School of Engineering

PRJ60503

Mechanical Engineering Group Project 1 (MEGP1)

Final Report of

PCM Heat-Exchanger

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1.0 Introduction

PCM is a kind of ideal product or a substance to solve thermal management problems. This is because the PCM absorbs and releases a large amount of latent heat from the surrounding environment when the surrounding temperature reaches the melting and freezing point of the PCM by changing its physical state. The PCM absorbs large amount of latent heat from the surrounding environment while the PCM is in the process of melting (from solid to liquid). Conversely, the PCM releases equal amount of latent heat that was absorbed earlier to the surroundings during the process of solidification (PCM Products Ltd, 2019).

The concept of PCM is like Rechargeable batteries that can be found in the market easily. The rechargeable batteries store a certain amount of electrical energy and releasing the equal amount of electrical energy after its fully charged. The latent heat absorbed by the PCM can be stored in the PCM and this resulting the PCM to be a highly efficient thermal storage. Nowadays, PCM is used as a wallboard to act as air-conditioning unit to absorb excess heat in a room during the daytime and chill the room. Then the heat will be released during the night to warm up the room. By doing so, PCM is a completely electrical consumption-free, minimised the usage of energy and emitted less CO2 compared with air-conditioning unit. This shows that the PCM is an environmentally friendly substance (Ho et al., 2011).

PCM can be classified into organic and inorganic materials. The organic PCM has the advantages of not corrosives, and chemical/thermal stability, whereas the disadvantages are poor thermal conductivity, flammable and low phase-change enthalpy. The inorganic PCM has the advantages of better phase-change enthalpy, whereas the disadvantages of it is corrosive, thermal instability and phase separation (Bhatia. S. C, 2014). The PCM forms when two or more chemical (inorganic salts) mixed together and having higher or lower freezing/melting point than water. Examples of Organic PCM are wax, vegetable oil and soya/sugar, whereas the example of Inorganic PCM are Glauber's Salt, Calcium Chloride and Eutectic Salts.

In this project, our main objective is to conceive and design a phase change material (PCM) heat exchanger to be integrated into a heat pump as proposed by Daikin Malaysia. PCM was chosen as a potential replacement or improvement method for heat pumps in cold regions. In cold countries or during winter such as in Canada and the United Kingdom, or during winter in Japan and Korea, heat pumps are a common necessity. In extremely cold conditions, heat pumps are used as a method to extract heat from a region of lower temperature to a region of higher temperature and is the reverse of air conditioners. In the process of extracting heat, the outer coils on the outdoor unit experiences extremely low temperatures, and the water that condenses on the coils freeze and forms icicles and frost. The frost in turn hinders heat transfer, causing the heat pump efficiency to drop drastically.

For current heat pumps available in Daikin, when frost forms are that the heat pump switches into reverse cycle, one that is like an air conditioner cycle, and draws heat from the indoors to melt the frost formed on the outer coils. The downside to this method is that the customers experience major discomfort when the reverse cycle runs, as the heat pump is no longer providing heat, and is drawing heat from an already cold indoor environment. Currently, Daikin does not have any heat pump that utilizes phase change materials (PCM) to melt frost that forms on the outer coils during winter and is planning to research into using PCM as a method of heat storage to improve the defrost cycle. Hence, our group are required to generate ideas and come out with the prototype which includes list of materials, budget plan, 3D model of the design, simulation for the whole project within 14 weeks. During the 14 weeks, the group has constantly updated our progress to the project supervisor, Mr Thoo and also our lecturer, Dr Faizal. At the end of week 14, the team presented all the compiled results and prototype to Daikin supervisor and also the panel judge during the Engineering Fair in July 2019.

Figure 1:Team FaiDitLah comprising of (from the left) Zhi Heng, Alwyn Yip, Jian Hua, Jia Hao and Jason Chong

2.0 Objective

- To design a phase change material (PCM) heat exchanger for reduction in defrost time of heat pump.
- To integrate the phase change material (PCM) heat exchanger into the heat pump system.
- To improve the heating efficiency of the heat pump unit under various ambient conditions with the phase change material (PCM).

3.0 Conceive

After the team chose the project topic for this semester, the team begin to identify the root causes of the inefficient of the current heat pump design to get a better understanding of the project and help the team to identify the objective and requirement of the project clearly. In order to achieve that, the team constructed an Ishikawa Diagram that illustrates the root causes of the inefficient of the current heat pump design.

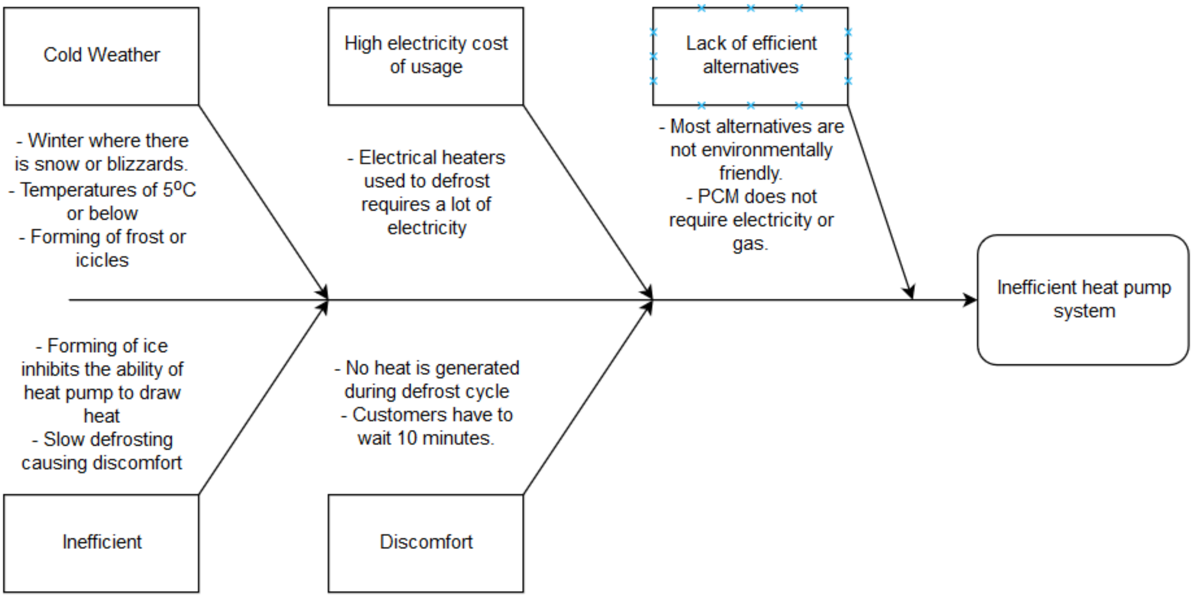

Figure 2:Root causes of inefficiency of heat pump system

As shown on the diagram above, some of the main challenges of the current heat pump systems were the drop-in performance under cold weather and the high electricity usage and cost. After identifying the root causes of the inefficient of the current heat pump, the team moved on to the next step which is to identify the challenges that the team might encounter during the design phase of the project. There are several challenges identified, such as the sizing limitations for the PCM storage tank, the design of the copper pipe within the PCM storage tank, the manufacturability of the copper pipe and overall design to achieve the desired heating efficiency and defrosting time. PCM, short for phase change material is a material that changes its physical properties according to external stimuli. To improve the defrosting time of an air conditioning unit, the team is required to use PCM to absorb heat energy from the refrigerant during heating cycle and reject heat energy from the PCM to the refrigerant during defrosting cycle and melt any frost formed on the outer coil and fins of the outdoor unit. Formation of frost of the outdoor unit not only reduces the efficiency of the air conditioning unit, at extreme cases it could potentially damage the outdoor unit which the owner would then need to hire a professional to fix it. Other than that, when an air conditioning unit is not able to function properly during cold weather, it could cause discomfort and irritation to the user as the humidity of the air is too low. Furthermore, it can cause individuals to get sick easily when they are not able to stay warm during cold weather.

The product was split into three main system, which were the PCM storage tank, the frost detection system and lastly the electronic circuit that controls the flow of the refrigerant using solenoid valve. The current average time needed to defrost an outdoor unit is about 15 minutes. By building an air conditioning unit with a PCM heat exchanger, the team was expected to reduce this time to 10 minutes or less. By taking into consideration the properties of the PCM the team is using, the storage tank needs to be made from plastic material or a metal with a layer of coating. The tank also needs to be sealed completely to prevent any leakage of the PCM. Other factors that needed to be taken into consideration during the design phase of the storage tank are the amount of PCM that will be filled into the tank and the design of the copper pipe. To overcome these challenges, the team had regular meetings and applied various thinking learnt from previous semesters to brainstorm an idea that would meet all the requirements mentioned above.

The first step was to determine the length of the copper pipe needed to be immersed into the PCM to achieve maximum efficiency. With help provided by industrial supervisor Mr. Thoo, the team was able to formulate and calculate the length of the copper pipe design. The main factor the team taken into consideration was the inner diameter of the copper pipe that would be used which was roughly 19mm and was able to determine the length of the pipe needed to be around 12.6m. After knowing the length of the copper pipe, the next stage would be to determine the design for the copper pipe.

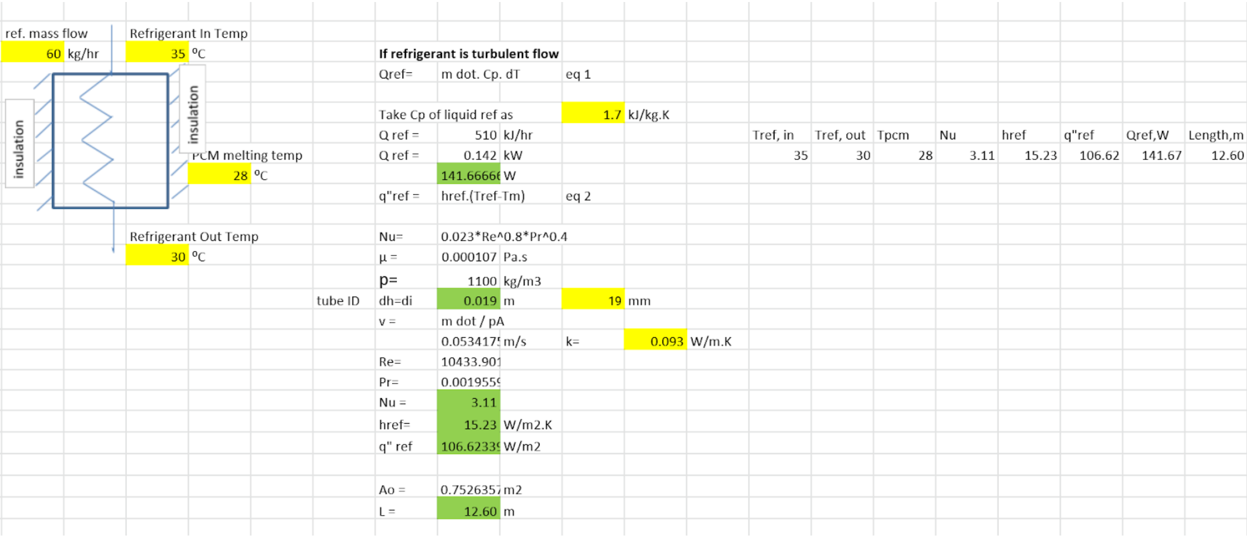

Figure 3: Sample of calculation to determine the length of the pipe

During the brainstorming stage of the copper pipe design, one of the challenges the team faced was minimizing the space usage of the design due to the immense length of the copper pipe needed to be submerged into the PCM tank. Other than that, the spacing between the copper pipe to any solid surface had to be half of the outer diameter of the pipe in order to achieve maximum heat exchange efficiency as it is submerged into the PCM storage tank. To overcome this challenge, the team used random entry technique where team members gave a random word based on surrounding object or sounds and others attempted to build a design based on the spoken word. The team eventually came out with 3 ideas for the copper pipe design. The first one was the spiral shaped design which was inspired by suspension coil spring. The second design was circular design inspired by common mosquito coils and the third design was the rectangular design based on the evaporator coil in air conditioning unit. In order to determine which design would be the ideal design, a decision matrix was made to determine the final design as shown in **Table 1**. The team also schedule a meeting with the industrial supervisor, Mr. Thoo hoping that he could provide the team with some insight on the proposed designs.

Table 1: Decision matrix on the three design

Attributes	**Sub-Attributes**	**Weightage**	**Spiral**	**Circular**	**Rectangular**
	Defrost Time	13	9	9	9

Productivity	Heat storing Time	12	9	9	9
	Precision	11	9	9	9
Cost	Material Cost	10	8	7	5
	Manufacturing Cost	9	7	7	7
	Maintenance Cost	8	6	6	6
Reliability	Ease of Maintenance	7	5	5	5
	Leakage	6	1	1	1
	Lifespan	5	9	9	9
	Ease of Assembly	4	6	6	6
Safety	Leakage of PCM	3	1	1	1
Sizing	Space Saver	2	8	5	7
Environmental Impact	Lesser usage of material	1	7	5	6
		Total	651	634	618

Based on the results obtained from the decision matrix, the most ideal design in descending order were the spiral design, the circular design and the rectangular design. All three designs were evaluated for their attributes of productivity, cost, reliability, safety, sizing and environmental impact with the primary attribute being the productivity of the product. The main attributes were broken down to sub attributes to allow better assessment of the design. Productivity was the priority for the team as the main goal of the product is to reduce the time taken to defrost the outdoor unit. The cost and reliability of the product was also taken into consideration as the team would want to build a product that is not only affordable but also durable and can be used for a long period of time. After applying the decision matrix, the most ideal copper pipe design would be the spiral design. This is due to the efficiency of the heat transfer ability of the design and the size of the design does not take up much space making it easy to be placed around the indoor space of a home.

After deciding on the design for the copper pipe that the team would be using, the team proceeds to begin the design of the storage tank based on the copper pipe design. The team first identify some of the factors that needed to be taken into consideration were that size of the tank, the user-friendly of the tank and the ease of maintenance of the tank. The team then calculate the amount of PCM that the tank needed to hold by using the density of the PCM The finalize design the team came out with was a storage tank with a lid at the top so it can be open and close and a drainage at the bottom side of the tank. This design is to allow ease of access to change the PCM material when required. The initial material used for the tank was metal, however, after further consideration and researched on the PCM that the team would be using, the team realised that metal would not be a suitable material unless it was coated with a protective layer on the inner wall of the tank as the PCM used is corrosive to metal. After further discussion, the team opt to use plastic instead for the construction of the PCM storage tank. Plastic was considered as not only it is not affected by the corrosive nature of the PCM, it is also able to withstand the operating temperature of the copper pipe and melting temperature of the PCM which is around 30 to 32 degrees celsius.

