INVESTIGATING THE FEASIBILITY OF IMPLEMENTING GEOTHERMAL COOLING SYSTEM IN TROPICAL COUNTRIES

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A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering (Mechanical)

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"INVESTIGATING THE FEASIBILITY OF IMPLEMENTING GEOTHERMAL COOLING SYSTEM IN TROPICAL COUNTRIES"** was prepared by **WONG CHU VUI** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering (Mechanical) at Universiti Tunku Abdul Rahman.

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ABSTRACT

The project aims to evaluate the feasibility of implementing geothermal cooling system in tropical countries. Due to the hot environment in tropical countries, the demand of air conditioner increases substantially. The electrical consumption increases as the demand of air conditioner increases. It is important to find alternatives in order to reduce the electrical consumption. Geothermal cooling system is not widely used in tropical countries due to lack of development in this field. The objectives of this experiment were to determine the ideal air speed to compensate for increased air and radiant temperature and to determine the weakness and to provide recommendation for the existing geothermal cooling system. Graphical method and Standard Effective Temperature (SET) method were used in order to determine the optimum air speed as the supply air temperature to the space was fairly high due to the hot ambient temperature. The mean room temperature was measured at 33.5 degree Celsius with an air speed of 0.2 m/s. Several simulations were carried out and it was concluded that the optimum velocity to compensate the increased operative temperature is 3 m/s. The optimum flow rate for the experiment was calculated at 120 m3/hr at 10 air change rate and the ideal pipe diameter was 60 mm. Jet diffuser shall be installed at the supply air inlet as it would enhance the flow distribution. In conclusion, the geothermal cooling system for the prototype performed below average due to the unusual hot ambient temperature. The supply air temperature obtained is 3 degree Celsius higher than the predicted. Therefore, it can be concluded that it is feasible to implement geothermal cooling system in tropical countries provided that the optimum velocity is achieved and the underground pipe diameter is properly designed.

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LIST OF SYMBOLS / ABBREVIATIONS

c_p	specific heat capacity, J/(kg·K)
h	height, m
K_d	discharge coefficient
M	mass flow rate, kg/s
P	pressure, kPa
P_b	back pressure, kPa
R	mass flow rate ratio
T	temperature, K
v	specific volume, m^3
α	homogeneous void fraction
η	pressure ratio
ρ	density, kg/m^3
ω	compressible flow parameter
ID	inner diameter, m
MAP	maximum allowable pressure, kPa
MAWP	maximum allowable working pressure, kPa
OD	outer diameter, m
RV	relief valve

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CHAPTER 1

INTRODUCTION

1.1 Background

As household incomes rise around the world and global temperatures go up, it was witnessed that the electricity consumption increase tremendously due to the use of air conditioners. The sales of air conditioners grow exponentially especially in tropical countries. For example, the sales of air conditioners in China have nearly doubled over the last five years. In 2013 alone, there were 64 million units sold, more than eight time many as were sold in the United States (Davis and Gertler, 2015). Direct expansion (DX) and variable refrigerant flow (VRF) type air conditioners are commonly used for residential development while chilled water system (CHW) are commonly used for commercial development.

According to World Watch Institute, buildings consumed about 40% of the world’s energy production. As a result, about 40% of the sulphur dioxide and nitrogen oxide were produced which lead to the formation of smog and acid rain. Building energy used also produces 33% of all annual carbon dioxide emission which significantly contribute to the climate change brought about by the accumulation of heat-trapping gas (Mohammad, 2012).

The world’s energy consumption could be greatly reduced if the people begin to rely on renewable energy. Typically, renewable energy are classified into five categories - solar power, wind power, hydroelectric power, biomass and geothermal energy. Each category represents a different method of generating electricity from natural resources that are replenished as part of the normal life cycle.

Geothermal energy can be further classified into shallow and deep geothermal system. Shallow geothermal system is a sustainable system of extracting heat from the ground for heating purposes and removing surplus heat energy to the ground for cooling purposes (Thomas, Claus and Anker, n.d.) while deep geothermal system is the use of steam from the Earth to run power stations, which turn steam into electricity. The subsoil is a good heat sink during the summer time and good heat source during the winter time. In tropical countries, the subsoil temperature at a depth of 1.5 meter remains constant throughout the year, which is 27.6 degree Celsius (Tan, 2013).

1.2 Geothermal Cooling System

In general, the underground loop can be categorized into two main category – open and closed loop. The selection of underground loop is crucial as it would affect the overall efficiency of the geothermal system. Each category has their own characteristic and is further discussed in subsection 1.21, 1.22 and 1.23.

1.2.1 Closed Loop – Horizontal

If the land size is permissible, horizontal underground loops as shown in Figure 1. It is commonly used for landed residential development due to the ease of installation and cost effectiveness. The underground loops are laid in the trenches and in general, the depth of the trenches are 1.5 m to 2 m and the length of the underground loops are 30 m to 120 m.

Figure 1.1: Horizontal Loop (Geothermalmontana, 2015)

1.2.2 Closed Loop – Vertical

Vertical loops as shown in Figure 2 are widely used in urban areas due to land constraint and terrible soil condition (Geothermalmontana, 2015). This method is preferred when the creation of trenches are impossible. Drilling equipment is required to bore small-diameter holes from 30 m to 120 m, 6 m apart. Pipes place in these holes are connected at the bottom with a u-bend to form a loop. Vertical loops are generally more expensive to install, but require less piping than horizontal loops because the earth temperature is warmer and more stable below. As such, vertical loops are generally used for heating application.

Figure 1.2: Vertical Loop (Geothermalmontana, 2015)

1.2.3 Closed Loop – Lake / Pond

Lake or pond loops as shown in Figure 3 are not commonly used due to the absence of water. It can only be used if there is adequate water that has minimum volume, depth and quality (Geothermalmontana, 2015). The pipe is run underground from the building to the water and coiled into circles deep under the surface of water to prevent freezing.

Figure 1.3: Lake/Pond Loop (Geothermalmontana, 2015)

1.3 Tropical Countries

The tropical zone is located in between 23.5 degree north and 23.5 degrees south of the equator as shown in Figure 1.4. The word tropical means hot and humid and the average temperature and humidity for the tropical countries are around 28 degree Celsius to 33 degree Celsius with a humidity of 50% to 80% depending on the time.

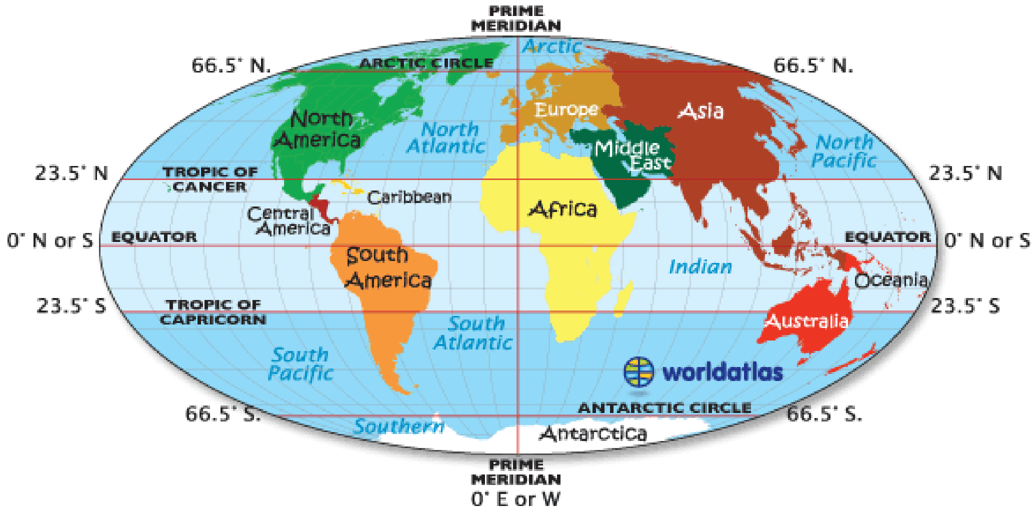

Figure 1.4: Earth Climate (Geothermalmontana, 2015)

1.4 Problem Statements

There are several factors that affect the feasibility of implementing geothermal cooling system in tropical countries. The factors are initial setup cost, operating cost and comfort level.

Initial setup cost is the main concern for most people. The initial setup cost shall include excavation, backfill, supply and installation of underground loop, testing and commissioning of underground loop and etc. The design and installation of the geothermal system shall be carried out by expert and as such, the professional fee shall be included in the initial setup cost.

The operating costs which are related to the rate of return and coefficient of performance (COP) of the system appears to be the second concern by most people. The operating cost is inversely proportional to coefficient of performance (COP) and rate of return (ROR). The higher the coefficient of performance (COP), the lower the operating cost.

The thermal comfort appears to be the least concern, but the most important factor. The thermal comfort is related to the supply air temperature, air flow rate and air speed provided to the space. The supply air temperature is direct proportional to the air speed and vice versa. Several key parameters such as clothing insulation value, metabolic rate, humidity and etc shall be identified prior to the commencement of the experiment.

1.5 Aim and Objectives

The aim of this project is to study the feasibility of implementing geothermal cooling system in tropical countries.

1. To determine air speed required to offset increased air and radiant temperature for thermal comfort.
2. To determine weakness in the existing geothermal cooling system and to provide recommendation to enhance the overall system performance.

CHAPTER 2

LITERATURE REVIEW

2.1 Thermal Comfort

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment (ASHRAE Standard 55, 2010). It is difficult to satisfy everyone in a space as everyone is different in terms of physiologically and psychologically. For example, a person sat still in an open office with coat might feel cold whilst someone sat still in the same open office without coat might feel hot. Since it is difficult to satisfy everyone in a space, an environment can be said to achieve reasonable comfort when at least 80% of its occupants are thermally comfort. Thermal comfort can be assessed by surveying occupants to find out whether they are satisfied or dissatisfied with the thermal environment. Thermal sensation scale ranging from +3 (hot), +2 (warm), +1 (slightly warm), 0 (neutral), -1 (slightly cool), -2 (cool), -3 (cold) was developed by ASHRAE for use in quantifying people's thermal sensation.

There are six primary factors that must be addressed when defining conditions for thermal comfort. Metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and humidity (ASHRAE Standard 55, 2010). The indoor comfort temperature for human during summer is 23.9 degree Celsius to 25.6 degree Celsius with 50% to 55% relative humidity (Soong, YZ, 2013).

