CERTIFICATION OF APPROVAL

STUDY OF A WATER COOLED WALL TO REDUCE RESIDENTIAL INDOOR TEMPERATURES AT NIGHT

by

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Approved by,

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CERTIFICATION OF ORIGINALITY

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

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SAW SOON WEI

ABSTRACT

High indoor temperatures during the early night cause a reduction in the occupants' comfort, resulting in a higher energy and cost demand. This in turn calls for a study on the usage of a specialised cooling system for night time usage that utilizes natural resources. Not many studies have been conducted to examine the feasibility of a water cooled wall. This study aims to address the issue. The objective of this research is to study the feasibility of a water cooled wall to reduce indoor temperatures at night. This is done through removal of heat stored in the walls by countering the heat storage and time lag effects. This system is also intended to reduce the temperature differences between the indoors and outdoors during the night. The methodology of this study includes a review of the relevant heat transfer principles, a look at the existing passive cooling strategies, selecting a concept and design, building and testing a model, and collecting and analysing the results obtained from the tests. A CLTD calculation of the cooling load for a UTP hostel room was also calculated. It is found that a water cooled wall is feasible and more studies and research should be conducted to further improve the designed system.

ACKNOWLEDGEMENTS

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ABBREVIATIONS

CLTD	Cooling Load Temperature Distribution
ETP	Engineering Team Project
EER	Energy Efficiency Ratio
RSCL	Room Sensible Cooling Load
UTP	Universiti Teknologi PETRONAS

NOMENCLATURES

Symbol	**Meaning**	**Unit**
A	Area	m^2
h	Convection Heat Transfer Coefficient	$W/m^2.K$
k	Thermal Conductivity	W/m.K
P	Power	kW
Q	Heat	J
T	Temperature	°C, K
t	Time	s
x	Length	m

CHAPTER 1
INTRODUCTION

1.0 Background of Study

With the rising cost of energy and the global movement towards environmentally friendly technology with minimum emissions and energy usage, there is an increase focus in maximising the usage of natural resources in the temperature control of buildings and structures. For example, technology has improved the efficiencies of air conditioners up to 4 times better than previous models (US Department of Energy, 2007). Higher efficiencies mean less energy wasted, and thus more money saved. The Energy Information Administration of the United States, in its International Energy Outlook 2009 report, projects an increase of 44 percent in the total world consumption of marketed energy from the year 2006 to 2030 as seen in Figure 1.2 (United States Energy Information Administration, 2009). This calls for a change in how cooling systems are designed. While some commercial designs such as solar chimneys and cooling towers make use of solar and wind energy, the utilization of water to cool homes has not been studied in detail.

The current solutions for reducing indoor temperatures at night include the usage of fans, air-conditioners, and so forth. But these devices consume energy, and there have been continuing efforts to increase their efficiencies. In countries that have tropical climates like Malaysia, the usage of cooling devices at night are much higher compared to countries in the Western Hemisphere.

A study was conducted regarding the usage of air conditioners during night time in the tropics. This study was based in Hong Kong, and managed to show that cooling requirements are different during the night compared to day, and that with proper planning, the optimum cooling system can be installed, saving both money and energy (Lin & Deng, 2004).

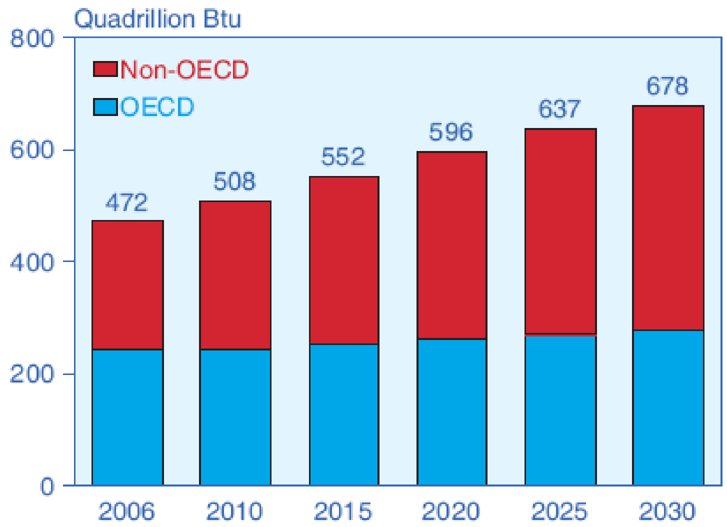

Figure 1.1: World marketed energy consumption 2006-2030 (EIA, 2009)

During the day, heat is conducted and radiated into a building. This heat not used up instantaneously, but is stored in the walls, columns, furnitures, and so forth through the heat storage effect. It is released at a later time, through the Time Lag Effect, thus further heating up the building. The high cooling load at night can thus be reduced by minimizing the heat storage and time lag effects, and can be done by trying to remove the heat stored before it is released into the building.

As spelt out by the study mentioned above, most residential cooling systems are designed based on estimated daytime usage. This results in cooling systems that are not efficient during the night as the cooling loads are different. This difference is due to the number of occupants in the residence at night, and also because the number of air conditioning units operating are generally higher due to the higher occupant number. Air conditioners are used in the daytime, but mostly during the weekends, or holidays, when most people are at home.

The night time situation in a typical house in Malaysia is as such. The windows and doors are shut to avoid mosquitoes and also for security purposes. This creates a situation where every room requires at least a fan to be comfortable. Adults that have just returned from a long day at work would like to be comfortable at home. The children also have homework and activities to be done. This creates a situation where the cooling requirements in homes at night are high compared to daytime because most occupants are at home during this period. The usage of air conditioners in Malaysia has increased from 13 251 units in 1970 to 253 399 units in 1990, and will be about 1 511 276 in the year 2020 (Nasution, 2005).

Noting this situation, the Malaysian Government has formulated the National Energy Policy, and one of the objectives of this policy is to reduce the negative impacts of energy production, usage, and consumption on the environment (KeTTHA, 2008). This also includes emissions, discharges, and noise issues.

Table 1.1: Table of indoor temperatures for a house in Taman Maju between 1600-2400 hours (Zubir et al, 2009)

	26th Jan 09	29th Jan 09	10th Feb 09
Time	Temperature °C		
1600	34.5	33.4	33.9
1700	34.1	33.2	33.2
1800	34.1	32.5	31.8
1900	34.1	31.4	31.6
2000	33.9	31.8	31.3
2100	32.5	29.5	31.1
2200	31.9	31.0	29.9
2300	30.5	31.1	29.5
2400	30.4	29.6	29.1

A study was conducted by UTP students, where they measured the indoor temperatures of a single storey house in Taman Maju to observe the temperature distribution. Table 1.1 shows the results from their measurements. From the table, it can be seen that the indoor temperatures are high, rarely reaching below 30°C. These high temperatures are not a conducive environment for the occupants and efforts should be made to bring them down (Zubir et al, 2009).

Based on the present situation, where the heat storage and time lag effects are deemed to be contributing to a higher cooling load at night, this project aims to study the development of a water cooled wall system that is able to reduce the aforementioned effects, and to reduce indoor temperatures of residential buildings at night.

This study is aimed at achieving a cooling system that works hand in hand with existing systems, but with a reduced usage of energy. Water was chosen as the medium of cooling simply due to its availability, comparatively low price, and good heat conducive qualities. Although there have been many studies on the usage of air to cool homes, it cannot be said of the same for the usage of water.

1.1 Problem Statement

Due to the high indoor temperatures during the early night, as seen from the aforementioned study (Zubir et al, 2009), a high indoor temperature reduces the comfort of the occupants, and more energy is needed to cool the building down. This in turn leads to a higher energy demand and cost, especially in homes where multiple air conditioner units are installed. This calls for a study on the usage of a specialized system for night time usage. This system has to use natural resources, and be able to meet the comfort requirements of the inhabitants. It is hoped that with this study, non airconditioner users will be able to enjoy a better level of comfort compared to that currently available through the usage of fans alone. For air conditioner users, it is hoped that the usage cost will be reduced as the water cooled wall will be able to remove the stored heat, and thus the cooling load necessary.

1.2 Objectives and Scope of Study

The objective of this project is to study the feasibility of a water cooled wall system that utilizes heat transfer principles to reduce indoor temperatures in residential buildings at night. This is done through the removal of the heat stored in the walls. The system is also intended to reduce the temperature differences between indoors and outdoors during the night.

The scope of study for this project includes studying the various heat transfer principles to determine the relevant ones to be used. These studies focused mainly on conduction and convection. Air conditioning principles, such as the cooling load were also paid attention to. It should be noted that the scope of study is limited to that of new residential buildings, where the cooling system can be incorporated at the construction stage to reduce modification and labor costs.

A study of the other solutions currently in used was also conducted. Studies of other mediums and systems such as air, reflective material, insulation, and so forth were also done to compare them against the idea of a water cooled wall. Designs of the system have been created and evaluated, a model has been built, and experiments run to determine the success of the proposed concept. The UTP hostel room is used as a case study in the calculation of the cooling load and other necessary issues.

1.3 Relevancy and Feasibility

This project is relevant in terms of the real world applications that it can be based upon. Designers around the world are focusing more on energy saving designs, either by increasing the efficiencies of current technology, or by designing new systems that maximize the usage of natural resources. Most current designs focus on the usage of air to cool the interior of buildings. Designs such as solar chimneys attempt to maximize the usage of air and the concept of natural ventilation to reduce indoor temperatures.

Some commercial products that are based on the usage of water to cool homes are already available. Designs and concepts such as swamp coolers, the usage of water as a thermal mass, and so forth already exist. Nevertheless, this study is different in that the focus is on designing a cooling system that utilizes water to cool the walls in an effort to reduce the heat storage and time lag effects.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.0 Conduction

Conduction in a solid is the transfer of heat from one part to another. It is influenced by a temperature gradient that exists in different parts of the solid. Conduction involves the transfer of kinetic energy from one molecule to the other (Srivinasan, 2003).

