PRE-DESIGN LATENT HEAT THERMAL ENERGY STORAGE USING ENERGY FROM ELECTRICITY GRID

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

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(AP. Ir Dr Chalilullah Rangkuti)

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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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WAN MOHD HARIRI B. MOHD NASIHUDDIN

ABSTRACT

Universiti Teknologi Petronas currently uses Gas District Cooling (UTP GDC) as cooling system in the university. UTP GDC system stores chilled water thermal energy storage and using electricity generated from gas turbine. The current set up is using huge volume of tank storage and high capacities of equipments then lead to high operation cost. Based on previous research, there is still room of improvement for UTP air conditioning system. In this project, the chilled water thermal energy storage will be replaced with ice thermal energy storage and the gas turbine as electricity generator will be replaced with direct electricity from the Tenaga Nasional Berhad grid. The basic principle of this project is the chillers only run during the off-peak rate to charge the storage tank for day use. It is to minimize the operating cost. For that purpose, 37100 RTh cooling load needs to be stored. By using ice, the volume of tank storage can be reduced to $2700m^3$. Existing tank needs to undergo several modifications to store ice. For ice storage, it will contain 3 297 700 nodules AC.00. In order to ensure sufficient storage for the system, 6 brine chillers are used to replace existing 4 electric chillers and 2 steam absorption chillers. Chillers will be operating for 11 hours during the off-peak rate while the existing chillers are running 24 hours. The system is going to use four pumps. Each pump consists of 210 kW. Heat exchanger capacity is 29700 kW. Economic analysis and design justifications are done to ensure the feasibility of the project. Based on operation and maintenance cost analysis, this project can save a lot of money for each month of operation. The saving is at least about RM 100000 per month and value of energy per unit volume increases 13 times from the existing design. Other design justifications are environmental protection and high reliability. All of those justifications prove that this project is viable to develop.

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LIST OF ABBREVIATIONS

UTP   Universiti Teknologi PETRONAS

GDC   Gas District Cooling

TES   Thermal Energy Storage

PCM   Phase Change Material

FYP   Final Year Project

RTH   Refrigerant tonne hour

STL   Storage tank latent

HVAC   Heating, Ventilation and Air Conditioning

KLCC   Kuala Lumpur City Center

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 Background of Study

Thermal energy storage can refer to a number of technologies that store energy in a thermal reservoir for later reuse. They can be employed to balance energy demand between day time and night time. The principal application today is storing ice or chilled water, which is then used to cool environments during the day [9].

To implement this project, thermal energy storage will store latent heat which is ice. Latent heat is the amount of energy in the form of heat released or absorbed by a substance during a change of phase. For this project, thermal energy storage stores ice compare to current UTP set up which stores chilled water.

Chillers are used to charge the thermal energy storage. Currently in UTP, electric chillers are run by electricity generated by gas turbine. For this project, brine chillers will directly run by electricity from the grid.

1.2 Problem Statement

UTP GDC is currently using thermal energy storage system. For UTP GDC system, thermal energy storage stores chilled water. Chilled waters are cooled by electric chillers that run by electricity generated from gas turbine. The current set up is using huge volume of tank storage for the system and high operating cost of the equipments. The study shows that by storing latent heat in thermal energy storage, it will reduce capacity in term of volume for energy storage, power of cooling system and power of pump. Then, to reduce operating cost, gas turbine as a source of electricity for electric chiller will be replaced with the electricity from grid Tenaga National Berhad. By using electricity from grid, ice can be stored at night which is lower rate than day time.

1.3 Significant of Project

This project is mainly to reduce energy consumption and operating cost for air conditioning system in UTP. It is significant due to the high electricity rate and high energy consumption for air conditioning system in UTP. This project also can be basis to the HVAC engineer especially for designing HVAC in campus. This project will analyze whether latent heat thermal energy storage is worth or not to develop.

1.4 Objectives

Objective of this project is to pre-design latent heat thermal energy storage using energy from electricity grid for replacing current UTP GDC set up. This new design is based on UTP requirements for UTP GDC. It also includes economy analysis and design justification between new design and current design to justify whether this project is feasible or not to develop.

1.5 Scope of Study

In order to accomplish the objective, the scopes of study are:

i.   To understand the process involve in GDC

In achieving the purpose in understanding the process involve in UTP GDC, the author should know how the current set up work. The description of TES including value of charging, discharging temperatures and cooling load for university can be known by referring to the manual and data of UTP GDC.

ii.   To design new latent heat thermal energy storage set up

Cooling load for the university is obtained from UTP GDC and UTP control room. Then, the calculations for thermal energy storage are done in determining the new volume, height, diameter and number of nodules should be filled in the energy storage tank. After tank volume is known, all the equipments capacity such as pump and heat exchanger are calculated. Sufficient numbers of chillers need to be decided to ensure the charging period is not more than 11 hours. Mode of operation and pipe routing is also important so that the system can be run effectively.

iii.   To make economic analysis between new design and current design

   After done with power consumption calculation, the rate of electricity used is calculated. Capital and operation cost are also estimated. Economy analysis can be done for new design and current design. Both designs are economically analyzed to justify whether the new design is feasible or not. In top of that other justifications are also taken into account such as environment protection and reliability.

1.6 Feasibility of Project

This project includes economy analysis to see whether it is economically feasible or not. Based on research done, latent heat thermal energy storage can reduce the operating cost. It will use smaller volume of tank storage and capacity of the equipment used. Latent heat thermal energy storage is site-specific. So this project takes UTP as site. This project also optimized by chooses the best option for the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Latent Heat Thermal Energy Storage

Latent heat is the energy either stored or liberated when a substance changes phase. These changes occur at constant temperature. To melt a material, a quantity of energy is required and then this energy is released when the material is cooled down and returns to solid phase. Each material has different fusion points. For Thermal Energy Storage, different materials are used to satisfy the requirements of a wide range of applications. These materials are called Phase Change Material (PCM). Latent heat storage presents two advantages which are high thermal densities can be achieved and the energy are released at almost constant temperature [9].

The most suitable PCM for the new TES system is ice because water can be changed easily to solid phase which is ice when temperature is 0 °C and below. Furthermore, for this system, ice has the lowest cost when compare to the other PCM.