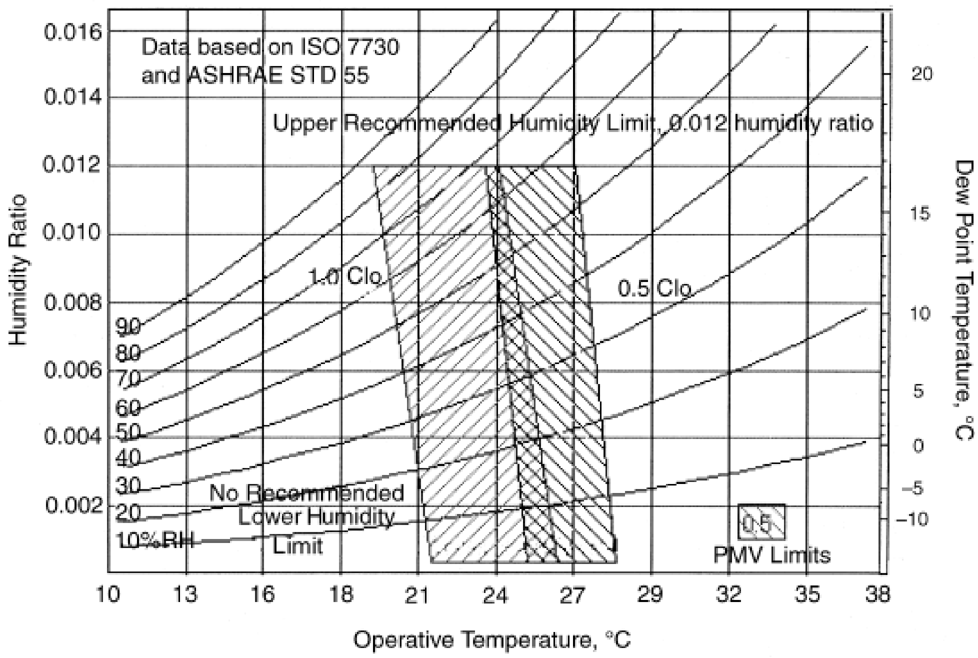

Figure 2.1: Opetive Temperature vs Humidity Ratio (ASHRAE Standard 55, 2010)

2.2 Coefficient of Performance (COP)

The definition of coefficient of performance (COP) is the ratio of cooling provided to electrical energy consumed. Coefficient of performance (COP) is derive as in Equation 2.1. Higher coefficient of performance (COP) equate to lower operating cost.

$$COP_{cooling} = \frac{Q_c}{W} \tag{2.1}$$

Where

Q_c = heat removal from the reservoir

W = electrical input

From Equation 2.1, the heat removed from the reservoir is direct proportional to the coefficient of performance (COP). For Example, a coefficient of performance (COP) of 3 indicates that 1kW of electrical input can generate 3kW of cooling load.

The unit of coefficient of performance (COP) is dimensionless and hence, it represents the efficiency of the object. The coefficient of performance of a conventional direct expansion (DX) split unit is at around 3.3.

2.3 Ideal Depth of Underground Loop

The ground temperature is important when designing geothermal cooling system. The performance of geothermal cooling system is highly dependent on the ground temperature. The underground loop shall be buried in depth that there is no direct sunlight as the solar radiation of the sunlight would affect the heat transfer rate of the underground loop. The ground temperature at the depth of 1.2 m is around 26 degree Celsius to 28 degree Celsius (Tan, 2013).

Georgios and Soteris, 2004 claimed that the earth temperature is quite constant at the depth of 1.5 m to 20 m. The temperature rises up as it goes deeper. Vibhute, 2013 claimed that the suitable depth for underground loop is located in between 1.2 m to 1.8 m. Sanusi, Li and Zamri (2014) conducted an experiment to study the potential of geothermal cooling system in tropical country. The ambient temperature, ground surface temperature and ground temperature at the depth of 1 m to 5 m were measured. The results of this experiment shows that the soil temperature increases with the depth up to 5 m. From the experiment, it was concluded that the ideal depth for underground pipe is at around 1 m as the maximum differences in between the ambient temperature and the soil temperature is at around 6.5 degree Celsius.

Nik, Kasran and Hassan (1986) shows that the shading effect plays an important role to the ground temperature. The soil temperature under shade was found to be lower in temperature by about 4 degree Celsius to 6 degree Celsius generally. It was concluded that the shading effect caused a lower soil temperature. The heat rejection rate increases and the supply air temperature to the space is lower. As such, it is possible to achieve thermal comfort if the experiment area is heavily shaded.

2.4 Underground Piping Material

There are several key factors that need to be considered before selecting the underground pipe material. It is important as the pipe buried underground will never be seen again. The underground pipe material must be high chemical and corrosion resistance to prevent degradation. In some case where price is not a major concern, copper pipes or galvanized steel are used due to their excellent heat transfer ability, rigidity, chemical resistance and corrosion resistance. The most common types of underground pipe are polyethylene (PE), high density polyethylene (HDPE) and polyvinyl chloride (uPVC).

Polyethylene (PE) pipe can be manufactured to be straight or curved, giving versatility to be used as not only traditional wells but also in a slinky configuration. Polyethylene (PE) pipe cannot be glued and connected like other types of pipe. It must be heat fused by a fusion machine. The advantages of polyethylene (PE) pipe are good chemical resistance, average pressure rating and great sealed loop. The only disadvantage is the price as it is more expensive than polyvinyl chloride (uPVC) pipe.

High density polyethylene (HDPE) pipe is considered to be the first choice for geothermal underground pipe. It has better rigidity, thermal properties, great pressure rating, and chemical resistance. Most manufacturers provide a warranty of 50 to 100 years. The only disadvantage is the price as it is more expensive than polyvinyl chloride (uPVC) and polyethylene (PE) pipe.

Polyvinyl chloride (uPVC) pipe is commonly used in residential development, typically for sanitary plumbing services. It has good chemical resistance. Polyvinyl chloride (uPVC) is preferred for most plumbers due to the ease of installation and low price. It is not a great sealed loop as the joint method is not heat fused joint.

2.5 Underground Pipe Diameter

The underground pipe diameter is one of the key element when it comes to geothermal cooling system. It should be properly design in order to achieve the highest efficiency. An oversized of underground pipe is a wastage as the cooling capacity provided is not fully utilized whilst the cooling load provided to the space is insufficient if undersized of underground pipe occurred. It is almost impossible to redo the piping as extensive works such as excavation, backfilling are required and the process is time consumption.

Peretti, et al, 2013 claimed that the typical pipe diameters for underground pipes are normally around 100 mm to 300 mm for non-commercial building and 1000 mm for commercial building. The cooling capacity provided is direct proportional to the underground pipe diameter as there are more heat rejected to the ground (sink). The underground pipe design shall be carried out by competent engineer in order to minimize the oversized or undersized phenomena.

Mongkon, et al, 2014 claimed that system performance and heat rejection rate provided is direct proportional to the underground pipe diameter and length. The system coefficient of performance (COP) and heat rejection rate increase tremendously with the increase of underground pipe diameter. It was found that the air velocity of the system decreases as the underground pipe diameter increases, provided that the mass flow rate remained constant throughout the experiment.

CHAPTER 3

METHODOLOGY

3.1 Experiment Setup and Location

The experiment was conducted at University Tunku Abdul Rahman Sungai Long Campus. The globe coordinate is 3.040191 latitude and 101.79444 longitude and the exact location of the experiment is circled in red and shown in Figure 3.1.

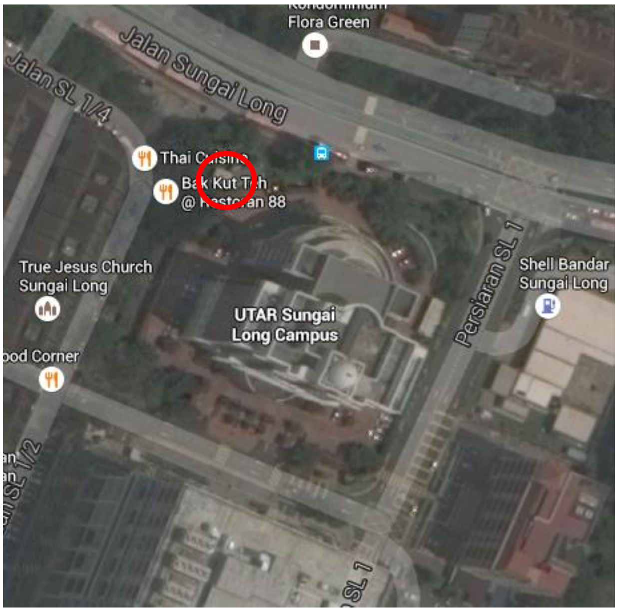

Figure 3.1: Plan View of the Experiment Location

The experiment was carried out in room 1 as indicated in Figure 3.3 and the room dimension is 3,000 mm in length, 1,700 mm in width and 2,300 mm in height. As the experiment room is located inside a metal cabin, plaster ceilings and walls were installed to reduce the solar heat gain from the ambient.

Figure 3.2: External View of the Experiment Room

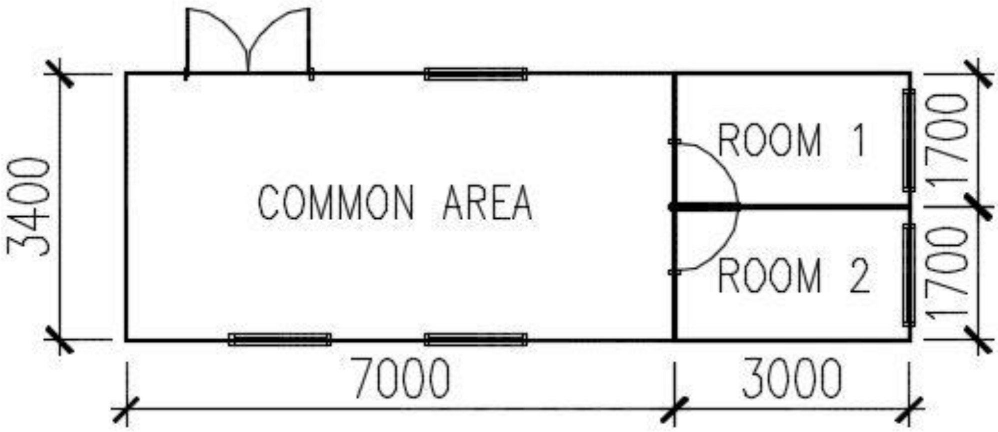

Figure 3.3: Room Configuration of Metal Cabin

3.2 On-site Measurement of Room and Ambient Temperature

Three thermosensors were installed in the experiment room as indicated in Figure 3.4. Thermosensors T_2 was placed approximate 400 mm from the supply air inlet as shown in Figure 3.5. Thermosensors T_3 was installed approximate 200 mm from the return air inlet and T_c was installed at the centre of the room as indicated in Figure 3.6.

The room temperature are recorded on hourly basis from 11:00 am to 5:00 pm by the thermosensors as indicated in Figure 3.5 and Figure 3.6 whilst the ambient temperature and humidity are captured by the sling psychrometer as shown in Figure 3.7. The results obtained from the thermosensors are then further verified by the sling psychrometer. The experiment were carried out twice, first is without geothermal cooling system and second is with geothermal cooling system. Data are collected, tabulated, analysed and discussed in Chapter 4.

