 %	26.4 °C	26.1 °C	81.6 %	88.6 %
19	11:00 AM	77.0 °F	25.0 °C	24.0 °C	24.0 °C	70.8 %	68.8 %	26.5 °C	26.2 °C	80.2 %	87.2 %
20	11:10 AM	77.5 °F	25.3 °C	24.0 °C	24.0 °C	70.8 %	68.8 %	26.6 °C	26.3 °C	79.6 %	86.6 %
21	11:20 AM	78.0 °F	25.6 °C	24.0 °C	24.0 °C	70.8 %	68.8 %	26.6 °C	26.3 °C	79.5 %	86.5 %
22	11:30 AM	78.5 °F	25.8 °C	24.0 °C	24.0 °C	70.8 %	68.8 %	26.7 °C	26.4 °C	81.7 %	88.7 %
23	11:40 AM	78.0 °F	25.6 °C	24.0 °C	24.0 °C	70.9 %	68.9 %	26.8 °C	26.5 °C	82.2 %	89.2 %
24	11:50 AM	77.5 °F	25.3 °C	24.0 °C	24.0 °C	71.3 %	69.3 %	26.8 °C	26.5 °C	82.3 %	89.3 %
25	12:00 PM	77.0 °F	25.0 °C	24.0 °C	24.0 °C	71.6 %	69.6 %	26.6 °C	26.3 °C	83.8 %	90.8 %
26	12:10 PM	76.5 °F	24.7 °C	24.0 °C	24.0 °C	71.7 %	69.7 %	26.6 °C	26.3 °C	85.2 %	92.2 %
27	12:20 PM	76.0 °F	24.4 °C	24.0 °C	24.0 °C	71.9 %	69.9 %	26.4 °C	26.1 °C	83.8 %	90.8 %
28	12:30 PM	75.5 °F	24.2 °C	24.0 °C	24.0 °C	72.1 %	70.1 %	26.3 °C	26.0 °C	83.6 %	90.6 %
29	12:40 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	72.2 %	70.2 %	26.2 °C	25.9 °C	83.4 %	90.4 %
30	12:50 PM	75.5 °F	24.2 °C	24.0 °C	24.0 °C	71.9 %	69.9 %	26.0 °C	25.7 °C	83.2 %	90.2 %
31	01:00 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	72.3 %	70.3 %	25.9 °C	25.6 °C	83.7 %	90.7 %
32	01:10 PM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	72.6 %	70.6 %	25.8 °C	25.5 °C	84.1 %	91.1 %
33	01:20 PM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	72.5 %	70.5 %	25.8 °C	25.5 °C	84.4 %	91.4 %
34	01:30 PM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	72.7 %	70.7 %	25.9 °C	25.6 °C	83.4 %	90.4 %
35	01:40 PM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	72.6 %	70.6 %	25.8 °C	25.5 °C	83.4 %	90.4 %
36	01:50 PM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	72.4 %	70.4 %	25.8 °C	25.5 °C	83.4 %	90.4 %
37	02:00 PM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	72.3 %	70.3 %	25.9 °C	25.6 °C	82.4 %	89.4 %
38	02:10 PM	75.5 °F	24.2 °C	23.8 °C	23.8 °C	71.8 %	69.8 %	26.0 °C	25.7 °C	82.2 %	89.2 %
39	02:20 PM	76.0 °F	24.4 °C	23.9 °C	23.9 °C	71.6 %	69.6 %	26.1 °C	25.8 °C	81.8 %	88.8 %
40	02:30 PM	76.5 °F	24.7 °C	23.9 °C	23.9 °C	71.4 %	69.4 %	26.1 °C	25.8 °C	81.0 %	88.0 %
41	02:40 PM	77.0 °F	25.0 °C	23.9 °C	23.9 °C	71.2 %	69.2 %	26.0 °C	25.7 °C	80.9 %	87.9 %
42	02:50 PM	77.5 °F	25.3 °C	23.8 °C	23.8 °C	71.1 %	69.1 %	26.0 °C	25.7 °C	81.4 %	88.4 %
43	03:00 PM	78.0 °F	25.6 °C	23.8 °C	23.8 °C	71.0 %	69.0 %	26.0 °C	25.7 °C	81.6 %	88.6 %
44	03:10 PM	78.5 °F	25.8 °C	23.8 °C	23.8 °C	71.0 %	69.0 %	25.9 °C	25.6 °C	81.6 %	88.6 %
45	03:20 PM	78.0 °F	25.6 °C	23.8 °C	23.8 °C	70.9 %	68.9 %	25.9 °C	25.6 °C	81.7 %	88.7 %
46	03:30 PM	77.5 °F	25.3 °C	23.8 °C	23.8 °C	70.9 %	68.9 %	25.8 °C	25.5 °C	81.6 %	88.6 %
47	03:40 PM	77.0 °F	25.0 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	25.8 °C	25.5 °C	81.7 %	88.7 %
48	03:50 PM	76.5 °F	24.7 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	25.8 °C	25.5 °C	81.9 %	88.9 %
49	04:00 PM	76.0 °F	24.4 °C	23.8 °C	23.8 °C	70.9 %	68.9 %	25.7 °C	25.4 °C	82.2 %	89.2 %
50	04:10 PM	75.5 °F	24.2 °C	23.8 °C	23.8 °C	70.9 %	68.9 %	25.6 °C	25.3 °C	82.6 %	89.6 %
51	04:20 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	70.8 %	68.8 %	25.6 °C	25.3 °C	82.8 %	89.8 %
52	04:30 PM	75.5 °F	24.2 °C	23.8 °C	23.8 °C	70.9 %	68.9 %	25.6 °C	25.3 °C	83.1 %	90.1 %
53	04:35 PM	75.5 °F	24.2 °C	23.8 °C	23.8 °C	70.7 %	68.7 %	25.6 °C	25.3 °C	82.6 %	89.6 %

* outside air temperatures and relative humidity are obtained from Data Logger at placement B'