2.2 The Nodules

The quantity of energy stored for each type of nodule is directly proportional to the storage volume. The nodule has many types of size like diameter of 77mm, 78mm and 98mm. The nodule's envelope is made of polyolefin. The exchange surface of nodules is 1.0 m^2/kWh stored for 77 or 78 mm diameter nodules while 0.6 m^2/kWh stored for 98 mm diameter nodules [5].
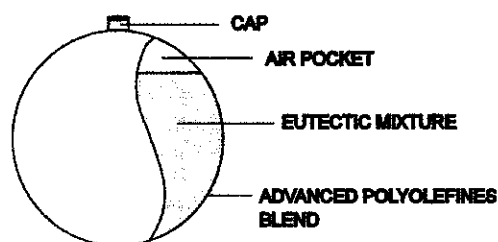
Figure 2.1: The nodule characteristic

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Figure 2.1 shows the nodule characteristic. The air pocket is to ensure no stress on the nodule shell when having expansion. Once the nodule is filled by PCM the nodule plug is sealed by ultrasonic to ensure no leakage is possible. The nodule has more than 10000 cycle life. For sizing purpose, it depends on the diameter of the nodule. For example, for 78mm diameter, 2444 number of nodules per m^3[15].

2.3 Tank Manufacturing

The dimensions of the tank(s) are calculated based on the plant space available at site and to satisfy the thermal performance requirements. The tank may be cylindrical with design service pressures up to 10 bars or rectangular (concrete or steel) for atmospheric pressure. Cylindrical tanks can be designed horizontally, vertically or for burial underground. Tanks are fitted with upper manholes for installing the nodules and a lower manhole in the event of emptying. Two internal headers (top and bottom) are designed to generate maximum heat transfer efficiency. The heat exchange between the nodules and the system is achieved by circulating the heat transfer fluid through the tank [8].

In order for the TES to reach interior temperatures high enough for energy stored, the walls, roof and the bottom of the TES must have good insulation. So, it is important to choose right insulator and their thickness of the materials. The common insulating materials for low temperature tank include cellular glass, perlite concrete, foamed or aerated concrete, timber, polyvinyl chloride foam, polyisocyanurate foam, phenolic foam, polystyrene foam, polyurethane foam, glass reinforced polyurethane foam, and mineral wool or glass fiber blankets [7].

Ethylene glycol goes in

Ethylene glycol goes out
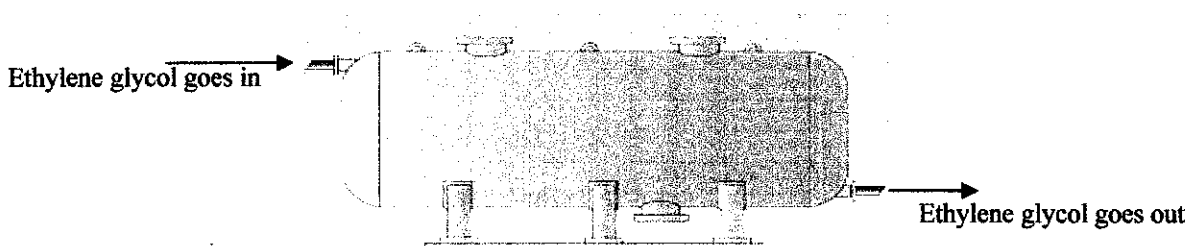
Figure 2.2: Example of tank by Cristopia Energy

Based on Figure 2.2, that is the example of tank that manufactured by Cristopia Energy. Inside the tank, it will be filled with nodule and ethylene glycol. Ethylene glycol will go in and out. During the charge mode, ethylene glycol will cool the nodules until become ice and during the discharge mode, ethylene glycol will be cooled by ice nodule in the tank.

2.4 Economy Study on Water-Ice Storage

Water-ice storage is the most common cooling storage in smaller applications. Because latent heat storage (phase change between water and ice) has a smaller volume, it is often chosen for retrofit applications with limited space. In general, the buildings that offer the highest potential are offices, retail, and medical facilities.

The Dallas Veterans Affairs Medical Center installed a 24,628 ton-hours chilled water TES that resulted in a reduction in demand of 2,934 kW and a reduction in annual electricity cost of US $223,650. The local utility provided US $500,000 of the total cost of US $2.2 million required for design and installation. Savings resulting from installation of the thermal storage technology will allow the VA to recoup its investment within 7 years [18].

Table 2.1: Monthly demand saving of using thermal energy storage to shift* chiller charges at night time

Utility Demand Rate	Cost Per Ton Hour of Cooling	Monthly Demand Savings
US $6/kW	US $4.20	US $1008
US $12/kW	US $8.40	US $2016
*Assumes 300 ton chiller operating at average load-80% of full load, or 240 tons. Chiller efficiency assumed at 0.7kW/ton. Chiller operation assumed to operate at night when building is unoccupied so that peak demand is not increased by chiller operation		

Source: Washington State University Cooperative Extension Energy Program

Table 2.1 shows the monthly demand savings if the shift chiller are using during night time. Although it is for chilled water, it just prove this project will be economic feasible because it will run the brine chiller during night. This is not Malaysia's rate but the pattern of rate is same with another countries.

Table 2.2: Comparison of Thermal Storage Media

	Chilled Water	Ice
Chiller Cost	200-300 US $/ton	200-1500 US $/ton
Storage Tank Cost	30-150 US $/ton-hr	20-70 US $/ton-hr
Storage Volume	6-20 ft^3 / ton-hr	2.5-3.3 ft^3/ton-hr

Source: Washington State University Cooperative Extension Energy Program

Table 2.2 shows the comparison thermal storage media. Those comparison shows that the cost of ice tank storage is much cheaper. The volume of ice storage tank is also smaller. But [18] suggests that feasible study must be done because TES are site-specific and system specific.

2.5 Electric Tariff Starting March 2009

Electric will be the main source of energy of the system. For electricity tariff, there are off peak time and peak time. The peak time will be at 9.00 am till 9.00 pm and the off peak time will be at 9.00 pm till 9.00 am next day [14].

Table 2.3: Electricity tariff starting March 2009

Tariff Category	Unit	1st March 2009
Medium Volatge: Thermal Energy Storage For each kilowatt of maximum demand per month during the peak period	RM/kW	35.60
For all kWh during the peak period	sen/kWh	28.8
For all kWh during the off-peak period	sen/kWh	16.2
The Minimum Monthly Charge is	RM	600.00

Source: New tariff Booklet March 2009, Tenaga Nasional Berhad

By referring to the Table 2.3, there is a special tariff for thermal energy storage. It is cheaper than normal tariff as thermal energy storage has recognized under a program called Demand Site Management. Because of the lower rate during the off-peak time, this project, the thermal energy storage will run the electric chiller to store the thermal energy storage during the night time. The system has 12 hours to store the latent heat thermal energy which is ice.