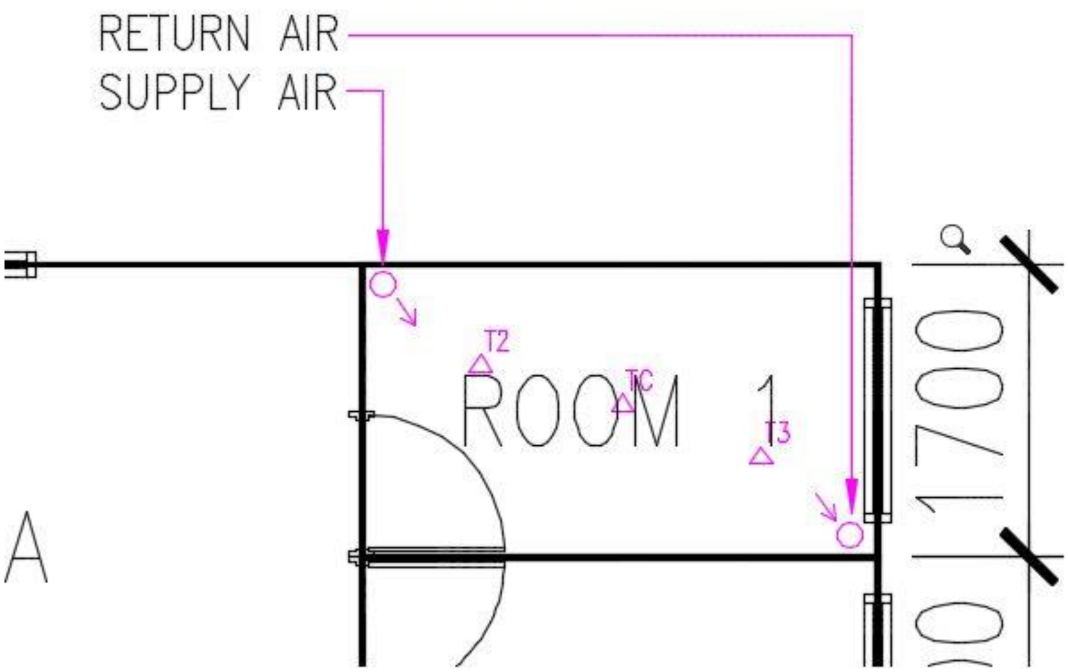

Figure 3.4: Room 1 Layout

Figure 3.5: Location of Thermosensors T_2

Figure 3.6: Location of Thermosensors T_3 and T_c

Figure 3.7: Sling Psychrometer

3.3 Measurement of Air Velocity

The supply air velocity, return air velocity and air velocity at the centre of the room are recorded by handheld anemometer as indicated in Figure 3.8 on hourly basis from 11:00 am to 5:00 pm. The point of measurements are taken at T_2, T_3 and T_c as indicated in Figure 3.5 and Figure 3.6. In order to identify and understand the thermal condition in the room, the velocity profile shall be identified. The results are then tabulated, analysed and discussed in Chapter 4. The technical specification of the anemometer can be found at Appendix B.

Figure 3.8: Anemometer

3.4 Measurement of Thermal Comfort

The thermal condition of a room can be identified by using graphical method and Standard Effective Temperature (SET) method and is further elaborate under section 3.4.1 and 3.4.2.

3.4.1 Graphical Method

Graphical method can be used when the air speed is less than 0.8 m/s. Figure 3.9 is used when the air speed is lower than 0.2 m/s and Figure 3.10 is used when the air speed is more than 0.2 m/s and less than 0.8 m/s. The operative temperature, metabolic rate and clothing insulation shall be identified as the graphical method can only cater for 1.0 to 1.3 metabolic rate and 0.5 to 1.0 clothing insulation value. There are two regions in Figure 3.10. The dark grey area shall be used if the occupants are able to control the local air speed whilst the light grey area shall be used if the control of the local air speed is not provided to the occupants.

Based on Figure 3.10 and Figure 3.11, the clothing insulation value and metabolic rate is set at 0.65 and 1.1 respectively as the occupants in the room are working adults and mainly doing office work. The working attire is assumed to be long sleeve shirt, trousers, socks and shoes.

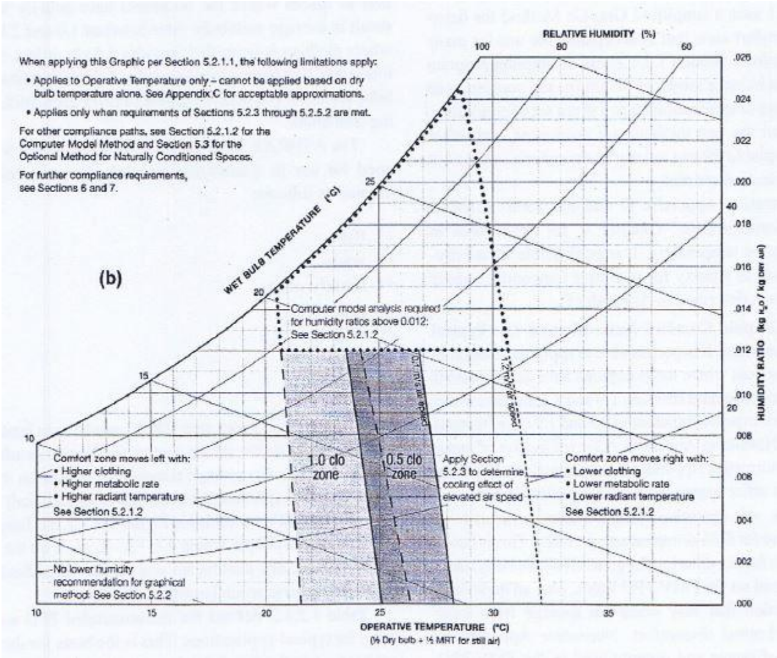

Figure 3.9: Graphic Comfort Zone Method: Acceptable range of Operative Temperature and Humidity for Spaces (ASHRAE Standard 55, 2010)

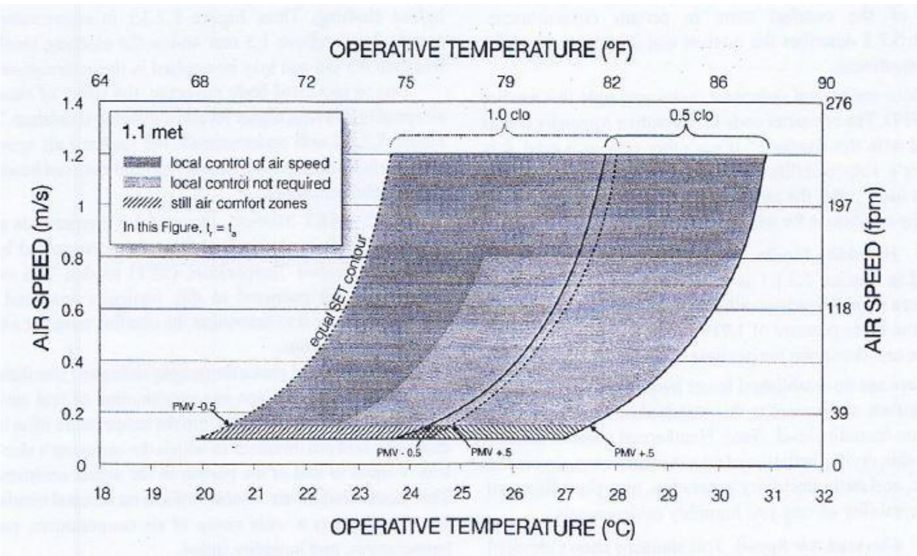

Figure 3.10: Acceptable Range of Operative Temperature and Air Speeds for the Comfort Zone (ASHRAE Standard 55, 2010)

TABLE A1 Metabolic Rates for Typical Tasks

Activity	Metabolic Rate		
	Met Units	W/m^2	(Btu/h·ft^2)
Resting			
Sleeping	0.7	40	(13)
Reclining	0.8	45	(15)
Seated, quiet	1.0	60	(18)
Standing, relaxed	1.2	70	(22)
Walking (on level surface)			
0.9 m/s, 3.2 km/h, 2.0 mph	2.0	115	(37)
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	(48)
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	220	(70)
Office Activities			
Reading, seated	1.0	55	(18)
Writing	1.0	60	(18)
Typing	1.1	65	(20)
Filing, seated	1.2	70	(22)
Filing, standing	1.4	80	(26)
Walking about	1.7	100	(31)
Lifting/packing	2.1	120	(39)

Figure 3.11: Metabolic Rates for Typical Tasks (ASHRAE Standard 55, 2010)

TABLE B1

Clothing Insulation Values for Typical Ensembles*

Clothing Description	Garments Included†	I_{cl}, (clo)
Trousers	1) Trousers, short-sleeve shirt	0.57
	2) Trousers, long-sleeve shirt	0.61
	3) #2 plus suit jacket	0.96
	4) #2 plus suit jacket, vest, T-shirt	1.14
	5) #2 plus long-sleeve sweater, T-shirt	1.01
	6) #5 plus suit jacket, long underwear bottoms	1.30
Skirts/Dresses	7) Knee-length skirt, short-sleeve shirt (sandals)	0.54
	8) Knee-length skirt, long-sleeve shirt, full slip	0.67
	9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater	1.10
	10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket	1.04
	11) Ankle-length skirt, long-sleeve shirt, suit jacket	1.10
Shorts	12) Walking shorts, short-sleeve shirt	0.36
Overalls/Coveralls	13) Long-sleeve coveralls, T-shirt	0.72
	14) Overalls, long-sleeve shirt, T-shirt	0.89
	15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms	1.37
Athletic	16) Sweat pants, long-sleeve sweatshirt	0.74
Sleepwear	17) Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks)	0.96

Figure 3.12: Clothing Insulation Values for Typical Ensembles (ASHRAE Standard 55, 2010)

3.4.2 Standard Effective Temperature (SET) Method

The Standard Effective Temperature (SET) method shall be used if the air velocity is more than 0.8 m/s. The Standard Effective Temperature (SET) model uses a thermophysiological simulation of the human body to reduce any combination of real environmental and personal variables into the temperature of an imaginary standard environment in which the occupant's skin heat loss is equal to that of the person in the actual environment (ASHRAE Standard 55, 2010). This model enables air velocity effects on thermal comfort to be related with a wide range of applications, radiant temperatures and humidity ratios. A sample for thermal comfort tool is shown in Figure 3.13.

The procedures for the Standard Effective Temperature (SET) simulation are as follows:-

1. Enter the air temperature, radiant temperature, relative humidity, clo value and met rate from Chapter 3 section 3.2 and 3.3 and Figure 3.10 and Figure 3.11.
2. Uncheck the local air speed control.
3. Set the elevated air velocity at 0.2 m/s, 0.8 m/s, 3 m/s, 4 m/s, 5m/s and 6m/s.
4. Record the calculated value for Standard Effective Temperature (SET) in the output data.
5. Reduce the air speed to 0.2 m/s.
6. The Standard Effective Temperature (SET) will be different from the previous value.
7. Calculate the difference between the two Standard Effective Temperature (SET) values.
8. The difference is the cooling effect of the elevated air speed.

Besides Standard Effective Temperature (SET) value, the Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), Sensation, dry bulb temperature, cooling effect and compliance to ASHRAE Standard 55, 2010 are recorded, tabulated, analysed and discussed in Chapter 4. Additional information such as humidity ratio, enthalpy and etc can be obtained from the psychrometric chart.