Table 6-13: Constant indoor set-point temperature mode of BHEUU Background Measurements at placement C (performed on 06th December 2011 as the repeated experiment)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Outside Temperature (raw)*	Outside Temperature (corrected)	Outside Relative Humidity (raw)*	Outside Relative Humidity (corrected)
1	08:00 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	73.4 %	71.4 %	25.4 °C	25.1 °C	80.6 %	87.6 %
2	08:10 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	73.5 %	71.5 %	25.4 °C	25.1 °C	80.6 %	87.6 %
3	08:20 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	73.1 %	71.1 %	25.5 °C	25.2 °C	80.4 %	87.4 %
4	08:30 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	73.4 %	71.4 %	25.6 °C	25.3 °C	80.2 %	87.2 %
5	08:40 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	73.3 %	71.3 %	25.6 °C	25.3 °C	80.1 %	87.1 %
6	08:50 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	72.9 %	70.9 %	25.7 °C	25.4 °C	80.1 %	87.1 %
7	09:00 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	73.3 %	71.3 %	25.7 °C	25.4 °C	79.9 %	86.9 %
8	09:10 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	73.1 %	71.1 %	25.8 °C	25.5 °C	79.8 %	86.8 %
9	09:20 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	72.7 %	70.7 %	25.9 °C	25.6 °C	79.7 %	86.7 %
10	09:30 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	72.9 %	70.9 %	26.0 °C	25.7 °C	79.5 %	86.5 %
11	09:40 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	72.9 %	70.9 %	26.1 °C	25.8 °C	79.3 %	86.3 %
12	09:50 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.5 %	70.5 %	26.2 °C	25.9 °C	78.6 %	85.6 %
13	10:00 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.4 %	70.4 %	26.3 °C	26.0 °C	78.6 %	85.6 %
14	10:10 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.7 %	70.7 %	26.4 °C	26.1 °C	78.5 %	85.5 %
15	10:20 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.8 %	70.8 %	26.5 °C	26.2 °C	77.8 %	84.8 %
16	10:30 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.4 %	70.4 %	26.6 °C	26.3 °C	77.6 %	84.6 %
17	10:40 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.4 %	70.4 %	26.7 °C	26.4 °C	77.4 %	84.4 %
18	10:50 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.4 %	70.4 %	26.8 °C	26.5 °C	77.4 %	84.4 %
19	11:00 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.5 %	70.5 %	26.9 °C	26.6 °C	77.4 %	84.4 %
20	11:10 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.2 %	70.2 %	27.0 °C	26.7 °C	77.2 %	84.2 %
21	11:20 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.1 %	70.1 %	27.1 °C	26.8 °C	76.6 %	83.6 %
22	11:30 AM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	71.8 %	69.8 %	27.2 °C	26.9 °C	76.2 %	83.2 %
23	11:40 AM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	72.1 %	70.1 %	27.2 °C	26.9 °C	75.8 %	82.8 %
24	11:50 AM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	72.3 %	70.3 %	27.3 °C	27.0 °C	75.1 %	82.1 %
25	12:00 PM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	71.8 %	69.8 %	27.4 °C	27.1 °C	75.3 %	82.3 %
26	12:10 PM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	72.0 %	70.0 %	27.4 °C	27.1 °C	74.8 %	81.8 %
27	12:20 PM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	71.8 %	69.8 %	27.5 °C	27.2 °C	74.1 %	81.1 %
28	12:30 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	71.8 %	69.8 %	27.6 °C	27.3 °C	73.7 %	80.7 %
29	12:40 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	71.9 %	69.9 %	27.7 °C	27.4 °C	72.9 %	79.9 %
30	12:50 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	71.5 %	69.5 %	27.9 °C	27.6 °C	72.1 %	79.1 %
31	01:00 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	71.7 %	69.7 %	28.0 °C	27.7 °C	71.3 %	78.3 %
32	01:10 PM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	71.8 %	69.8 %	28.1 °C	27.8 °C	71.4 %	78.4 %
33	01:20 PM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	71.6 %	69.6 %	28.2 °C	27.9 °C	71.3 %	78.3 %
34	01:30 PM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.1 %	70.1 %	28.3 °C	28.0 °C	71.5 %	78.5 %
35	01:40 PM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	72.1 %	70.1 %	28.5 °C	28.2 °C	70.6 %	77.6 %
36	01:50 PM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	71.8 %	69.8 %	28.7 °C	28.4 °C	70.1 %	77.1 %
37	02:00 PM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	72.3 %	70.3 %	28.8 °C	28.5 °C	68.4 %	75.4 %
38	02:10 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	72.0 %	70.0 %	29.1 °C	28.8 °C	66.8 %	73.8 %
39	02:20 PM	75.0 °F	23.9 °C	23.8 °C	23.8 °C	71.5 %	69.5 %	29.4 °C	29.1 °C	66.3 %	73.3 %
40	02:30 PM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	71.6 %	69.6 %	29.5 °C	29.2 °C	65.9 %	72.9 %
41	02:40 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	71.6 %	69.6 %	29.8 °C	29.5 °C	65.2 %	72.2 %
42	02:50 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	71.1 %	69.1 %	30.0 °C	29.7 °C	65.2 %	72.2 %
43	03:00 PM	75.0 °F	23.9 °C	24.0 °C	24.0 °C	71.2 %	69.2 %	30.2 °C	29.9 °C	64.6 %	71.6 %
44	03:10 PM	75.0 °F	23.9 °C	24.1 °C	24.1 °C	71.3 %	69.3 %	30.4 °C	30.1 °C	63.6 %	70.6 %
45	03:20 PM	75.0 °F	23.9 °C	24.2 °C	24.2 °C	71.1 %	69.1 %	30.5 °C	30.2 °C	63.3 %	70.3 %
46	03:30 PM	75.0 °F	23.9 °C	24.3 °C	24.3 °C	70.3 %	68.3 %	30.8 °C	30.5 °C	61.7 %	68.7 %
47	03:40 PM	75.0 °F	23.9 °C	24.4 °C	24.4 °C	70.5 %	68.5 %	31.8 °C	31.5 °C	56.8 %	63.8 %
48	03:50 PM	75.0 °F	23.9 °C	24.5 °C	24.5 °C	70.2 %	68.2 %	31.8 °C	31.5 °C	58.4 %	65.4 %
49	04:00 PM	75.0 °F	23.9 °C	24.6 °C	24.6 °C	70.0 %	68.0 %	31.2 °C	30.9 °C	59.5 %	66.5 %
50	04:10 PM	75.0 °F	23.9 °C	24.6 °C	24.6 °C	70.1 %	68.1 %	30.8 °C	30.5 °C	59.5 %	66.5 %
51	04:20 PM	75.0 °F	23.9 °C	24.7 °C	24.7 °C	69.8 %	67.8 %	30.9 °C	30.6 °C	60.9 %	67.9 %
52	04:30 PM	75.0 °F	23.9 °C	24.7 °C	24.7 °C	69.4 %	67.4 %	30.8 °C	30.5 °C	60.2 %	67.2 %
53	04:35 PM	75.0 °F	23.9 °C	24.7 °C	24.7 °C	69.5 %	67.5 %	30.7 °C	30.4 °C	60.5 %	67.5 %

* outside air temperatures and relative humidity are obtained from Data Logger at placement B'