2.6 Study on GDC UTP Existing Design

GDC UTP is currently supply chilled water to UTP for air conditioning system. UTP GDC is using co-generation system. Co-generation is a process that converts a fuel into both thermal and electrical energy. The thermal energy may be in the form of steam, hot water, or hot air, or any combination of the three. For UTP GDC, heat waste produced from the gas turbine will be flow to the heat recovery steam generator to generate steam. The steam will flows to the steam absorption chiller as a source of energy.

Currently, GDC UTP is also using thermal energy storage. The tank storage can store 10000 RTh. The tank is 5400 m^3 in volume and stored chilled water. But storage is not sufficient enough to comply the cooling load for UTP. So the system needs to have direct production mode and back up to comply the client requirement [16].
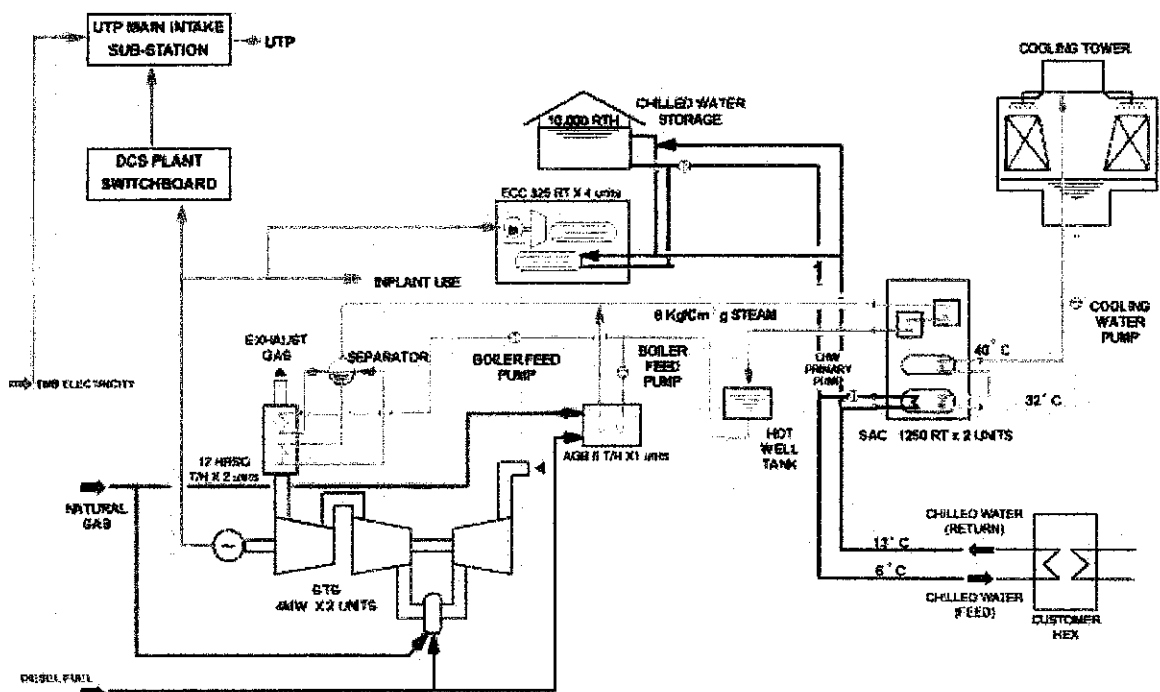
Figure 2.3: Schematic diagram of the UTP GDC system [16]

Based on the Figure 2.3 above, those are the process to cool the chilled water from UTP. Basically there are three ways for chilled water cooling either use thermal energy storage, direct production from the electric chiller or steam absorption chiller.

Steam absorption chiller is used during the day time only because it only have direct production mode. So the absorption chiller will start at 6.00 am to 6.00pm. Steam absorption chillers are using steams as energy that generated by heat recovery steam generator.

Electric chiller will run during the off-peak time to charge the thermal energy storage tank from 6.00pm to 6.00 am. Electric chillers also run during the day time for back-up system. Electric chillers are using electricity that generated by gas turbine generator.

Gas turbine generators are the main energy source of the system. Gas turbine generator can generate up to 8.4 MW. Heat waste from gas turbine will go to the heat recovery steam generator to generate steams as energy source for steam absorption chillers.

Thermal energy storage will discharge during the day time from 6.00 am to 6.00 pm.

Those are technical data from UTP GDC existing set up:

    i.   Shape: Cylindrical
   ii.   Position: Vertical
  iii.   Diameter: 22.3 m
  iv.   Height: 14 m
   v.   Design Temperature: 6°C for supply temperature and 13.5°C for return temperature.
  vi.   Chillers: 4 numbers of 325 RT electric chillers, 2 numbers of 1250 RT Steam Absorption Chillers.

Based on the existing design, the new project will reduce the volume of tank, increase the capacity of storage, replace the numbers of chillers and replace gas turbine with direct electricity from the grid [16].

2.7 Study on KLCC latent heat storage

GDC KLCC is using latent heat thermal energy storage. It also has direct cooling by using steam absorption chiller and electric chiller to cool chilled water [11].

Table 2.4: Characteristic of latent heat storage in KLCC

Characteristics	Latent Heat in KLCC GDC
Shape	Square
Position	Horizontal
Diameter	11 m
Height	10.6 m
Volume	3200 m^3 for 4 tanks. Each tank has 800 m^3 of volume.
Design Temperature	4.5°C for supply temperature and 14.5°C for return temperature.
Chillers	Have three numbers of ice chillers. Each one has 2000 RT. Total direct cooling of 6000 RT.
Tank Capacity	45000 RTh ice storage systems (nominal discharge load of 4500 RT over 10 hours).
Tank contain	Total quantity of nodules in four tanks is 3.45 million numbers which has 937500 nodules per tank.