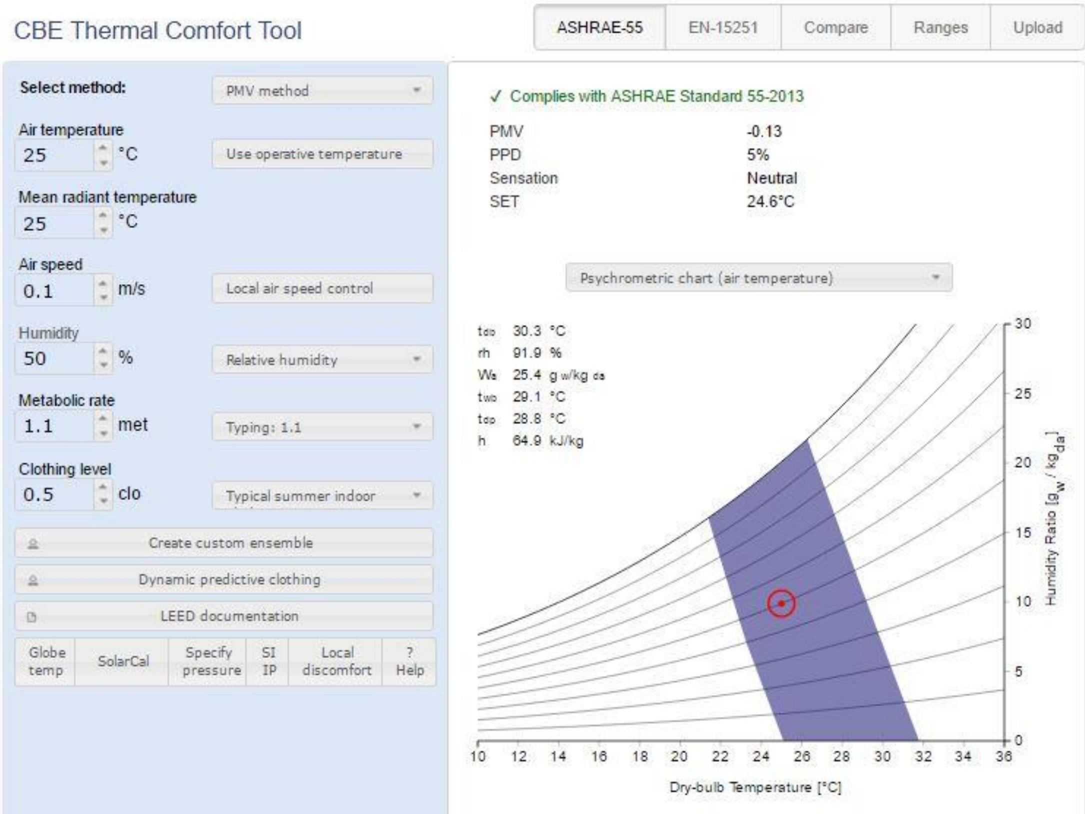

Figure 3.13: Sample of Thermal Comfort Tool

3.5 Underground Pipe Diameter

It is important to determine the underground pipe size as the heat transfer process occurred here. The mass flow rate required is first identified using Equation 3.1 prior to the calculation of pipe size.

$$\dot{M} = V \times ACH \qquad (3.1)$$

Where

$\dot{M}$ = Mass flow rate required for the room

V = Volume of the experiment room

ACH = Air change rate required by the room

$$\dot{Q} = A \times V \qquad (3.2)$$

where

$\dot{Q}$ = Mass flow rate going into underground loop

A = Area of underground pipe

V = Air velocity in the underground pipe

The underground pipe diameter is calculated by using Equation 3.2. The result is shown on Chapter 4 Section 4.3.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Room Temperature Profile

As mentioned in Chapter 3 section 3.2, the room temperature profile was recorded on hourly basis from 11:00 am to 5:00 pm. The ambient temperature (T_a), temperature at the centre of the room (T_c), supply air temperature (T_2) and return air temperature (T_3) were captured by various thermosensors at different locations as shown in Figure 3.4.

4.1.1 Room Temperature Profile without Geothermal Cooling System

This section describes the room temperature profile without geothermal cooling system. It is important to identify the room temperature profile prior to the commencement of the experiment. The room temperature profile without geothermal cooling system was tabulated in Table 4.1 and graphically presented in Figure 4.1.

Table 4.1: Room Temperature Profile (Without Geothermal Cooling System)

Description / Time	Ambient Temperature, T_a	Centre of the Room, T_c	Supply Air Temperature, T_2	Return Air Temperature, T_3
11:00 AM	34.1	30.2	31.9	31.1
12:00 PM	35.3	31.6	34.2	33.2
01:00 PM	37.3	33.2	37.1	36.3
02:00 PM	37.0	34.3	37.9	37.0
03:00 PM	36.4	35.3	38.1	37.5
04:00 PM	35.7	36.0	39.0	38.1
05:00 PM	34.6	35.7	38.0	37.1
Max Temperature	37.3	36.0	39.0	38.1
Min Temperature	34.1	30.2	31.9	31.1
Temperature Different	3.2	5.8	7.1	7.0

From Table 4.1 and Figure 4.1, it is observed that the ambient temperature rose gradually from 34.1 degree Celsius and reached its peak at 37.3 degree Celsius at 1:00 pm. The ambient temperature dropped soon after that whilst the temperature at the centre of the room, supply air temperature and return air temperature continued to rise and reached the peak at 4:00 pm. The temperature at the centre of the room, supply air temperature and return air temperature decreased linearly after 4:00 pm.

From Figure 4.1, a lagging phenomenon can be clearly seen. Despite that the ambient temperature decreased, the temperature at the centre of the room, supply air temperature and return air temperature continued to rise. The above phenomenon occurred due to the existence of plaster ceiling and wall which act as thermal insulator. The heat loss from the room to the ambient is slow as the plaster ceiling and wall is still hot. The heat is accumulated in the room and hence the temperature climbed steadily.

There are two main factors contributing to the risen of temperature of the room, namely heat transfer and lack of ventilation system. Heat transfer occurs when there is a temperature gradient across a body. In this case, the energy is transferred from the ambient to the room in the form of conduction, convection and solar radiation.

The absence of passive and active ventilation system is the secondary factor that caused the elevating of indoor temperature. Passive ventilation system is referring to a building design approach that focuses primarily on heat control and heat dissipation in a building in order to improve the indoor thermal comfort with low energy consumption. It uses natural outside air movement and pressure differences to both passively cool and ventilate a building. Design strategies include wind ventilation, the stack effect and night purge ventilation. Active ventilation system is referring to a mechanical ventilation system. Such system include the usage of exhaust fan to circulate the indoor air with a certain air change requirement.

Without the geothermal cooling system, there is no air movement in the room and hence, thermal comfort does not exist at all as the room operative temperature recorded value from 30.2 degree Celsius to 36.0 degree Celsius. According to ASHRAE Standard 55, 2010, the maximum operative temperature for thermal comfort shall fall in between 23.9 degree Celsius to 25.6 degree Celsius with a minimum air speed of 0.15 m/s. The occupants in the room would definitely feel hot as there is no air movement in the room at all.

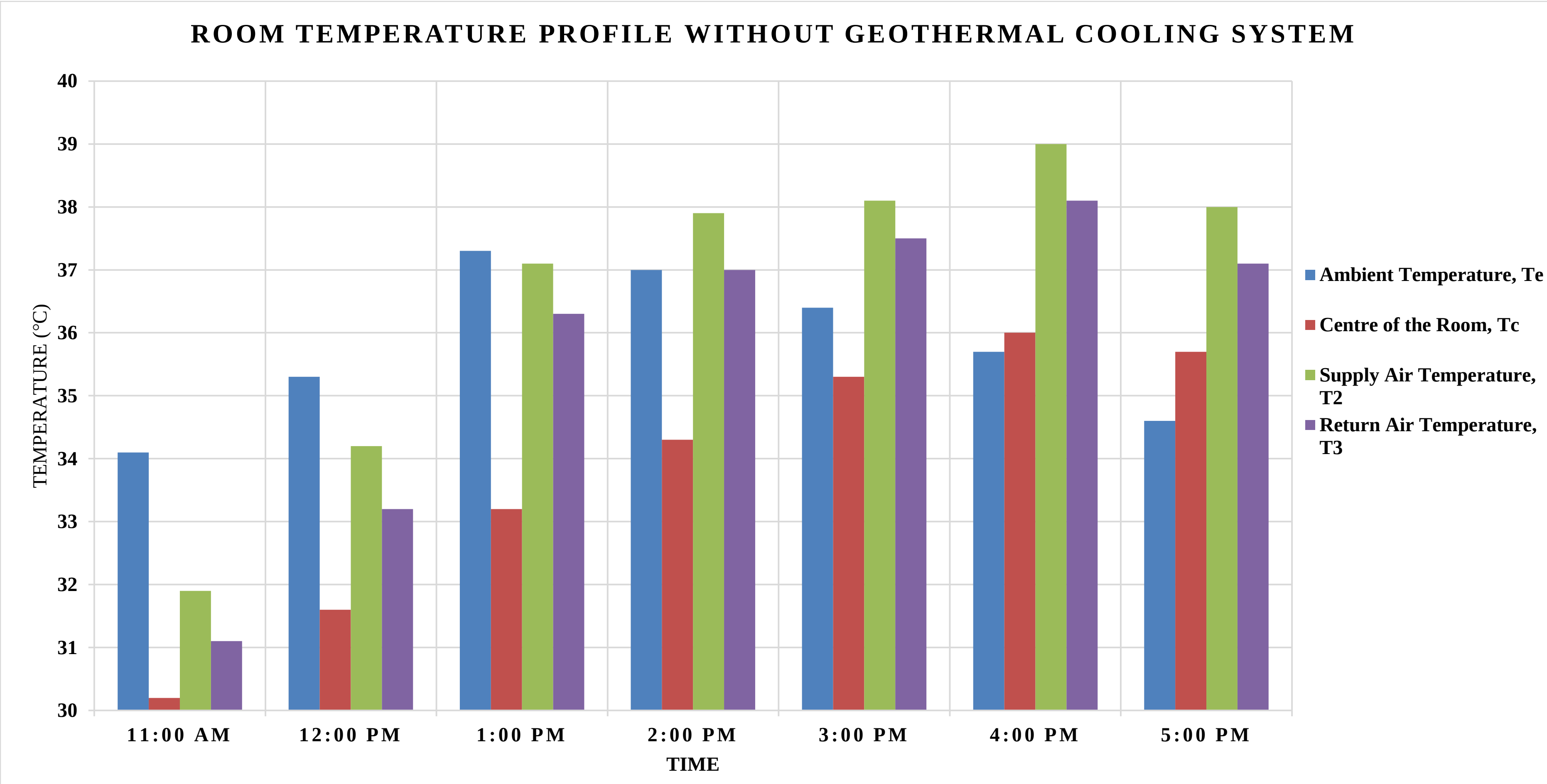

Figure 4.1: Room Temperature Profile without Geothermal Cooling System

4.1.2 Room Temperature Profile with Geothermal Cooling System

The room temperature profile with geothermal cooling system is tabulated in Table 4.2 and graphically presented in Figure 4.2.

Table 4.2: Room Temperature Profile with Geothermal Cooling System

Description / Time	Ambient Temperature, T_e	Centre of the Room, T_c	Supply Air Temperature, T_2	Return Air Temperature, T_3
11:00 AM	34.1	30.1	30.9	30.2
12:00 PM	35.3	31.9	32.1	31.8
01:00 PM	37.3	32.8	32.2	33.1
02:00 PM	37.0	34.2	34.2	34.0
03:00 PM	36.4	34.8	34.5	34.2
04:00 PM	35.7	35.3	35.0	34.9
05:00 PM	34.6	35.5	35.1	34.9
Max Temperature	37.3	35.5	35.1	34.9
Min Temperature	34.1	30.1	30.9	30.2
Temperature Different	3.2	5.4	4.2	4.7

From Table 4.2 and Figure 4.2, it is observed that the ambient temperature rose gradually from 34.1 degree Celsius and reached its peak at 37.3 degree Celsius at 1:00 pm. The ambient temperature dropped soon after that whilst the temperature at the centre of the room, supply air temperature and return air temperature continued to rise. It can be clearly seen that results of temperature at the centre of the room, supply air temperature and return air temperature are different from Table 4.1.