Table 6-14: Ramp indoor set-point temperature mode of BHEUU Background Measurements at placement C (performed on 07th December 2011 as the repeated experiment)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Outside Temperature (raw)*	Outside Temperature (corrected)	Outside Relative Humidity (raw)*	Outside Relative Humidity (corrected)
1	08:00 AM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	73.7 %	71.7 %	25.9 °C	25.6 °C	80.3 %	87.3 %
2	08:10 AM	75.5 °F	24.2 °C	23.7 °C	23.7 °C	73.4 %	71.4 %	25.8 °C	25.5 °C	79.6 %	86.6 %
3	08:20 AM	76.0 °F	24.4 °C	23.6 °C	23.6 °C	73.4 %	71.4 %	25.8 °C	25.5 °C	79.1 %	86.1 %
4	08:30 AM	76.5 °F	24.7 °C	23.5 °C	23.5 °C	73.4 %	71.4 %	25.8 °C	25.5 °C	79.0 %	86.0 %
5	08:40 AM	77.0 °F	25.0 °C	23.5 °C	23.5 °C	73.8 %	71.8 %	25.9 °C	25.6 °C	79.1 %	86.1 %
6	08:50 AM	77.5 °F	25.3 °C	23.5 °C	23.5 °C	73.9 %	71.9 %	25.9 °C	25.6 °C	78.7 %	85.7 %
7	09:00 AM	78.0 °F	25.6 °C	23.5 °C	23.5 °C	73.7 %	71.7 %	26.1 °C	25.8 °C	79.2 %	86.2 %
8	09:10 AM	78.5 °F	25.8 °C	23.5 °C	23.5 °C	73.7 %	71.7 %	26.2 °C	25.9 °C	78.7 %	85.7 %
9	09:20 AM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	73.5 %	71.5 %	26.2 °C	25.9 °C	78.7 %	85.7 %
10	09:30 AM	75.5 °F	24.2 °C	23.5 °C	23.5 °C	73.5 %	71.5 %	26.2 °C	25.9 °C	78.3 %	85.3 %
11	09:40 AM	76.0 °F	24.4 °C	23.5 °C	23.5 °C	73.5 %	71.5 %	26.4 °C	26.1 °C	78.4 %	85.4 %
12	09:50 AM	76.5 °F	24.7 °C	23.6 °C	23.6 °C	73.7 %	71.7 %	26.4 °C	26.1 °C	77.8 %	84.8 %
13	10:00 AM	77.0 °F	25.0 °C	23.6 °C	23.6 °C	73.5 %	71.5 %	26.5 °C	26.2 °C	77.1 %	84.1 %
14	10:10 AM	77.5 °F	25.3 °C	23.6 °C	23.6 °C	73.4 %	71.4 %	26.6 °C	26.3 °C	76.8 %	83.8 %
15	10:20 AM	78.0 °F	25.6 °C	23.6 °C	23.6 °C	73.1 %	71.1 %	26.6 °C	26.3 °C	75.6 %	82.6 %
16	10:30 AM	78.5 °F	25.8 °C	23.6 °C	23.6 °C	73.2 %	71.2 %	26.6 °C	26.3 °C	75.6 %	82.6 %
17	10:40 AM	75.0 °F	23.9 °C	23.6 °C	23.6 °C	73.3 %	71.3 %	26.7 °C	26.4 °C	76.1 %	83.1 %
18	10:50 AM	75.5 °F	24.2 °C	23.6 °C	23.6 °C	72.9 %	70.9 %	26.7 °C	26.4 °C	76.3 %	83.3 %
19	11:00 AM	76.0 °F	24.4 °C	23.7 °C	23.7 °C	73.0 %	71.0 %	26.9 °C	26.6 °C	75.9 %	82.9 %
20	11:10 AM	76.5 °F	24.7 °C	23.7 °C	23.7 °C	72.9 %	70.9 %	27.0 °C	26.7 °C	74.4 %	81.4 %
21	11:20 AM	77.0 °F	25.0 °C	23.7 °C	23.7 °C	72.8 %	70.8 %	27.1 °C	26.8 °C	71.7 %	78.7 %
22	11:30 AM	77.5 °F	25.3 °C	23.7 °C	23.7 °C	72.5 %	70.5 %	27.3 °C	27.0 °C	70.5 %	77.5 %
23	11:40 AM	78.0 °F	25.6 °C	23.7 °C	23.7 °C	72.6 %	70.6 %	27.5 °C	27.2 °C	69.8 %	76.8 %
24	11:50 AM	78.5 °F	25.8 °C	23.7 °C	23.7 °C	72.8 %	70.8 %	27.7 °C	27.4 °C	69.9 %	76.9 %
25	12:00 PM	75.0 °F	23.9 °C	23.7 °C	23.7 °C	72.2 %	70.2 %	27.8 °C	27.5 °C	69.9 %	76.9 %
26	12:10 PM	75.5 °F	24.2 °C	23.7 °C	23.7 °C	72.4 %	70.4 %	27.9 °C	27.6 °C	69.7 %	76.7 %
27	12:20 PM	76.0 °F	24.4 °C	23.8 °C	23.8 °C	72.4 %	70.4 %	28.0 °C	27.7 °C	68.7 %	75.7 %
28	12:30 PM	76.5 °F	24.7 °C	23.7 °C	23.7 °C	71.9 %	69.9 %	28.0 °C	27.7 °C	68.6 %	75.6 %
29	12:40 PM	77.0 °F	25.0 °C	23.7 °C	23.7 °C	72.2 %	70.2 %	28.2 °C	27.9 °C	67.7 %	74.7 %
30	12:50 PM	77.5 °F	25.3 °C	23.5 °C	23.5 °C	72.4 %	70.4 %	28.3 °C	28.0 °C	66.4 %	73.4 %
31	01:00 PM	75.0 °F	23.9 °C	23.4 °C	23.4 °C	72.3 %	70.3 %	28.5 °C	28.2 °C	66.8 %	73.8 %
32	01:10 PM	75.0 °F	23.9 °C	23.4 °C	23.4 °C	72.6 %	70.6 %	28.5 °C	28.2 °C	66.0 %	73.0 %
33	01:20 PM	75.0 °F	23.9 °C	23.4 °C	23.4 °C	73.0 %	71.0 %	28.7 °C	28.4 °C	65.2 %	72.2 %
34	01:30 PM	75.0 °F	23.9 °C	23.4 °C	23.4 °C	72.5 %	70.5 %	29.0 °C	28.7 °C	64.4 %	71.4 %
35	01:40 PM	75.0 °F	23.9 °C	23.3 °C	23.3 °C	73.0 %	71.0 %	29.2 °C	28.9 °C	63.8 %	70.8 %
36	01:50 PM	75.0 °F	23.9 °C	23.4 °C	23.4 °C	73.0 %	71.0 %	29.4 °C	29.1 °C	62.5 %	69.5 %
37	02:00 PM	75.0 °F	23.9 °C	23.5 °C	23.5 °C	72.6 %	70.6 %	29.5 °C	29.2 °C	62.3 %	69.3 %
38	02:10 PM	75.5 °F	24.2 °C	23.6 °C	23.6 °C	73.0 %	71.0 %	29.7 °C	29.4 °C	61.4 %	68.4 %
39	02:20 PM	76.0 °F	24.4 °C	23.7 °C	23.7 °C	72.9 %	70.9 %	30.0 °C	29.7 °C	60.2 %	67.2 %
40	02:30 PM	76.5 °F	24.7 °C	23.9 °C	23.9 °C	72.3 %	70.3 %	30.3 °C	30.0 °C	58.3 %	65.3 %
41	02:40 PM	77.0 °F	25.0 °C	24.0 °C	24.0 °C	72.3 %	70.3 %	30.6 °C	30.3 °C	57.9 %	64.9 %
42	02:50 PM	77.5 °F	25.3 °C	24.0 °C	24.0 °C	72.1 %	70.1 %	30.8 °C	30.5 °C	58.1 %	65.1 %
43	03:00 PM	78.0 °F	25.6 °C	24.1 °C	24.1 °C	71.5 %	69.5 %	31.0 °C	30.7 °C	57.9 %	64.9 %
44	03:10 PM	78.5 °F	25.8 °C	24.2 °C	24.2 °C	71.6 %	69.6 %	31.2 °C	30.9 °C	57.3 %	64.3 %
45	03:20 PM	75.0 °F	23.9 °C	24.2 °C	24.2 °C	71.5 %	69.5 %	31.3 °C	31.0 °C	56.7 %	63.7 %
46	03:30 PM	75.5 °F	24.2 °C	24.3 °C	24.3 °C	71.1 %	69.1 %	31.3 °C	31.0 °C	55.6 %	62.6 %
47	03:40 PM	76.0 °F	24.4 °C	24.4 °C	24.4 °C	71.9 %	69.9 %	31.5 °C	31.2 °C	62.7 %	69.7 %
48	03:50 PM	76.5 °F	24.7 °C	24.7 °C	24.7 °C	74.0 %	72.0 %	31.1 °C	30.8 °C	65.0 %	72.0 %
49	04:00 PM	77.0 °F	25.0 °C	24.9 °C	24.9 °C	74.2 %	72.2 %	31.0 °C	30.7 °C	64.8 %	71.8 %
50	04:10 PM	77.5 °F	25.3 °C	24.8 °C	24.8 °C	72.0 %	70.0 %	31.3 °C	31.0 °C	63.2 %	70.2 %
51	04:20 PM	78.0 °F	25.6 °C	24.8 °C	24.8 °C	71.2 %	69.2 %	31.1 °C	30.8 °C	63.0 %	70.0 %
52	04:30 PM	78.5 °F	25.8 °C	24.7 °C	24.7 °C	70.9 %	68.9 %	30.9 °C	30.6 °C	64.2 %	71.2 %
53	04:35 PM	78.5 °F	25.8 °C	24.7 °C	24.7 °C	71.1 %	69.1 %	30.9 °C	30.6 °C	63.7 %	70.7 %