Table 2.4 above shows only the characteristic of latent heat thermal energy storage. With those characteristics, below is the schematic diagram to show how it is operate.
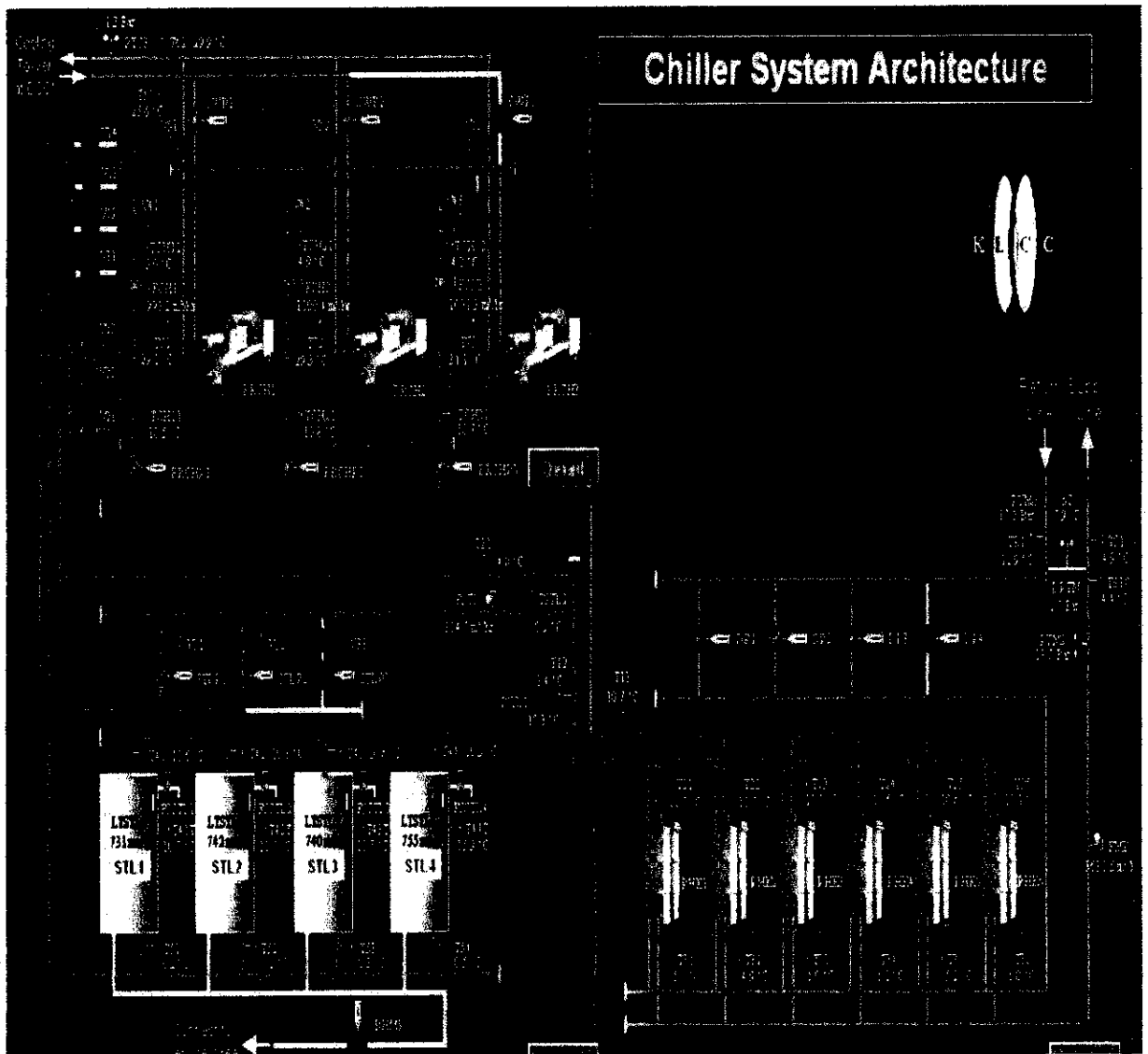
Figure 2.4: Schematic diagram of KLCC ice storage [11]

Based on the Figure 2.4, those are how ice in the storage made and melt:

1. Making the ice

During the making ice, the water contain glycol will come in and out to and from the ice storage tank continuously until the temperature of PCM in the nodules is 0°C and below. In this condition, the system is charged. It takes 10 hours to complete the charging. Normally, the charging system is done during "off-peak" hours.

2. Melting the ice

During the melting ice, the water contain glycol will come in and out and to and from ice storage tank continuously. The nodules cool the glycol solution that is then pumped to the load to provide air conditioning or process cooling. In this condition, the system is discharged.

From all those literature review, the basic principal of this new design is almost likely KLCC design because it also uses latent heat thermal energy storage. But, the new design will use electricity from the grid. The system will fully store their energy during the off-peak time for day use. So no chiller will be running during the day time.

CHAPTER 3

METHODOLOGY

3. METHODOLOGY

The project is designing latent heat thermal energy storage using electricity from the grid to replace current UTP GDC set-up. All the requirements of the design must as per require from UTP. The new design will equipped with latent heat tank storage in order to replace chilled water storage. Gas turbine generator as source of energy will be replaced with direct electricity grid. Basic principle of this design is the chillers only running during the off-peak time which is lower electricity rate.

For completing the project, there are several methodologies need to be done. The project will start by literature review, existing project analysis, gathering data, visiting sites, calculation for tank, calculation for equipment used, optimization design and economy analysis.

Softwares used are AutoCad, Microsoft Word and Microsoft Excel. Figure 3.1 will illustrate the flow chart of the project.