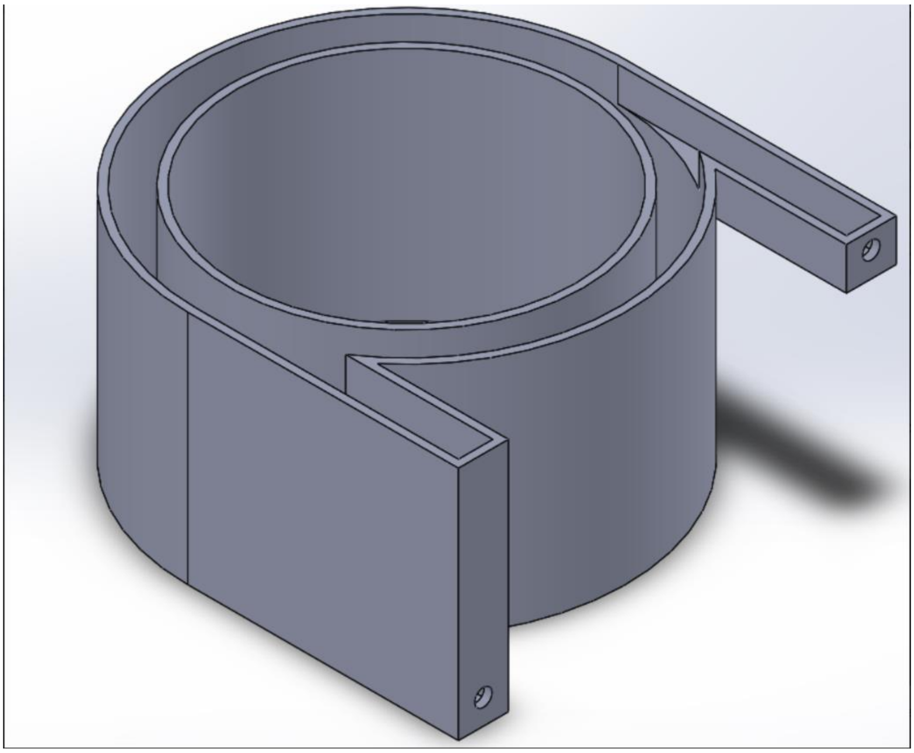

Figure 4: Design for the PCM storage tank

The other two systems of the product would be the frost detection and the activation system. For the frost detection system, the team decided to use an arduino unit, dry bulb, wet bulb and an ice detector. The dry bulb, wet bulb and ice detectors will be lined along the copper pipe of the outdoor unit to detect temperature and formation of ice or frost on the pipe. The data collected by the sensors placed on the outdoor copper pipe were then transfer and stored into an arduino unit. The activation system of the product was conceived using the systems thinking method. Taken into consideration that Daikin required this product to operate automatically, the simplest way to achieve that was by using an arduino unit. Based on **figure 5,** it can be seen that multiple solenoid valve was involved in the complex circuit. The purpose of the solenoid valve is to open and close, controlling the flow of refrigerant throughout the entire system as it switches between heating and defrost mode. These solenoid valves were controlled by the arduino unit and would open and closed based on the data stored within the arduino unit.

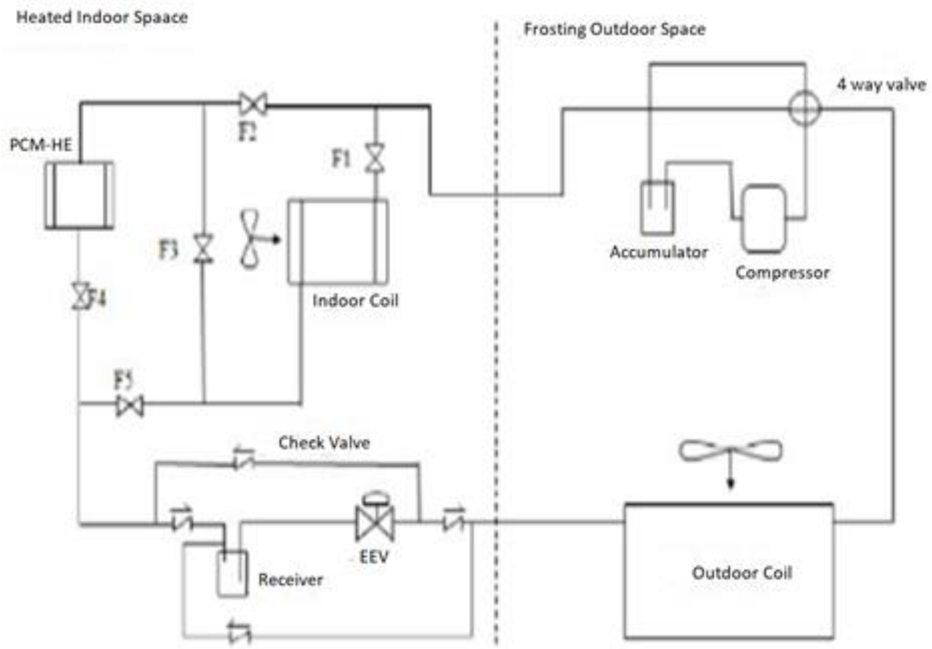

Figure 5:Circuit diagram of the whole system

4.0 Design

The following design stage was conducted after initiating the idea. There are four parts of this stage, which is Architectural Design (A), Configuration Design (C), Integrated Design (I), and Detailed Design (D). All these sections represent the entire design of the final product that was proposed in the earlier stages.

The first part, architectural design, which is the breakdown of the whole system into smaller subsystems. The configuration design is based on the specification of the components of the product as well as the reasoning behind it. The integrated design includes the combination of the mechanical systems of the product itself. Lastly, detailed design includes the engineering drawings and Bill of Material (BOM) of each component regarding the product.

4.1 Architectural Design

Several sub-systems were involved in this PCM-HE. As PCM-HE is used to let the heat transfer happened in between the PCM and the refrigerant. The sub-systems would be:

1. Storage Tank
2. PCM-HE Copper Pipe
3. Piping System

<u>Storage Tank</u>

The Storage tank acts an important role in the product. As the storage tank is to fill up with PCM or carry the PCM in another word. The storage tank was filled up with PCM and let the copper pipe immersed into the tank. By doing so, it allows the copper pipe and the PCM to have heat transfer during the heat pump is operating. Moreover, the storage tank also helps in storing heat. As the PCM is meant to absorb and storing heat energy by extracting the heat from the copper pipe, therefore the precious heat energy cannot be wasted. Therefore, the storage tank could help here by avoiding the precious heat energy that stored in the PCM lost to the surrounding environment and avoiding the overall heating performance due to the energy lost.

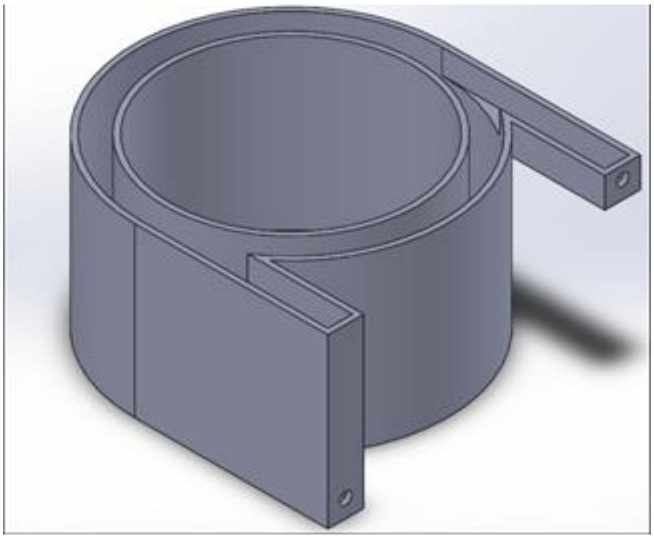

Figure 6: Design of Storage Tank

PCM-HE Copper pipe

PCM-HE Copper pipe in this product is taking the responsibility of allowing the refrigerant to flow through it. Besides, the entire PCM- HE Copper pipe with the unwind length of 12.6m is completely immersed into the PCM fluid to achieve the maximum efficiency of heat transfer. When the heat-pump is operating, the high temperature refrigerant would flow through the PCM-HE Copper pipe and undergo heat transfer with the PCM. Therefore, the material of the pipe must have a property of good thermal conductivity.

Figure 7: PCM-HE Copper Pipe

Piping system

The piping system consists of Arduino, Solenoid Valve and Copper pipe. As this product is an additional part that would be added into the normal heat pump, therefore, piping system was necessary. The piping system helps to control the flow path of the refrigerant.

When the normal heat pump running the defrost cycle, the heat pump works the same as the normal air-conditioning unit. The low temperature refrigerant flows through the indoor coil and causing the indoor temperature got affected even though the fan of the indoor unit was off. Resulting the end user felt discomfort due to the defrost cycle, as the low temperature flows through the indoor coil.

By adding the PCM-HE along with the piping system, it could overcome this problem as the piping system could direct the flow path of the refrigerant. During the defrost cycle, the heat pump with PCM-HE along with the piping system, the low temperature refrigerant would flow through the PCM-HE instead of the indoor coil.

4.2 Configuration Design

Every individual sub-system was built by different materials and components. And all the materials and components are different from each other. All the components and materials were selected wisely by applying relevant research and other conceiving methods.

Storage tank

Technical Data	
Model	Storage Tank
Materials	ABS Plastics
Total Weight	3.7kg
Height	0.295m
Width	0.57m
Length	0.57m
Thickness	0.01m

Figure 8: Technical Data of Storage Tank

The design of the storage tank was fixed and was designed according to the PCM-HE Copper pipe. As the storage tank was designed to let the PCM-HE Copper pipe to be fitted in. As the PCM-HE Copper pipe was in the shape of Spiral, therefore the Diameter of it was fixed to be 0.54m, and the height of it was 0.275m. Therefore, the height of the storage was as shown above, and all the dimensions were considered about the tolerance for the PCM and the thickness of the storage tank. Besides, the thickness of 0.01m of the storage tank was recommended by the industrial supervisor as the thickness of 0.01m could cap the heat. The material of ABS plastic was chosen, it was because this material is environmentally friendly.

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PCM-HE Copper pipe

Technical Data	
Model	PCM-HE Copper pipe
Materials	Copper
Total Weight	7kg
Length	12.6m
Outer Diameter	0.022225m
Inner Diameter	0.019m
Thermal Conductivity	231Btu

Figure 9: Technical Data of PCM-HE Copper Pipe

The design of PCM-HE Copper pipe was chosen due to the limitation on manufacturability. The sizing and the length of the PCM-HE Copper pipe were achieved by applying general calculation that provided by the industrial supervisor. The equation of the calculation was extract from the real-life experiment in the industrial lab. By applying the calculation, the length of the PCM-HE Copper pipe was to be fixed at 12.6m, and the OD and ID to be 0.022225m and 0.019m respectively. According to the calculation, these sizing and length of the copper pipe could maximize the heat transfer that would happened between the copper pipe and the PCM. The calculation was shown below. Some of the parameters were fixed and the design of the PCM-HE Copper pipe could only be designed based on the sizing and the length of the results.

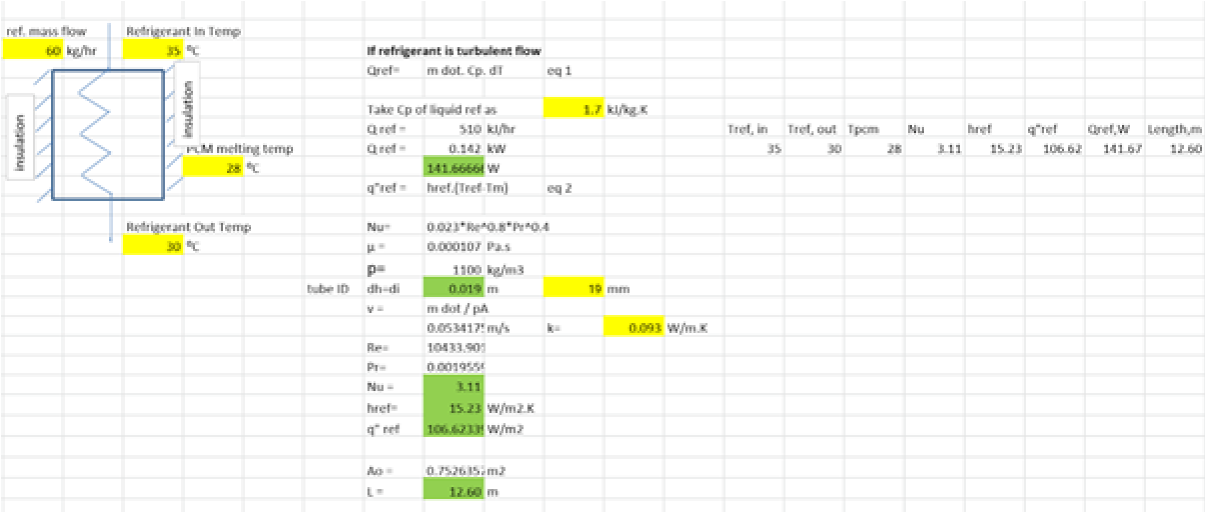

Figure 10: Calculation for PCM-HE Copper Pipe length

Piping System

5 SANHUA-FDF8A08 solenoid Valves were involved in the circuit system. The Solenoid valves could withstand the pressure and the temperature of the refrigerant. Besides, the circuit system was controlled by an Arduino. The Arduino was programmed to control the solenoid valves to control which solenoid valve to be opened or closed on that specified timing.

4.3 Integrated Design

The storage tank and the PCM-HE Copper pipe would be integrated into one main system which allow the heat transfer occurred in between the PCM and the refrigerant. Frist, the storage tank was filled with full of PCM. Then, the PCM-HE Copper pipe would be completely immersed into the PCM. By doing so, the PCM-HE could be completely covered by the PCM and maximize the efficiency at the same time.

Moreover, the piping system consists of 5 solenoid valves and one Arduino. The Arduino would control the circuit system by controlling the solenoid valve to be opened or closed.

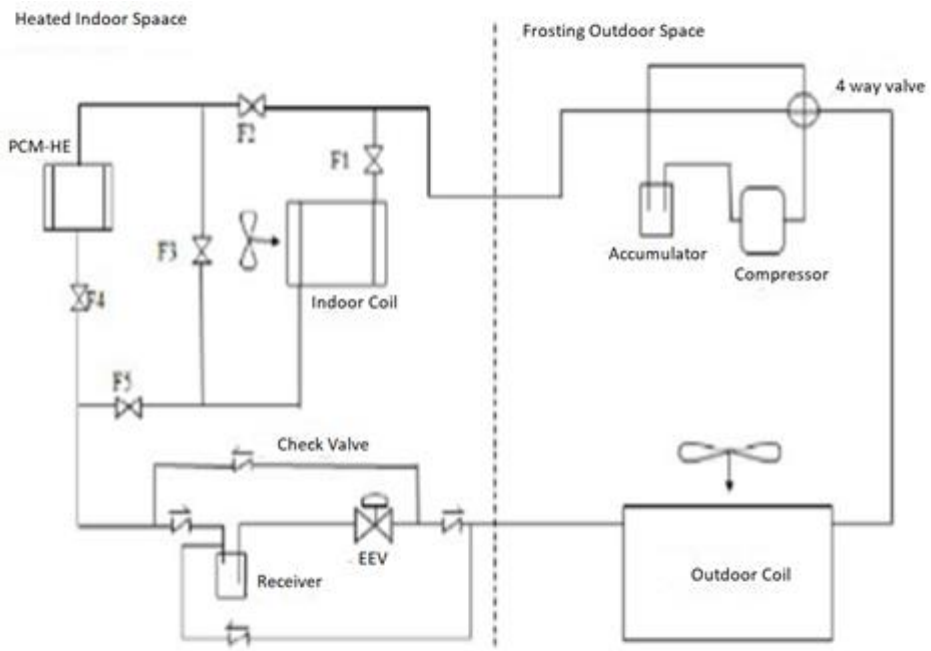

Figure 11: Whole system of the heat pump with PCM-HE

According to the figure above, F1, F2, F3, F4 and F5 indicates all the 5 solenoid valves. During the heat pump operating normal cycle, F1, F3 and F4 solenoid valves would be opened and F5 and F2 would closed to allow the refrigerant to flow through. At the same time, when the refrigerant passed through the PCM-HE, the PCM-HE could absorb heat energy from the wasted refrigerant. During the heat pump was running defrost cycle, F4 and F2 solenoid valves would opened, F5, F3 and F1 solenoid valves would closed, to allow the refrigerant to flow through. At the same time, the PCM-HE releases heat energy to the passing by refrigerant. All these solenoid valves would controlled by Arduino.