* outside air temperatures and relative humidity are obtained from Data Logger at placement B'

Table 6-15: Cyclic indoor set-point temperature mode of BHEUU Background Measurements at placement C (performed on 08th December 2011 as repeated experiment)

No	Date Time, GMT+08:00	Indoor Set Point Temperature	Indoor Set Point Temperature	Dry Bulb Temperature (raw)	Dry Bulb Temperature (corrected)	Relative Humidity (raw)	Relative Humidity (corrected)	Outside Temperature (raw)*	Outside Temperature (corrected)	Outside Relative Humidity (raw)*	Outside Relative Humidity (corrected)
1	08:00 AM	75.0 °F	23.9 °C	23.9 °C	23.9 °C	73.4 %	71.4 %	26.1 °C	25.8 °C	82.0 %	89.0 %
2	08:10 AM	75.5 °F	24.2 °C	23.9 °C	23.9 °C	73.3 %	71.3 %	26.1 °C	25.8 °C	82.4 %	89.4 %
3	08:20 AM	76.0 °F	24.4 °C	23.7 °C	23.7 °C	73.6 %	71.6 %	26.1 °C	25.8 °C	82.4 %	89.4 %
4	08:30 AM	76.5 °F	24.7 °C	23.5 °C	23.5 °C	73.5 %	71.5 %	26.1 °C	25.8 °C	82.3 %	89.3 %
5	08:40 AM	77.0 °F	25.0 °C	23.4 °C	23.4 °C	74.2 %	72.2 %	26.2 °C	25.9 °C	82.3 %	89.3 %
6	08:50 AM	77.5 °F	25.3 °C	23.1 °C	23.1 °C	74.5 %	72.5 %	26.2 °C	25.9 °C	82.1 %	89.1 %
7	09:00 AM	78.0 °F	25.6 °C	23.0 °C	23.0 °C	75.0 %	73.0 %	26.2 °C	25.9 °C	82.2 %	89.2 %
8	09:10 AM	78.5 °F	25.8 °C	22.9 °C	22.9 °C	75.4 %	73.4 %	26.3 °C	26.0 °C	82.4 %	89.4 %
9	09:20 AM	78.0 °F	25.6 °C	22.8 °C	22.8 °C	75.9 %	73.9 %	26.3 °C	26.0 °C	82.4 %	89.4 %
10	09:30 AM	77.5 °F	25.3 °C	22.8 °C	22.8 °C	75.7 %	73.7 %	26.3 °C	26.0 °C	81.9 %	88.9 %
11	09:40 AM	77.0 °F	25.0 °C	22.7 °C	22.7 °C	76.1 %	74.1 %	26.3 °C	26.0 °C	82.1 %	89.1 %
12	09:50 AM	76.5 °F	24.7 °C	22.7 °C	22.7 °C	75.7 %	73.7 %	26.2 °C	25.9 °C	81.8 %	88.8 %
13	10:00 AM	76.0 °F	24.4 °C	22.6 °C	22.6 °C	76.2 %	74.2 %	26.3 °C	26.0 °C	82.0 %	89.0 %
14	10:10 AM	75.5 °F	24.2 °C	22.6 °C	22.6 °C	76.1 %	74.1 %	26.3 °C	26.0 °C	82.1 %	89.1 %
15	10:20 AM	75.0 °F	23.9 °C	22.6 °C	22.6 °C	76.3 %	74.3 %	26.4 °C	26.1 °C	82.1 %	89.1 %
16	10:30 AM	75.5 °F	24.2 °C	22.6 °C	22.6 °C	76.2 %	74.2 %	26.3 °C	26.0 °C	82.5 %	89.5 %
17	10:40 AM	76.0 °F	24.4 °C	22.6 °C	22.6 °C	76.1 %	74.1 %	26.3 °C	26.0 °C	82.9 %	89.9 %
18	10:50 AM	76.5 °F	24.7 °C	22.6 °C	22.6 °C	76.2 %	74.2 %	26.4 °C	26.1 °C	81.6 %	88.6 %
19	11:00 AM	77.0 °F	25.0 °C	22.6 °C	22.6 °C	76.3 %	74.3 %	26.5 °C	26.2 °C	80.2 %	87.2 %
20	11:10 AM	77.5 °F	25.3 °C	22.6 °C	22.6 °C	76.4 %	74.4 %	26.6 °C	26.3 °C	79.6 %	86.6 %
21	11:20 AM	78.0 °F	25.6 °C	22.5 °C	22.5 °C	76.5 %	74.5 %	26.6 °C	26.3 °C	79.5 %	86.5 %
22	11:30 AM	78.5 °F	25.8 °C	22.5 °C	22.5 °C	76.4 %	74.4 %	26.7 °C	26.4 °C	81.7 %	88.7 %
23	11:40 AM	78.0 °F	25.6 °C	22.6 °C	22.6 °C	76.8 %	74.8 %	26.8 °C	26.5 °C	82.2 %	89.2 %
24	11:50 AM	77.5 °F	25.3 °C	22.6 °C	22.6 °C	77.0 %	75.0 %	26.8 °C	26.5 °C	82.3 %	89.3 %
25	12:00 PM	77.0 °F	25.0 °C	22.6 °C	22.6 °C	76.8 %	74.8 %	26.6 °C	26.3 °C	83.8 %	90.8 %
26	12:10 PM	76.5 °F	24.7 °C	22.6 °C	22.6 °C	76.8 %	74.8 %	26.6 °C	26.3 °C	85.2 %	92.2 %
27	12:20 PM	76.0 °F	24.4 °C	22.6 °C	22.6 °C	76.8 %	74.8 %	26.4 °C	26.1 °C	83.8 %	90.8 %
28	12:30 PM	75.5 °F	24.2 °C	22.5 °C	22.5 °C	76.6 %	74.6 %	26.3 °C	26.0 °C	83.6 %	90.6 %
29	12:40 PM	75.0 °F	23.9 °C	22.6 °C	22.6 °C	76.8 %	74.8 %	26.2 °C	25.9 °C	83.4 %	90.4 %
30	12:50 PM	75.5 °F	24.2 °C	22.6 °C	22.6 °C	76.7 %	74.7 %	26.0 °C	25.7 °C	83.2 %	90.2 %
31	01:00 PM	75.0 °F	23.9 °C	22.6 °C	22.6 °C	76.7 %	74.7 %	25.9 °C	25.6 °C	83.7 %	90.7 %
32	01:10 PM	75.0 °F	23.9 °C	22.6 °C	22.6 °C	76.4 %	74.4 %	25.8 °C	25.5 °C	84.1 %	91.1 %
33	01:20 PM	75.0 °F	23.9 °C	22.6 °C	22.6 °C	76.5 %	74.5 %	25.8 °C	25.5 °C	84.4 %	91.4 %
34	01:30 PM	75.0 °F	23.9 °C	22.6 °C	22.6 °C	76.8 %	74.8 %	25.9 °C	25.6 °C	83.4 %	90.4 %
35	01:40 PM	75.0 °F	23.9 °C	22.6 °C	22.6 °C	76.7 %	74.7 %	25.8 °C	25.5 °C	83.4 %	90.4 %
36	01:50 PM	75.0 °F	23.9 °C	22.5 °C	22.5 °C	76.8 %	74.8 %	25.8 °C	25.5 °C	83.4 %	90.4 %
37	02:00 PM	75.0 °F	23.9 °C	22.5 °C	22.5 °C	76.3 %	74.3 %	25.9 °C	25.6 °C	82.4 %	89.4 %
38	02:10 PM	75.5 °F	24.2 °C	22.5 °C	22.5 °C	76.5 %	74.5 %	26.0 °C	25.7 °C	82.2 %	89.2 %
39	02:20 PM	76.0 °F	24.4 °C	22.5 °C	22.5 °C	76.6 %	74.6 %	26.1 °C	25.8 °C	81.8 %	88.8 %
40	02:30 PM	76.5 °F	24.7 °C	22.4 °C	22.4 °C	76.3 %	74.3 %	26.1 °C	25.8 °C	81.0 %	88.0 %
41	02:40 PM	77.0 °F	25.0 °C	22.4 °C	22.4 °C	76.6 %	74.6 %	26.0 °C	25.7 °C	80.9 %	87.9 %
42	02:50 PM	77.5 °F	25.3 °C	22.4 °C	22.4 °C	76.5 %	74.5 %	26.0 °C	25.7 °C	81.4 %	88.4 %
43	03:00 PM	78.0 °F	25.6 °C	22.3 °C	22.3 °C	76.6 %	74.6 %	26.0 °C	25.7 °C	81.6 %	88.6 %
44	03:10 PM	78.5 °F	25.8 °C	22.3 °C	22.3 °C	76.9 %	74.9 %	25.9 °C	25.6 °C	81.6 %	88.6 %
45	03:20 PM	78.0 °F	25.6 °C	22.3 °C	22.3 °C	76.6 %	74.6 %	25.9 °C	25.6 °C	81.7 %	88.7 %
46	03:30 PM	77.5 °F	25.3 °C	22.3 °C	22.3 °C	76.9 %	74.9 %	25.8 °C	25.5 °C	81.6 %	88.6 %
47	03:40 PM	77.0 °F	25.0 °C	22.3 °C	22.3 °C	77.0 %	75.0 %	25.8 °C	25.5 °C	81.7 %	88.7 %
48	03:50 PM	76.5 °F	24.7 °C	22.2 °C	22.2 °C	76.9 %	74.9 %	25.8 °C	25.5 °C	81.9 %	88.9 %
49	04:00 PM	76.0 °F	24.4 °C	22.2 °C	22.2 °C	77.1 %	75.1 %	25.7 °C	25.4 °C	82.2 %	89.2 %
50	04:10 PM	75.5 °F	24.2 °C	22.2 °C	22.2 °C	77.0 %	75.0 %	25.6 °C	25.3 °C	82.6 %	89.6 %
51	04:20 PM	75.0 °F	23.9 °C	22.2 °C	22.2 °C	77.1 %	75.1 %	25.6 °C	25.3 °C	82.8 %	89.8 %
52	04:30 PM	75.5 °F	24.2 °C	22.2 °C	22.2 °C	77.0 %	75.0 %	25.6 °C	25.3 °C	83.1 %	90.1 %
53	04:35 PM	75.5 °F	24.2 °C	22.1 °C	22.1 °C	75.4 %	73.4 %	25.6 °C	25.3 °C	82.6 %	89.6 %