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              ┌─────────────────────┐
              │  Literature Review  │
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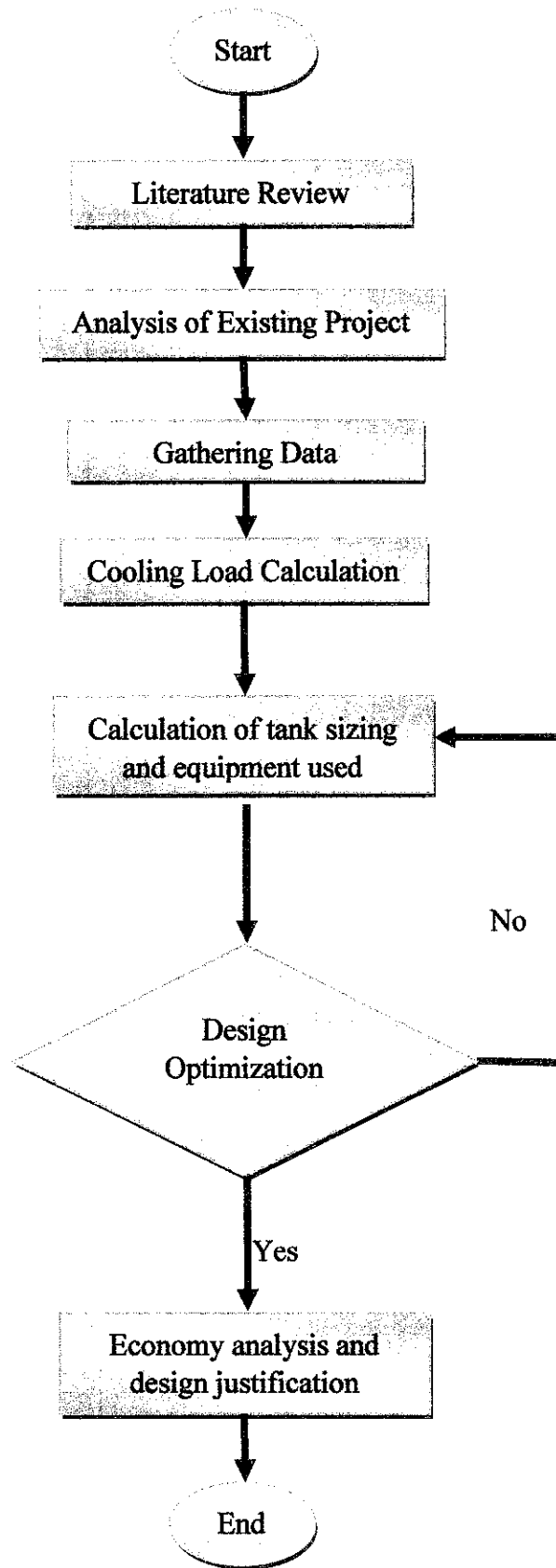
Figure 3.1: Steps involve in project

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3.1 Start the Project

The project will start with proposal to the supervisor. Rough idea of this project is to pre-design a latent heat thermal energy storage using electricity from the grid for UTP. The focus of the project is to set-up a latent heat thermal energy storage system and using electricity directly from the grid. Then, the economy analysis is done to ensure the project is feasible to develop. It also can be reference to other HVAC engineer for any campus site.

3.2 Literature Review

First of all, understanding the basic theory of latent heat thermal energy storage is very important. Paper works, journal, engineering books or anything relevant to the project are reviewed.

3.3 Analysis of Existing Project

In order to design a new set up based on common industrial practice, the author analyzes the current ice storage project which is KLCC GDC. The purpose of this visit is to have information about ice storage system which has been applied in KLCC GDC. During the visit, the author experienced to see how the ice is made and how the system in KLCC GDC operates.

Project analyzing also been done using journal or project reports that published by the site. Bangsar project, Putrajaya project and UiTM Shah Alam project have been reviewed.

3.4 Gathering Data

After understanding the basic theory of processing making ice, data are collected. Data for cooling load and current set up technical specification are collected from UTP GDC. For ice storage data like nodules, heat transfer fluid, chillers, heat exchanger and also estimated cost are collected from Cristopia Energy System.

3.5 Calculation for Ice Storage Cooling Load

For cooling load, data are collected for year 2005 for each month, day and hour. Data is analyzed to get the maximum value of cooling load in month and day. Then cooling load on the highest day is plotted per hour. By plotted the graph for that day, the pattern for cooling load for each hour can be predicted. The results are tabulated in Chapter 4.

In order to calculate how much energy need to stored in ice storage, the maximum cooling load per day is added with 10% of safety factor then minus all the cooling load during the of peak-rate which is from 9 pm to 9am.

3.6 Calculation for Latent Heat Thermal Energy Storage and Equipment Used

After cooling load is obtained, the equipment size or capacity is calculated. First is tank sizing. Since existing tank will be used some sort of modification should be done. The other equipments need to be calculated are pump, heat exchanger, piping and fitting.

3.6.1 Tank Sizing and Nodule Calculation

Tank sizing are based on the energy need to be stored and how much energy can be stored in each nodule. The nodules for the storage are calculated. From the number of nodules, we can know the volume of tank. Sample calculation for nodules is in Appendix E and sample calculation of volume of tank is on the Appendix F.

3.6.2 Piping and fitting

For piping, we need to calculate the length of the pipe need and also the insulation material for the pipe. For the fitting, type and numbers of fitting are calculated based on the schematic diagram to ensure mode of operation can be done properly. Those pipes and fitting will affected the power of pump because of the friction loss. So calculations must be done on friction loss because of pipe and fittings. Sample calculation on friction loss is in Appendix I.

3.5.3 Pump Calculation

Pump calculation is based on friction loss. So to calculate the power of pump, we need to know several variables like Darcy friction factor, minor pressure loss, Reynolds number, diameter and the length of the pipe. Sample calculation of pump is on Appendix J.

3.5.4 Heat Exchanger Calculation

Heat exchanger calculation is based on formula given in Cristopia Handbook. The discharge capacity of heat exchanger is based on temperature of heat transfer liquid to heat exchanger and chilled water to heat exchanger. The sample calculation is in the Appendix H.

3.7 Optimization the design of Thermal Energy Storage

Although this design not using specific software such as Stockaid 2002, the optimization of the design is done by recalculate until the values obtained are optimize. Since software Stockaid 2002 is unavailable, the author tabulates the formula from Cristopia handbook into Microsoft Excel 2007 spreadsheet.

Initially the author comes out to with alternatives with various numbers of tanks. The various numbers of tanks will give different result in discharge rate for each tank. With this option, the existing set up is kept in order to reduce the ice tank storage. Then the best option is chosen.

But after present the alternatives to the manufacturer which is Cristopia Energy System, the author work out to optimize the system. The author decides to modify the existing tank into ice tank because it will be waste of storage to store chilled water. The system can be manipulated by using several numbers of pumps instead of using several numbers of tanks. So the optimization design is about choosing the best option of the system. But only the chosen alternative will be shown in the Chapter 4, Result and Discussion.

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3.8 Economic Analysis and Design Justification

Economy analysis is important to justify the design is worthy to develop. But there are some problems in getting the exact data because some of costs are confidential. So the author analyzes the operational cost based on electricity tariff. But to make justification stronger, all the advantages of new design is evaluated to ensure this new project is worthy to develop.

3.9 End of Project

As the end of the project, the final report of Pre-Latent Heat Thermal Energy Storage is completed. There are also some of recommendation that been made for future study.

CHAPTER 4

RESULT AND DISCUSSION

4. RESULT AND DISCUSSION

4.1 Cooling Load for Ice Storage

Data has been collected for year 2005. Data are approximately same in every year because there is not much change in load after 2005. Data are taken for every hour and every day for year 2005. Monthly cooling load for year 2005 is shown in Appendix B.