Moreover, each component would have their own respective material. The explanation on choosing the materials would be explained further below:

Materials	**The reason of choosing the materials**	**How does the material fit into the product**
ABS Storage Tank	ABS plastics is an environmentally friendly plastic. Besides, ABS storage tank would be lighter than metal storage tank in terms of mass. The cost of ABS storage would be cheaper compared with metal storage tank.	The usage of the Storage tank is to fill up with PCM, where the PCM is corrosive to metal. Hence, the material of the storage tank was chosen to be plastic.
PCM-HE Copper Pipe	The sizing of the copper pipe was chosen according to the results of calculation. After calculation was done, the OD of the copper pipe is 22.225mm and the ID is 19mm.	Copper pipe has a property of high thermal conductivity. The copper pipe acts as a wall separated the PCM and the refrigerant, therefore, the thermal conductivity must be good to transfer the heat from one to the other. The Copper pipe could withstand the pressure of the refrigerant.

4.4 Detailed Design

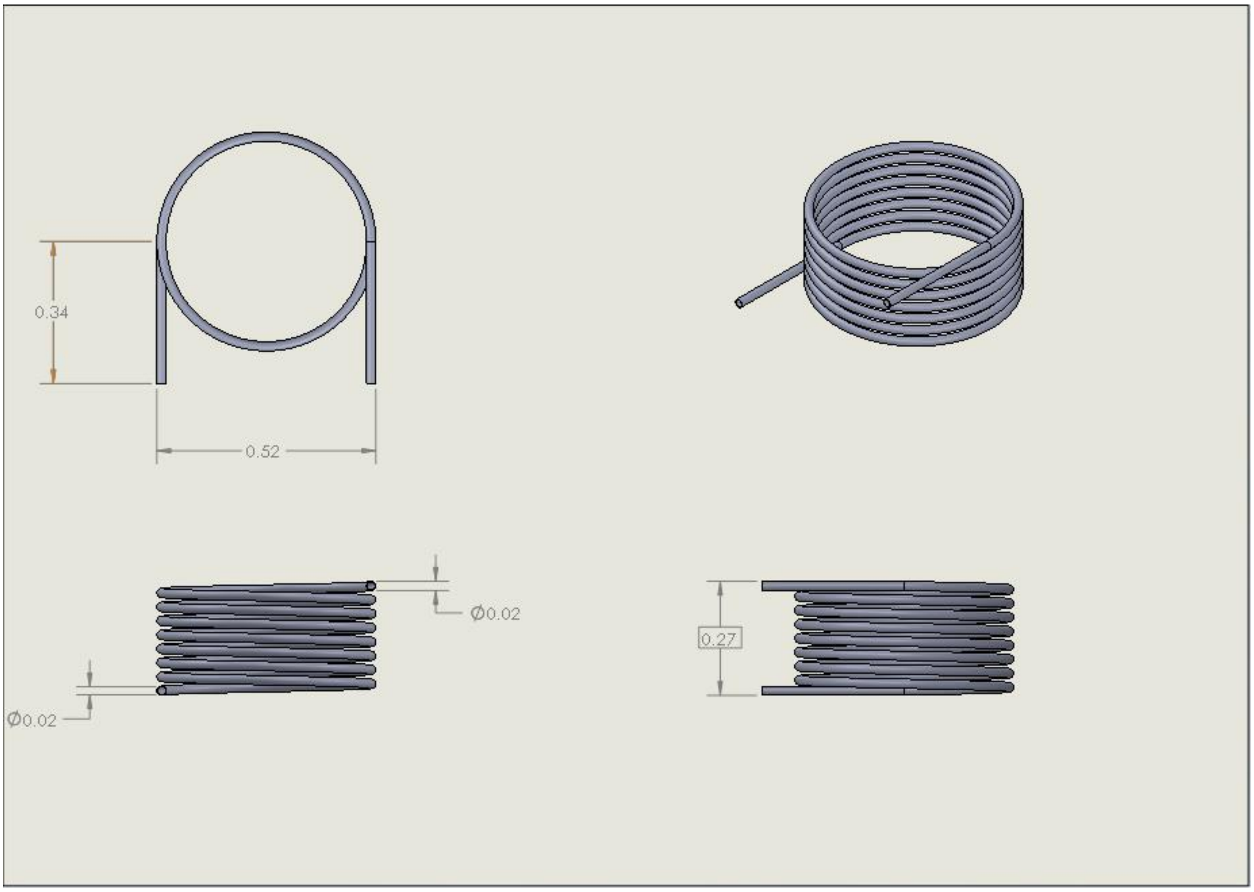

Figure 12: Detailed drawing of PCM-HE Copper Pipe

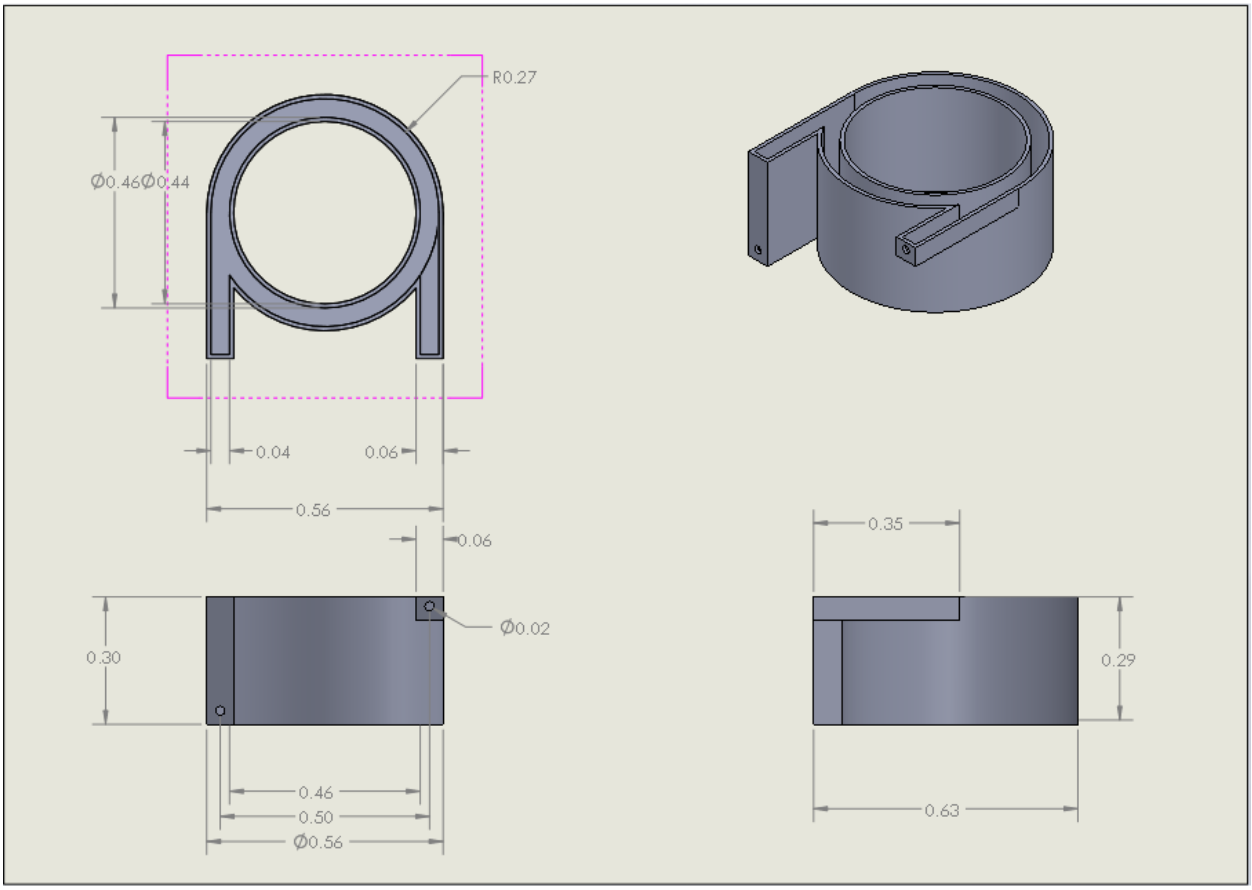

Figure 13: Detailed Drawing of Storage Tank

The bill of materials shown below and it was clearly show that the entire project cost RM1606.88. As Taylor's University was providing a budget of RM2000, therefore, this project was below the budget.

Material	Function	Unit	Vendors	Specifications	Pricing
Solenoid valve	**To control the flow of PCM during cycle change**	**4**	**Sponsored by Daikin**	**Name: SANHUA-FDF8A08 Port size diameter: 8mm**	**RM 35 each**

PCM	**To provide heat energy to the refrigerant during defrost cycle**	**1kg**	**Sponsored by Daikin**	**SP31**	**RM 70/ kg**
Copper pipe	**To allow refrigerant to flow within of the PCM storage tank**	**12.6m**	**Sponsored by Daikin**	**Inner diameter of 19 mm, outer diameter ⅞ inches**	**RM 170/ 3m**
Container (Metal or Plastic)	**To contain the PCM for heat exchange**	**1**	**Lam Seng Plastic Industries / Soon Soon Manufacturing & Trading**	**Depending on the design**	**RM700/project (Metal) RM500/project (Plastic)**
Arduino	**To store the programme and coding of the circuit**	**1**	**Robotedu**	**Arduino Uno R3**	**RM 16.88**
				TOTAL	**RM 1606.88**

5.0 Engineering Analysis

This section includes key engineering analysis parts, which are broken down into several parts.

Calculations for the length of the pipe

Due to pressure drops when refrigerant travels across long pipes, calculations are necessary to determine the maximum length of the pipe allowed, and Daikin has provided the templates with fixed in and out values for simplicity. The yellow values are input, while the green values are output values.

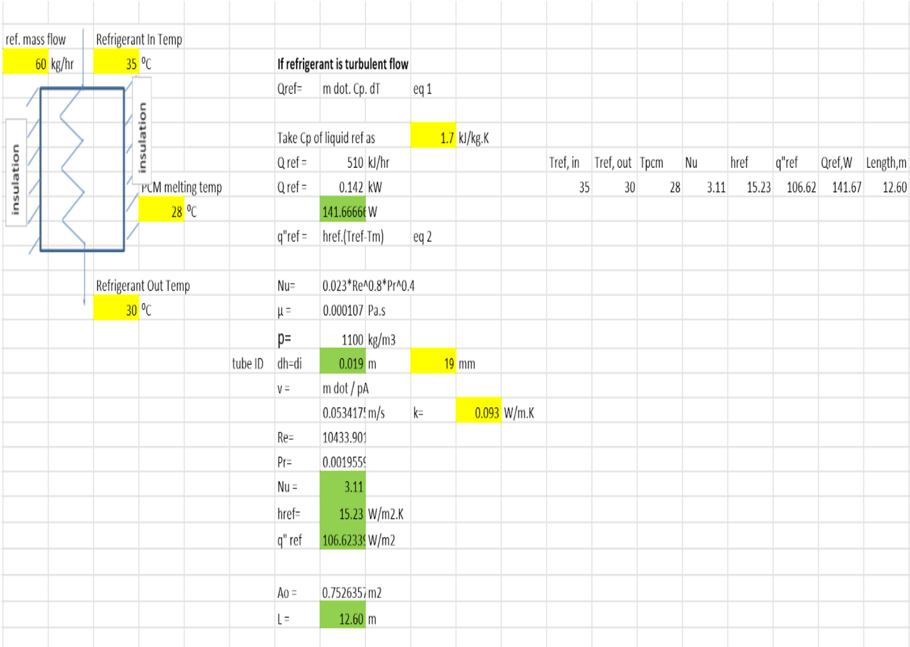

Figure 14: Fixed template for calculations provided by Daikin

From the template, it can be seen that the reference mass flow and thermal conductivity are inputted as 60 kg/hr and 0.093 W/mK, while also setting the inner diameter as 19mm, or ⅞". As a result, the length of pipe was calculated to be 12.6 meters for the PCM to effectively transfer heat in and out of the refrigerant. The main reason the pipe size was chosen instead of the industrial standard of ⅜" or ¼" is due to the fact that ⅞" has a significantly larger heat transfer area, resulting in a shorter pipe required for the heat exchanger. Also, due to Mr. Thoo's recommendation, we went ahead with analysis of the pipe sizing of ⅞" or 19mm inner diameter, and a length of 12.6 m.

Analysis of best design

Analysis of rectangular design

To increase the number of ideas we had for proper analysis, we used the system-thinking technique to formulate the rectangular design, which was commonly seen in air conditioner industries, where standard air-conditioners use U-joints in their heat exchanger units to create layers of pipes, creating a compact design where flat layers pile on one another, creating a layered version of the circular design, which is more compact and efficient heat transfer method.

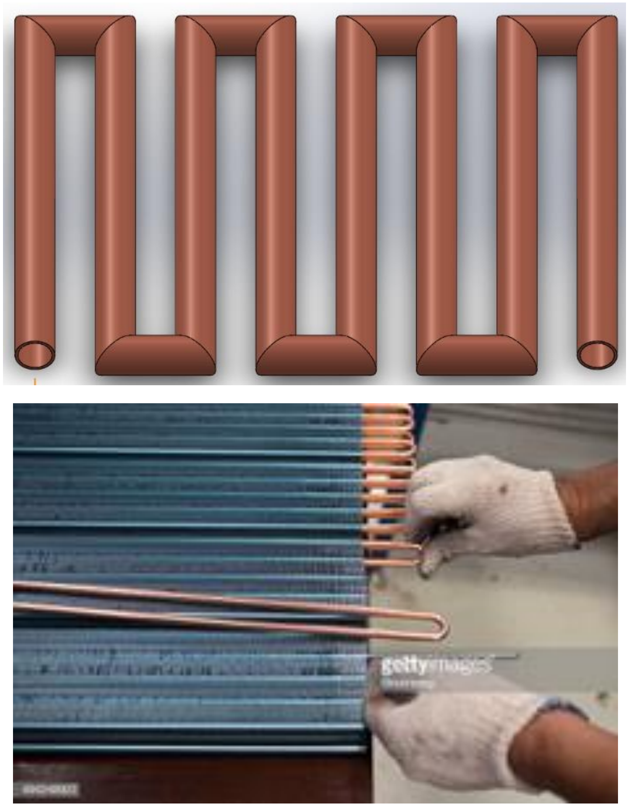

Figure 15: Rectangular shaped heat-exchanger, commonly used in air conditioning

After ideation, this idea was brought forward to Mr. Thoo for advice, and then we were told that due to the sizing of the pipe we were using, which was ⅞" the stiffness of the copper pipe causes two problems. The first problem being that the pipe cannot be bent with a small radius of bend because of the diameter of the pipe, which would lead to a very large base area of the resultant heat exchanger, even when separated into several layers. Also, the other option which was to use U-joint would be unavailable because there are no such joints available at Daikin sized at ⅞".