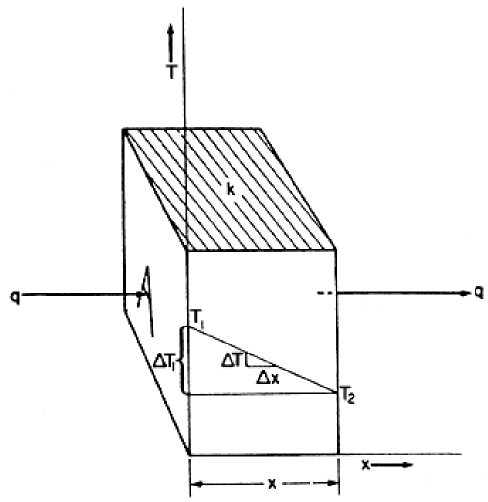

Figure 2.1: Process of conduction (Earle, 1983)

Fourier's law of heat conduction is an empirical law based on observation. Figure 2.1 shows an illustration of thermal conduction and Equation 2.1 shows the written equation. Fourier's Law states that the rate of heat flow, $\frac{dQ}{dt}$, through a homogeneous solid is directly proportional to the area, A, of the section at right angles to the direction of heat flow, and to the temperature difference along the path of heat flow, $\frac{dt}{dx}$ (Taftan Data, 1998).

Thermal conductivity is a physical characteristic or property of the material from which the wall is made. The value of k depends on the material of which the body is made, and also upon its temperature. *k* does not vary much with temperature and when applied for short periods of time, may be considered as constant, where *q* is the heat transfer rate and *x* are the boundaries, i.e distance (Srivinasan, 2003).

$$q = \frac{kA\Delta t}{x2 - x1} \qquad (2.1)$$

2.1 Convection

Figure 2.2 shows an illustration of the process of convection. According to the Sci-Tech Dictionary, convection is a type of heat transfer that results entirely from the presence of a hot body in the fluid, causing temperature and hence density gradients to develop, so that the fluid moves under the influence of gravity (Sci-Tech Dictionary, 2009).

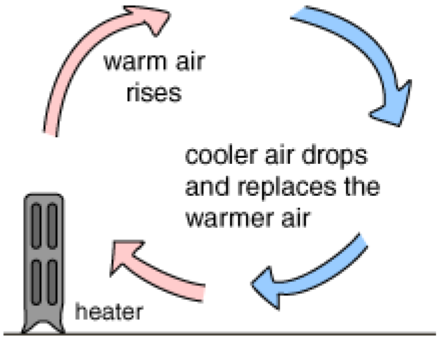

Figure 2.2: Process of convection (Naves, 2000)

Equation 2.2 shows the written equation for convection and also describes Newton's Law of Cooling, where $\dot{Q}$ represents the rate of heat transfer. ΔT represents the difference between the object and fluid temperatures, and *h* is termed the convection heat transfer coefficient (Efunda, 2009).

$$\dot{Q} = hA(T_w - T_\infty) = hA \cdot \Delta T \qquad (2.2)$$

The convection heat transfer coefficient, *h,* is dependent on the type of media, gas or liquid, the flow properties such as velocity, viscosity and other flow and temperature dependent properties. *h* is also influenced by the existence of laminar or turbulent flow. Usually, h is comparatively lower for laminar flow compared to turbulent flow. This is due to turbulent flow having a thinner stagnant fluid film layer on the heat transfer surface.

2.2 Heat Storage and Time Lag Effect

During the night, indoor temperatures are higher than outdoor (Santamouris & Asimakopoulos, 1996). This is due to the heat storage and time lag effects. Figure 2.3 shows the difference between instantaneous heat gain and cooling load as a result of the heat storage effect. Of the total amount of heat entering a room at any instant, only a portion heats up the room instantaneously, the rest are absorbed by the walls, rooms, and furnishings. This is known as the heat storage effect. Only at a later time does the stored heat contribute to the heating of the room. This is then known as the time lag effect (Pita, 2001).

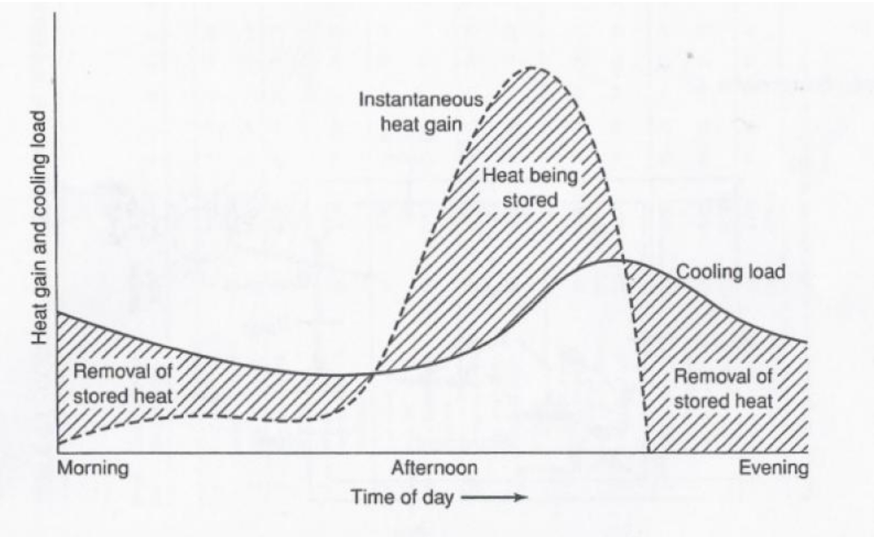

Figure 2.3: Differences between instantaneous heat gain and cooling load (Pita, 2001)

An example of both these effects is in the huge European cathedrals built of massive, thick stone walls. On a very sunny and hot day, the church interior remains quite cool as the entering heat does not enter the interior, but merely heats up the walls. Due to the time lag effect, the heat is only released at night, and the building may even exhibit a reverse heat flow, where the heat flows out from the hot walls to the cool outdoors (Pita, 2001). It is because of these effects that it is important to look at methods of reducing the trapped heat at night.

The seriousness of the effect of stored heat is demonstrated in that the time taken to reach the design temperature can reach up to one hour in some cases. By reducing the heat storage effect, one can then select equipment designed for a load that is less than the peak load calculated, thus saving cost and energy (Stamper et al, 1979). By utilizing passive cooling systems which are based on natural principles such as ventilation and thermal mass, the effects can be reduced with minimal energy usage.

2.3 Cooling Load

The cooling load is the amount of heat that has to be removed from a building. The size of the cooling load of a particular residential building is affected by the heat storage effect as well. The cooling load of a building at night can be reduced if the heat storage effect can be reduced as well. Factors that contribute to the cooling load in residential buildings at night include the occupants, lighting, electrical equipment, stored heat from the walls and floor and so forth (Capehart et al, 2003).

2.4 Passive Cooling Strategies

2.4.0 Cavity Wall

A cavity wall is two sections of masonry, separated by a cavity of varying dimension. The masonry sections usually consist of solid brick, structural clay tile, or concrete masonry units and are bonded together with masonry ties. The cavity (ranging from 50.8 mm to 114.3 mm in width) may or may not contain insulation (Masonry Advisory Council, 2002).

Cavity walls are usually installed in tall or large residential buildings. They are popular due to superior resistance to rain penetration, excellent thermal properties, resistance to sound transmission, and also resistance to fire (Masonry Advisory Council, 2002).

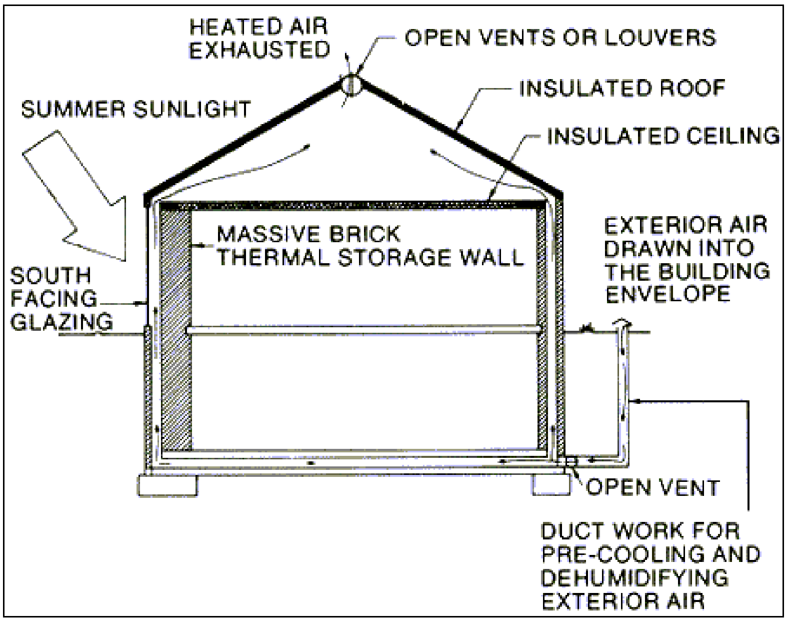

Figure 2.4: Cavity wall cooling mode (The Brick Industry Association, 2001)

As can be seen from Figure 2.4, the walls of the structure are un-insulated cavity walls. The cavity of the wall which is open to ductwork extended through the basement floor provides an air passageway within the building envelope components. As the air rises, it is vented to the exterior from the top of the cavity, and exterior air is drawn into the cavity via the ductwork system and exterior vents. This provides a means of keeping the entire building envelope cooled. The cooled building envelope and interior require a longer time period to be heated up to uncomfortable temperatures during the daytime hours of the next day (The Brick Industry Association, 2001).

The disadvantages of this system include the need for the residence to be designed right from the beginning for such a system. Maintenance also appears to be an issue, especially regarding any moisture in the vents and ducts.

2.4.1 Evaporative Cooling Pads

Evaporative Cooling Pads are based on the evaporative cooling principle. Figure 2.5 shows the system. The pads are made of cellulose paper and impregnated with insoluble anti-rot salts, stiffening saturants, and wetting agents. When used in conjunction with fans, there can be a temperature reduction of up to 25 degrees Fahrenheit. The American Coolair Corporation describes the features of the Evaporative Cooling Pad system to include a life time of at least 5 years and that the system will not sag or rot. Edge Coated Pads, as seen from Figure 2.5, are also offered. These are pads that help reduce the growth of algae (American Coolair Corporation, 2001).