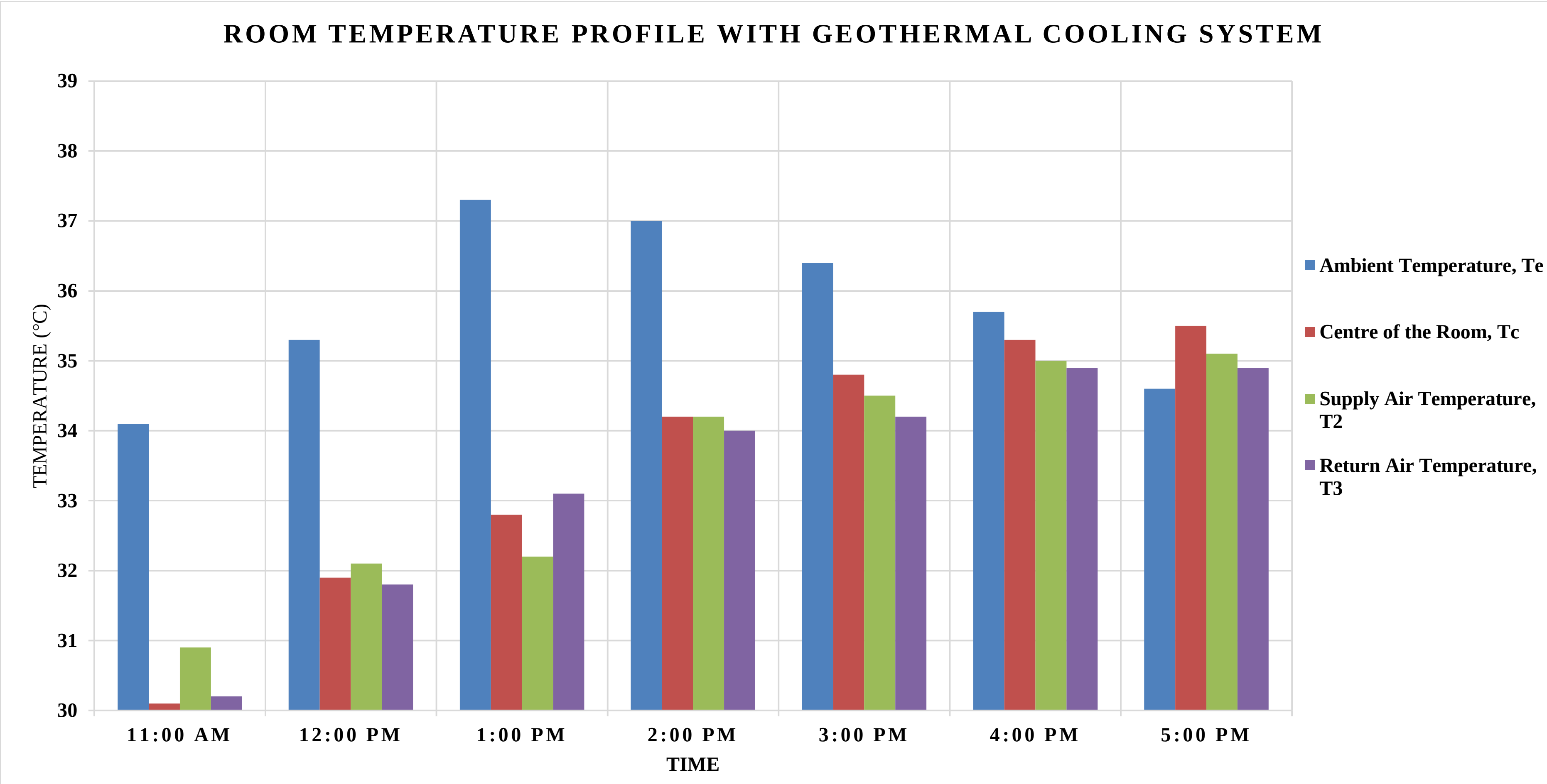

Figure 4.2: Room Temperature Profile with Geothermal Cooling System

4.1.3 Comparison in between the System

The comparison in between the system is tabulated in Table 4.3 and graphically presented in Figure 4.3. It can be clearly seen that the maximum temperature at the centre of room, supply air temperature and return air temperature is now valued at 35.5 degree Celsius, 35.1 degree Celsius and 34.9 degree Celsius respectively. It is observed that the maximum temperature different for the centre of the room is recorded at 0.7 degree Celsius, 4.9 degree Celsius for the supply air side and 3.5 degree Celsius for the return side.

Similar to experiment at Chapter 4 Section 4.1.1, a lagging phenomenon can be clearly seen. The temperature at the centre of the room, supply air temperature and return air temperature continued to rise even though the ambient temperature decreases. Heat trapped and accumulated in the room due to plaster ceilings and wall which act as thermal insulator, reduces the heat transfer process from the room to the ambient.

The hot air in the room was circulated by the centrifugal pump to the underground loop and the heat transfer process occurred in between the underground loop and the earth. The earth would act as heat sink would absorb the heat from the underground loop. The colder air is then channelled back to the space. In general, the room operative temperature decreases due to the heat transfer process.

The operative indoor temperature was recorded at 30.1 degree Celsius to 35.5 degree Celsius and hence, thermal comfort is not achieved for the experiment with geothermal cooling system. In general, the occupants in the room would feel slightly warm or warm depending on the air speed.

Table 4.3: Comparison in between the System

Description / Time	Room Centre Without Geothermal	Room Centre With Geothermal	∆ T	Supply Air Temperature Without Geothermal	Supply Air Temperature With Geothermal	∆ T	Return Air Temperature Without Geothermal	Return Air Temperature With Geothermal	∆ T
11:00 AM	30.2	30.1	0.1	31.9	30.9	1.0	31.1	30.2	0.9
12:00 PM	31.6	31.9	0.3*	34.2	32.1	2.1	33.2	31.8	1.4
01:00 PM	33.2	32.8	0.4	37.1	32.2	4.9	36.3	33.1	3.2
02:00 PM	34.3	34.2	0.1	37.9	34.2	3.7	37.0	34.0	3.0
03:00 PM	35.3	34.8	0.5	38.1	34.5	3.6	37.5	34.2	3.5
04:00 PM	36.0	35.3	0.7	39.0	35.0	4.0	38.1	34.9	3.2
05:00 PM	35.7	35.5	0.2	38	35.1	2.9	37.1	34.9	2.2

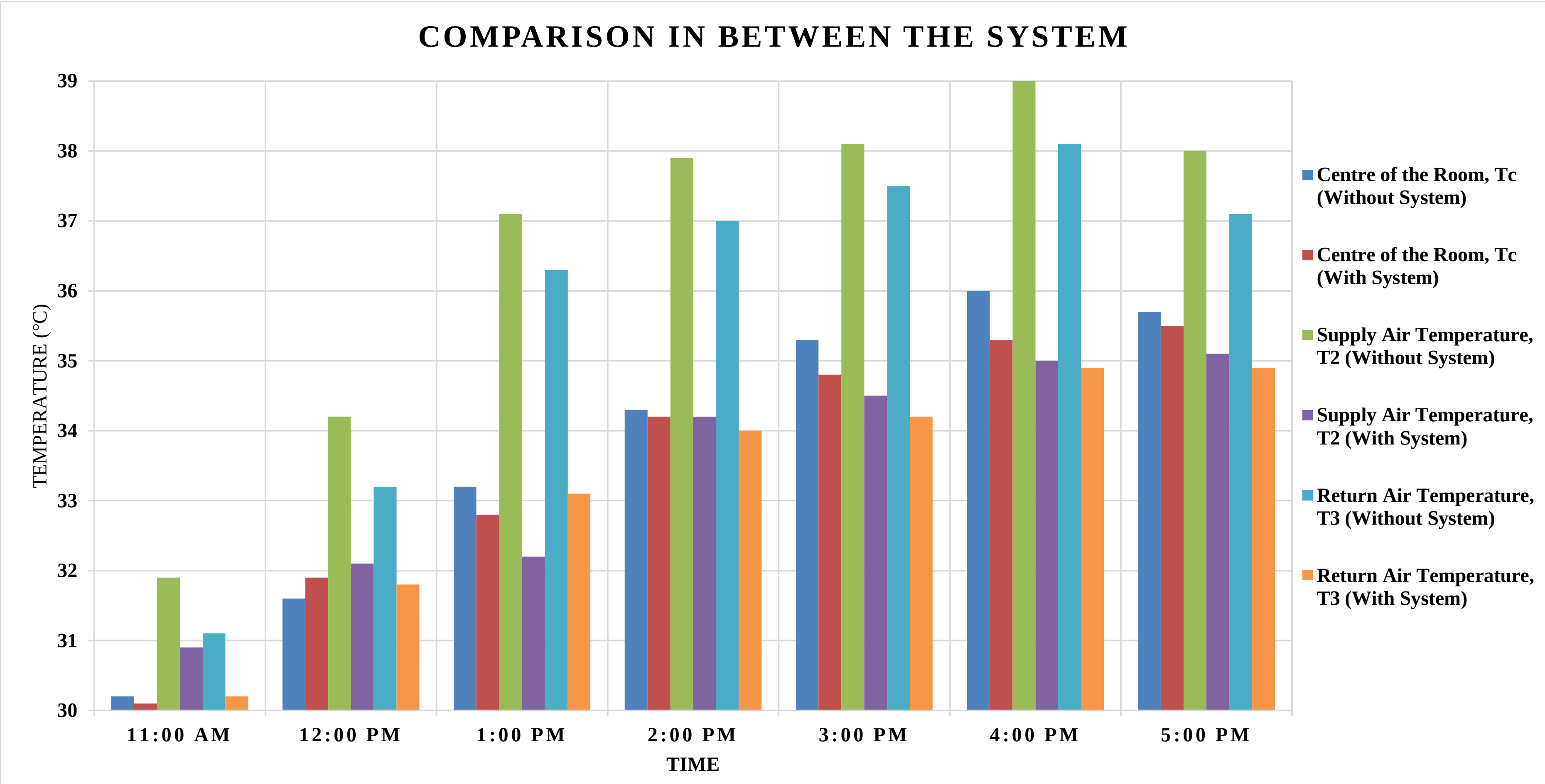

Figure 4.3: Comparison in between the System

4.2 Room Velocity Profile

Based on Chapter 3 section 3.3, the room velocity profile was captured on hourly basis from 11:00 am to 5:00 pm. The results are shown in Table 4.4.

Table 4.4: Room Temperature and Velocity Profile

Description / Time	Centre of the Room, T_c	Air Velocity at Centre of the Room	Supply Air Temperature, T_2	Supply Air Velocity	Return Air Temperature, T_3	Return Air Velocity
11:00 AM	30.1	0.2	30.9	4	30.2	2
12:00 PM	31.9	0.2	32.1	4	31.8	2
01:00 PM	32.8	0.2	32.2	4	33.1	2
02:00 PM	34.2	0.2	34.2	4	34	2
03:00 PM	34.8	0.2	34.5	4	34.2	2
04:00 PM	35.3	0.2	35	4	34.9	2
05:00 PM	35.5	0.2	35.1	4	34.9	2

From Table 4.4, it is observed that the air velocity at the supply side is greater than the return side followed by the centre of the room. The air velocities were recorded at 4 m/s, 2 m/s and 0.2 m/s respectively. Due to the usage of centrifugal fan, the supply velocity would always be greater than the return side. The air velocity for the supply side, return side and the centre of the room remained constant throughout the experiment as the centrifugal fan used is single speed.