* outside air temperatures and relative humidity are obtained from Data Logger at placement B'

B : Transverse Survey with Energy Comparison Trial Results

Table 6-16: The experiment results when the ramp mode was applied in level 6 BHEUU (13th September 2011)

No	Time	Dry Bulb Temperature	Relative Humidity	Globe Temperature	Mean Radiant Temperature	Operative Temperature	Air Velocity	CO2 Concentration	Thermal CV*	Airflow CV*	Humidity CV*	Clothing Insulation
1	8:30 AM	24.8 °C	63.0 %	24.7 °C	24.7 °C	24.7 °C	0.01 m/s	543 ppm	2	-1	-1	0.65 clo
2	8.50 AM	25.0 °C	64.0 %	24.9 °C	24.9 °C	24.9 °C	0.02 m/s	543 ppm	0	0	1	0.65 clo
3	9:10 AM	24.5 °C	63.0 %	24.6 °C	24.7 °C	24.6 °C	0.08 m/s	565 ppm	0	-1	-1	0.65 clo
4	9:30 AM	24.9 °C	63.0 %	24.3 °C	24.1 °C	24.5 °C	0.02 m/s	578 ppm	1	-2	0	0.95 clo
5	9:50 AM	24.9 °C	63.0 %	24.3 °C	24.0 °C	24.5 °C	0.04 m/s	575 ppm	0	-1	-1	0.65 clo
6	10:10 AM	24.0 °C	65.0 %	24.0 °C	24.0 °C	24.0 °C	0.07 m/s	585 ppm	0	1	0	0.76 clo
7	10:30 AM	24.8 °C	63.0 %	24.0 °C	23.6 °C	24.2 °C	0.04 m/s	603 ppm	1	-1	0	0.76 clo
8	10:55 AM	24.8 °C	63.0 %	24.0 °C	23.4 °C	24.1 °C	0.10 m/s	626 ppm	1	-2	-1	0.65 clo
9	11:05 AM	24.8 °C	63.0 %	24.2 °C	23.6 °C	24.2 °C	0.21 m/s	626 ppm	1	0	0	0.76 clo
10	11:25 AM	25.0 °C	63.0 %	23.9 °C	23.5 °C	24.3 °C	0.02 m/s	643 ppm	0	-1	0	0.65 clo
11	11:40 AM	25.5 °C	58.0 %	24.7 °C	24.5 °C	25.0 °C	0.01 m/s	672 ppm	0	-2	0	0.69 clo
12	12:00 PM	23.9 °C	66.0 %	24.2 °C	24.4 °C	24.1 °C	0.05 m/s	647 ppm	-1	0	0	0.65 clo
13	2:10 PM	24.9 °C	67.0 %	24.9 °C	24.9 °C	24.9 °C	0.07 m/s	568 ppm	1	-1	1	0.65 clo
14	2:25 PM	22.5 °C	72.0 %	22.5 °C	22.5 °C	22.5 °C	0.33 m/s	562 ppm	0	0	1	0.68 clo
15	3:15 PM	23.0 °C	72.0 %	22.7 °C	22.6 °C	22.8 °C	0.02 m/s	616 ppm	0	-1	0	0.55 clo
16	3:30 PM	26.2 °C	62.0 %	25.1 °C	24.0 °C	25.1 °C	0.18 m/s	658 ppm	0	0	1	0.76 clo
								Mean Value ==>	**0.4**	**-0.8**	**0.0**	**0.69 clo**