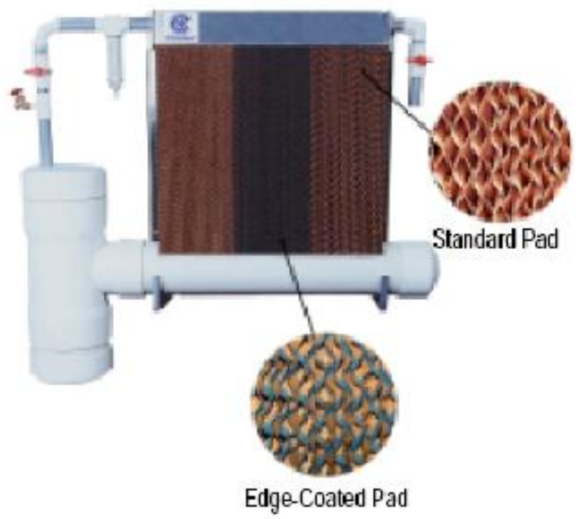

Figure 2.5: An evaporative cooling pad system (American Coolair Corp., 2001)

This system appears to be ideal as it does not require a lot of renovation to the building where it will be installed. There is also a big temperature difference if the system is applied appropriately. Nevertheless, this system was developed specially for greenhouses, and not residential buildings. The resulting humidity increase would not provide a comfortable environment for the residents. De-humidifiers would have to be installed to insure that the humidity levels remain comfortable.

2.4.2 Natural Ventilation

One common strategy in passive cooling is by utilizing and encouraging natural ventilation. Figure 2.6 shows an example of such a system. Natural ventilation depends solely on air movement to cool occupants. Window openings on opposite sides of the building enhance cross ventilation driven by breezes. Advantages of natural ventilation include a reduction in electrical consumption due to the minimal usage of cooling equipment, an increase in natural lighting if skylights are used, a reduction in construction costs due to the downsizing or eliminating of cooling equipment, and a general improvement in indoor air quality caused by the constant flow of fresh air into the building (Brown et al, 2004).

Figure 2.6: Roof mounted, wind driven natural ventilators (Teekaram, 2003)

Disadvantages of utilizing natural ventilation include a lack of precise control of the air flow as it depends mainly on the availability of wind, which can change randomly. This means that a building runs the risk of under ventilation on calm, hot days and over ventilation on cold days. Because natural ventilation depends on prevailing wind currents, the target building must be in the open and not blocked by taller structures. Good natural ventilation is also a combination of the right design, location, and construction. Therefore the allowance for any errors to occur during design and construction is very small as any mistake would be both difficult and expensive to correct (Jones et al, 2009)

2.4.3 Insulation

Figure 2.7 shows an example of a fiberglass insulation. Insulation is commonly installed in homes where the attic roofs are insulated to prevent heat absorbed by the roof to be conducted downwards. It is also used at doors and windows, to prevent outside heat from seeping into the house. Common types of insulation include fiberglass and foams. Benefits of insulation include allowing indoor temperatures to be maintained, reducing the amount of heat conducted and radiated into the home and so forth. Insulation is also a relatively low cost and simple way of reducing the need to actively cool the building (Eartheasy, 2009).

Figure 2.7: Fiberglass insulation (Ebuild, 2009)

The limitations of insulation mainly involve health issues. Fiberglass is known to cause skin allergies and there is debate on whether or not it may cause cancer. It may also trigger reactions in those people who are chemically sensitive since most fiber glass insulation is produced using a phenol formaldehyde binder to hold the fibers together. These binder materials may release offending amine or "dear-fish" odors in high humidity situations. Some types of insulation are prone to infestation from wood boring insects such as termites. Tunnel and nesting capacities will affect both the thermal properties and general structure integrity (Aerias AQS IAQ Resource Center, 2009).

2.4.4 Radiant Barriers

Radiant barriers are materials that are installed in buildings to reduce summer heat gain and winter heat loss. Figure 2.8 illustrates how a radiant barrier works. It reflects radiant heat back towards its source, reflecting as much as 97%. When a radiant barrier is placed on the attic floor, much of the heat radiated from the hot roof is reflected back toward the roof. This reduces the amount of heat that moves into the rooms below the ceiling. Studies have shown that radiant barriers can lower a cooling bill by between 5 and 10 percent when used in warm, sunny climates.

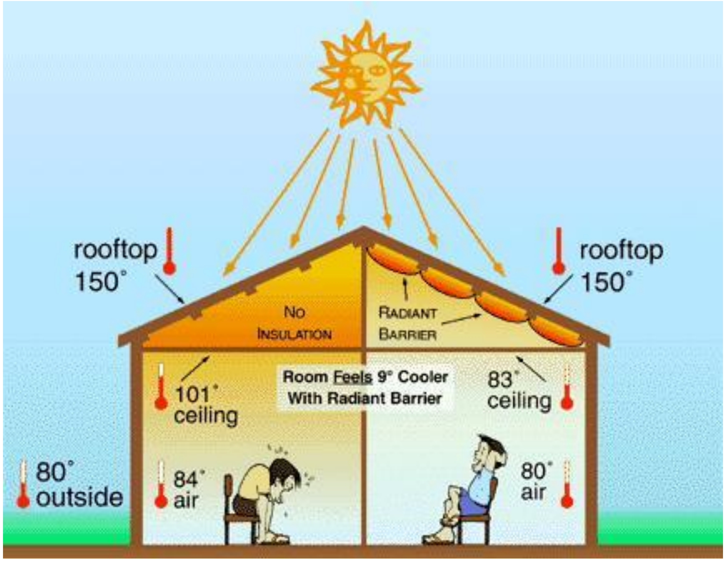

Figure 2.8: Illustration of how radiant barriers work (McLane, 2007)

Radiant barriers come in various forms, including: reflective foil, reflective paint coatings, and reflective chips. The main disadvantage of radiant barriers is that dust can seriously impair the performance of a radiant barrier by dulling the reflective surface resulting in the radiant heat being absorbed instead of reflected.

2.4.5 Terracotta Panels

A study was conducted by UTP students using terracotta wall panels to absorb the radiated heat from the sun. During the day, the panels block the heat radiated from the sun whilst at night, they absorb the heat from the wall of the house, thus cooling the house. The advantages touted include energy savings, the usage of a natural resource, and making the target building more comfortable by helping to maintain a uniform temperature throughout the house. Figure 2.9 and 2.10 show the results of the experiment that was conducted to study the temperature effect when the terracotta panels are used. The results of the experiment showed that the indoor temperature rises more slowly with the usage of the terracotta panels.

The disadvantages of using clay panels are that they are heavy and brittle, rendering them unsuitable for use outside the house as they would be easily damaged. The panels have also not been proven to be weather resistant, and could be easily damaged due to factors such as wind, rain, and air pollution. More studies have to be conducted to really prove the system (Zubir et al, 2009).

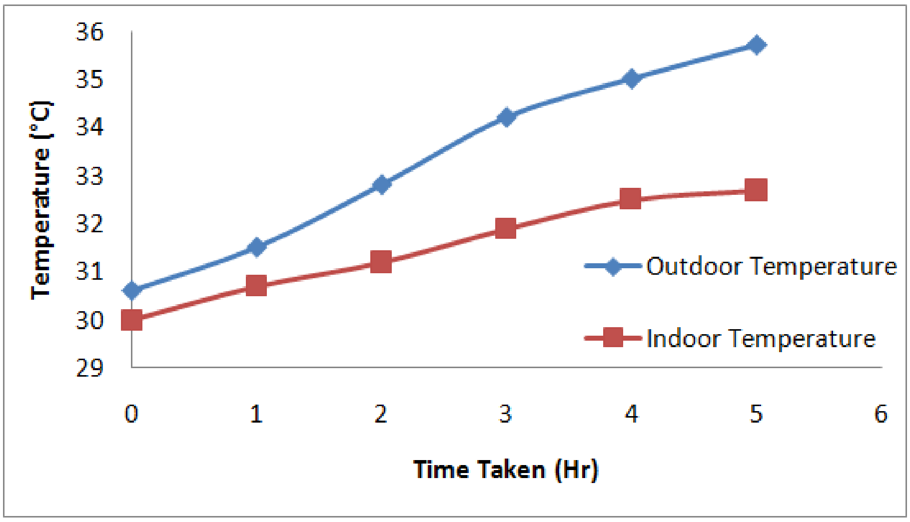

Figure 2.9: Graph of temperatures vs time without panel. Reproduced from (Zubir et al, 2009)

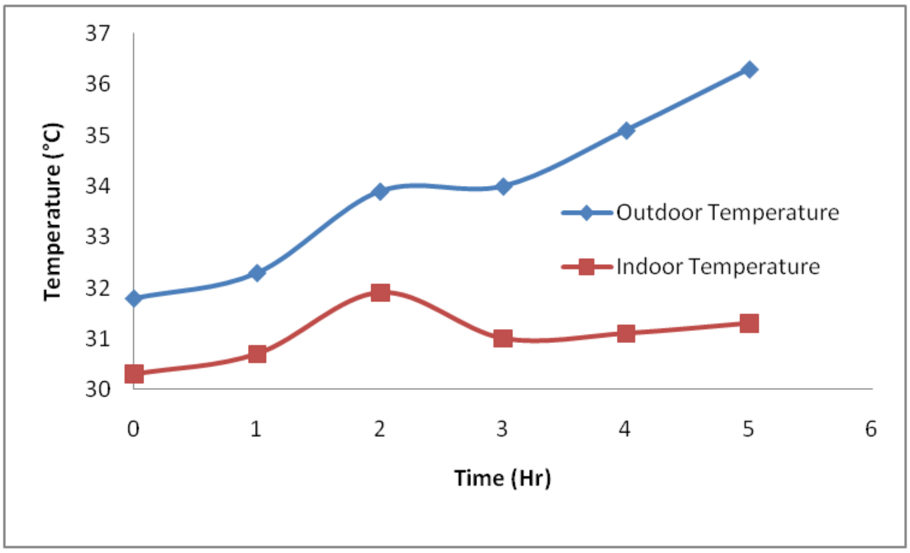

Figure 2.10: Graph of temperatures vs time With Panel. Reproduced from (Zubir et al, 2009)

CHAPTER 3

METHODOLOGY

3.0 Project Flow

Figure 3.1 shows the projected project flow comprising of the literature review, the concept and design selection, and finally the testing and analysis of the model that was built.