Referring to Table 4.4, the mean temperature and air velocity captured at the centre of the room is 33.5 degree Celsius and 0.2 m/s respectively. According to ASHRAE Standard 55, 2010, there are six primary factors shall be identified in order to conclude that the results are thermally acceptable or not. The factors include air temperature, mean radiant temperature, air velocity, relative humidity, metabolic rate and clothing insulation. The air temperature was measured by using thermosensors and further verified by sling psychrometer. The air velocity was measured by using handheld anemometer. The relative humidity was measured by sling psychrometer. The metabolic rate and clothing insulation were obtained from Chapter 3, Figure 3.10 and Figure 3.11.

The air speed required to compensate increased air and radiant temperature can be identified by using two different method. The first method is graphical elevated air speed method. Figure 4.4 shows the acceptable range of operative temperature and air speeds for the comfort zone. The metabolic rate and clothing insulation shall first be identified. The metabolic rate is set at 1.1 as the occupants in the room are mainly doing office activities. The clothing insulation is set at 0.65 as the occupants in the room are normally wearing long sleeve shirt, trousers, socks and shoes.

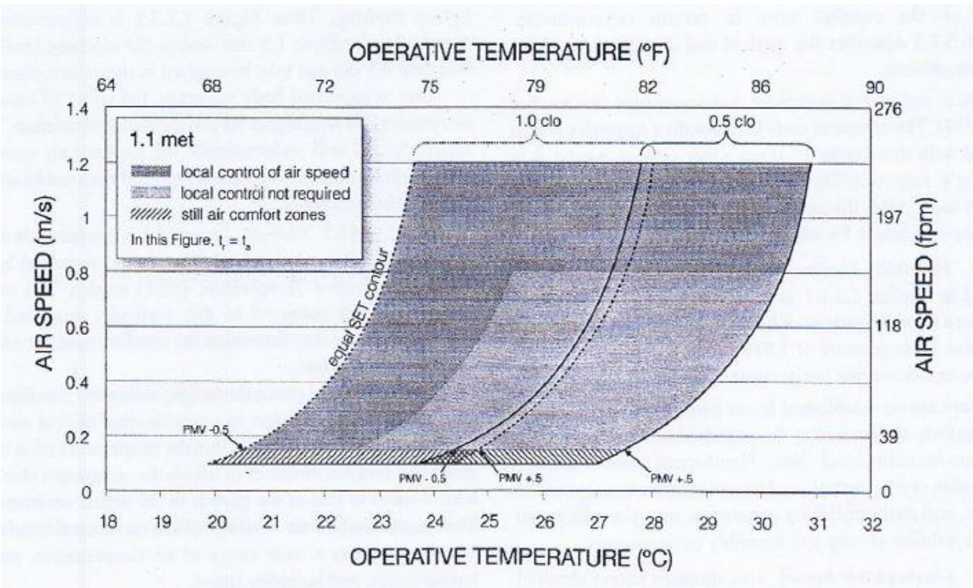

Figure 4.4: Acceptable Range of Operative Temperature and Air Speeds for the Comfort Zone

From Figure 4.4, it is observed that there are two different regions. Dark grey region applies when control of local air speed is provided to the occupants whilst light grey region applies when control of local air speed is not provided to the occupants. Since the control of local air speed is not provided to the occupants in this experiment, the data shall be obtained from the light grey region. From Figure 4.4, the upper limit to air speed shall be 0.8 m/s for light, primary sedentary offices activities for operative temperature above 25.5 degree Celsius. This means the maximum air speed at the centre of the room shall not be more than 0.8 m/s. The thermal comfort with 0.8 m/s shall be further verified by second method, namely the Standard Effective Temperature (SET) method.

Based on Figure 4.5, the Standard Effective Temperature (SET) value of 31.2 degree Celsius is obtained from the simulation. The result does not comply with ASHRAE Standard 55, 2010. The dry bulb temperature of the room is 30.2 degree Celsius and the occupants in the room would definitely feel warm. The cooling effect of 0.8 m/s is approximate 3.2 degree Celsius. Since the air speed is limited at 0.8 m/s for graphical method, the occupants of the room may be subjected to significant heat stress when the room temperature and humidity are high. The cooling effect of the elevated air speed as compared to 0.2 m/s is 3.2 degree Celsius.

Figure 4.5: Thermal Comfort Tool with Air Velocity of 0.8 m/s

For Standard Effective Temperature (SET) method, two sets of value are required in order to determine the cooling effect of the elevated air speed. In this case, the elevated air speed is 0.8 m/s and the reduced air speed shall be 0.2 m/s as per Figure 4.6. Air temperature, mean radiant temperature, humidity, metabolic rate and clothing insulation value were maintained. The SET value of 33.6 degree Celsius was obtained from the second simulation. The air speed of 0.2 m/s does not comply with ASHRAE Standard 55, 2010. There is no cooling effect at all for this air speed.

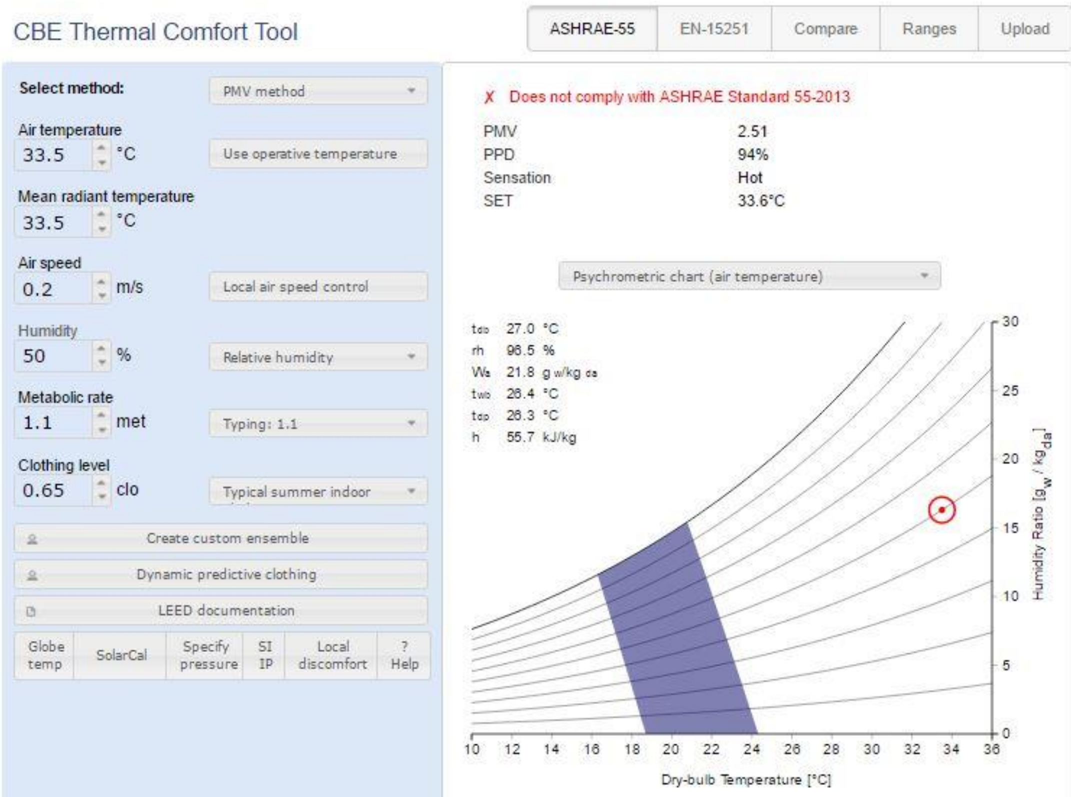

Figure 4.6: Thermal Comfort Tool with Air Velocity of 0.2 m/s

Third simulation is to determine the optimum air speed at the room centre in order to maximize human thermal comfort. All parameters were maintained except the air speed. Since the SET method has no limit on the air speed, trial and error is required in order to obtained the ideal air speed for maximize thermal comfort. In this simulation, air speed of 3 m/s is used and the result is shown in Figure 4.7. The SET value obtained is 29.9 degree Celsius, which it is still does not comply with ASHRAE Standard 55, 2010. The dry bulb temperature is 28.9 degree Celsius and the cooling effect is 4.6 degree Celsius. The cooling effect of elevated air speed as compared to 0.2 m/s is 3.8 degree Celsius.

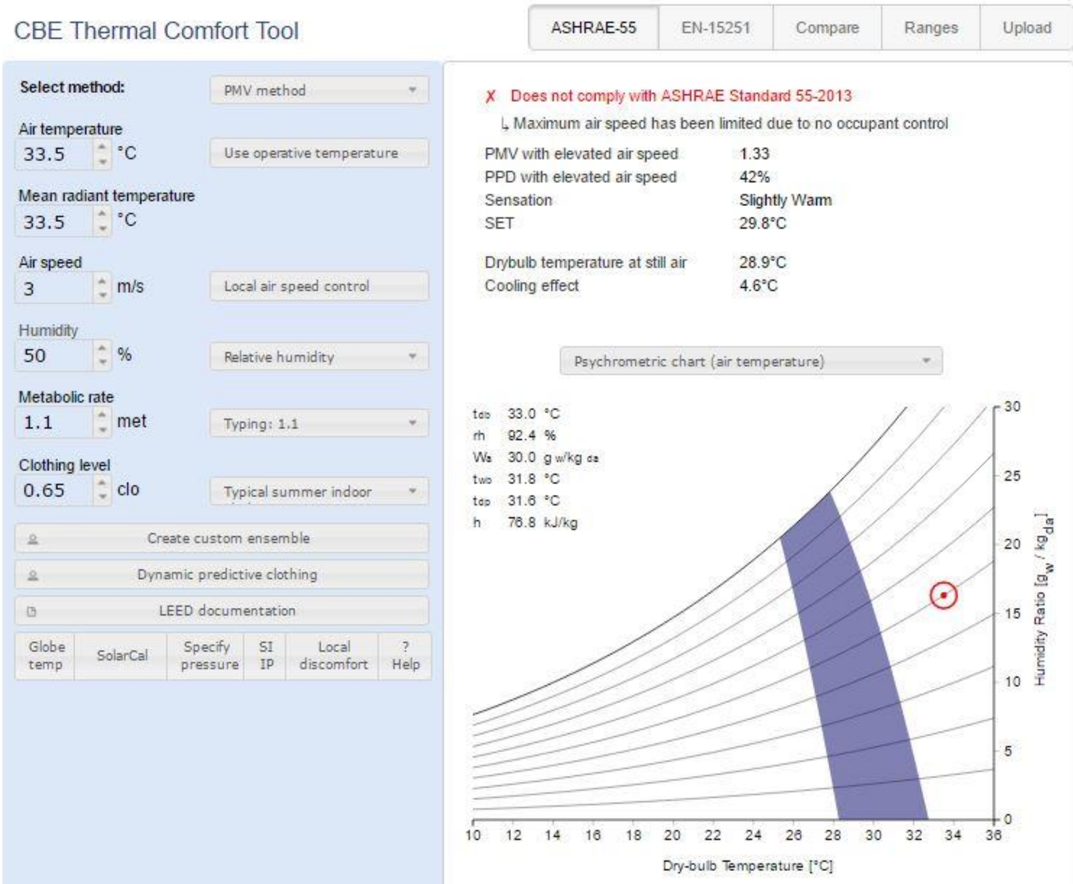

Figure 4.7: Thermal Comfort Tool with Air Velocity of 3 m/s

Forth simulation of 4 m/s air speed is conducted in order to identify the optimum air speed. Similar to the previous process, all parameters were maintained except the air speed. A SET value of 29.7 degree Celsius was obtained. The occupants in the room feel slightly warm. It is still doesn't comply with ASHRAE Standard 55, 2010. The dry bulb temperature is 28.7 degree Celsius and the cooling effect is 4.8 degree Celsius. The cooling effect of elevated speed at 4 m/s is compared and it is 4 degree Celsius.