Analysis of circular design

Another idea we had was a circular piping design, where the idea originated from random entry of a mosquito coil. After discussion, the team found the idea decent, as it gave the possibility of implanting the flat storage tank inside walls and under the floors or ceilings due to the thin design. The thin design also simplifies the design and manufacture of the storage tank, as no complicated parts are required on the PCM storage tank.

Figure 16: The circular pipes and the source of the idea

However, due to its large base area, such a design would be difficult to carry around, and would not be ideal especially for a prototype for our project which we would need to carry around for testing and demonstration purposes. After deciding that the idea was good enough for consideration, we mentioned it to Mr. Thoo and our project supervisor Dr. Faizal for advice.

Soon after asking, Mr. Thoo replied that due to technical difficulties, it would be near impossible to produce the shape of the mosquito coil that is correct to dimensions. This was mainly because such a shape is out of the range of industrial standards and brings a challenge to the production crew in Daikin factories. Then, Mr. Thoo asked us to revert to the original spiral design, as it was the easiest to manufacture from all available ideas.

Analysis of Spiral Design

The spiral design was the design that was recommended by Mr. Thoo initially. The main reason for the design was because it was straightforward and simple, as the spiral pipes maximizes the contact area between the PCM in a storage tank, and the copper pipes carrying refrigerant that needs heat transfer. By maximizing the contact area, heat transfer is maximized, increasing the speed which PCM melts or solidifies.

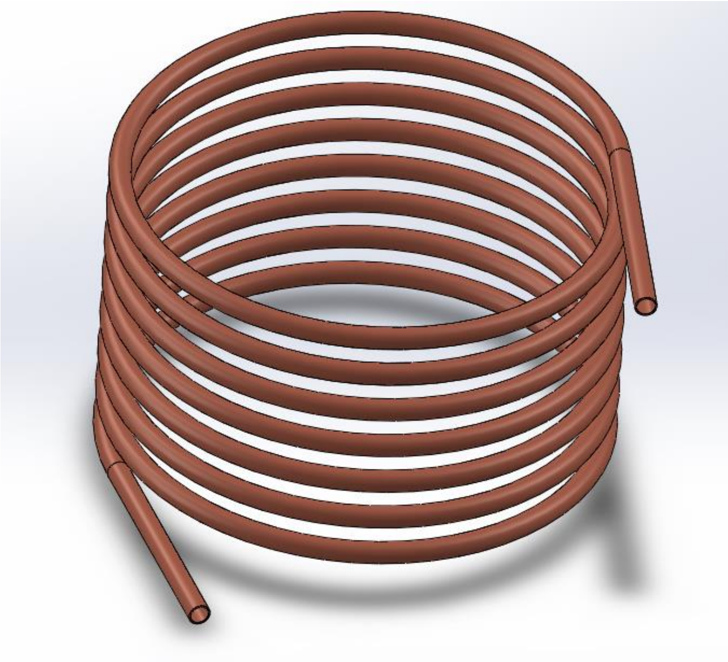

Figure 17: Spiral copper pipes with the extruded part for inlet and outlets

However, there were downsides to this simple design. Due to the extrusion of the inlet and outlet pipes, the team expected difficulties in the future when integrating the pipes into the storage tank. From the circular storage tank below, it can be seen that the spiral pipes with extrusions would not fit well. As such, the team decided to improve on the design of the storage tank with simple modifications, and then proceed to simulations and modelling.

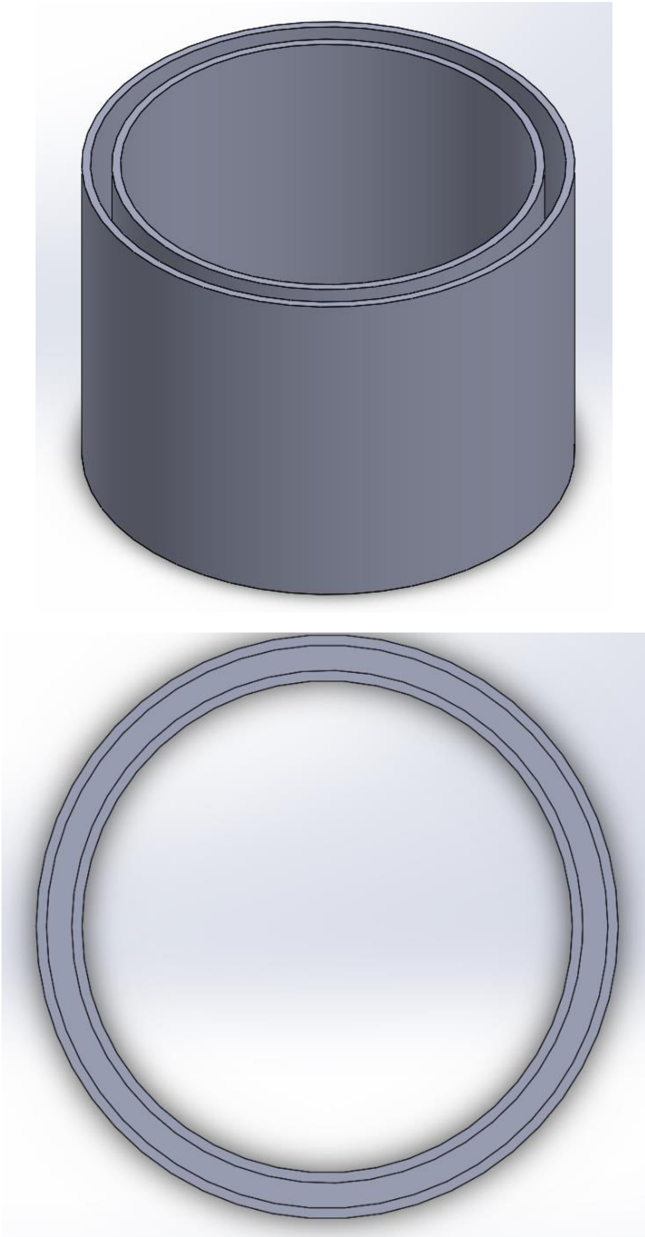

Figure 18: The design of a circular tank to fit the spiral coils

To overcome this problem, we improved the storage tank design to accommodate the extruded parts of the pipes. Additional extrusions are added below to allow for the spiral coils with extruded areas to be put into the tank before any welding or flaring. The figures below show the improved designs to overcome the problems of being unable to integrate spiral pipes properly. However, there were still downsides to the improved design of the PCM storage tank.

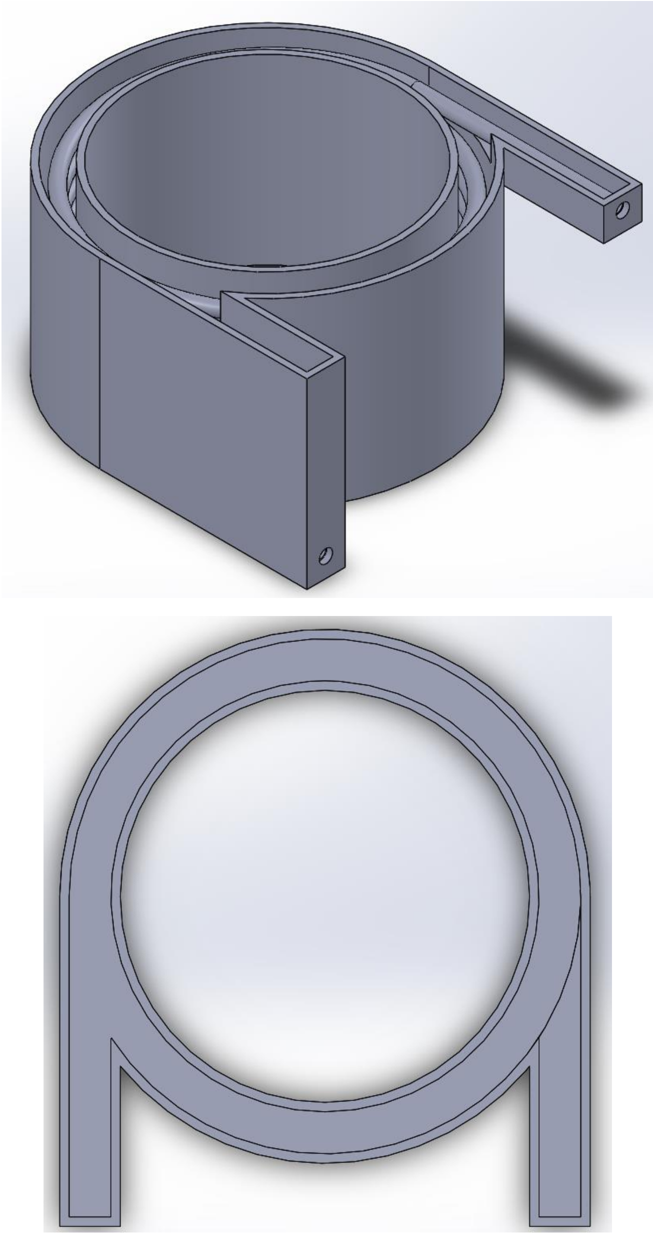

Figure 19: The design after improvement to accommodate extruded pipes

Decision matrix

Table 2: Decision Matrix

Attributes	Sub-Attributes	Weightage	Spiral PCM-HE	Circular PCM-HE	Rectangular PCM-HE
Productivity	Defrost Time	13	9	9	9
	Heat storing Time	12	9	9	9
	Precision	11	9	9	9
Cost	Material Cost (higher better)	10	7	8	5
	Manufacturing Cost	9	7	7	7
	Maintenance Cost	8	6	6	6
Reliability	Ease of Maintenance	7	5	5	5
	Leakage	6	1	1	1
	Lifespan	5	9	9	9
	Ease of Assembly	4	6	6	6
Safety	Leakage of PCM	3	1	1	1
Sizing	Space saver	2	5	8	7
Environmental Impact	Lesser usage of material	1	5	7	6
		TOTAL	634	651	618

The initial decision matrix pointed to the circular design as the best design, however due to objections by Mr. Thoo, and the difficulties in producing the circular pipings, we went back to the original suggestion provided by Mr. Thoo, which was the spiral pipes shown previously.

Basic calculations for required mass of PCM

To determine the total mass of PCM, data sheet provided by Rubitherm Germany was taken into consideration, where the given density of the PCM SP-31 is determined as 1.31 kg/l or 1310 kg/m^3, then the internal volume of the PCM storage tank finalized during interim report was taken for analysis. The total volume of the storage tank was found using the base area of the PCM tank, multiplied by the height of the tank.

Density of PCM SP-31= 1350 kg/m^3

Base area of the storage tank = $(535.5^2\ \text{mm})^2(\pi) - (491.05\ \text{mm})^2(\pi)$

= 143351 mm^2 or 0.143351 m^2

Height of the storage tank = 290 mm or 0.29 m

Volume capacity of the storage tank = 0.29 x 0.143351

= 0.041572 m^3

Volume occupied by the copper pipe = length of pipe x area of pipe

= 12600 mm x $(22.225\ \text{mm})^2(\pi)$

$= 19552575 \text{ mm}^3$ or 0.019553 m^3

Volume of PCM that is able to fit in the storage tank

= volume capacity of storage tank - volume occupied by the copper pipe

$= 0.041572 \text{ m}^3 - 0.019553 \text{ m}^3$

$= 0.02202 \text{ m}^3$

Mass of PCM SP-31 required = density of PCM x volume of required PCM

$= 1350\text{kg/m}^3 \times 0.02202\text{m}^3$

= 29.7 kg of PCM SP-31

The most important data:	**Typical Values**	
Melting area	**31-33** main peak: 32	**[°C]**
Congealing area	**28-30** main peak: 30	**[°C]**
Heat storage capacity ± 7,5% Combination of sensible and latent heat	**210**	**[kJ/kg]**
in a temperatur range of 23°C to 38°C.	**58**	**[Wh/kg]***
Specific heat capacity	**2**	**[kJ/kg·K]***
Density solid at 15 °C	**1,35**	**[kg/l]**
Density liquid at 35 °C	**1,3**	**[kg/l]**
Volume expansion	**3-4**	**[%]**
Heat conductivity	**n.b.**	**[W/(m·K)]**
Max. operation temperature	**50**	**[°C]**
Corrosion	**corrosive effect on metals**	

Note: The product must be initialized (melt, homogenize and cool to 0 ° C) once before use to achieve the specified properties.
All SP-product are hygroscopic and may absorb moisture if stored improperly. This can result in a change of the physical properties given.

Figure 20: Data table provided by Rubitherm

Analysis of suitable materials for the PCM storage tank

For the analysis of suitable materials for PCM storage tank, we referred to the data table provided by Rubitherm Germany again. The main concern we had was for the material used to be able to handle the weight of the PCM, copper pipes, as well as the corrosive properties of the PCM SP-31. From the table below, it was seen that the PCM is of somewhat high density, with a density of 1350 kg/m^3 which is heavier than water, as well as exerting corrosive properties only towards metals. This is shown in the table below.

The most important data:	Typical Values	
Melting area	**31-33** main peak: 32	**[°C]**
Congealing area	**28-30** main peak: 30	**[°C]**
Heat storage capacity ± 7,5% Combination of sensible and latent heat	**210**	**[kJ/kg]**
in a temperatur range of 23°C to 38°C.	**58**	**[Wh/kg]***
Specific heat capacity	**2**	**[kJ/kg·K]***
Density solid at 15 °C	**1,35**	**[kg/l]**
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Volume expansion	**3-4**	**[%]**
Heat conductivity	**n.b.**	**[W/(m·K)]**
Max. operation temperature	**50**	**[°C]**
Corrosion	**corrosive effect on metals**	

Note: The product must be initialized (melt, homogenize and cool to 0 ° C) once before use to achieve the specified properties.
All SP-product are hygroscopic and may absorb moisture if stored improperly. This can result in a change of the physical properties given.

Figure 21: Data table provided by Rubitherm

As a result, we would have to pick between a standard plastic container or a metallic container coated with a protective anti-corrosion layer. To determine which one was better, we conducted analysis on the total weight of the entire storage tank.

Pros of using plastic include cheaper manufacturing costs, less amount of work required, as we do not need to paint the inner layer with a protective layer, and also do not need to proceed with any welding works. Also, a plastic storage tank would be lighter, and easily carried to and fro from Daikin R&D Sungai Buloh, allowing for easy transportation when demonstrating and conducting test runs as well as setting up. Metallic material would have been a better long term solution, due to the durability and ductility of metals, as plastic storage tanks may crack due to human mistakes or accidents such as knocking over the tank, or dropping something heavy on the tank.

In the end, plastic was chosen as the desired material due to the cheaper costs, ease of transportation, lightweight properties, unreactive properties towards the corrosion of the PCM SP-31.