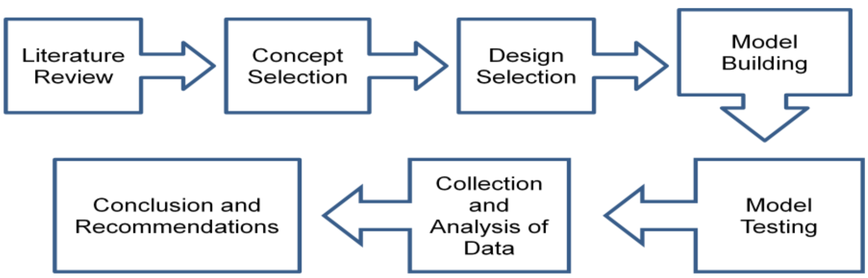

Figure 3.1: Project flow

The research methods used include reading and researching textbooks and journals for the various applicable theories. The Internet was also scoured to look for the latest designs and studies that were helpful in this project. Several concepts were looked into, and the best concept was selected. Several designs were then made based on the selected concept. The designs took into account the cost, ease of manufacture, need for maintenance and so forth. A model was then built based on the selected design. This was followed by testing and collection of data. The data was then analyzed, and conclusions and further recommendations were made.

3.1 Project Activities

3.1.0 Concept Selection

Figure 3.2 shows the 3 different concepts while Table 3.1 shows the comparison of the 3 concepts of which the highest scoring concept will be chosen. Each factor of comparison has been given a weightage of 0.1 to 0.2. This weightage is given based on how important that factor is to the overall system design. Factors such as currently available technology, resistance to leakage, ease of maintenance, and the system being proven to work are considered more important, thus have weightages of 0.2. Each factor would also have a grading from 1 to 5, with 5 being the best.

The piping concept is based on that of the conventional radiator, where hot water flows through the pipes, transmitting heat out into the room. The modular cooling pad can be installed on walls, and also has water that flow through them continuously. It is a new design, and was created by an Austrian company and has a dual purpose usage of both heating and cooling. The cavity wall has already been used for cooling purposes where air instead of water is used.

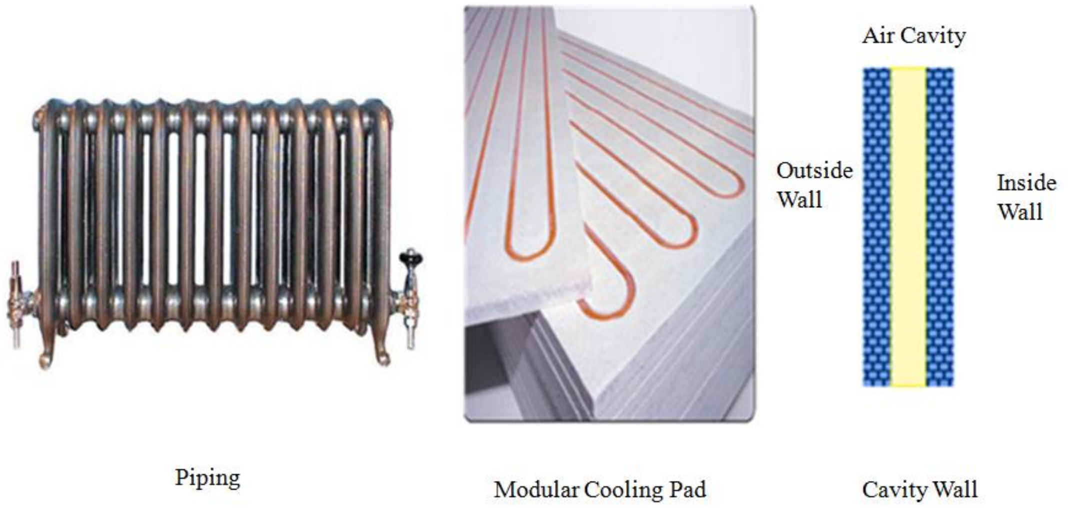

Figure 3.2: Shortlisted concepts

The cavity wall concept was chosen as the datum because it is an existing system that is already in usage though the utilization of water still does not exist. The cavity wall system is incorporated during the design and construction of a home. The occurrence of leakage or seepage should not occur as the interior of the wall will be waterproofed. It is not really easily assembled and requires some knowledge about laying walls and so forth.

Table 3.1: Comparison table for concept selection

Concepts			
Factors	Piping	**Cavity Wall (Datum)**	Modular Cooling Pad
Aesthetics (0.1)	2	**4**	3
Ease of Assembly (0.1)	3	**3**	4
Available Technology (0.2)	3	**4**	3
Resistance to Leakage (0.2)	2	**4**	3
Ease of Maintenance (0.2)	2	**3**	3
Proven to Work (0.2)	2	**3**	3
Total Points	2.3	**3.3**	3.1

3.1.1 Design Selection

Two main designs were created. Figure 3.3 shows the first design which utilizes water to absorb heat from the wall. Water would be let into the system during the day, and released at night. This was so the water would absorb the heat that would normally be absorbed by the walls. This first design focuses on reducing the heat storage and time lag effect.

Figure 3.4 shows the second design where water flows continuously into and out of the wall cavity, thus using convection to remove heat. The system would be switched on during the night time and would require a continuous flow of water. This design focuses on the removal of heat from the occupants, electrical equipment, and so forth.

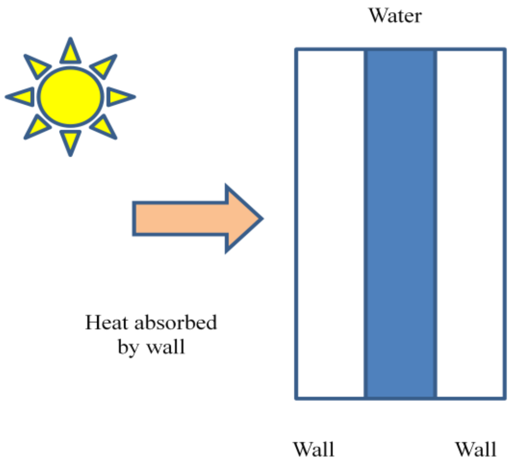

Figure 3.3: Design1: Thermal Mass

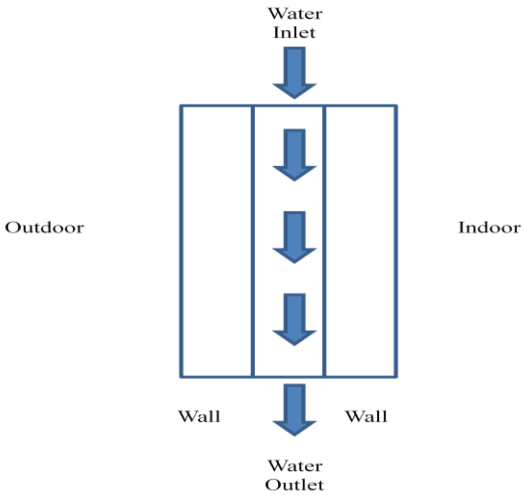

Figure 3.4: Design2: Continuous Flow

Both designs were compared based on cost, peripheral equipment, energy usage, and also a general calculation of their respective heat transfer rates. The calculation of heat transfer rates were conducted based on the assumption of a temperature difference, ΔT of 5 K, and a water temperature of 230K. Figure 3.5 shows the dimensions of the wall that were made based on the dimensions of a hostel room in V5 village, UTP and can be seen below.

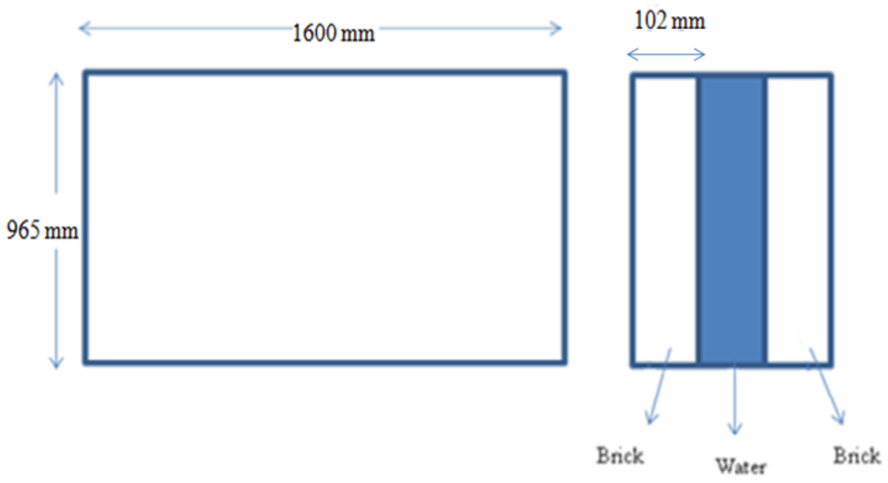

Figure 3.5: Dimensions of wall

Equation 2.1 is used for the first calculation where the water is treated as a still body. The assumptions are that conduction is the main mode of heat transfer and this is a one dimensional steady state plane wall conduction. The *k* value for water at 300 K is 613 x 10^3 W/m.K, and for common brick it is 0.72 W/m.K.

Equation 2.2 is used for the second calculation, where water flows continuously into and from the wall cavity. The relevant assumptions are that convection is the main mode of heat transfer. The *h* value for water at 300 K is 200 W/m^2.K and the *k* value is still the same for common brick at 0.72 W/m.K.

3.1.2 Solar Intensity Readings

Table 3.2 shows the readings taken to obtain the average Solar Intensity value. The readings were taken using a Solarimeter, and were conducted throughout a period of 4 days. The average value derived from the readings is 461.1 W/m^2. The purpose of obtaining the value is so that a general idea of the intensity of the sun can be obtained, and thus the relevant spot lights can be purchased to simulate the intensity of the sun.