The maximum used per day is in October which is 24th October 2005. The cooling load is 42289 RTh. Hourly cooling load on 24th October 2005 is shown in Appendix C. In order to ensure the system will be comply with any additional load, 10 % safety factor is added in the cooling load. 10 % safety factor is added since expansion of cooling load for previous years is within 10%. So the cooling load per day is 46520 RTh.

During the off-peak time, the system is use direct cooling and charge mode, so the cooling load for ice storage can be reduced. Based on Appendix C, the cooling load between 9.00 pm to 9.00 am is 9500 RTh.

So total cooling load for latent heat storage is,

New storage = Total Cooling Load per Day – Cooling Load during off-peak time

The total cooling load for latent heat storage is 37100 RTh. By using this mechanism, it obeys the basic principle of the design which is the chillers only running during off peak time.

4.2 Maximum Cooling Load Based on Daily Basis

The data for each hour is as per Appendix C. These data are taken to see the pattern of the cooling load for each hour. The peak hour is from 08:00 to 16:00 due to the occupants start entering the building and environment temperature. The highest

cooling load is at 08:00 which is 4446 RT. The cooling loads are lower from 18:00 to 23:00. There are zero cooling loads from 00:00 to 05:00. Based on cooling load per hour, the system can has four pumps as per current set up. By using several pumps, the system can comply the load based on cooling load per hour. So there will be no waste of energy during the low load.

4.3 Selecting Nodule

The selection of nodule depends on phase change material (T_{st}) and the operating condition.

$$T_{st} < T_d - 4$$

Where T_d is operating temperature [15].

When a phase change material is set to be 0^oC, the AC 00 can be used to reduce system cost. However if the maximum instantaneous is highly demand, IC 00 should be selected as output performance (i.e.: backup cooling).

For chilled water produced at 5^oC, the AC 00 is chosen. ($T_{st} < 5 - 4$). In addition, this type of nodule is chosen because it is designed for air conditioning system. The expansion of this nodule is 1% because it is for atmospheric storage latent tank. The function of air pocket in this nodule is to avoid the stress on the nodule's shell when it expends. The capacity for each nodule to produce energy is 0.0396 kWh. Each 1 m^3 of tank will be filled with 1222 numbers of nodules. Other properties of the AC 00 are shown in Appendix D.

4.4 Heat Transfer Fluid

Heat transfer fluid is very important for this system. Heat transfer fluid is used as fluid that exchange heat to the nodules in the tank and in UTP heat exchanger. Approximately 60% of the volume of the tank is occupied by the nodules and the remaining 40% is fluid. The heat transfer fluid is usually ethylene glycol because it is most effective than other brines such as propylene glycol or calcium chloride. It contains of 30% glycol and 70% of water. T_{st} for ethylene glycol is at -11^oC. So it will not become ice during the nodule charged [10]. Comparison between properties of ethylene glycol and propylene glycol is shown in Appendix A.

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4.5 Number of chillers

If we design ice storage, brine chiller is necessary to install in close system for ice charging purpose. The design of the system in parallel mode which the chiller can produce individual cooling energy and ice storage also can produce cooling energy independently. Numbers of chillers are basically based on the ice storage load. For this project, total load is 37100 RTh. For storage purpose, the cooling capacity loss is about 30%. The capacity lost is due to the temperature of the chiller. Usually a chiller lost 3 % of its cooling capacity by degree C, i.e. when the temperature outlet of the chiller leave from +5 to =5 °C, the chiller will lost 30% of its cooling capacity, thus the effective cooling is only 70%. This is due to the refrigerant evaporation inside the evaporator. The maximum time for charging which is off peak time is 12 hours. Since this mode is controlled manually, tolerance 1 hour is given for any human error. So 11 hours are taken as charging time.

37100 RTh = 0.7 x 2000RT x 11 hours x Number of chillers

Number of chillers = 6 numbers of chillers.

Type of the brine chillers used is HydroCIAT 850 RT water chiller. Water cooled chillers are used since cooling tower is exist in current set-up. Type of refrigerant used is R-134a. R-134a is a refrigerant that complied Malaysia act and Protocol Montreal. By using this refrigerant, it will be better for the environment.

4.6 Size of tank

Cooling loads are determined from cooling load calculation. Storage needs to store is 37100 RTh. The numbers of nodules need to comply that cooling load is 3297770 nodules. The sample calculation for number of nodules is in Appendix E. Total volume of tank is 2700m^3. Since the existing tank is used the diameter of tank is 22.3m and the height of tank is 7m. The calculation sample of tank sizing is in the Appendix F.

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4.7 Tank Modifications

Since the existing tank is used as ice storage, the tank should have some sort of modification. Modification will be to the whole size of tank although not whole tank will be used. It is because the empty space is allowed for campus to expand its cooling load and it also exhibits the empty space affecting the ice tank. The design of tank is in the Appendix G.

4.7.1 Tank insulation

Currently the existing Thermal Energy Storage is insulated with 100mm PU slab cw zincalume cladding. The insulation thickness is based on Cristopia tank manufacturing [8]. Since the insulation material for thermal energy storage tank is almost equal to the KLCC ice tank, there is no need for additional insulation.

4.7.2 Grid and supports

Grid is necessary for this tank. It is because the existing tank is not fully used for ice storage. The grid also functions as to exert the buoyancy force from the nodules. In order to put grid in the tank there will be grid support to support the grid. Figure 4.1 will shows the grid of tank and Figure 4.2 will shows the illustration of its support. Grid needs to exert buoyancy force as per calculation in Appendix F. The buoyancy force is 113 kN.