Analysis of the solenoid valve used

For the solenoid valve, the team would be provided with SANHUA-FDF8A08 for the project by Daikin. This valve has a diameter port size of 8mm. It can withstand high operation pressure up to 4.2MPa. The applicable refrigerants for this valve are R134a, R22, R407C, R410A, R32, etc. SANHUA-FDF8A08 is produced by Zhejiang SANHUA Company from China. This valve would be the key to switching the refrigerant flow in the heat pump during the cycle change, directing the refrigerant fluid through the PCM heat-exchanger.

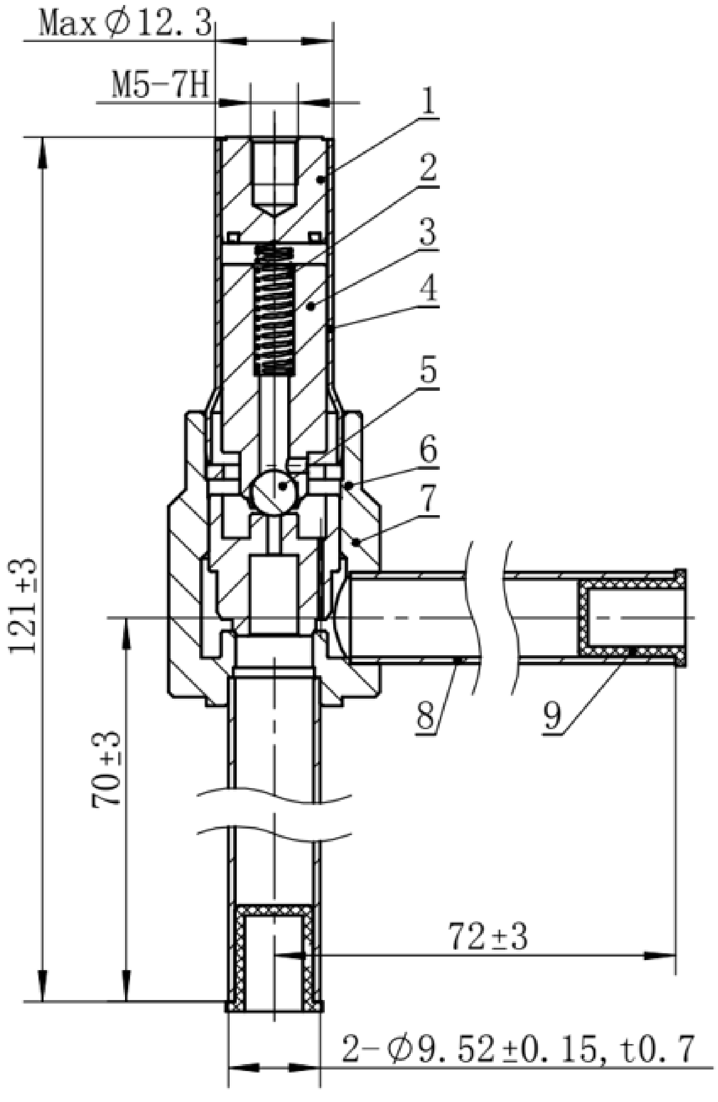


Figure 22: Solenoid valve design drawing

Risk Analysis

Table 3: Risk management table for risks and prevention methods

Identification	Prevention	Mitigation
Project prototype may not be completed on time due to its high technical complexity.	Divide assemblement of subsystem between members and chart a due date for each task and calculate timing and priority of each task.	Assign more members to the task that requires a larger amount of time and fast track the project by performing task parallel with other tasks.
The final product of the project may not achieve the expected performance.	Identify and run simulation to identify origins of poor performance. Research new materials or reexamine project design to improve performance.	Conduct further research and clarify any doubts with supervisors of the project.
Leakage occurring on the PCM storage tank.	Research and practice on how to wield two materials together properly. Ask for assistant from lab supervisors when needed.	Outsource the fabrication of the storage tank to a credible and reliable manufacturing workshop.

Also, the team analysed the potential risks of using the PCM heat-exchanger, and found that there were only minor risks, as the use of every material and part are relatively safe. PCM SP-31 is not a high flammable material, non-toxic and only slightly irritating when in direct contact to the eyes and skin. This information was obtained from the safety data sheet provided by Rubitherm Germany and would be available in the appendix.

6.0 Simulations and Modelling

3D modelling of the 3 initial ideas

As a team, we modelled the 3 initial ideas ideated during the conceiving phase, which were the spiral pipes, rectangular pipes, and circular pipes, using solidworks to show to our project supervisor Mr. Thoo and Dr. Faizal. The three designs drawn using solidworks are shown below.

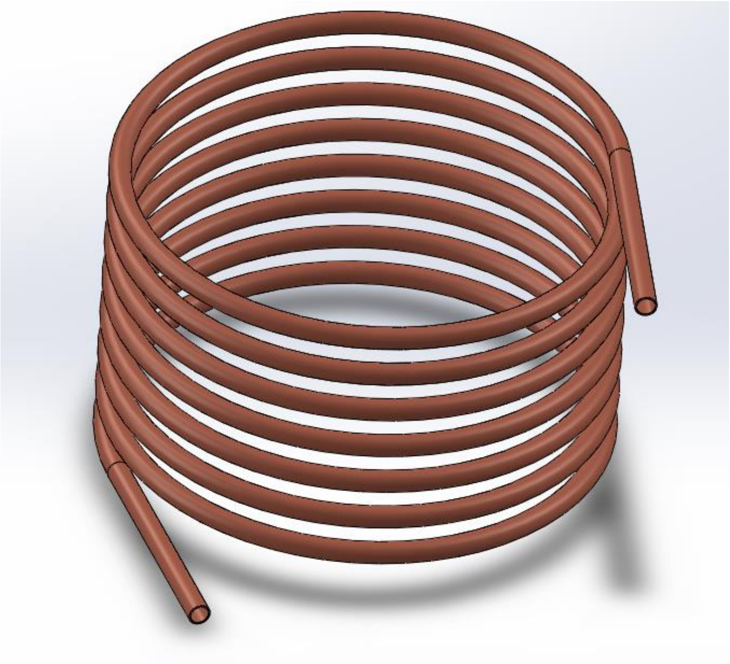


Figure 23: Spiral design approved by Mr. Thoo

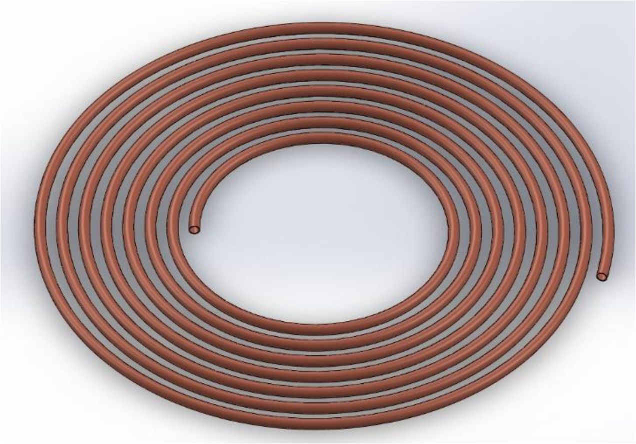


Figure 24: Circular pipes ideated from mosquito coil by random entry

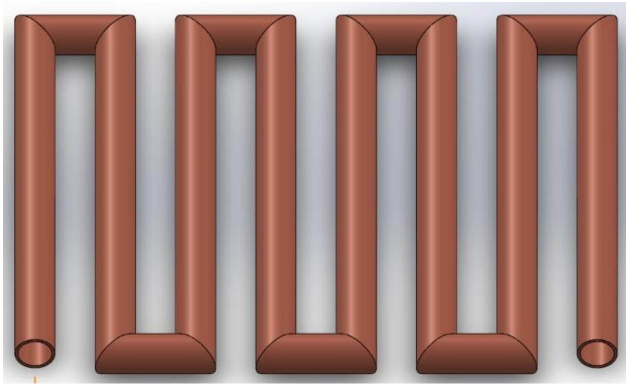


Figure 25: Rectangular shaped pipes ideated from system thinking

All three ideas were modelled for demonstrations and comparisons, as well as to provide information for potential problems in the future, such as problems during manufacturing or problems with storage or implementation. From the models, we were able to obtain key information such as the manufacturability of each design, and the practicality of each design. In the end, the finalized design was the spiral pipes, with the dimensions shown in the design drawing below.

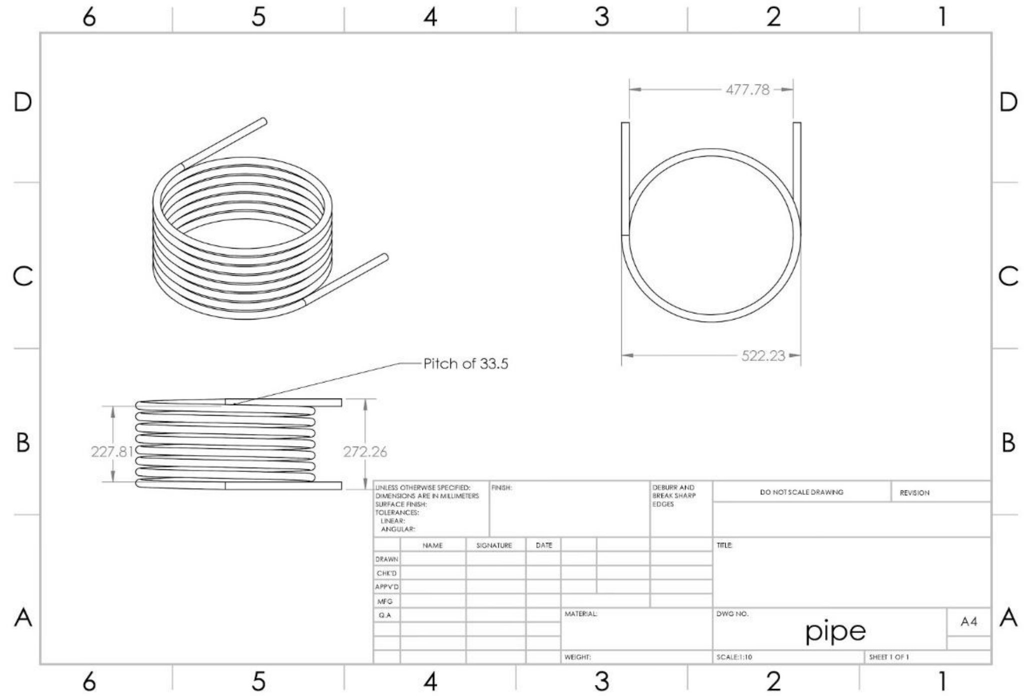


Figure 26: Design drawing of the copper pipes

3D modelling of the storage tank

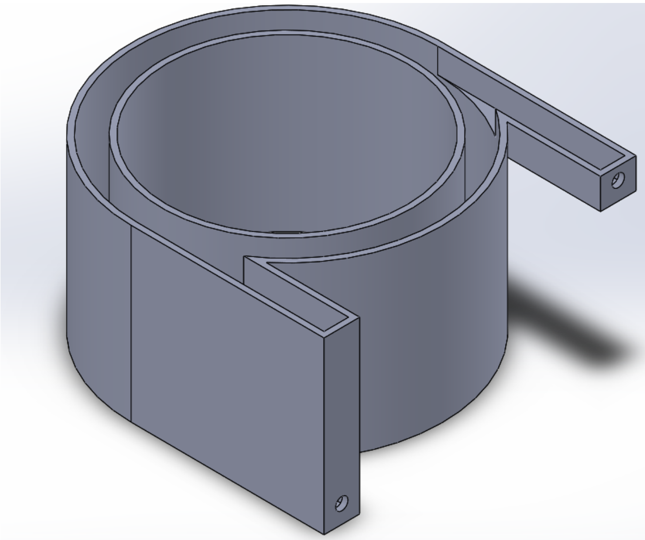


Figure 27: 3D model of the PCM storage tank drawn by using SolidWorks

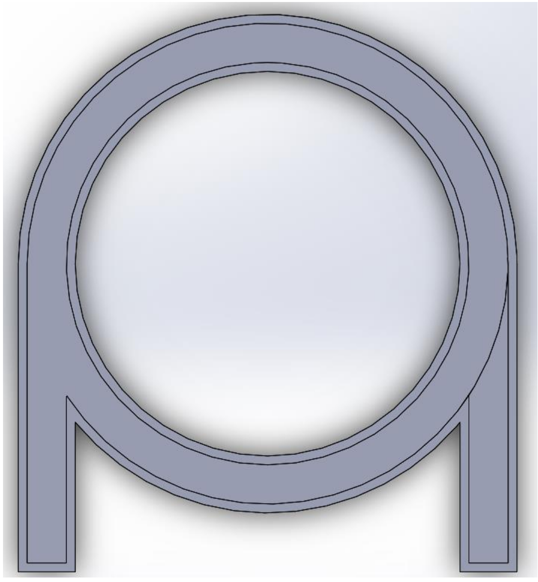


Figure 28: 3D model of the PCM storage tank drawn by using SolidWorks

To accommodate the extruded parts of the spiral pipes, a similarly shaped storage tank was drawn. The thickness of the storage tank was set at 1mm initially, for simulation and analysis purposes, with the main reason being that the thin storage tank decreases cost and weight. The main purpose of the drawing was to allow the simulation stage to move forward, and the design will still be improved in the future, after refining and modifications during MEGP2 next semester.

3D modelling of the scaled down model

For the engineering fair, a separate, scaled down model was drawn for the ease of presentation and demonstration of our idea. The scaled down model included our future improvements that we could think of, such as a slanted base at the bottom to allow easy drainage, as well as a drainage cap at the bottom along with a small hole. Also, we included in our plans to further improve the prototype with something similar to a filter funnel, so that pouring in PCM would be easier, as the prototype has a very small area for liquid inlet. The photo sample of the scaled down model is shown below.

Figure 29: Jia Hao holding the scaled down model that was meant for demonstration and presentation purposes

Simulations of the 3D model using ANSYS Fluent

Initially, the team tried to run the simulations based on the guidance of youtube videos found online, and we were able to find many useful videos that were able to point us in the right way. The first few runs were able to generate results, and the results are shown below.