Table 6-17: The corresponding results when the constant mode was applied in level 7 BHEUU as a controlled floor (13th September 2011)

No	Time	Dry Bulb Temperature	Relative Humidity	Globe Temperature	Mean Radiant Temperature	Operative Temperature	Air Velocity	CO2 Concentration	Thermal CV*	Airflow CV*	Humidity CV*	Clothing Insulation
1	8:30 AM	24.0 °C	77.0 %	23.3 °C	22.8 °C	23.4 °C	0.10 m/s	552 ppm	-1	-1	-1	0.74 clo
2	9:00 AM	24.0 °C	69.0 %	23.7 °C	23.5 °C	23.8 °C	0.15 m/s	583 ppm	0	0	0	0.65 clo
3	9:12 AM	24.0 °C	69.0 %	24.2 °C	24.2 °C	24.1 °C	0.03 m/s	567 ppm	-2	0	0	0.70 clo
4	9:30 AM	24.0 °C	77.0 %	23.7 °C	23.5 °C	23.8 °C	0.03 m/s	536 ppm	-1	0	1	0.65 clo
5	10:00 AM	24.0 °C	69.0 %	23.8 °C	23.7 °C	23.9 °C	0.02 m/s	660 ppm	1	-2	1	0.74 clo
6	10:15 AM	23.5 °C	69.0 %	23.6 °C	23.7 °C	23.6 °C	0.12 m/s	556 ppm	0	0	1	0.96 clo
7	10:35 AM	24.0 °C	73.0 %	23.8 °C	23.7 °C	23.9 °C	0.05 m/s	673 ppm	-1	0	0	0.65 clo
8	10:55 AM	23.0 °C	72.0 %	22.8 °C	22.7 °C	22.8 °C	0.04 m/s	615 ppm	-1	0	0	0.93 clo
9	11:15 AM	23.5 °C	69.0 %	23.9 °C	24.1 °C	23.8 °C	0.04 m/s	600 ppm	1	-1	-1	0.65 clo
10	11:30 AM	24.0 °C	73.0 %	23.7 °C	23.5 °C	23.7 °C	0.06 m/s	660 ppm	1	-2	1	0.65 clo
11	12:00 PM	23.5 °C	72.0 %	23.7 °C	23.9 °C	23.7 °C	0.06 m/s	510 ppm	-1	0	-1	0.93 clo
12	2:15 PM	24.0 °C	77.0 %	24.1 °C	24.1 °C	24.0 °C	0.01 m/s	538 ppm	1	-1	0	0.80 clo
13	2:30 PM	24.0 °C	73.0 %	24.4 °C	24.5 °C	24.2 °C	0.02 m/s	562 ppm	0	0	1	0.65 clo
14	2:45 PM	24.5 °C	66.0 %	24.0 °C	23.8 °C	24.2 °C	0.03 m/s	575 ppm	0	-2	-3	0.67 clo
								Mean Value ==>	**-0.2**	**-0.6**	**-0.1**	**0.74 clo**

* CV stands for Comfort Vote on ASHRAE thermal sensational scale.

Table 6-18: The experiment results when the cyclic mode was applied in level 6 BHEUU (15th September 2011)

No	Time	Dry Bulb Temperature	Relative Humidity	Globe Temperature	Mean Radiant Temperature	Operative Temperature	Air Velocity	CO2 Concentration	Thermal CV*	Airflow CV*	Humidity CV*	Clothing Insulation
1	8:20 AM	25.5 °C	63.0 %	24.9 °C	24.3 °C	24.9 °C	0.18 m/s	543 ppm	0	-1	-1	0.65 clo
2	8:40 AM	25.5 °C	63.0 %	24.8 °C	24.1 °C	24.8 °C	0.16 m/s	564 ppm	0	0	-1	0.65 clo
3	8:55 AM	25.1 °C	60.0 %	25.0 °C	24.9 °C	25.0 °C	0.15 m/s	546 ppm	0	0	0	0.65 clo
4	9:10 AM	24.8 °C	67.0 %	24.5 °C	24.4 °C	24.6 °C	0.02 m/s	571 ppm	-1	1	1	0.65 clo
5	9:30 AM	25.0 °C	60.0 %	24.2 °C	23.4 °C	24.2 °C	0.17 m/s	583 ppm	0	-1	0	0.57 clo
6	9:45 AM	24.8 °C	66.0 %	24.0 °C	23.2 °C	24.0 °C	0.16 m/s	581 ppm	-1	-1	0	0.76 clo
7	10:05 AM	24.0 °C	69.0 %	23.9 °C	23.9 °C	23.9 °C	0.01 m/s	579 ppm	-1	0	-1	0.65 clo
8	10:20 AM	25.0 °C	67.0 %	23.9 °C	23.0 °C	24.0 °C	0.13 m/s	597 ppm	2	-2	-2	0.61 clo
9	10:35 AM	24.9 °C	65.0 %	23.9 °C	22.9 °C	23.9 °C	0.18 m/s	502 ppm	1	0	1	0.65 clo
10	10:55 AM	25.0 °C	65.0 %	23.9 °C	22.9 °C	23.9 °C	0.15 m/s	605 ppm	0	-2	-1	0.57 clo
11	11:25 AM	25.1 °C	63.0 %	23.7 °C	22.1 °C	23.6 °C	0.23 m/s	619 ppm	0	0	0	0.76 clo
12	11:40 AM	25.2 °C	63.0 %	23.7 °C	23.0 °C	24.1 °C	0.04 m/s	640 ppm	0	0	0	0.65 clo
13	2:30 PM	23.9 °C	69.0 %	23.1 °C	22.9 °C	23.4 °C	0.01 m/s	687 ppm	-1	0	0	0.76 clo
14	3:00 PM	23.5 °C	69.0 %	22.7 °C	21.7 °C	22.6 °C	0.28 m/s	680 ppm	-1	1	1	0.76 clo
15	3:30 PM	24.0 °C	66.0 %	22.7 °C	21.6 °C	22.8 °C	0.14 m/s	651 ppm	-1	1	1	0.55 clo
16	3:50 PM	25.8 °C	61.0 %	24.2 °C	22.7 °C	24.2 °C	0.16 m/s	637 ppm	1	-1	1	0.76 clo
								Mean Value ==>	**-0.1**	**-0.3**	**-0.1**	**0.67 clo**

Table 6-19: The corresponding results when the constant mode was applied in level 7 BHEUU as a controlled floor (15th September 2011)