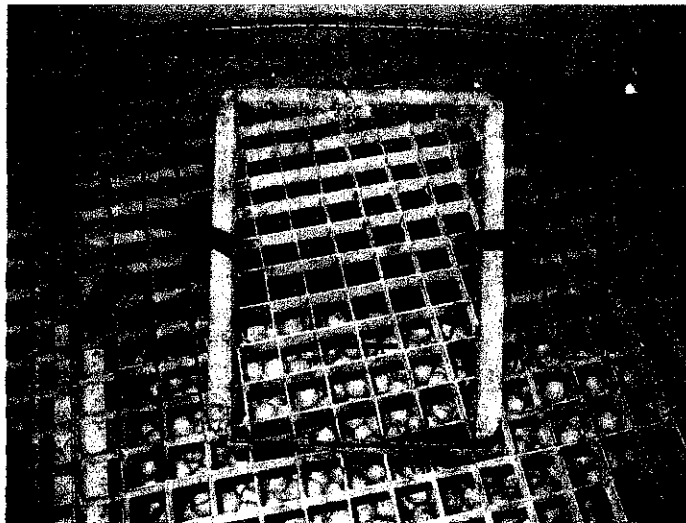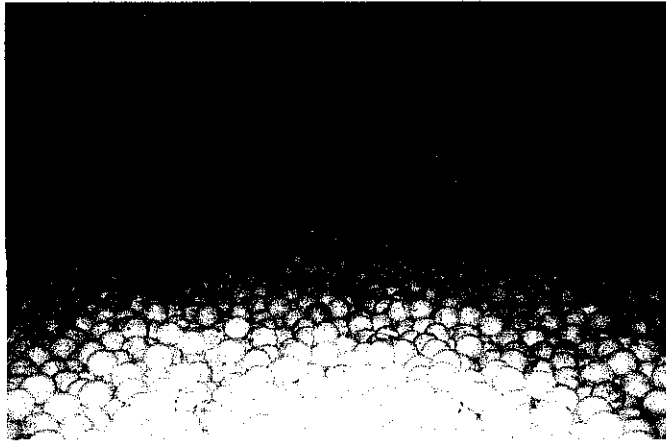Figure 4.1: Example of grid from top view

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Figure 4.2: Example of grid support

4.8 Mode of tank and schematic diagram

In order to ensure the system will run properly. There will be 3 modes of operations which are charge mode, discharge mode and charge and direct production mode. Figure 4.3 will show the production mode based on cooling load per hour.
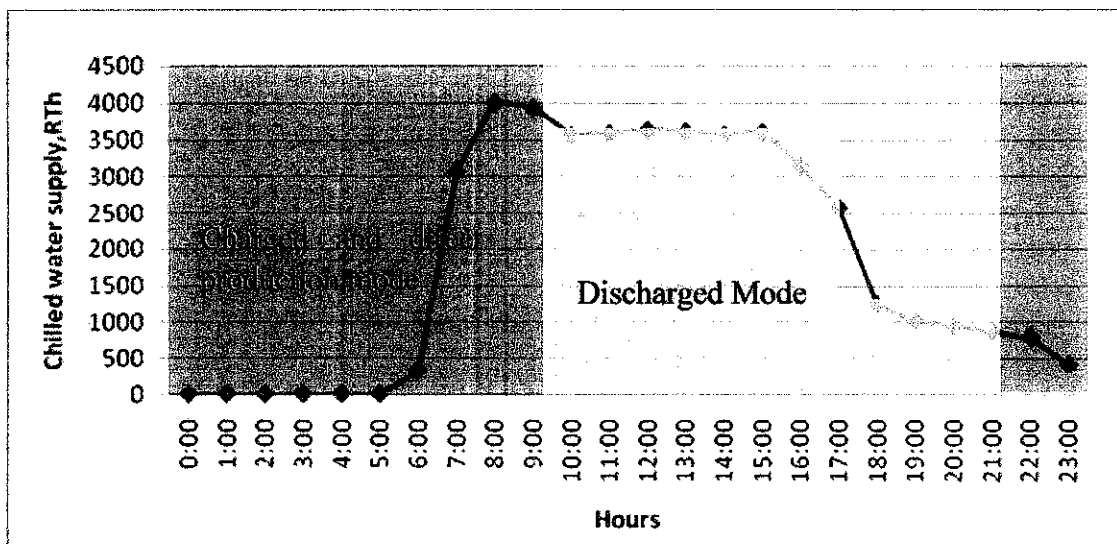
Figure 4.3 Chilled water supply vs hour per day

Those are the details of each mode:

1. Charge mode

In this condition, the ethylene glycol will be cooled by brine chiller from 10°C until -5°C. Ethylene glycol will flow into the ice tank and start charging the nodules until it become ice. The temperature for ethylene glycol flows out of the tank is around -2°C. Then, it flows back to the brine chiller. See Figure 4.5 for the schematic diagram.

2. Discharge mode

In this condition, brine chiller will be off. The ethylene glycol will be cooled by nodules in ice tank. Then, it will pump into heat exchanger. It will cool the chilled water that return from UTP and supply back to the UTP after the cooling in heat exchanger by ethylene glycol. Temperature supply to UTP is 6°C while return temperature is 13.5°C. Temperature heat transfer fluid supply from ice storage system to the heat exchanger is 5°C while the return temperature into the ice storage tank is 10°C. See Figure 4.6 for the schematic diagram.