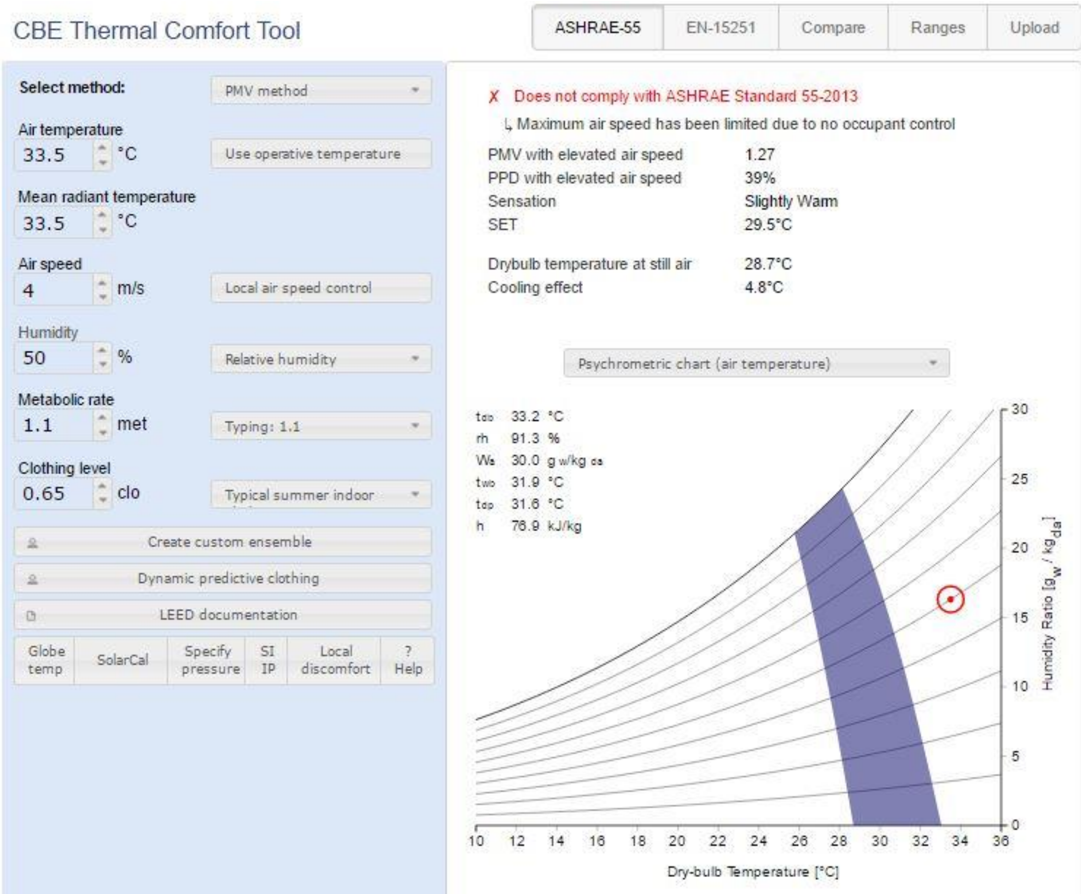

Figure 4.8: Thermal Comfort Tool with Air Velocity of 4 m/s

From Figure 4.9 and Figure 4.10, it can be observed that the optimum air speed falls at 3 m/s. There is no significant increment in the cooling effect as the air velocity increases. The cooling effect of the elevated air speed at 3 m/s as compared to 0.2 m/s (benchmark) is 4.4 degree Celsius. The dry bulb temperature at the room is 28.9 degree Celsius and the occupants in the room would still feel slightly warm as the operative temperature is still above ASHRAE Standard 55, 2010 upper limit, which is 25.9 degree Celsius.

The optimum air speed at the centre of the room is concluded at 3 m/s as any air speed beyond 3 m/s is not acceptable at industrial practice. Figure 4.11 demonstrated the effect of air speed at various value with the mechanical effect and occupant’s sensation. Since the optimum air speed was concluded at 3 m/s, the occupant would experience an air speed equivalent to a fast walking speed in order to compensate the increased air and radiant temperature.

Table 4.5: Room Temperature and Velocity Profile

Description / Air Velocity	SET Value	Dry Bulb Temperature (°C)	Sensation	Cooling Effect (°C)	Cooling Effect of the Elevated Air Speed (°C)	PMV	PPD (%)	Comply with ASHRAE Standard 55, 2010
0.2 m/s	33.6	33.6	Hot	Nil	Nil	2.51	94	No
0.8 m/s	31.2	30.3	Warm	3.2	3	1.76	65	No
3 m/s	29.8	28.9	Slightly Warm	4.6	4.4	1.33	42	No
4 m/s	29.5	28.7	Slightly Warm	4.8	4.7	1.27	39	No
5 m/s	29.4	28.5	Slightly Warm	5.0	4.8	1.22	36	No
6 m/s	29.3	28.4	Slightly Warm	5.1	4.9	1.19	35	No

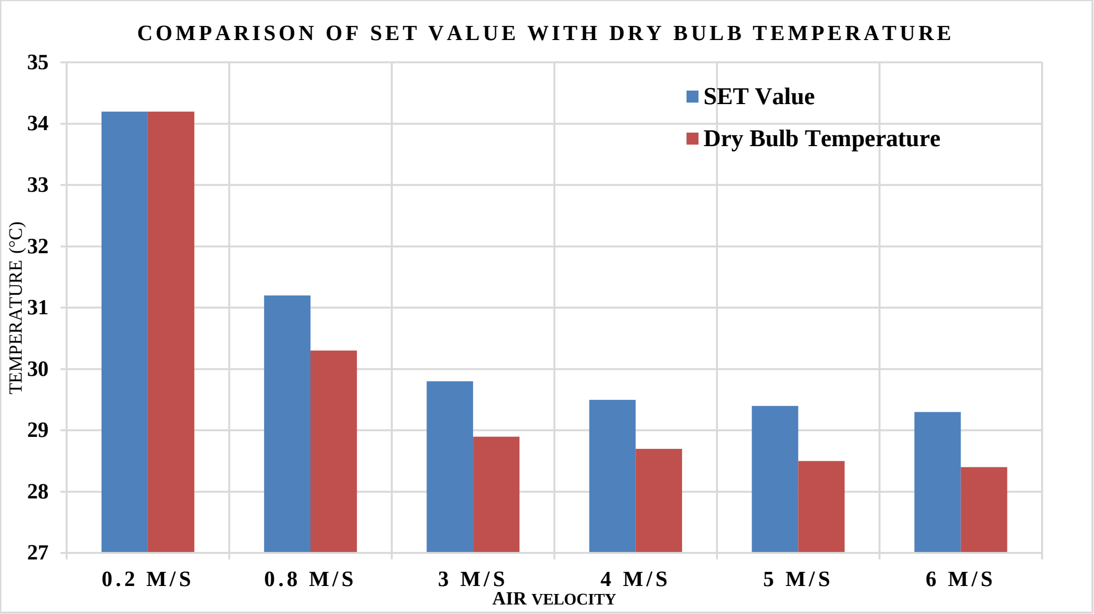

Figure 4.9: Comparison of SET Value with Dry Bulb Temperature

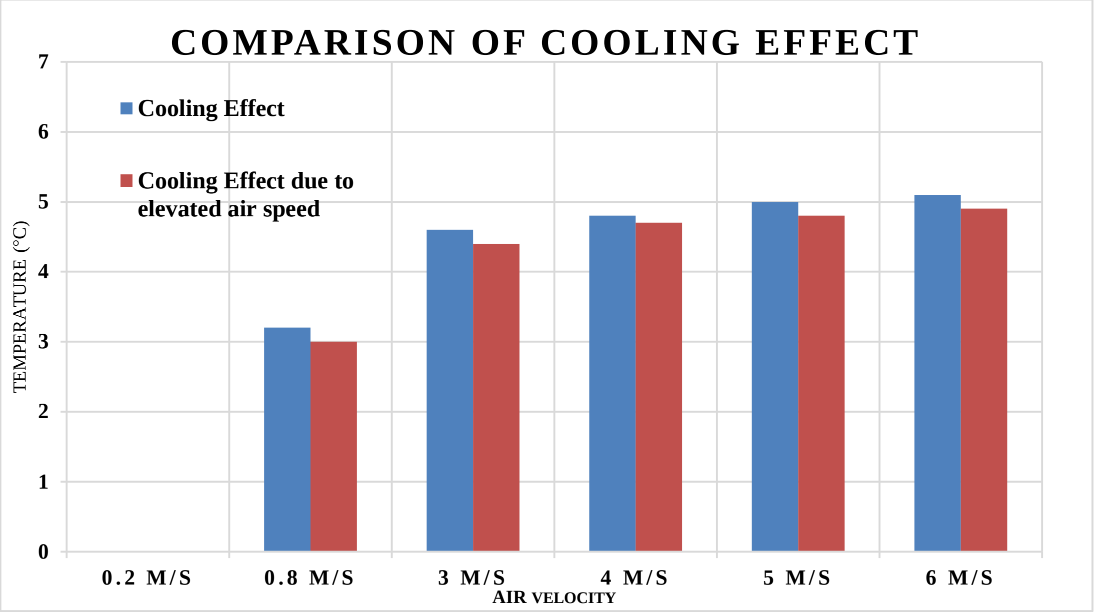

Figure 4.10: Comparison of Cooling Effect

Air speed (m/s)	Mechanical Effect	Occupant Sensation
≤0.25	Smoke (from cigarette) indicates movement	Unnoticed, except at low air temperatures.
0.25 – 0.5	Flame from a candle flickers	Feels fresh at comfortable temperatures, but draughty at cool temperatures.
0.5 – 1.0	Loose papers may be moved. Equivalent to walking speed.	Generally pleasant when comfortable or warm, but causing constant awareness of air movement.
1.0 – 1.5	Too fast for deskwork with loose papers	Acceptable in warm conditions but can be from slightly to annoyingly draughty
> 1.5	Equivalent to a fast walking speed	Acceptable only in very hot and humid conditions when no other relief is available. Requires corrective measures if comfort and productivity are to be maintained.

Figure 4.11: Impact of Air Velocity on Occupants (ASHRAE Standard 55, 2010)

4.3 Underground Pipe Diameter

The underground pipe diameter is inverse proportional to the air speed. The bigger the pipe diameter, the lower the air speed. As the optimum air speed of 3 m/s is required at the centre of the room, the air speed at the supply air side shall be determined. There is no specific calculation to calculate the initial air speed at a certain location and the final air speed at another location. There is only a way to determine the supply air speed in industrial practice, which is to refer to supplier's diffuser technical data sheet. The flow rate supply, throw distance, face velocity are stated in the technical data sheet as they have conducted the actual experiment on each of the diffuser.