No	Time	Dry Bulb Temperature	Relative Humidity	Globe Temperature	Mean Radiant Temperature	Operative Temperature	Air Velocity	CO2 Concentration	Thermal CV*	Airflow CV*	Humidity CV*	Clothing Insulation
1	8:30 AM	23.0 °C	76.0 %	22.6 °C	22.4 °C	22.7 °C	0.10 m/s	475 ppm	-1	0	-1	0.63 clo
2	8:50 AM	24.0 °C	69.0 %	23.9 °C	23.9 °C	23.9 °C	0.05 m/s	518 ppm	0	0	0	0.64 clo
3	9:00 AM	24.0 °C	69.0 %	23.7 °C	23.7 °C	23.8 °C	0.01 m/s	531 ppm	-1	0	0	0.60 clo
4	9:15 AM	23.0 °C	69.0 %	23.0 °C	23.0 °C	23.0 °C	0.04 m/s	565 ppm	-1	0	0	0.65 clo
5	9:25 AM	24.0 °C	73.0 %	23.1 °C	22.6 °C	23.3 °C	0.05 m/s	584 ppm	-1	-3	-1	0.63 clo
6	9:35 AM	24.0 °C	66.0 %	23.4 °C	23.1 °C	23.5 °C	0.05 m/s	628 ppm	-1	0	1	1.03 clo
7	9:50 AM	23.0 °C	69.0 %	23.5 °C	23.6 °C	23.3 °C	0.01 m/s	524 ppm	-1	0	0	0.93 clo
8	10:05 AM	23.0 °C	69.0 %	22.2 °C	21.8 °C	22.4 °C	0.04 m/s	605 ppm	-1	0	0	0.93 clo
9	10:20 AM	24.0 °C	66.0 %	23.7 °C	23.6 °C	23.8 °C	0.04 m/s	676 ppm	0	0	0	0.65 clo
10	10:30 AM	23.0 °C	69.0 %	23.6 °C	23.8 °C	23.4 °C	0.03 m/s	596 ppm	-1	0	1	0.65 clo
11	10:50 AM	23.5 °C	69.0 %	23.8 °C	24.0 °C	23.7 °C	0.05 m/s	621 ppm	-1	0	0	0.95 clo
12	2:25 PM	23.5 °C	69.0 %	24.2 °C	24.4 °C	23.9 °C	0.02 m/s	494 ppm	0	0	0	0.80 clo
13	2:40 PM	24.0 °C	69.0 %	23.8 °C	23.7 °C	23.9 °C	0.02 m/s	569 ppm	0	0	1	0.67 clo
14	2:50 PM	24.0 °C	69.0 %	24.1 °C	24.1 °C	24.1 °C	0.05 m/s	528 ppm	0	0	0	0.67 clo
								Mean Value ==>	**-0.6**	**-0.2**	**0.1**	**0.75 clo**

* CV stands for Comfort Vote on ASHRAE thermal sensational scale.

Table 6-20: The experiment results when the ramp mode was applied in level 7 BHEUU (20th September 2011)

No	Time	Dry Bulb Temperature	Relative Humidity	Globe Temperature	Mean Radiant Temperature	Operative Temperature	Air Velocity	CO2 Concentration	Thermal CV*	Airflow CV*	Humidity CV*	Clothing Insulation
1	8:30 AM	23.0 °C	69.0 %	23.9 °C	24.5 °C	23.7 °C	0.07 m/s	526 ppm	-1	0	0	0.64 clo
2	8:45 AM	23.0 °C	72.0 %	23.6 °C	23.9 °C	23.4 °C	0.04 m/s	531 ppm	-1	0	0	0.65 clo
3	9:00 AM	24.0 °C	73.0 %	23.9 °C	23.9 °C	23.9 °C	0.01 m/s	563 ppm	0	0	0	0.64 clo
4	9:15 AM	24.0 °C	69.0 %	24.0 °C	24.0 °C	24.0 °C	0.05 m/s	565 ppm	-2	0	-2	0.65 clo
5	9:30 AM	23.0 °C	69.0 %	23.8 °C	24.3 °C	23.6 °C	0.06 m/s	580 ppm	0	0	0	0.64 clo
6	9:40 AM	24.0 °C	77.0 %	23.9 °C	23.8 °C	23.9 °C	0.06 m/s	605 ppm	1	-1	0	0.64 clo
7	9:50 AM	25.0 °C	70.0 %	23.8 °C	23.4 °C	24.2 °C	0.02 m/s	650 ppm	-1	-1	-1	0.65 clo
8	10:05 AM	23.0 °C	72.0 %	23.5 °C	23.7 °C	23.4 °C	0.03 m/s	661 ppm	-1	0	0	0.93 clo
9	10:15 AM	24.0 °C	69.0 %	23.2 °C	22.7 °C	23.4 °C	0.06 m/s	652 ppm	0	-1	2	0.65 clo
10	10:30 AM	24.0 °C	69.0 %	23.5 °C	23.3 °C	23.7 °C	0.02 m/s	633 ppm	0	0	0	0.65 clo
11	2:37 PM	25.0 °C	63.0 %	24.0 °C	23.8 °C	24.4 °C	0.01 m/s	527 ppm	0	0	1	0.76 clo
12	2:50 PM	25.0 °C	63.0 %	24.2 °C	23.9 °C	24.4 °C	0.03 m/s	526 ppm	2	0	2	0.84 clo
13	3:10 PM	24.0 °C	69.0 %	24.2 °C	24.3 °C	24.2 °C	0.05 m/s	544 ppm	0	0	0	0.93 clo
								Mean Value ==>	**-0.2**	**-0.2**	**0.1**	**0.66 clo**

Table 6-21: The corresponding results when the constant mode was applied in level 6 BHEUU as a controlled floor (20th September 2011)

No	Time	Dry Bulb Temperature	Relative Humidity	Globe Temperature	Mean Radiant Temperature	Operative Temperature	Air Velocity	CO2 Concentration	Thermal CV*	Airflow CV*	Humidity CV*	Clothing Insulation
1	8:30 AM	25.2 °C	63.0 %	24.7 °C	24.4 °C	24.8 °C	0.05 m/s	513 ppm	0	0	-1	0.65 clo
2	8:40 AM	25.2 °C	62.0 %	24.8 °C	24.6 °C	24.9 °C	0.05 m/s	536 ppm	0	0	0	0.65 clo
3	8:50 AM	25.3 °C	62.0 %	24.6 °C	24.2 °C	24.7 °C	0.06 m/s	587 ppm	0	-1	0	0.65 clo
4	9:00 AM	24.8 °C	63.0 %	24.4 °C	24.2 °C	24.5 °C	0.07 m/s	599 ppm	0	-1	0	0.65 clo
5	9:15 AM	25.3 °C	63.0 %	24.4 °C	23.7 °C	24.5 °C	0.11 m/s	524 ppm	0	-1	0	0.86 clo
6	9:38 AM	25.0 °C	62.0 %	24.2 °C	23.6 °C	24.3 °C	0.11 m/s	579 ppm	0	0	0	0.65 clo
7	9:45 AM	24.0 °C	69.0 %	23.6 °C	23.4 °C	23.7 °C	0.05 m/s	648 ppm	0	-1	-1	0.95 clo
8	9:55 AM	25.1 °C	63.0 %	23.8 °C	23.4 °C	24.2 °C	0.02 m/s	587 ppm	0	-1	-1	0.61 clo
9	10:25 AM	24.9 °C	61.0 %	24.0 °C	23.3 °C	24.1 °C	0.12 m/s	637 ppm	0	1	-1	0.65 clo
10	10:55 AM	25.3 °C	61.0 %	24.0 °C	23.3 °C	24.3 °C	0.05 m/s	722 ppm	-1	0	0	0.68 clo
11	11:09 AM	24.8 °C	66.0 %	23.9 °C	23.2 °C	24.0 °C	0.10 m/s	693 ppm	0	-1	-1	0.57 clo
12	11:20 AM	24.3 °C	66.0 %	23.6 °C	23.4 °C	23.8 °C	0.02 m/s	631 ppm	1	-2	-1	0.76 clo
13	11:35 AM	23.0 °C	65.0 %	22.3 °C	19.8 °C	21.4 °C	2.40 m/s	652 ppm	0	0	0	0.76 clo
14	2:45 PM	25.6 °C	63.0 %	24.8 °C	24.3 °C	24.9 °C	0.08 m/s	578 ppm	1	-1	0	0.76 clo
15	3:00 PM	24.5 °C	66.0 %	23.5 °C	22.8 °C	23.7 °C	0.08 m/s	543 ppm	0	-1	0	0.76 clo
16	3:30 PM	23.8 °C	69.0 %	22.8 °C	22.3 °C	23.1 °C	0.04 m/s	588 ppm	0	0	0	0.76 clo
								Mean Value ==>	**0.1**	**-0.6**	**-0.4**	**0.71 clo**

* CV stands for Comfort Vote on ASHRAE thermal sensational scale.