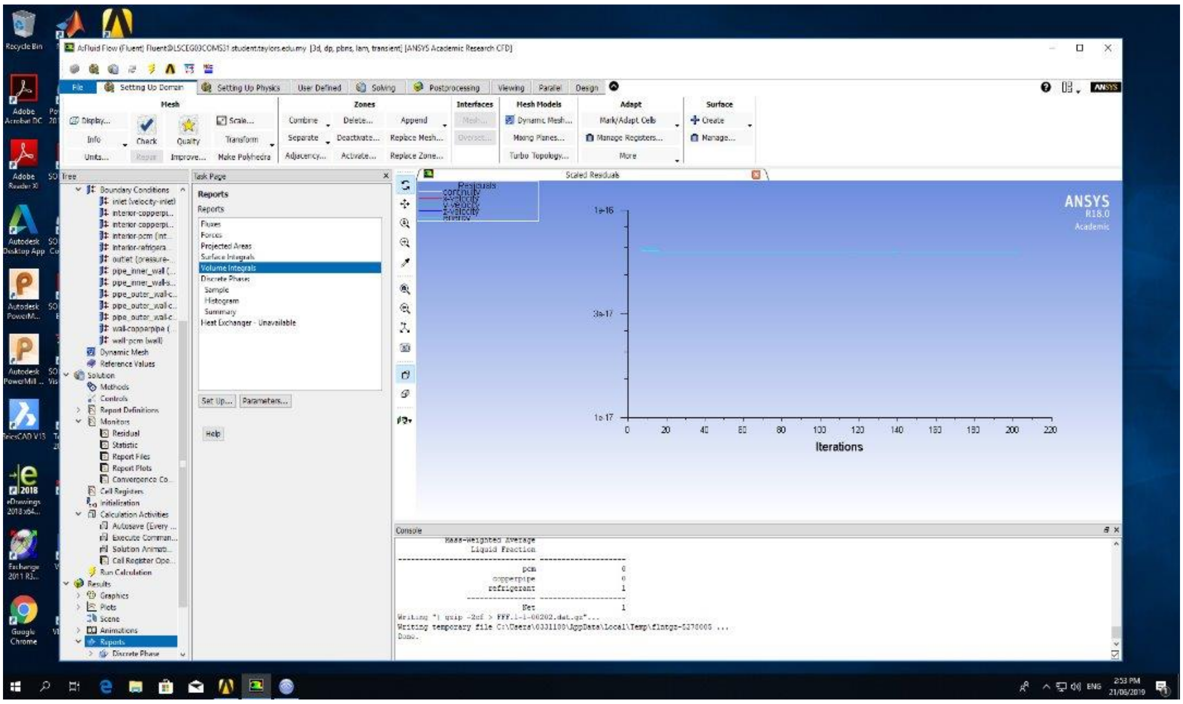


Figure 30: Initial simulation run

However, after analysing the results, we found out that it was invalid, due to the fact that the graph on the above shows that the energy in the system was always constant. In a heat exchanger, heat should always be flowing, and the results should yield graphs that demonstrate a change in energies. Hence, the team determined that the simulation run had invalid results and needed to do corrections.

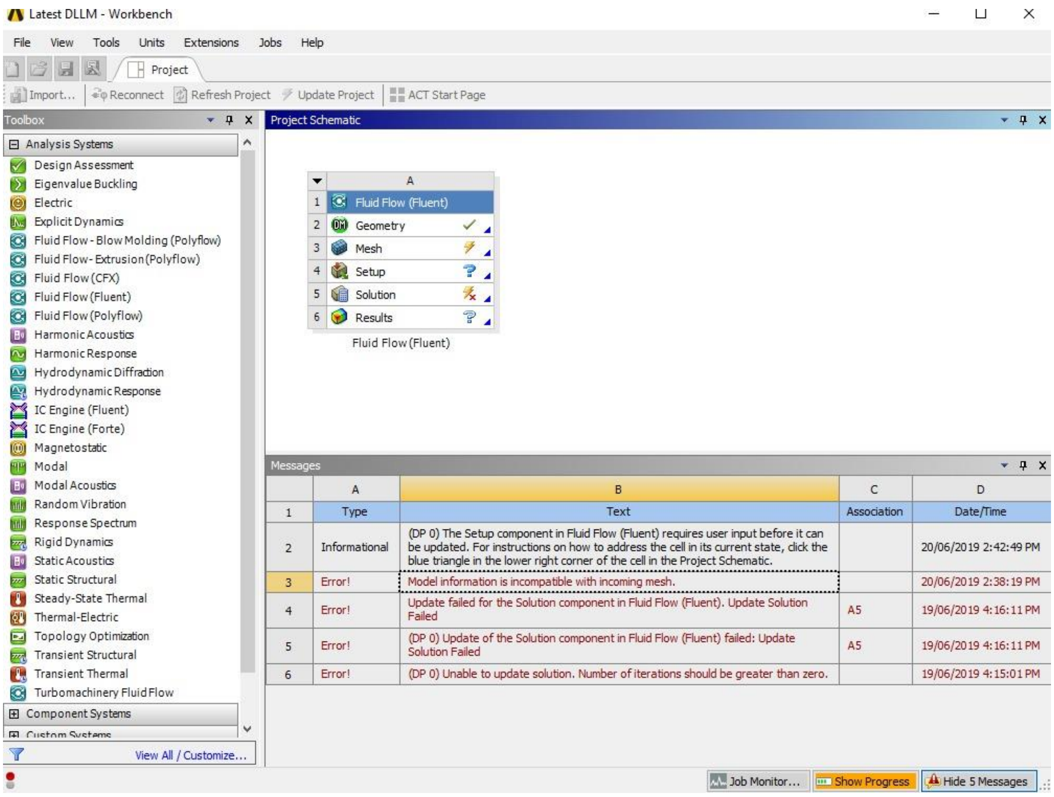


Figure 31: Simulation errors during our initial trials

Both Zhi Heng and Jian Hua tried several times, to simulate the results of the heat exchanger according to tutorials, but to no avail. Initially, the team was met with errors, that may have been the result of inexperience in drawing using the ANSYS SpaceClaim and Design Modeler. After several attempts over a period of two days, the team decided to consult an expert, and met up to discuss the problems we were met with. Dr. Faizal, our program director, recommended someone who was a former colleague of Mr. Thoo at Daikin R&D, and someone who is an expert in CFD analysis. He referred us to Dr. Ng Khai Ching.

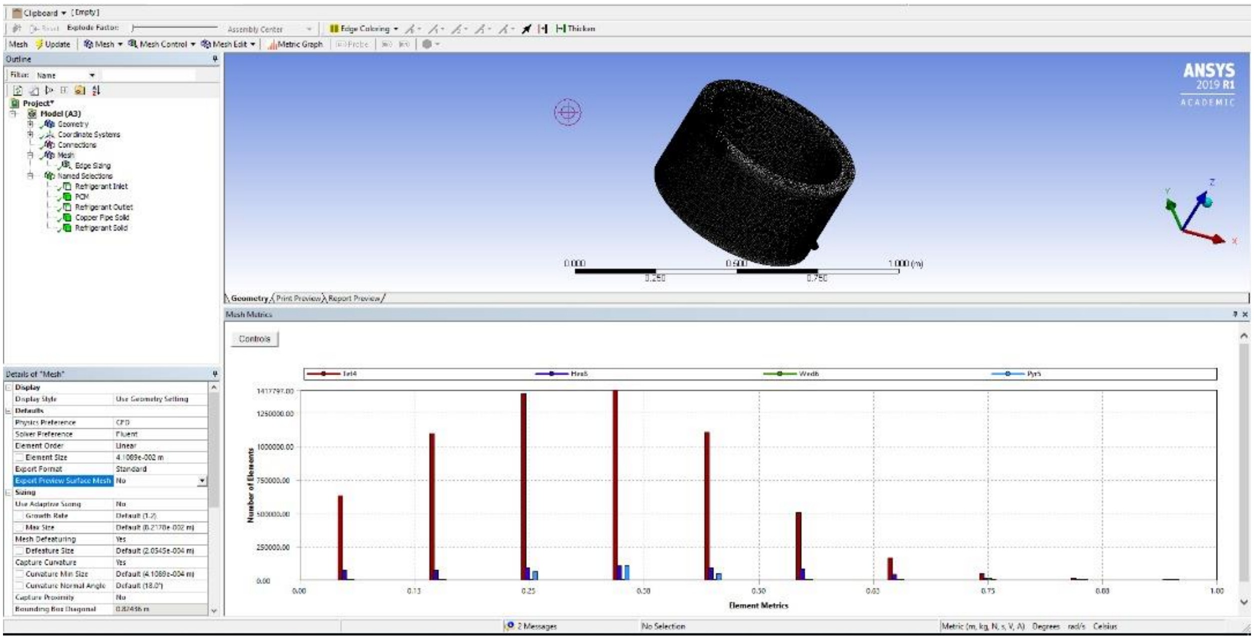


Figure 32: Screenshot of meshing and quality of mesh during our second try

For our second try, the team found out that solidworks drawing was not compatible with an ANSYS fluent analysis. This was because for our analysis, we were required to create two or more entities, separately for the PCM, copper pipes, and the refrigerant. For the solution, the team found out that by using ANSYS's own drawing system, the Design Modeler, this problem could be overcome. Then, we proceeded to draw using the Design Modeler, set the object as separate entities, and proceeded to key in values for each variable. The figure above shows the meshing state of our product drawn using ANSYS design modeler, with a skewness of average 0.2974 after meshing, with the maximum skewness being 0.6903. This was considered as an excellent skewness as it was of high quality. Overall, the meshing itself took 30 minutes due to the amount of elements and nodes in the object.

Next, we proceeded with a simplified simulation due to failure of the initial simulation after several tries. Results obtained were invalid due to the lack of energy change shown in the initial graph, as usual. After investigation, the team then found out that the main reason the simulations failed was due to lack of specific data such as a varying data line of the different viscosities of the PCM under different temperature conditioners. Another reason for the failed simulation was due to the lack of experience in CFD, or computational fluid dynamics. Even under the guidance of Dr. Ng, we were pointed towards the right direction, but were unable to achieve the desired simulation results.

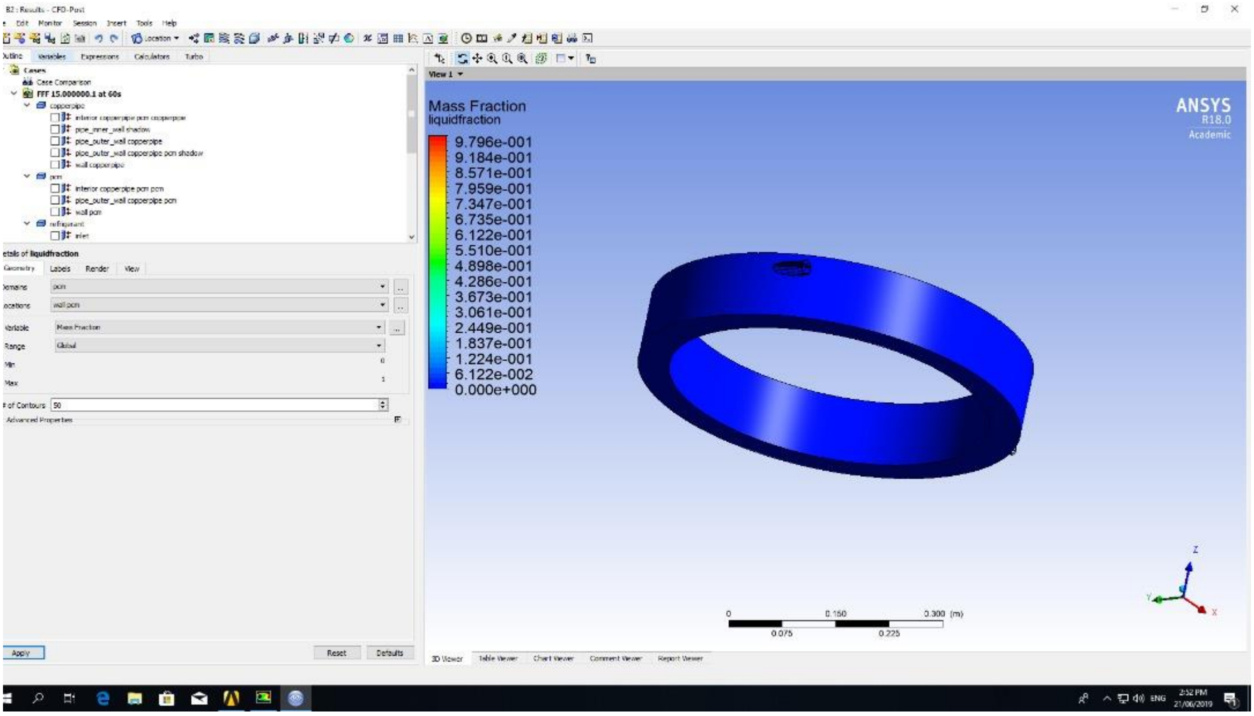
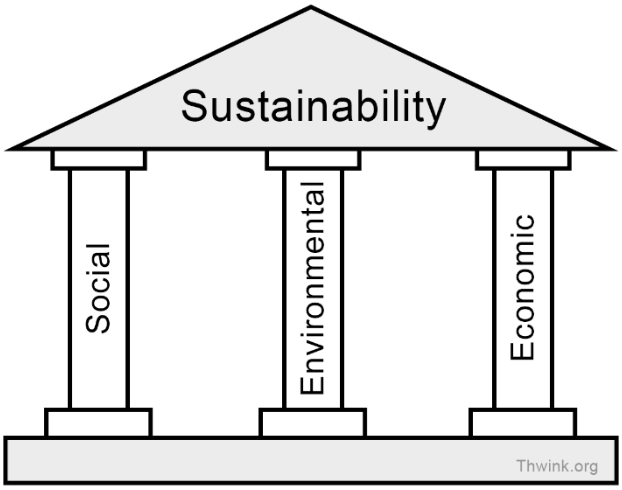


Figure 33: Screenshot of simplified simulation and results

In the end, the team decided to stop the simulation attempts due to multiple failures, and we were left with only work done and failed simulations to show. However, further attempts would be done in the next module MEGP2 to ensure that the design is able to work smoothly without any problems, and fine tuning would be done with more hands on testing than simulations. Last but not least, this was a valuable lesson for us, as we were not able to complete the assigned task of simulating the results of the heat exchanger properly. However, Dr. Ng reassured us that it was okay to have failures every now and then, even more so when we had such a complicated simulation to begin with, and we were only inexperienced students. He also added that we should learn from this failure and grow from it.

7.0 Sustainability



To meet the requirement of the current generation is called sustainability without compromising the flexibility of the future generation to fulfill their needs. Three pillar that composes the concept of sustainability is economic, environmental and social which is also known as profits, planet and people. Phase change material was chosen as the solution to the defrosting issue which affects the efficiency of the heat pump based on these three pillars of sustainability.

Environmental Pillar

The environmental pillar is the eye-catching pillar of all as most companies are focusing on taking care of the environment by reducing carbon footprints, waste, and water which will affect the environment. PCM was chosen was due to the huge impact when it comes to environment sustainability. One of the key measures is to reduce greenhouse gas emissions. Currently, most building uses air conditioning units which increase the energy demand of the building due to the high usage of electricity. In addition, the increased usage of air conditioning will increase the carbon gasses emission which will lead to the thinning of the ozone layer. Hence, Phase change materials has been introduced in buildings to improve energy efficiency and to reduce the energy consumption in buildings. PCM can remove excess heat from a room during the day and release it at night. This is achieved by storing heat for cooling and release heat when it is demanded. The usage of PCM also helps to improve the performance of heating, allowing better ventilation and also uses minimum energy.

Economic Pillar

The economic pillar is what most businesses will put their attention on. To ensure that the object is sustainable, the business from the product needs to be a profitable business. Conventionally, a heat pump would require to constantly go through different load shift which consumes high amount of electricity. During extreme weather conditions, frost is formed on the outer coil which will be melted by drawing heat from the indoor unit. This happens by switching the cycle of the heat pump as only one cycle can run at a time. By implementing PCM, it is able to store and release heat when the condition is required without affecting the defrost cycle. This will ensure that the amount of electricity will reduce which will benefit the user to save the electricity consumed by the whole product. Moreover, PCM is longer lasting which will have a longer lifespan and the maintenance of the product is not that expensive to change the PCM in the storage tank.