Table 3.2: Solar intensity readings

	Fri	Sat	Sun	Mon
Time	Solar Intensity Readings W/m²			
1100	250.5	335.7	233.2	362.3
1130	231.2	461.6	326.1	420.1
1200	347.3	402.3	268.3	394.4
1230	357.5	367.4	251.3	503.8
1300	303.4	562.8	285.4	487.5
1330	702.4	482.6	462.7	529.7
1400	623.9	387.4	602.3	510.3
1430	683.4	451.2	612.5	508.4
1500	585.2	578.4	682.4	487.2
1530	453.7	544.1	710.2	409.1
1600	578.4	631.7	580.2	341.5

3.1.3 Model Construction

Figure 3.6 shows the model that has been constructed. The detailed design can be found in Appendix II. The model has been built to a scale of 1:6 in accordance with the proposed wall as mentioned above. The cavity is the only aspect of the model that could not be built according to scale simply due to the fact of it being too small. Instead, the cavity has been increased from its original scaled size of 2 to 18 mm. The materials used in constructing the model include plasterboards, silicone for waterproofing purposes, and also glue. The thicknesses of the walls are 9 mm, and the model rests on the floor.

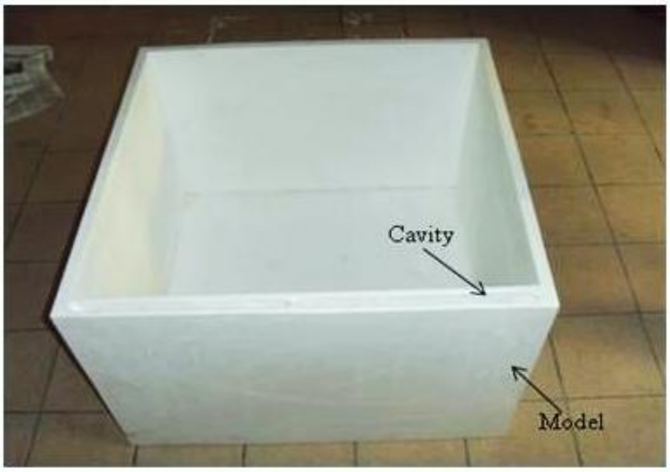

Figure 3.6: Picture of constructed model

3.1.4 Proof of Concept

The model was tested under 3 different situations, the first being just a normal wall, the second, with an air gap, and the third, with a water filled gap. A test was conducted before to determine the maximum temperature that the wall can achieve, where a constant beam of 500 W/m² was shined onto the wall surface for 5 hours, with the temperatures recorded at hourly intervals. The results of the test showed that after 2 hours, the wall would have already achieved its maximum temperature, and that any longer time period would not make a big difference to the wall temperature. The test also showed that the wall would cool down relatively fast, and would usually reach ambient temperatures within 30 minutes.

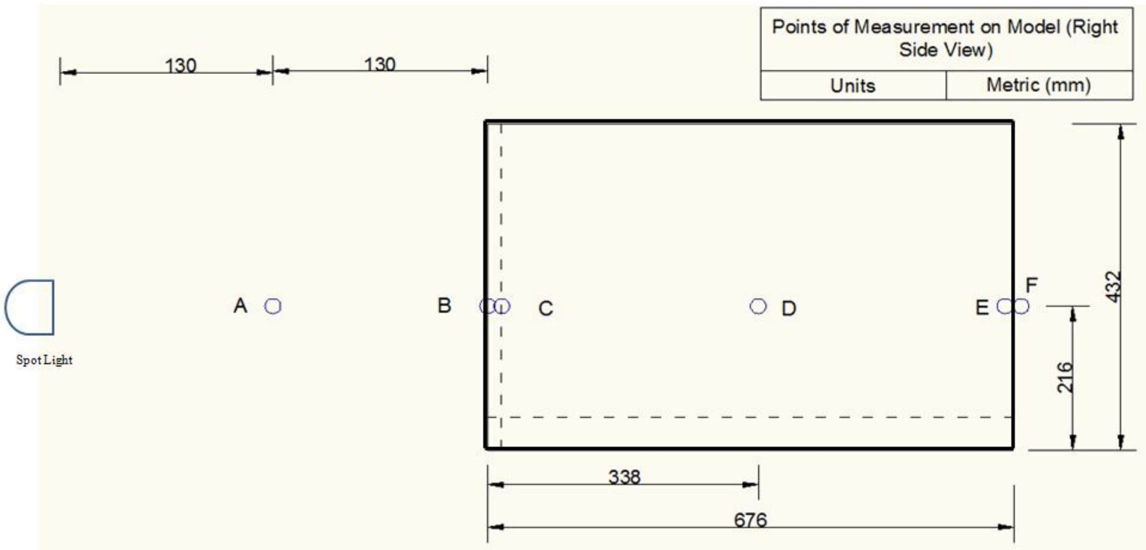

Figure 3.7: Points of measurement on model (right side view)

It was then decided to shine the beam for a period of 2 hours, with temperatures recorded at hourly intervals on the points of 6 points of A,B, C, D, E, and F as seen in Figure 3.7. After the spotlight was shut off, the temperatures would then be taken every 5 minutes for a 30 minute period. The temperature differences are then examined to prove the concept that a water cooled wall will work. The spotlight used is 500 watts, and the initial water temperature is 30 °C. The points of measurements are located at a height of 216 mm from the base of the model, and 343 mm from the sides of the model. They are located at the centre of the model.

3.2 Key Milestones

The key milestones for this project includes researching on the various available technologies, deciding on the concept to be used, selecting and finalizing details of the design, building a model, and finally testing and evaluating the model. The Gantt charts which indicate the key milestones can be seen in Appendix I.

3.3 Project Planning

The project was planned in steps, where the literature review was done first, followed by the concept and design selection, the building and testing of the model, and finally the collection and analysis of the results.

CHAPTER 4
DESIGN BASIS

4.0 Design Requirements

This system aims to reduce the heat storage effect that has been explained in the Literature Review section. The system works alongside existing cooling systems such as fans and air conditioners. The benchmark set for this system utilizes the Energy Efficiency Ratio, or EER which is used by Energy Star, which is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy (Energy Star, 2009). The EER measures steady-state efficiency, which is the efficiency of the air conditioner once it is up and running. EER rates the energy efficiency of an air conditioning unit by looking at the ratio of output cooling (in BTU/hour) to the input power in Watts for a given period of an hour (Green Energy Efficient Homes, 2009). The average ratings for an air conditioner are between 9.0 – 10.8, and the higher the EER, the more efficient the air conditioner is (Energy Star, 2009). The system also has to be aesthetically pleasing or unnoticeable as possible. This is so that it will be able to attract users to install it.

4.1 Design Constraints

One of the constraints placed on this design is it should have a negligent impact on the strength of the wall. This is to ensure that the entire building structure remains stabile, and that will be no risk to the occupants inside. This is also to ensure that costs are kept low as no special materials or building methods need to be used in the construction of the wall.

There should also be no unnecessary modifications to existing wall building techniques. This is to reduce any special training that has to be conducted, and allow the installation of this system to be conducted widely by existing contractors. This will also reduce the associated costs of construction. The system should also only have a minimum need for auxiliary equipment such as pumps and piping. This is to reduce costs related to installation and maintenance.

4.2 Initial Drawings

Figure 4.1 shows the initial drawing with dimensions for the proposed wall. The proposed wall is based on a UTP hostel room. The room was chosen because the dimensions and building specifications were readily available from the UTP Maintenance Department. The model will be a third of the actual size of the wall. This is to reduce the related costs and work required to build it. As the minimum thickness of a brick is 62.5 mm, other materials that have the same properties will be looked into as substitutes.

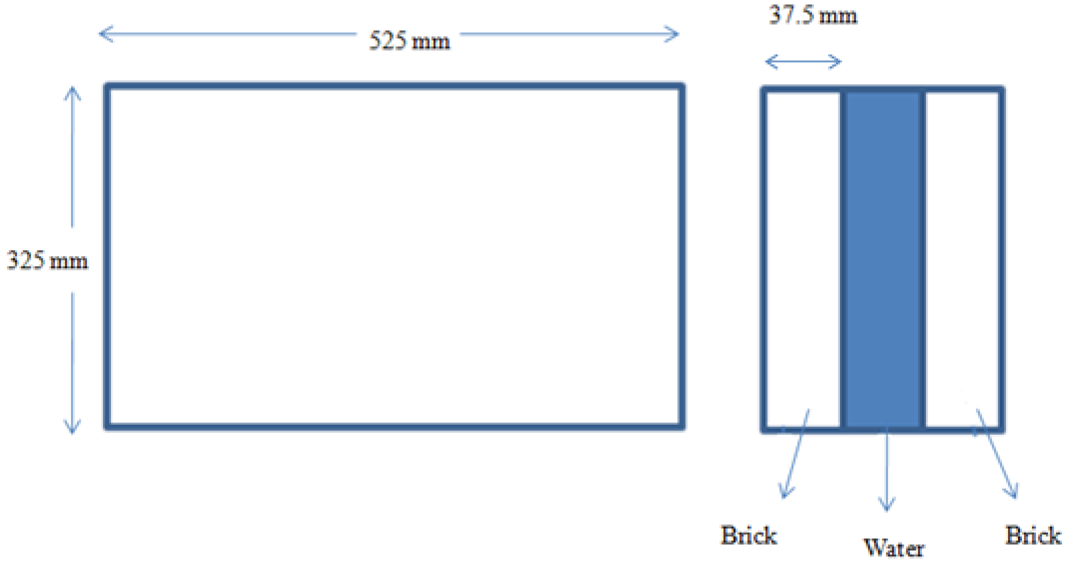

Figure 4.1: Dimensions of design based on UTP hostel room

CHAPTER 5
RESULTS AND DISCUSSION

5.0 Concept Selection

The three concepts were compared based on several factors such as aesthetics, ease of assembly, possibility of leakage or seepage, ease of maintenance, and so forth. These factors are chosen because they are considered important for the application of the design later on.