Table 6-22: The experiment results when the cyclic mode was applied in level 7 BHEUU (22nd September 2011)

No	Time	Dry Bulb Temperature	Relative Humidity	Globe Temperature	Mean Radiant Temperature	Operative Temperature	Air Velocity	CO2 Concentration	Thermal CV*	Airflow CV*	Humidity CV*	Clothing Insulation
1	8:30 AM	23.0 °C	76.0 %	24.2 °C	24.6 °C	23.8 °C	0.02 m/s	595 ppm	0	-1	-1	0.63 clo
2	8:40 AM	24.0 °C	69.0 %	23.9 °C	23.9 °C	23.9 °C	0.01 m/s	584 ppm	1	-1	0	0.64 clo
3	9:00 AM	23.5 °C	69.0 %	23.7 °C	23.9 °C	23.7 °C	0.14 m/s	575 ppm	-1	0	0	0.65 clo
4	9:10 AM	24.0 °C	69.0 %	23.3 °C	23.1 °C	23.6 °C	0.01 m/s	603 ppm	0	0	0	0.93 clo
5	9:23 AM	23.0 °C	69.0 %	23.3 °C	23.4 °C	23.2 °C	0.02 m/s	626 ppm	0	0	0	0.93 clo
6	9:33 AM	24.5 °C	66.0 %	23.1 °C	22.4 °C	23.4 °C	0.05 m/s	628 ppm	0	0	0	0.65 clo
7	9:48 AM	23.5 °C	65.0 %	23.5 °C	23.5 °C	23.5 °C	0.02 m/s	624 ppm	-2	0	-1	0.65 clo
8	9:58 AM	23.0 °C	72.0 %	23.4 °C	23.5 °C	23.3 °C	0.02 m/s	629 ppm	0	-1	0	0.71 clo
9	10:15 AM	23.0 °C	69.0 %	22.9 °C	22.9 °C	22.9 °C	0.03 m/s	617 ppm	0	0	0	0.93 clo
10	10:30 AM	23.3 °C	69.0 %	22.9 °C	22.7 °C	23.0 °C	0.05 m/s	617 ppm	-1	0	1	0.65 clo
11	10:45 AM	24.0 °C	69.0 %	23.1 °C	22.8 °C	23.4 °C	0.02 m/s	625 ppm	1	-1	1	0.64 clo
12	2:30 PM	24.0 °C	66.0 %	23.6 °C	23.4 °C	23.7 °C	0.06 m/s	607 ppm	0	0	0	0.64 clo
13	2:45 PM	24.0 °C	66.0 %	23.8 °C	23.7 °C	23.8 °C	0.05 m/s	629 ppm	0	0	0	0.65 clo
14	2:55 PM	23.0 °C	69.0 %	23.6 °C	24.3 °C	23.7 °C	0.25 m/s	636 ppm	-1	0	0	0.93 clo
								Mean Value ==>	**-0.2**	**-0.3**	**0.0**	**0.73 clo**

Table 6-23: The corresponding results when the constant mode was applied in level 6 BHEUU as a controlled floor (22nd September 2011)

No	Time	Dry Bulb Temperature	Relative Humidity	Globe Temperature	Mean Radiant Temperature	Operative Temperature	Air Velocity	CO2 Concentration	Thermal CV*	Airflow CV*	Humidity CV*	Clothing Insulation
1	8:25 AM	25.0 °C	63.0 %	24.5 °C	24.1 °C	24.5 °C	0.12 m/s	570 ppm	0	-1	-1	0.65 clo
2	8:40 AM	25.5 °C	63.0 %	24.7 °C	24.2 °C	24.9 °C	0.06 m/s	565 ppm	0	0	0	0.65 clo
3	9:00 AM	24.8 °C	67.0 %	24.3 °C	24.2 °C	24.5 °C	0.01 m/s	616 ppm	0	0	0	0.65 clo
4	9:10 AM	24.5 °C	67.0 %	23.9 °C	23.6 °C	24.0 °C	0.06 m/s	598 ppm	0	-1	0	0.65 clo
5	9:20 AM	25.0 °C	63.0 %	23.9 °C	22.9 °C	23.9 °C	0.15 m/s	608 ppm	1	-1	0	0.57 clo
6	9:35 AM	24.8 °C	67.0 %	24.2 °C	23.9 °C	24.3 °C	0.06 m/s	655 ppm	2	-1	1	0.65 clo
7	9:50 AM	25.0 °C	67.0 %	23.9 °C	23.1 °C	24.0 °C	0.10 m/s	642 ppm	0	0	0	0.76 clo
8	10:10 AM	25.4 °C	63.0 %	24.2 °C	23.4 °C	24.4 °C	0.09 m/s	591 ppm	0	0	0	0.61 clo
9	10:25 AM	24.0 °C	69.0 %	23.4 °C	23.1 °C	23.5 °C	0.05 m/s	634 ppm	0	0	0	0.58 clo
10	10:40 AM	23.7 °C	69.0 %	23.1 °C	22.7 °C	23.2 °C	0.08 m/s	669 ppm	0	0	0	0.76 clo
11	10:55 AM	24.5 °C	67.0 %	23.2 °C	22.6 °C	23.5 °C	0.04 m/s	658 ppm	0	0	-1	0.76 clo
12	11:20 AM	24.8 °C	63.0 %	23.5 °C	23.1 °C	23.9 °C	0.02 m/s	640 ppm	1	-1	0	0.57 clo
13	11:40 AM	24.8 °C	63.0 %	23.9 °C	23.7 °C	24.2 °C	0.01 m/s	645 ppm	1	-1	-1	0.65 clo
14	2:17 PM	22.6 °C	72.0 %	22.0 °C	21.3 °C	21.9 °C	0.25 m/s	557 ppm	-1	2	-2	0.76 clo
15	2:50 PM	24.5 °C	67.0 %	24.1 °C	23.8 °C	24.1 °C	0.12 m/s	562 ppm	0	0	0	0.65 clo
16	3:15 PM	24.6 °C	66.0 %	23.9 °C	23.5 °C	24.1 °C	0.05 m/s	632 ppm	0	0	0	0.65 clo
								Mean Value ==>	**0.3**	**-0.3**	**-0.3**	**0.66 clo**

* CV stands for Comfort Vote on ASHRAE thermal sensational scale.

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