Social Pillar

The social pillar states that with the support and approval of the employees and stakeholders that is working on the project will produce a sustainable business in terms of social pillar. It also relates to the product is safe to use and will bring benefits to the employee and the end user of this product. When designing this PCM heat exchanger, we take many aspects into consideration. The main goal of this product is to ensure that PCM is able to defrost the ice formed on the outdoor unit without affecting the comfortness of the user that is living in the house during the winter. The build of the materials used is also safe to use as the PCM is only corrosive to metal. To solve the storage tank, ABS plastic is used to build this tank to store the PCM while the copper pipe is immersed in it. When designing the model, few aspects such as weight, height and mobility of the tank is taken into consideration as the tank should not be heavy and tall for the user or the technician to move it during the installation and during the maintenance. A small hole was designed to ease the technician when changing the PCM during maintenance.

8.0 Business plan

As our product is air conditioning unit with PCM heat exchanger defrost system. The main demographic for our product would be countries with 4 seasons and experience extreme harsh cold weather. Countries such as the United States of America, People's Republic of China and the Russian Federation. To ensure the success of the product, the team drafted out plans and strategies on how to promote and have a successful business using this product. To create a successful business plan, there are six important elements that needed to be included which are premise, processes, production, people, price, and promotion.

Main Purpose

Conventional methods of staying warm during the winter is using a heater or air conditioning unit with a heating mode option. However, both of these methods consumes huge amount of electricity. One of the common ways to generate electricity is by burning coal, which releases carbon dioxide to the environment. Another issue with the conventional methods of staying warm is the drop in performance of the device during winter seasons as the extreme outdoor conditions impaired the heat pump system of the device, and it takes a long time to defrost the outdoor unit of the air conditioning unit and allowing it to perform as intended.

With the advancement of current technology, it is made possible for engineers to create a device that have a low defrosting time, high heat pump performance despite extreme outdoor conditions and is able to reduce the consumption of electricity compared to conventional heating methods. Such devices not only improve an individual's comfort during winter seasons, but also able to help the environment but reducing waste of electricity in a device.

With the implementation of the PCM heat exchanger, it is able to revolutionize the methods of staying warm during winter without causing any harm to the environment.

8.1 Premises

Selecting a premises that is strategically located is a crucial part in starting a successful business as the premises not allow need to accommodate any manufacturing and production processes, it also needs to be in a location where it gets enough attention from potential customers that would be interested in the product that is being sold. For our team, that strategic location would be the Daikin Research & Development Malaysia Sdn. Bhd. This premises is one of the existing subsidiaries of Daikin and is located at Sungai Buloh. During one of the teams' site visits to this premises lead by Mr. Thoo, the team observed that the premises has about 200 workers working on assembly parts of an air conditioning unit. The premises also have a well-equipped laboratory to accommodate various experiments on prototype the company has developed.

Strategic location

Due to the functions of the prototype the team is building, the main demographic of the product would not be local residents as Malaysia do not experience 4 seasons. Hence, the chosen location had to be close to a trading port in order to export the products. Port Klang is located roughly 46 to 55 km away from the premises and the duration to Port Klang is roughly 50 minutes drive depending on the route taken and impeding traffic conditions. Other than that, it is close to Kuala Lumpur, which is the national capital and economic centre of Malaysia. All business related tradings can be done there and the company could find or attract many potential customers to invest in any future products the company may offer.

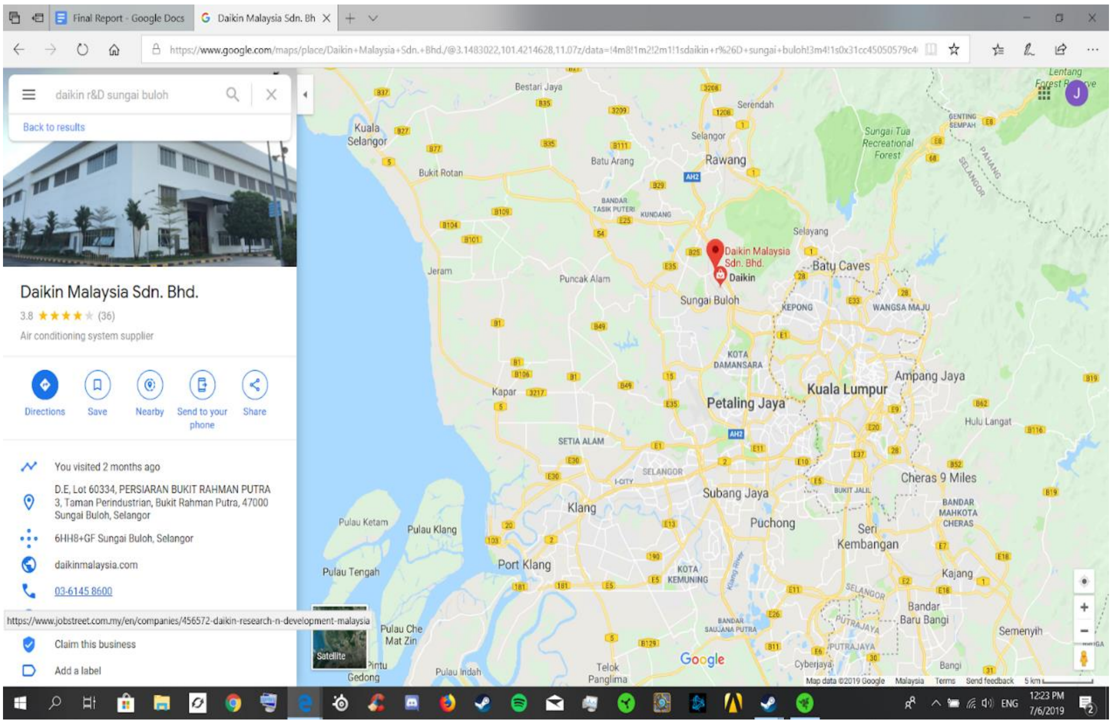


Figure 34: ??. Location of the premises

8.2 People

People who are involved in a project is the key point to determine the project is successful or not. And everyone who is involved in the project, they play an important role in their respective positions.

1.Project Manager

Project manager is to ensure the project complete the project on time without any delays and making sure the project flows in a correct path.

2.Engineer

Engineers came out ideas to overcome the real-life problems that people are facing. Besides, Engineers are responsible to ensure the system of the product is free from fraud and has no harm to the end users.

3.Finance Manager

Finance managers are responsible to manage the fund or the budget of the project. They must make sure that the project would have enough funds to complete the project.

4.Marketing Manager

Marketing Managers are responsible to manage the promotions for the product. And they are responsible to gain awareness for the product.

5.Sales Manager

Sales Managers are responsible to approach people to purchase the products, and deal with the sales transaction process if the deal was made.

6.Buyers

Buyers are the potential customers to buy the product, especially aircon manufacturing company for this project.

7.Business Administrator

Business administrators are responsible to update the business tractions daily and ensure sufficient inventory available. They must help to answer the customer’s enquiries as well if needed.

8.3 Promotion

1.Offering exclusive preview to the loyal customer

By conducting online preview, pre-launch event or special invitation to showcase the product to the loyal customers. At the same time, the loyal customers would feel good as the company always kept them in mind and keep them up to date on the latest technology. Therefore, offering exclusive preview to the loyal customer is a good way to promote the product as the loyal customers were mostly likely to be the first to buy the product.

2. Social Media

Nowadays, social media is everywhere and most of the people uses social media uncountable everyday. The company could register profile or page on Facebook or Instagram. All the new products could show under the company's Facebook or Instagram. It can help in getting exposure to the people. By doing so, the company could conduct contests through social media, such as giveaway. The campaign could be organised in this way, calling people on the social media to share the post about the new product by the company and stand a chance to win a price of the new product.

3. Offering Trade-In or upgrade

The company could offer an upgrade for the loyal customer. For this PCM-HE heat pump, it is basically a heat pump with additional of PCM-HE along with circuit system. The loyal customer could upgrade their current heat pump by adding a promotion price. Besides, the company could provide Trade-In service as long as the heat pump is working fine. By providing the Trade-In service, the customer or end-user could pay lesser. At the same time, the components from the old heat pump could be reused by the company.

4. Hosting an Event

The company could organise or join events and exhibition to showcase the latest product and technology. A traditional and costly way to promote and get exposure for the new product. The company could host some events and show the latest product or technology to the public. This traditional way would be costly as places must be paid, workers must be paid as well as the logistics. By hosting events like this, it could help in targeting people who weren't exposed to the internet. Therefore, hosting an event could be a good idea either.

5. Email Marketing

Company could send emails to the loyal customers or people who did registration during exhibition to acknowledge them that the company is having a new product or technology. And the product could be convenient or bill saving for the end user or customer. As the email is one of the effective channels to keep in touch with the customer. Besides, when the product was first introduced or launched, the company could send exclusive promotion code to the customer and by applying the code they could get a discount on price or some other promotions. At the same time, the customer would feel happy too.

9.0 Conclusion and Recommendation

To conclude the entire report, PCM is the best solution to enhance defrosting of the ice formed on the coil of the outdoor unit during the winter. PCM acts as a heat sink where it stores heat and releases heat back into the refrigerant through the copper pipe. This will provide more heat in the refrigerant which will travel to the outdoor unit to defrost the ice formed on the coil. It acts as a rechargeable battery where it absorbs heat during the melting process and releases heat during the solidification process. PCM is the best solution due to the fact that it is highly efficient thermal storage and it is only corrosive towards metal. The main objective of this project is to design a phase change material heat exchanger to be integrated into the heat pump to improve the heating method in the cold region. During the conceived stage, the team has used several methods to come out with the design of the prototype. The product has three main system which is the PCM storage tank, the frost detection system and the electronic circuit system which controls the flow of the refrigerant using the solenoid valve. Calculation were made before designing the copper pipe which is the length needed to achieve the maximum efficiency. Three designs were made with the length of the copper pipe needed which is the spiral, the mosquito coil and rectangular which commonly found in the air compressor. With the three design, a decision matrix is applied to see which design suits the most. The spiral shape is the best design as it has the highest point for decision matrix based on the criteria needed. The designing of the tank is next with few factors that need to be taken into consideration which is the size, user-friendly and ease of maintenance. After designing the tank and the copper pipe. Both is assemble in Solidwork to find out the amount of PCM needed in the tank. The material of the tank will be made out of plastic due to the fact that PCM is corrosive to metal. With the design completed, analysis is made based on the design to data. The analysis made is the simulation of the 3D model using ANSYS Fluent with the guidance of Youtube videos that can be found online. There were few errors along the way but the problem were settled with the help of an expert in CFD analysis, Dr Ng Khai Ching. The prototype we came out with is a sustainable product as it fulfills the three pillars of sustainability which is the social, environmental and economic pillars. The team managed to follow the timeline that is set in the Gantt Chart which is to complete conceive and design stage within 14 weeks of preparation towards the engineering fair. We even manage to print a 3D model of the prototype which is scaled down. Overall we manage to win during the Engineering fair for the Taylor’s Capstone 1 Award.

Few recommendations were given by few lecturers and advisor. The team were advised to learn CFD to have the proper simulation to get a much accurate data. We were advised to include more variable for the simulation. Dr. Abdulkareem gave us some good advice for the future. He advised us to take up more projects from companies like this for our final year that way we have a more comfortable title to research rather than picking up some title that you don't really know. Daikin advisor, Mr Thoo also gave us some tips on the upcoming stage which is the implement and operate stage. He advises us to complete everything as soon as possible and bring all the material and product to Daikin Research Center to complete the prototype before the testing day that way we have more time for testing. He also told us that we could do the simulation in Daikin to get the data. Few advice for the future, to have better computer that could support the CFD simulation.

10.0 References

Advameg Inc. (2019) "*Daikin INDUSTRIES, LTD. - Company Profile, Information, Business Description, History, Background Information on Daikin INDUSTRIES, LTD.*" Accessed 5 May 2019, Available at: https://www.referenceforbusiness.com/history2/34/Daikin-INDUSTRIES-LTD.html#ixzz5lMk1qmS6

Bhatia. S.C, (2014). Solar Thermal Energy. *Advanced Renewable Energy Systems*, Accessed 16 April 2019, (94-143), p.1. Available at: http://www.sciencedirect.com/science/article/pii/B9781782422693500048

Castillo, John. M (2010) "Relative Humidity : Sensors, Management and Environmental Effects" Nova Science Publication, New York

Daikin. (2019) "*Environment & CSR*." Accessed 22 April 2019, Available at: https://www.daikin-ce.com/en_us/about/environmental-responsibility.html

Daikin Malaysia. (2019) "*About Us | Daikin Malaysia*." Accessed 2 May 2019, Available at: https://www.daikin.com.my/about-us/

Ho. C, Fan. J, Newton E., and Au, R. (2011). "*Improving Thermal Comfort in Apparel*" Accessed 28 April 2019, Available at: http://www.sciencedirect.com/science/article/pii/B9781845695392500077

Hultén, M. and Berntsson, T. (2002). "The compression/absorption heat pump cycle—conceptual design improvements and comparisons with the compression cycle." *International Journal of Refrigeration*, 25(4), pp.487-497

Kiljunen. O, Tobias. H, 2010, "Air Conditioning Systems : Performance, Environment and Energy Factors" Nova Science Publication, New York

Madessa. H. B, 2014 "A review of the performance of buildings integrated with Phase change material: Opportunities for application in cold climate" accessed 2 May 2019, https://www.researchgate.net/publication/270053196_A_Review_of_the_Performance_of_Buildings_Integrated_with_Phase_Change_Material_Opportunities_for_Application_in_Cold_Climate

Mahdbi. M, 2018 "Phase Change Materials and Their Applications" Intech Open, The Shard, 25th Floor, 32 London Bridge Street, London SE19SG

Pause. B, (2010). "Phase change materials and their application in coatings and laminates for textiles. *Smart Textile Coatings and Laminates*" Accessed 28 April 2019, pp.236-250. Available at: http://www.sciencedirect.com/science/article/pii/B9781845693794500092

PCM Products Ltd (2019) “Phase Change Materials” Accessed 13 April 2019, Available at: http://www.pcmproducts.net/

Rubitherm, 2016 “SP31 Data Sheet” Accessed 3 May 2019, https://www.rubitherm.eu/media/products/datasheets/Techdata_-SP31_EN_02062016.PDF

Shen. J (2019) “A review of the defrosting methods of air source heat pumps using heat exchanger with phase change material.” *Energy Procedia*, 160, pp.491-498.

Meng Jie. S, (2018) “Review on Improvement for air source heat pump units during frosting and defrosting.” *Applied Energy*, 211, pp.1150-1170.

Wuttig. M, Raoux. S, 2009 “Phase Change Materials: Science and Applications” Springer Science+Business Media, LLC, 223 Spring Street, New York, NY 10013

11.0 Appendix

safety data sheet **SP31**

according to: 1907/2006/EG

RUBITHERM PHASE CHANGE MATERIAL

creation date: 22.12.2012 revised: 03.02.2014

SECTION 1: IDENTIFICATION OF THE SUBSTANCE/MIXTURE AND OF THE COMPANY

1.1 Product identifier:

Product name: SP31

1.2 Relevant identified uses of the substance or mixture

Application area: latent heat accumulators

1.3 Details of the supplier of the safety data sheet

Company: Rubitherm Technologies Gmbh

Address: Sperrenberg Straße 5a
DE - 12277 Berlin

Phone/Fax/E-Mail: 030 72000462 / 030 72000499 / msds@rubitherm.com

Internet: www.rubitherm.com

1.4 Emergency call number

0049 30 72 00 04 68; Mo-Fr; 8:00-16:00

SECTION 2: HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Regulation (EC) No 1272/2008

No hazardous product or mixture according to the directive (EG) Nr. 1272/2008.