The piping concept is based on the conventional heater concept, and thus is not easy to manufacture and requires outsourcing. It also faces a maintenance issue where the person requires knowledge about piping and tools. Leakage and seepage can also occur as the system has many connections and joints. This concept is also unproven in the area of cooling, as it is usually used for heating.

Modular cooling pads are quite new, and have only been in the market for a few years. Nevertheless, manufacturing still needs to be outsourced. Leakage and seepage could also happen but the pads are usually waterproofed to prevent this. This system has been proven to work with a continuous flow of cold water but has not been tested with the thermal mass concept.

Based on Table 3.1, it has been decided that the cavity wall concept is the best one amongst the three and thus designs will be made based on this concept.

5.1 Design Selection

As mentioned before, both concepts are compared based on the need for auxiliary equipment, energy usage, and heat transfer rates. Table 5.1 shows a comparison between the two designs.

Table 5.1: Comparison of the two designs

Design 1: Thermal Mass	**Design 2: Continuous Flow**
Waterproofing	Waterproofing
Heat sink for discharged water	A continuously working pump
Heat transfer rate = 2.94 MW	Water channels or piping
	Heat sink for discharged water
	Heat transfer rate = 97.92 W

As can be seen from Table 5.1, Design 2: Continuous Flow requires extra equipment compared to Design 1: Thermal Mass. The equipment required include a continuously working pump and water channels or piping for the continuously flowing water. All these translate into higher energy usage, and building materials, which equals to a higher building and installation cost, and also higher operating cost. Based on the cost issues, it has been decided to go with Design 1: Thermal Mass.

5.2 Cooling Load Calculation (CLTD)

The basic cooling load for a room at night is calculated. The dimensions, equipment, and persons in the room are based on a combination of 2 UTP hostel rooms. The rooms were chosen simply due to convenience purposes, as the dimensions were readily available. Both these rooms will be combined, and assumed to be one large room in the calculations. The rooms are facing east.

The Cooling Load Temperature Distribution (CLTD) method will be used to calculate the cooling load. Factors such as heat gain from the sun, equipment, and people will be considered. The steps to calculating CLTD include selecting indoor and outdoor temperatures, calculating areas of surfaces which have external heat gains, calculating heat gains through walls, roof, and floors, determining the occupancy and appliance load, determining infiltration and ventilation load, and so forth (Wang et al, 2000).

The indoor and outdoor temperatures were taken at 2000 hours, for 3 times each, and the average value was taken. The average values for indoor and outdoor temperatures were 30 °C and 29.3 °C respectively. Figure 5.1 shows the dimensions of the side of the room that faces the outside. The dimensions were obtained from the UTP Maintenance Department, as well as through measurements done by using a measuring tape. The measurements were also taken for 3 times, with an average value derived from the results.

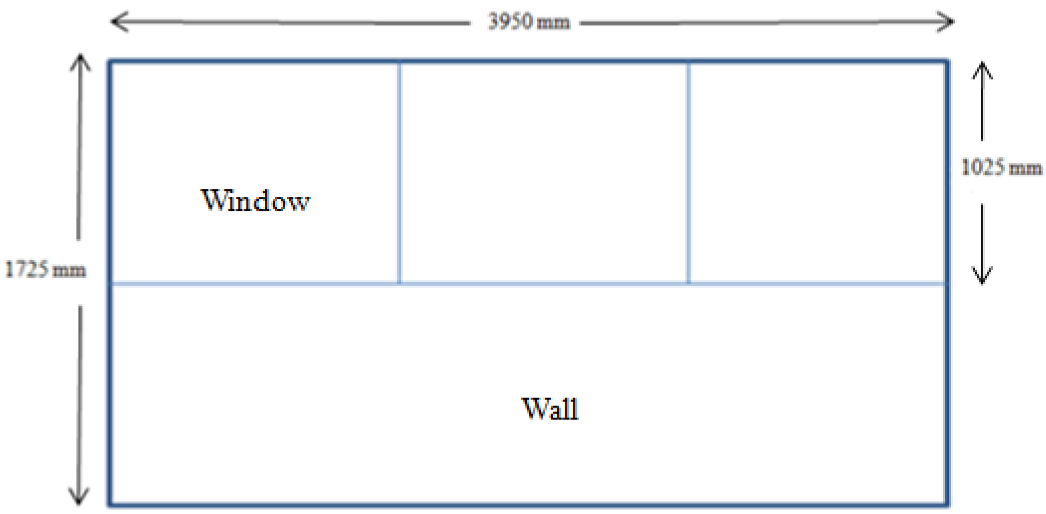

Figure 5.1: Dimensions of outer wall (front view)

It is normally practiced in Malaysia that the windows are left open for ventilation purposes. They are thus assumed as openings, and the glass properties will not be considered. Table 5.2 shows the Sensible Cooling Load Calculations form. Equation 4.1, where Q = U x A x CLTD, is used to calculate the heat gain values in Kilowatts. Values for appliances of 4 computers and also an occupancy load of 4 people are considered. Infiltration of air into or out of the room is not considered as this calculation is during the night and the outside temperature is usually higher. It can be seen from Table 5.2 that the water cooled wall should have an ability to reduce the cooling load of 5.29 KW. All heats are also considered as sensible heat because there is no change in the state of the air inside the room and all values are obtained from *Air Conditioning Principles and Systems* by Edward G. Pita (Pita, 2001).

Table 5.2: Room Sensible Cooling Load calculations form

Room Name	UTP Hostel Room				
Plan Size (m)	0.7 x 4.0				
Wall	**Direction**	U (W/m^2- K^2)	A (m^2)	CLTD	kW
	South	1.36	28.0	6	0.13
	East	1.36	24.0	13	0.24
Roof/Ceiling		1.02	32.0	37	0.67
People		4 x 1278			0.26
Appliances		4 x 19312			3.99
RSCL					5.29

5.3 Proof of Concept

Based on the previous description on how the tests were run, Figure 5.2 shows a picture of the test bed. Figure 5.3 shows a comparison of the variation of temperature with time for the different wall types. From the figure, it can be seen that the Wall with Water Gap reaches a lower temperature faster than the other walls. The general trend of the temperature is the same for all the types of walls. From the results obtained, the Wall with Water Gap has the lowest temperature distribution compared to the other types of walls.