In this case, a jet diffuser is recommended as its application is normally for spot cooling. The technical performance data is shown in Figure 4.14. The mass flow rate required for the room is obtained via Equation 3.1.

$$\dot{M} = V \times ACH$$

$$\dot{M} = 3m \times 1.7m \times 2.3m \times 10ACH$$

$$\dot{M} = 120m^3 / hr$$

In order to maximize thermal comfort of the room, the mass flow rate of 120 m3/hr shall be provided. The jet diffuser size of 150 mm diameter is then selected from the Figure 4.14. It is able to generate 196 m3/hr of airflow at 3 m/s and the throwing distance is approximate at 4 m. The noise generated by the jet diffuser is at 26 decibel and it is far lower than the office requirement, which is 30 decibel. The pressure loss of the jet diffuser is at around 15 Pa.

Building / Room	Air Change Rates - *ACR* - *(1/hr)*	Building / Room	Air Change Rates - *ACR* - *(1/hr)*
All spaces in general	min 4	Court Houses	4 - 10
Attic spaces for cooling	12 - 15	Dental Centers	8 - 12
Auditoriums	8 - 15	Department Stores	6 - 10
Bakeries	20	Dining Halls	12 -15
Banks	4 - 10	Dining rooms (restaurants)	12
Barber Shops	6 - 10	Dress Shops	6 - 10
Bars	20 - 30	Drug Shops	6 - 10
Beauty Shops	6 - 10	Engine rooms	4 - 6
Boiler rooms	15 - 20	Factory buildings, ordinary	2 - 4
Bowling Alleys	10 - 15	Factory buildings, fumes and moisture	10 - 15
Cafeterias	12 - 15	Fire Stations	4 - 10
Churches	8 - 15	Foundries	15 - 20
Club rooms	12	Galvanizing plants	20 - 30
Clubhouses	20 - 30	Garages repair	20 - 30
Cocktail Lounges	20 - 30	Garages storage	4 - 6
Computer Rooms	15 - 20	Homes, night cooling	10 - 18
Laundries	10 - 15	Jewelry shops	6 - 10
Libraries, public	4	Kitchens	15 - 60

Figure 4.12: Air Change Rate (ASHRAE Standard 55, 2010)

TECHNICAL PERFORMANCE DATA

Grille Neck Size, mm	Air Velocity, m/s	2.0	3.0	4.0	5.0	6.0	7.0	8.0	10.0
150 Dia	Airflow Volume, m^3/hr	130	196	262	323	393	460	525	655
	Throw Distance, m	2.6	4.0	5.5	5.8	8.2	9.6	11	15.2
	Total Pressure Loss, Pa	7	15	17	25	32	48	66	86
	Noise Rating (NR)	-	26	30	36	43	49	53	56
200 Dia	Airflow Volume, m^3/hr	233	350	467	583	700	816	933	1166
	Throw Distance, m	3.8	5.6	7.4	9.2	11	13	14.7	20.5
	Total Pressure Loss, Pa	7	15	17	25	32	48	66	86
	Noise Rating (NR)	-	26	30	36	43	49	53	56
250 Dia	Airflow Volume, m^3/hr	365	548	730	913	1095	1280	1460	1825
	Throw Distance, m	4.6	7.0	9.5	11.6	13.8	16.2	18.5	25.4
	Total Pressure Loss, Pa	7	15	17	25	32	48	66	86
	Noise Rating (NR)	-	24	28	33	38	42	46	50
300 Dia	Airflow Volume, m^3/hr	526	790	1052	1315	1580	1842	2105	2632
	Throw Distance, m	5.6	8.4	11.2	14	16.8	19.5	22.2	31
	Total Pressure Loss, Pa	7	15	17	25	32	48	66	86
	Noise Rating (NR)	-	24	29	33	38	42	46	50

NR20 NR30 NR40 NR50

Figure 4.13: Technical Performance Data for Jet Diffuser

Calculation Underground Pipe Diameter

$$\dot{Q} = A \times V$$

$$\dot{Q} = \pi r^2 \times V$$

$$120 m^3 / hr = \pi r^2 \times 3 m / s$$

$$0.03333 m^3 / s = \pi r^2 \times 3 m / s$$

$$r^2 = 0.0036 m$$

$$r = 0.06 m^2$$

From the above calculation, the underground pipe diameter of 60 mm is sufficient to provide 3 m/s air speed in order to achieve the optimum air speed. The current underground pipe size is one size up than the required pipe diameter. The advantage of upsize pipe is the total friction loss is lesser compared to 60 mm pipe.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As the project is all about feasibility study of implementing geothermal cooling system in tropical countries, it is important to obtain the room temperature profile of the room. The room temperature was recorded twice. The first experiment is to capture the room temperature without geothermal cooling system and the second experiment is to capture the room temperature with geothermal cooling system. Thermosensors were used to record the indoor temperature and is further verified by sling psychrometer. In general, the indoor temperature is at around 33 degree Celsius to 37 degree Celsius.

As the main objective of the project is to determine the optimum air speed required to offset the increased of air and radiant temperature, the velocity profile of the room shall be identified. A handheld anemometer is used to capture the velocity profile of the room. The results were then tabulated, analysed and discussed. The air speed at the centre of room is very low, which is 0.2 m/s. In order to compensate for the increased in operative temperature, the air speed has to reach minimum 3 m/s. Noise issue may arises when air speed is more than 1.5 m/s.

The second objective of the project is to determine the weakness of the existing system. The underground pipe size is one size upper, which deemed to be acceptable in this experiment as the air speed at the supply inlet is recorded at 4 m/s. Jet diffuser of 150 mm diameter shall be installed at the supply inlet in order to enhance the flow distribution to the space.

5.2 Recommendations

The location of supply air inlet shall be installed at the height of 1.3 m height from the floor finished level. This is because the colder air shall be supplied to upper body of the occupant, particularly the head for better thermal comfort. Besides, the soil above the underground pipe should be sprinkled in order to reduce the soil temperature and hence, the heat rejection rate is increased.

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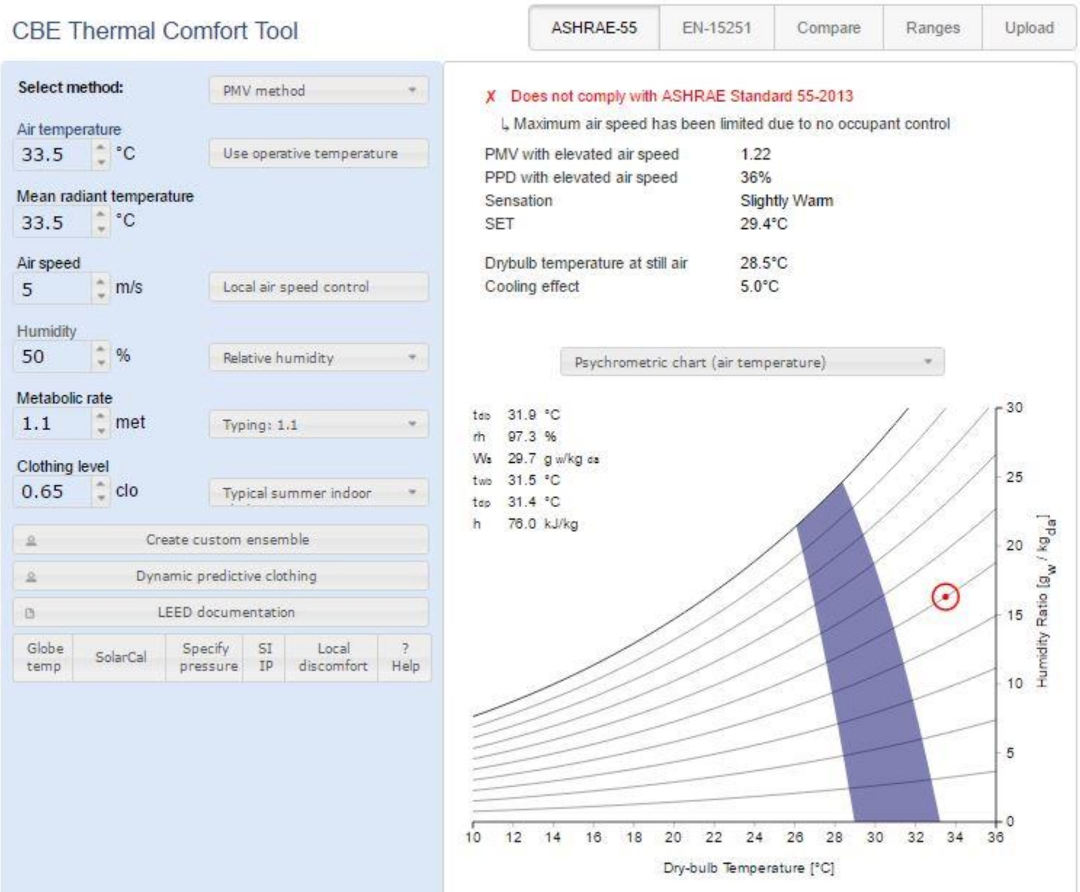
APPENDICES

APPENDIX A: Standard Effective Temperature (SET) Simulation Results




CBE Thermal Comfort Tool
ASHRAE-55
EN-15251
Compare
Ranges
Upload
Select method:
PMV method
Air temperature
33.5 °C
Use operative temperature
Mean radiant temperature
33.5 °C
Air speed
6 m/s
Local air speed control
Humidity
50 %
Relative humidity
Metabolic rate
1.1 met
Typing: 1.1
Clothing level
0.65 clo
Typical summer indoor
Create custom ensemble
Dynamic predictive clothing
LEED documentation
Globe temp
SolarCal
Specify pressure
SI IP
Local discomfort
? Help
✗ Does not comply with ASHRAE Standard 55-2013
↳ Maximum air speed has been limited due to no occupant control
PMV with elevated air speed 1.19
PPD with elevated air speed 35%
Sensation Slightly Warm
SET 29.3°C
Drybulb temperature at still air 28.4°C
Cooling effect 5.1°C
Psychrometric chart (air temperature)
tdb 31.9 °C
rh 97.3 %
Wa 29.7 g w/kg da
twb 31.5 °C
top 31.4 °C
h 78.0 kJ/kg
Dry-bulb Temperature [°C]
Humidity Ratio [gw / kgda]

APPENDIX B: Specification of Handheld Anemometer

SPECIFICATIONS

DIGITAL ANEMOMETER VELOCITY	Range	Accuracy
m/s (meter per second)	0.40~30.0	±(2.0% + 50)
ft/m (feet per minute)	80~5900	±(2.0% + 50)
km/h (kilometer per hour)	1.4~108.0	±(2.0% + 50)
mile/h(mile per hour)	0.9~67.0	±(2.0% + 50)
Knots(nautical miles per hour)	0.8~58.0	±(2.0% + 50)
Air Temperature	-20 to 60°C (-14 to 140°F)	1.5°C(±2.7°F)
Air Relative Humidity	0 to 100% RH	±3%
AIR FLOW	**RANGE**	**AREA**
CFM	0 to99990	0 to 9.999ft²
CMM	0 to99990	0 to 9.999ft²
CMS	0 to9999	0 - 9.999 m²

General	
Flow Area Setting	√
MAX/MIN Function	√
Display Back light	√
Auto Power Off	√
° C/°F Selection	√
Ambient , Dew Point & Wet Bulb Temperature	√
Low Battery indication	√
USB Interface	√
Power Supply	1 x 9 V 6 F 22
Product Size	165mm x 85mm x 38mm
Category	CE RoHS