Regulation 67/548/EWG, 1999/45/EG

2.2 Label elements

Regulation (EC) Nr.1272/2008

Regulation 67/548/EWG bzw. 199/45/EG

Hazard statements

not applicable

not applicable

Precautionary statements:

not applicable

2.3 Other hazards

No further information available.

SECTION 3: COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

This product is a mixture.

3.2 mixture

Composition/Information on Ingredients

Substance	**sodium acetate**	**Substance**	**urea**
CAS.Nr.	127-09-3	CAS.Nr.	204-823-8
EG-Nr.	204-823-8	EG-Nr.	
Index-Nr.		Index-Nr.	
REACH reg.-Nr.		REACH reg.-Nr.	
EINEC-Nr.		EINEC-Nr.	204-823-8
Konzentration	20-50%	Konzentration	30-60%
Hazard		**Hazard**	
1999/45EG	none	1999/45EG	none
1272/2008/EG	none	1272/2008/EG	none

For the wording of the listed risk phrases refer to section 16

SECTION4: FIRST AID MEASURES

4.1 Description of first aid measures

General advice: Avoiding contact with the eyes.
Take off contaminated clothing immediately. If you feel unwell, seek medical

If inhaled: Supply fresh air; consult doctor in case of complaints.

In case of skin contact: Wash immediately with plenty of water; in case of persistent skin irritation get medical advice / attention.

In case of eye contact: Remove contact lenses; flush eyes immediately with excess water for at least 15 minutes, lifting lower and upper eyelids occasionally; get medical advice /

If swallowed: Rinse mouth with cold water and drink much water in many little drafts (dilution effect); avoid vomiting; get medical advice in case of persistent symptoms.

4.2 Most important symptoms and effects, both acute and delayed

No known symptoms to date.

4..3 Indication of any immediate medical attention and special treatment needed

Symptomatic treatment.

SECTION 5: FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media:
Adapt extinguishing measures to the environment. Product itself is non-combustible.

Unsuitable extinguishing media:
For this substance no limitations of extinguishing agents are given.

5.2 Special hazards arising from the substance or mixture specific hazards during firefighting

Product itself is non-combustible, ambient fire may liberate hazardous vapours.

5.3 Advice for firefighters special protective equipment for firefighters

Wear self-contained breathing apparatus and chemical protective suit. Adapt extinguishing measures to the environment. Dispose contaminated fire extinguishing water according to official directives.

SECTION 6: ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Avoid contact with eyes and skin.
Avoid dust formation and do not breathe in dust.
Ensure adequate ventilation. Use personal protective equipment.
Keep away from unprotected persons.

6.2 Environmental precautions

Knock down dust with water spray jet.
Do not flush into surface water or sanitary sewer system.
If the product contaminates rivers and lakes or sewers inform respective authorities.

6.3 Methods and materials for containment and cleaning up

Seal sewer system. Pick up mechanical or drain and post cleaning. Send in suitable containers for recovery or disposal.

6.4 Reference to other sections

Information for safe handling see section 7.
Information about personal protection equipment see section 8.
Information about disposal see section 13.

SECTION 7: HANDLING AND STORAGE

7.1 Precautions for safe handling

Advice on safe handling:
Use personal protective equipment. Avoid dust formation and do not breathe in dust. Avoid contact with eyes and skin.
Do not smoke, drink or eat in the working area.

Advice on protection against fire and explosion

Product itself is non-combustible. Usual measures of preventive fire protection. Keep away from flammable material. No smoking.

7.2 Conditions for safe storage, including any incompatibilities

Requirements for storage areas and containers:
Storage class (TRGS 510): VCI-storage category (LGK): 12: Non-flammable liquids

Store in a cool, dry and well ventilated place, away from foodstuffs in closed containers.
Protect against frost, heat and solar irradiation. Storage of product only in original package. Do not store in passages.

SECTION 8: EXPOSURE CONTROL/PERSONAL PROTECTION

8.1 Control Paramters

National Occupational Exposure Limits No data available.

European Occupational Exposure Limits No data available.

DNEL-value:

sodium acetate	Application area: DNEL, employees possible danger of health: long-term – systemic – effects exposure route: inhalation, value: 2068,6mg/m³
Urea	possible danger of health: long-term – systemic – effects exposure route: inhalation, value: 292mg/m³

PNEC-value:

sodium acetate	No data available.
Urea	freshwater : 0,047 mg/l

8.2 Exposure Controls

Personal Protective Equipment:
Please follow the usual instructions when dealing with chemicals.
Avoid contact with eyes and skin.
Wear suitable protective clothing, gloves and safety glasses.
Do not smoke, drink or eat in the working area.

Technological protection:

Ensure good ventilation at the workplace especially while woking with liquid product. Keep torage and handling temperatur as low as possible.

Material of gloves:

nitrile rubber(NBR), Polyvinylchlorid (PVC), Polychloroprene (CR), (observe the instructions of the manufacturer)

Hand protection:

Wear protective gloves. Consider the data of the manufacturers at the permeability and break-through times.Time of duration can be shortened by environmental and use conditions. Inspect for dameges after and bevor use, replace them if necessary. Use skincare after work.

unsuitable gloves:

The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer.

Eye protection:

Safety glasses with side guard. In case of high danger of splashing use additional face shield.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

Appearance:

Physical state:	solid; 20°C; 1013hPa
Form:	solid
Colour:	white
Odour:	odourless
Odour Threshold:	unapplicable

Safety related data:

Explosive properties:	unapplicable
Steam pressure:	No data available.
Density:	1,3g/cm³, 15°C
Water solubility:	unlimited miscible
pH-value:	No data available.
Melting point:	31-33°C
Boiling point:	>110°C
Flash point:	unapplicable
Ignition temperature:	unapplicable

9.2 Other data

The material is hygroscopic, improperly storage or handling can lead to the absorption of water which resu

SECTION 10: STABILITY AND REACTIVITY

10.1 Reactivity	Stable at room temperature and atmospheric pressure.
10.2 Chemical stability	At appropriate storage and handling, the product is stable.
10.3 Possibility of hazardous reactions	Corossive to metals. Exothermic reaction with alkali metals.
10.4 Conditions to avoid	Contact with water must avoided urgently. contamination, direct sunlight, UV or ionizing radiation and extrem heat or
10.5 Incompatible materials to avoid	Water, the product is hygroscopic. Strong oxidizing agents, aci
10.6 Hazardous decomposition products	sodium oxid, acetic acid, ammonia

SECTION 11: TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

The mixture was not examined in its entirety on toxicological effects. The data refer to the respective component.

sodium acetate

Acute toxicity: Oral, LD50 Rat: 3530mg/kg
Dermal, LD50 Rabbit: >10.000mg/kg

Skin corrosion/irritation: Skin: slight irritating
Eye: temporary, reversible irritating

Sensitisation: No sensitizing effect known.

Carcinogenicity: No data available.

Mutagenicity: No data available.

Reproductive toxicity: No data available.

Additional information: No data available.

Urea

Acute toxicity: Oral, LD50 Rat: 15.000 mg/kg

Skin corrosion/irritation: no irritating

Sensitisation: No sensitizing effect known.

Carcinogenicity: No data available.

Mutagenität: No data available.

Reproductive toxicity: No data available.

Additional information: No data available.

SECTION 12: ECOLOGICAL INFORMATION

12.1 Toxicity

substance	toxicity to fish	toxicity to daphnia	toxicity to algae
sodium acetate	LC50: >1000 mg/l (48h); (Leuciscus idus)	EC50: >1000 mg/ml (48h); (Daphnia magna)	/
urea	LC50: >6810 mg/l (48h); (Leuciscus idus)	EC50: >10000 mg/ml (48h); (Daphnia magna)	IC50: >10000mg/ml (8d), Scenedesmis quadricauda

12.2 Persistence and degradability The methods for determining the biological degradability are not applicable to inorganic substances.

12.3 Bioaccumulation potential No data available.

12.4 Mobility in soil No data available.

12.5 Results of PBT and vPvB assessment Not applicable.

12.6 Other adverse effects No data available.

SECTION 13: DISPOSAL CONSIDERATIONS

13.1Waste treatment methods

Recommendation: Disposal must be made according to official regulation.

Waste code: A waste code in accordance with the European Waste Catalogue (EWC) may not be assigned to this product since it admits of a classification only when the consumer uses it for some purpose. The waste code must be determined in agreement with the regional waste disposal authority or company. Disposal should be in accordance with applicable regional, national, and local laws and regulation

Contaminated packaging: Contaminated packaging must be handled in the same way as the product.

Cleaned packaging: Offer rinsed packaging material to local recycling facilities.

SECTION 14: TRANSPORT INFORMATION

14.1 UN number

International Carriage of Dangerous Goods by Road
ADR : The product is not covered by international regulation on the transport of dangerous goods.
International Carriage of Dangerous Goods by Rail
RID: The product is not covered by international regulation on the transport of dangerous goods.
International Carriage of Dangerous Goods by Inland Waterways
ADN: The product is not covered by international regulation on the transport of dangerous goods.
International Maritime Dangerous Goods
IMDG: The product is not covered by international regulation on the transport of dangerous goods.
Technical Instructions for the Safe Transport of Dangerous Goods by Air
ICAO/IATA: The product is not covered by international regulation on the transport of dangerous goods.

14.2 Proper shipping name

ADR: The product is not covered by international regulation on the transport of dangerous goods.
RID: The product is not covered by international regulation on the transport of dangerous goods.
ADN: The product is not covered by international regulation on the transport of dangerous goods.
IMDG: The product is not covered by international regulation on the transport of dangerous goods.
ICAO/IATA: The product is not covered by international regulation on the transport of dangerous goods.

14.3 Transport hazard clas

ADR: The product is not covered by international regulation on the transport of dangerous goods.
RID: The product is not covered by international regulation on the transport of dangerous goods.
ADN: The product is not covered by international regulation on the transport of dangerous goods.
IMDG: The product is not covered by international regulation on the transport of dangerous goods.
ICAO/IATA: The product is not covered by international regulation on the transport of dangerous goods.

14.4 Packaging group

ADR: The product is not covered by international regulation on the transport of dangerous goods.
RID: The product is not covered by international regulation on the transport of dangerous goods.
ADN: The product is not covered by international regulation on the transport of dangerous goods.
IMDG: The product is not covered by international regulation on the transport of dangerous goods.
ICAO/IATA: The product is not covered by international regulation on the transport of dangerous goods.

14.5 Environmental hazards

ADR:	No Environmentally Hazardous.
RID:	No Environmentally Hazardous.
ADN:	No Environmentally Hazardous.
IMDG:	Not marine pollutant.
ICAO/IATA:	No Environmentally Hazardous.

14.6 Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code

The product is not covered by international regulation on the transport of dangerous goods.

14.7 Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code

not relevant

SECTION 15: REGULATORY INFORMATION

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

Directive 96/82/EC	Directive 96/82/EC does not apply.
Occupational restrictions:	Employment restrictions for children and young workers in accordance with Directive 94/33/EC and the respective national provisions are to be observed.
water hazard class:	WGK 1: water hazard class 1; slightly hazardous to water; classification into Annex 3 of VwVwS;

15.2 Chemical Safety Assessment

A Chemical Safety Assessment has not been carried out.

SECTION 16: OTHER INFORMATION

Changes made since the last version:

This information is based on our present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship.

literature references and sources for data:

http://gestis.itrust.de/
http://echa.europa.eu/
http://www.reach-clp-helpdesk.de/

Rules:

Substance directive (67/548/EEC).
REACH Regulation 1907/2006/EC.
CLP Regulation (EC) No 1272/2008.

Full text of H-Statements referred to under sections 2 and 3.

none

Safety note:

P264 Wash face, hands and all exposed skin parts thoroughly after handling.
P270 Do no eat, drink or smoke when using this product.
P280 Wear protective gloves/protective clothing/eye protection/face protection.

Text of R-phrases mentioned in Section 3 and Section 2:

none

All information in this material safety data sheet (MSDS) is correct to the best of our knowledge, information and belief at the date of its publication. The data given is designed only as guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. Each customer shall make is own evaluation of appropriate use, shipping and storage for each specific material. Rubitherm makes no warranty either express or implied, including any warranties of fitness for a specific purpose. This safety datasheet does not replace any product information or specification.

Data Sheet

RUBITHERM

SP31

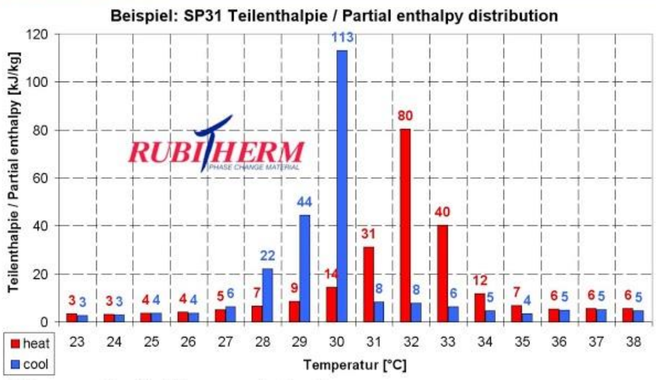
**The creation of the latent heat blended material RUBITHERM® SP has led to a new and innovative class of low flammability PCM. RUBITHERM® SP consists of a unique composition of inorganic components.
RUBITHERM® SP is preferably used as macroencapsulated material. Densities of 1,0 kg/l and more can be achieved. This and all properties mentioned below make RUBITHERM® SP to the preferred PCM used in the construction industry. Both passive and active cooling can easily be realized e.g. in wall elements and air conditioners.**

We look forward to discussing your particular questions, needs and interests with you.

Properties:
- stable performance throughout the phase change cycles
- high thermal storage capacity per volume
- limited supercooling, low flammability, non toxic
- different melting temperatures between -21°C und 70°C are available

The most important data:	**Typical Values**	
Melting area	**31-33** main peak: 32	**[°C]**
Congealing area	**28-30** main peak: 30	**[°C]**
Heat storage capacity ± 7,5% Combination of sensible and latent heat	**210**	**[kJ/kg]**
in a temperatur range of 23°C to 38°C.	**58**	**[Wh/kg]***
Specific heat capacity	**2**	**[kJ/kg·K]***
Density solid at 15 °C	**1,35**	**[kg/l]**
Density liquid at 35 °C	**1,3**	**[kg/l]**
Volume expansion	**3-4**	**[%]**
Heat conductivity	**n.b.**	**[W/(m·K)]**
Max. operation temperature	**50**	**[°C]**
Corrosion	**corrosive effect on metals**	

Note: The product must be initialized (melt, homogenize and cool to 0 ° C) once before use to achieve the specified properties.
All SP-product are hygroscopic and may absorb moisture if stored improperly. This can result in a change of the physical properties given.



**Measured with 3-layer-calorimeter.*

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