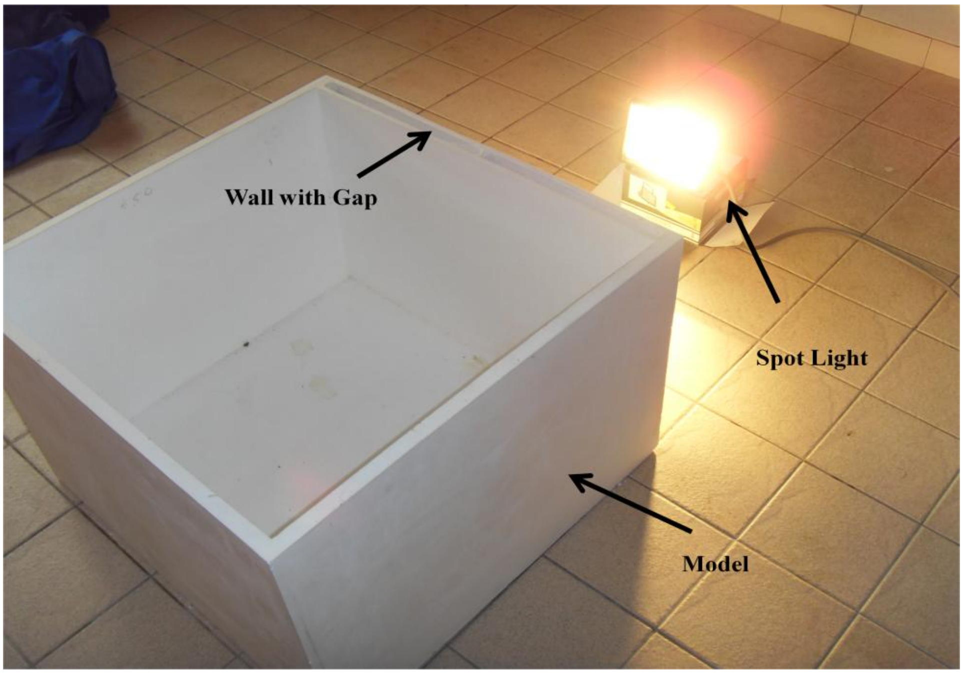

Figure 5.2: Picture of test rig

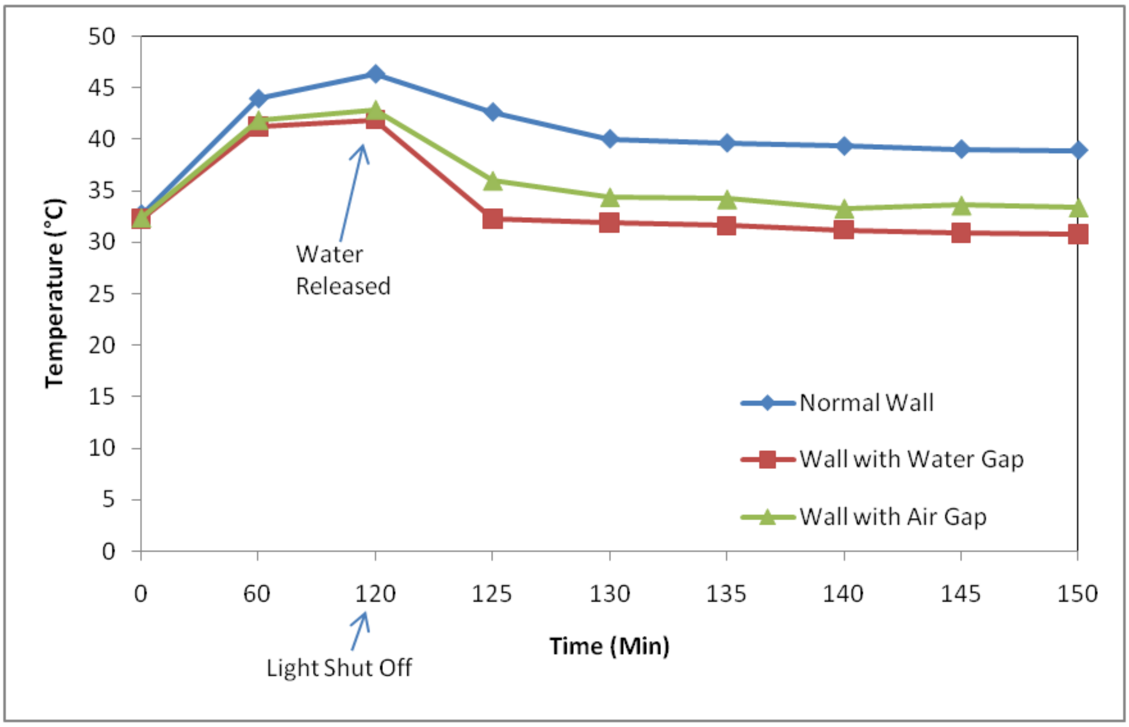

Figure 5.3: Variation of temperature with time for the different wall types

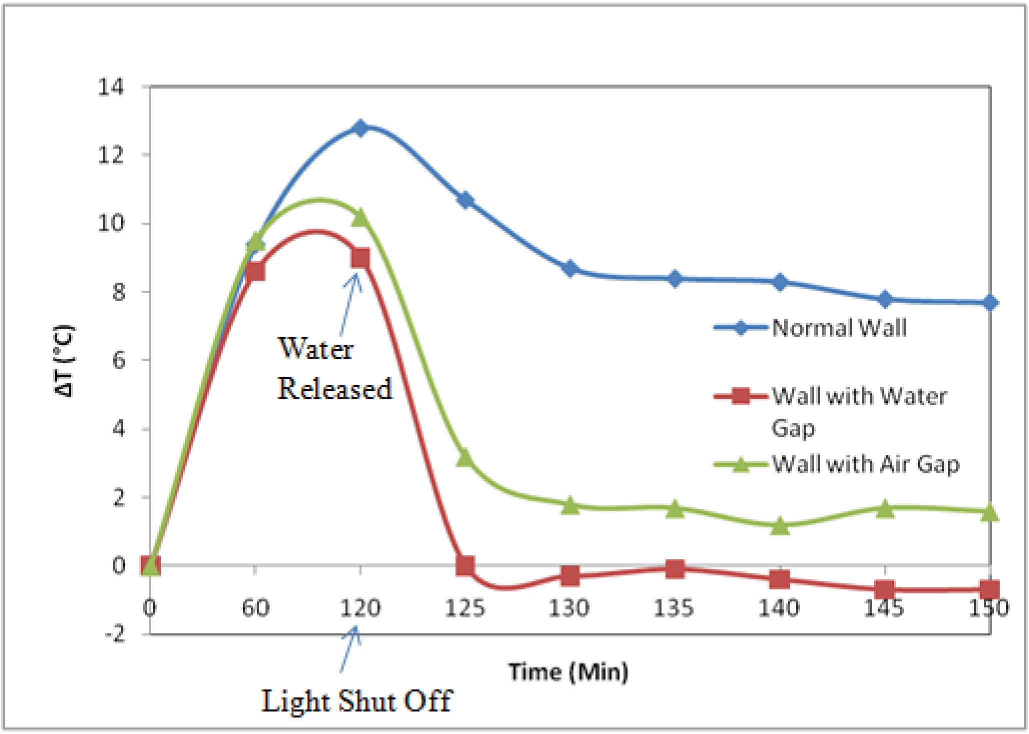

Figure 5.4: Variation of ΔT with time for the different wall types

Figure 5.4 shows a variation of ΔT with time for the different wall types. A low ΔT means that the differences between the indoor and outdoor temperatures are low. It must be noted that indoor temperatures at night are higher than outdoor as seen from the ETP recording of temperatures. The Wall with Water Gap has the lowest ΔT overall, and it also achieves that at a shorter time. The ΔT for the Wall with Water Gap actually falls into the negative zone, where the indoor temperature is becomes lower than that of the outdoor temperature. The complete data can be seen in Appendix III.

Table 5.3: Results from repeatability test

	Take 1	Take 2	Take 3	Take 4	Take 5	Mean	
Time(min)	Temperature °C						Std. Deviation
60	61.5	61.7	61.2	61.8	61.6	61.6	0.23
120	62.3	62.5	62.1	62.6	62.0	62.3	0.25
125	41.4	41.6	41.3	41.5	40.0	41.2	0.66
130	36.2	36.3	36.3	36.5	36.4	36.3	0.12
135	35.6	35.4	35.7	35.5	35.6	35.6	0.12
140	34.5	34.6	34.7	34.5	34.6	34.6	0.09
145	33.8	33.7	33.8	33.9	33.8	33.8	0.07
150	32.8	32.6	32.6	32.5	32.5	32.6	0.12

A repeatability test was also conducted, where Point B was measured for 5 times during each reading taking. This was to ensure that the results can be replicated. The results from the repeatability test are shown in Table 5.3. The results show that the repeatability of this experiment is good, and that the general results obtained should be able to be replicated.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.0 Conclusions

The work completed in this study includes a literature review of the relevant theory and passive cooling strategies currently available, a concept and design selection, the building and testing of the model, and finally, the collection and analysis of the tests results.

From the tests results obtained, the single layered wall seems to have the highest temperatures and also temperature differences. This is because it does not have a cavity, be it air or water that is able to absorb the heat. All the heat stored and released has no place to go, and thus heats up the model further. The wall reaches a maximum indoor temperature of 46 °C, which is very high for an indoor situation. This high temperature is due to a lack of ventilation, which also hindered the released heat from leaving the model.

The air cavity wall fares better, and has a much lower temperature and temperature difference compared to that of the single layered wall. This happened because the air cavity was able to absorb heat, and also because air is a good heat insulator. This helped stop the heat from being conducted into the walls. After the spot light was shut off, the air in the cavity is then able to release the heat stored into the surrounding environment. The maximum indoor temperature of 41 °C is lower than that of the Normal Wall by 5 °C, which shows how a small air cavity is able to make such a big difference. It is believed that the air cavity wall will be able to work better if ventilation is introduced into the air cavity, where the air inside is changed regularly.

The water cooled wall is the main focus of this study. Looking at the tests results, the water cooled wall has the lowest indoor temperatures and also the lowest temperature differences. It also takes the shortest time to achieve these temperatures. The water in the cavity has a higher specific heat capacity compared to that of air, and so is able to absorb more heat. The water is also released directly after the spot light is switched off, and this released water contained the heat absorbed. The releasing of the water helped counter the heat storage and time lag effects and this can be seen from the results obtained.

In general, it can be deduced that the water cooled wall has played its designed role in countering or reducing the heat storage and time lag effects.

The objectives of this project have been met successfully as it is now deemed feasible to further look into developing a water cooled wall. The secondary objectives to remove the heat stored in the wall and to reduce the temperature differences between indoors and outdoors have also been met, as can be seen from the results.

6.1 Recommendations

It must be noted that the materials used in the building of the model are not the exact same building materials in houses. The tests run have only proven the concept, and further research and tests have to be done.

One of the variations that can be done is by varying the heat of the spot light. If the results obtained are consistent with those from this study, then it will be able to prove the consistency of this concept.

Varying the size of the cavity can also be done. This variation would be able to show how a different cavity size is able to influence the results. A relationship can then be discovered, and a graph plotted to help future work in determining the appropriate cavity size.

Another variation that can be done is by introducing the element of ventilation. Gaps that represent windows can be made in the model. This would then be able to show if the difference between the different wall types is still obvious when ventilation is present. Ventilation can also be provided for in the cavity, and this will be able to show if a constantly moving fluid is able to produce even better results, and if so, the extent of the improvement.

A computer simulation can also be done to simulate the various building materials. Such a simulation can be used to show how the properties of the different building materials affect the tests results. The simulation can also be run to verify the results obtained in this study.

REFERENCES

Aerias AQS IAQ Resource Center. (2009). *Insulation: The Different Types and Their Advantages and Disadvantages*. Retrieved October 2, 2009, from http://www.aerias.org/DesktopModules/ArticleDetail.aspx?articleId=95

American Coolair Corporation. (2001, February). Evaporative Cooling Systems.

Brown G.Z., Kline J., Livingston G., Northcutt D., Wright D.. (2004). *Natural Ventilation in Northwest Buildings.* University of Oregon.

Capehart B.L, Turner W.C., Kennedy W.J. (2003). *Guide to Energy Management.* Marcel Dekker.

Construction Resources. (2009). Variotherm Radiant Heating Systems - Overview.

Earle, R. L. (1983). *Unit Operations in Food Processing.* Pergamon Press.

Eartheasy. (2009). *Natural Home Cooling*. Retrieved September 30, 2009, from http://www.eartheasy.com/live_naturalcooling.htm

Ebuild. (2009). *Fiberglass Insulation*. Retrieved October 2, 2009, from http://www.ebuild.com/articles/404379.hwx

Efunda. (2009). *Free Convection Theory in Heat Transfer*. Retrieved August 3, 2009, from http://www.efunda.com/formulae

Energy Star. (2009). *About Energy Star*. Retrieved 10 October, 2009, from http://www.energystar.gov/index.cfm?c=about.ab_index

Energy Star. (2009, September). *ENERGY STAR Qualified Room Air Conditioners*. Retrieved October 14, 2009, from http://www.energystar.gov/index.cfm?fuseaction=roomac.display_products_html

Georgia State University. (2000). *HyperPhysics*. Retrieved October 2, 2009, from http://hyperphysics.phy-astr.gsu.edu/HBASE/thermo/heatra.html

Green Energy Efficient Homes. (2009). *Air conditioning ratings* . Retrieved October 16, 2009, from http://www.green-energy-efficient-homes.com/air-conditioning-ratings.html

Jones D.D, Friday W.H. (2009). *Natural Ventilation for Livestock Housing.* Purdue University.

KeTTHA, Malaysian Ministry of Energy, Green Technology and Water. (2008, 1 13). *http://www.ktak.gov.my/template01.asp?contentid=19*. Retrieved 8 30, 2009, from http://www.ktak.gov.my.

Laili, M. H. (2009, October 20). Building Materials of UTP Hostels. (S. S. Wei, Interviewer)

Masonry Advisory Council. (2002). Design Guide for Taller Cavity Walls.

McLane, J. (2007). *Central Florida Energy & Environmental Consultant*. Retrieved October 2, 2009, from http://www.johnlmclane.com/home

Natsution, H. (2005). *Energy Efficiency at Usage of Air Conditioning Systems In the Effort of Electrics Energy Saving Consumption.*

Naves, R. (2000). *HyperPhysics*. Retrieved October 2, 2009, from http://hyperphysics.phy-astr.gsu.edu/HBASE/thermo/heatra.html

Pita, E. G. (2001). *Air Conditioning Principles and Systems (4th Edition).* Prentice Hall.

Santamouris, M., Asimakopoulos D. (1996). *Passive Cooling of Buildings.* James & James.

Sci-Tech Dictionary. (2009). *Natural Convection*. Retrieved August 16, 2009, from http://www.answers.com

Srivinasan, D. (2003). *Principles of Heat Transfer.* New Age Publications

Stamper K., Koral R.L, Strock C. (1979). *Handbook of Air Conditioning, Heating, and Ventilating.* Industrial Press Inc.

Taftan Data. (1998). *Fourier's Law of Conduction*. Retrieved August 2, 2009, from http://www.taftan.com/thermodynamics/FOURIER.HTM

Teekaram, A. (2003, April). *Building Services and Environmental Engineer: Confidence in Natural Ventilation*. Retrieved October 1, 2009, from http://www.bsee.co.uk/news/printpage.php/aid/2546/Confidence_in_natural_ventilation.html

The Brick Industry Association. (2001, February). *http://www.gobrick.com/BIA/technotes/t43c.htm.* Retrieved August 30, 2009, from http://www.gobrick.com/BIA.

United States Department of Energy. (2007). Coolerado Cooler Helps to Save Cooling Energy and Dollars. *Technology Installation Review* .

United States Energy Information Administration. (2009). *International Energy Outlook 2009.* Energy Information Administration.

Wang S.K., Lavan Z., Keith F., Norton P. (2000). *Air Conditioning and Refrigeration Engineering.* CRC Press.

Zubir B., Shaidan H., Jamil Y., Tuhaijan A., Rauf H.A., Azme F., Motloung L.M. (2009). *Natural Wall Cooling System By Using Terracotta Clay Panel.*

APPENDIX I

Gantt chart for FYP I

Week Number / Activities/Milestone	1	2	3	4	5	6	7	8	9	10		11	12	13	14
Literature Review	■	■	■	■	■	■	■	■	■	■		■	■	■	■
Concept Selection					■	■	■	■	■						
Design Creation						■	■	■	■						
Design Calculation									■	■					
Design Selection										■		■			
Material Selection												■	■		
Finalization Of Design												■	■		
Finalization of Design Details													■	■	■

Gantt chart for FYP II

Week Number / Activities/Milestone	1	2	3	4	5	6	7	8	9	10		11	12	13	14
Building of Model	■	■	■	■	■										
Testing of Model					■	■	■	■							
Data Collection of Tests						■	■	■							
Analysis of Data							■	■	■	■					
Evaluation and Modifications										■		■	■		
Conclusion and Recommendations													■	■	■

APPENDIX II

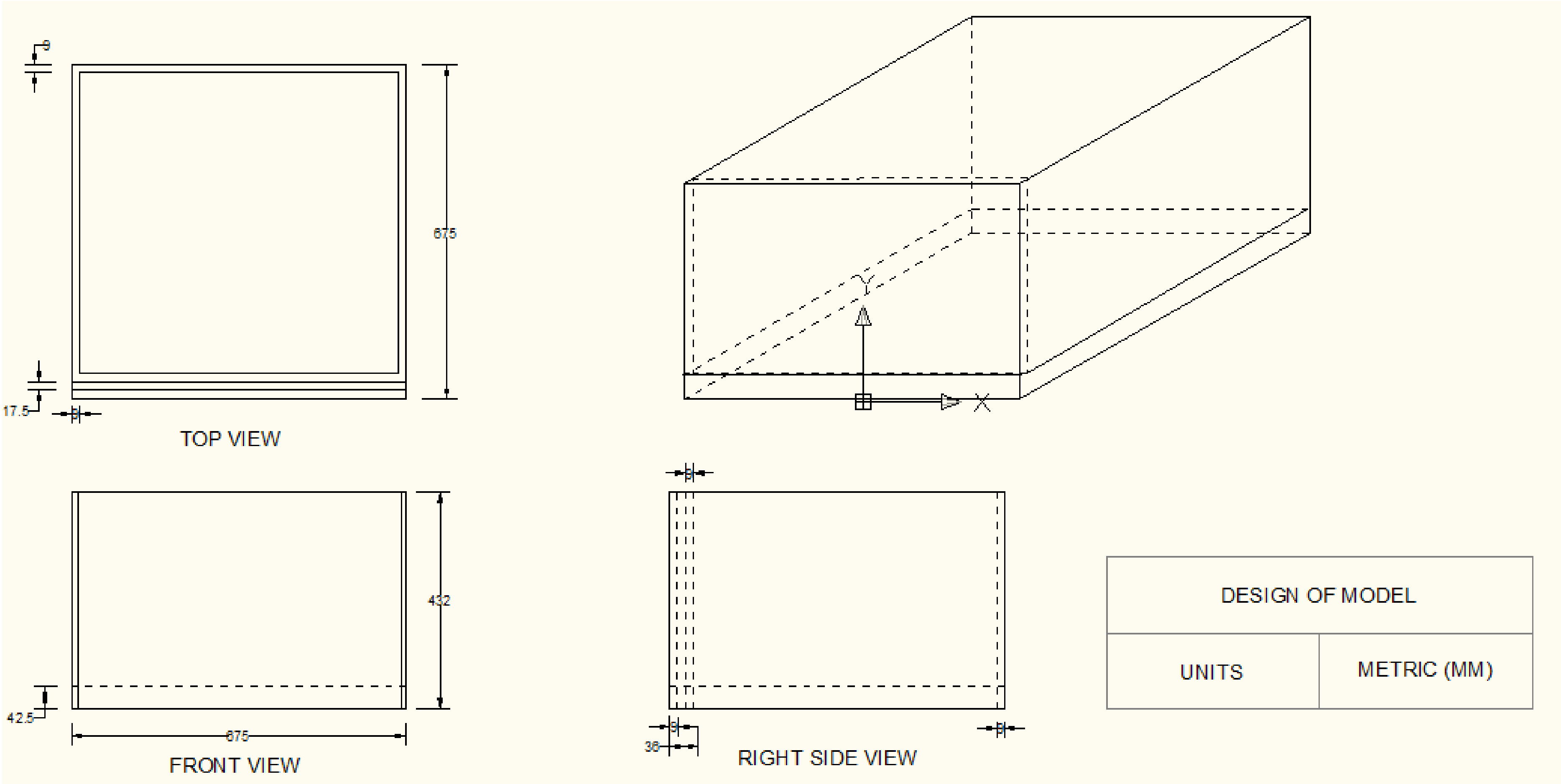

Figure I: Dimensions of built model

APPENDIX III

Normal Wall

Table 1: Results of test with normal wall.

Time (min)	A	B	C	D	E	F	Ambient T	ΔT (D-Ambient)
	Temperature (°C)							
60	62.7	62.7	47.7	43.9	35.8	34.7	34.5	9.4
120	63.1	66.7	50.1	46.3	37.5	35	33.5	12.8
Spotlight Shut Off								
125	37.6	49.2	46.4	42.6	36.2	34.7	31.9	10.7
130	34.5	43.1	44.2	40.0	35.5	33.9	31.3	8.7
135	34	42.5	43.9	39.6	35.0	33.1	31.2	8.4
140	33.2	42.1	43.1	39.3	34.7	32.9	31.0	8.3
145	33.0	41.7	42.8	39.0	34.1	32.7	31.2	7.8
150	33.0	41.3	42.5	38.9	34.0	32.5	31.2	7.7

Wall with Air Gap

Table 2: Results of test with wall with air gap.

Time (min)	A	B	C	D	E	F	Ambient T	ΔT (D-Ambient)
	Temperature (°C)							
60	62.0	61.5	46.0	41.9	38.6	35.8	32.4	9.5
120	63.0	62.3	46.5	42.9	39.5	35.9	32.7	10.2
Spotlight Shut Off								
125	36.0	41.5	40.9	36.0	34.8	34.2	32.8	3.2
130	34.7	36.2	36.7	34.4	33.7	32.8	32.6	1.8
135	33.7	35.6	35.2	34.2	33.6	32.3	32.5	1.7
140	33.0	34.5	34.2	33.3	32.9	32.2	32.1	1.2
145	33.2	33.8	33.5	33.6	32.7	32.2	31.9	1.7
150	32.8	33.4	32.6	33.4	32.4	32.1	31.8	1.6

Wall with Water Gap

Table 3: Results of test with wall with water gap.

Time (min)	A	B	C	D	E	F	Ambient T	ΔT (D-Ambient)
	Temperature (°C)							
60	62.0	59.4	45.3	41.2	34.3	32.0	32.6	8.6
120	63.6	59.9	45.9	41.9	35.0	32.5	32.9	9.0
Spotlight Shut Off and Water Released								
125	34.3	38.6	38.1	32.3	33.1	33.0	32.3	0.0
130	32.6	36.4	36.3	31.9	32.7	31.5	32.2	-0.3
135	32.0	35.2	35.0	31.6	32.1	31.1	31.7	-0.1
140	31.9	34.6	34.2	31.2	31.7	31.0	31.6	-0.4
145	31.8	33.9	33.9	30.9	31.6	31.0	31.6	-0.7
150	31.9	33.2	33.4	30.8	31.6	31.0	31.5	-0.7