3. Charge and direct cooling mode

During this mode, chiller will charge thermal energy storage like charge mode while chiller also produce direct cooling to the heat exchanger. This mode occurs during off peak time and there is demand from the client. See Figure 4.7 for the schematic diagram.
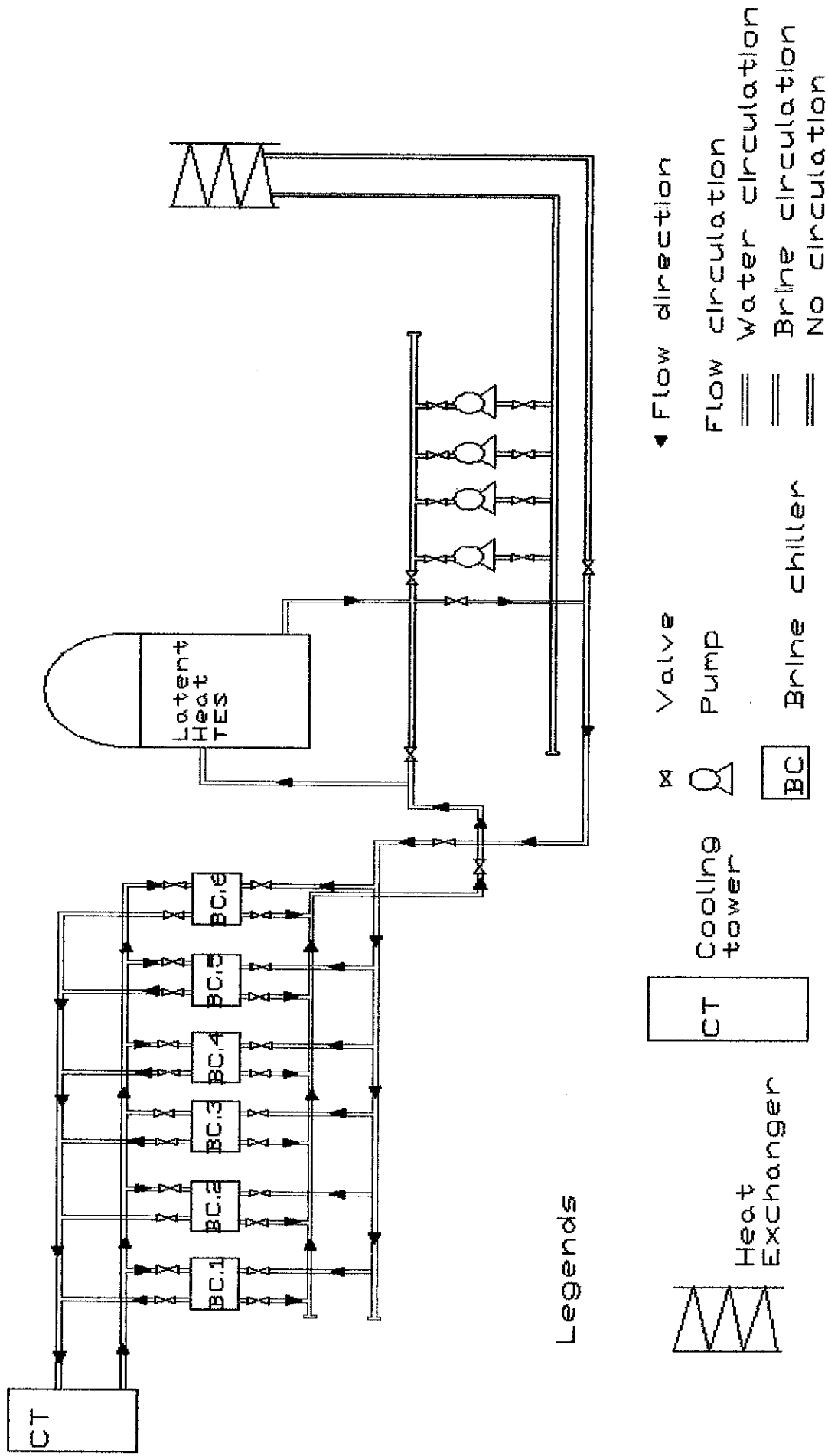
Figure 4.4: Schematic diagram for charging mode
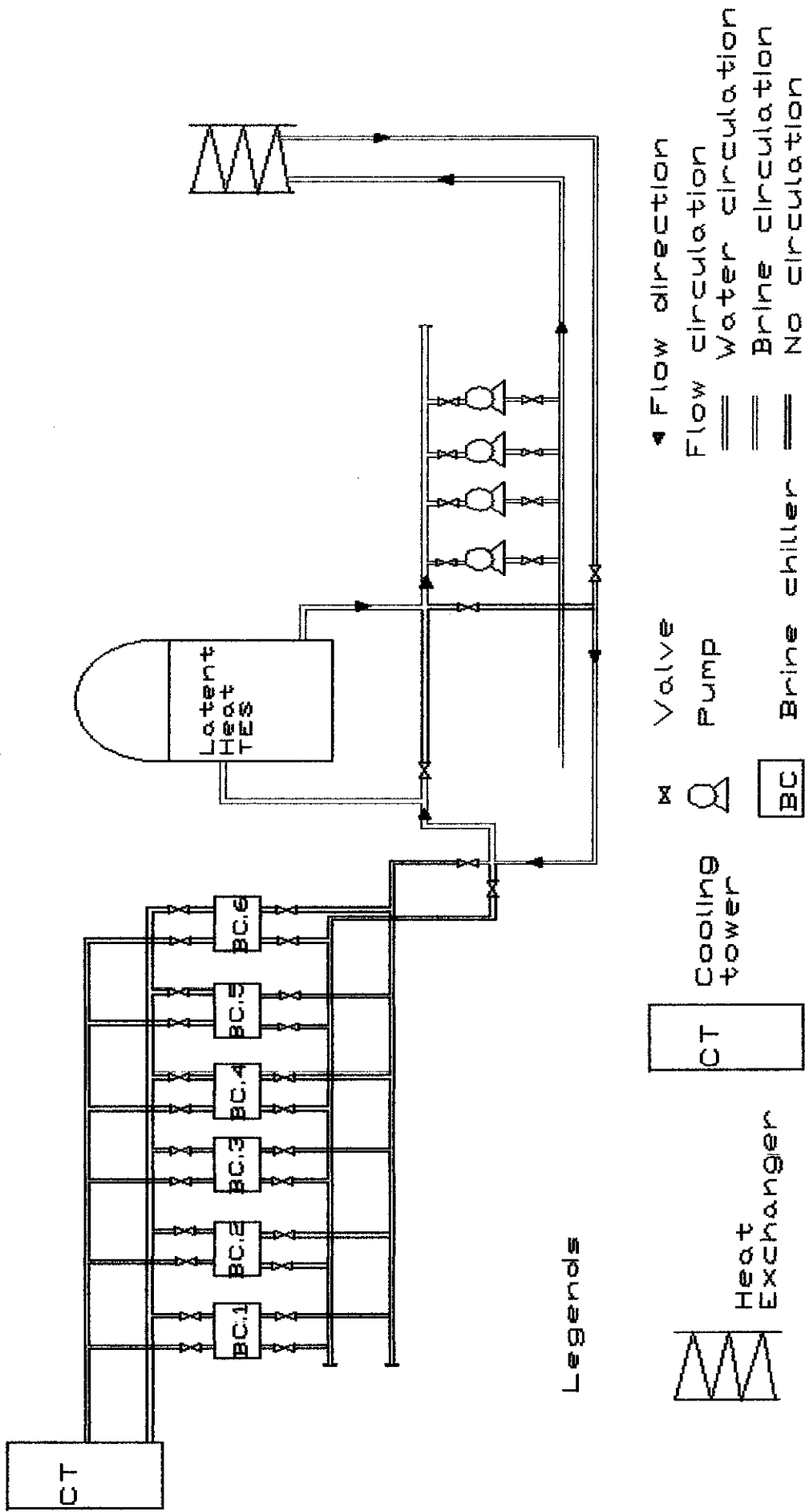
Figure 4.5: Schematic diagram for discharge mode

Legends

Heat Exchanger

Cooling tower — CT

Valve — ⋈

Pump — ◁

Brine chiller — BC

◀ Flow direction

Flow circulation
Water circulation
Brine circulation
No circulation
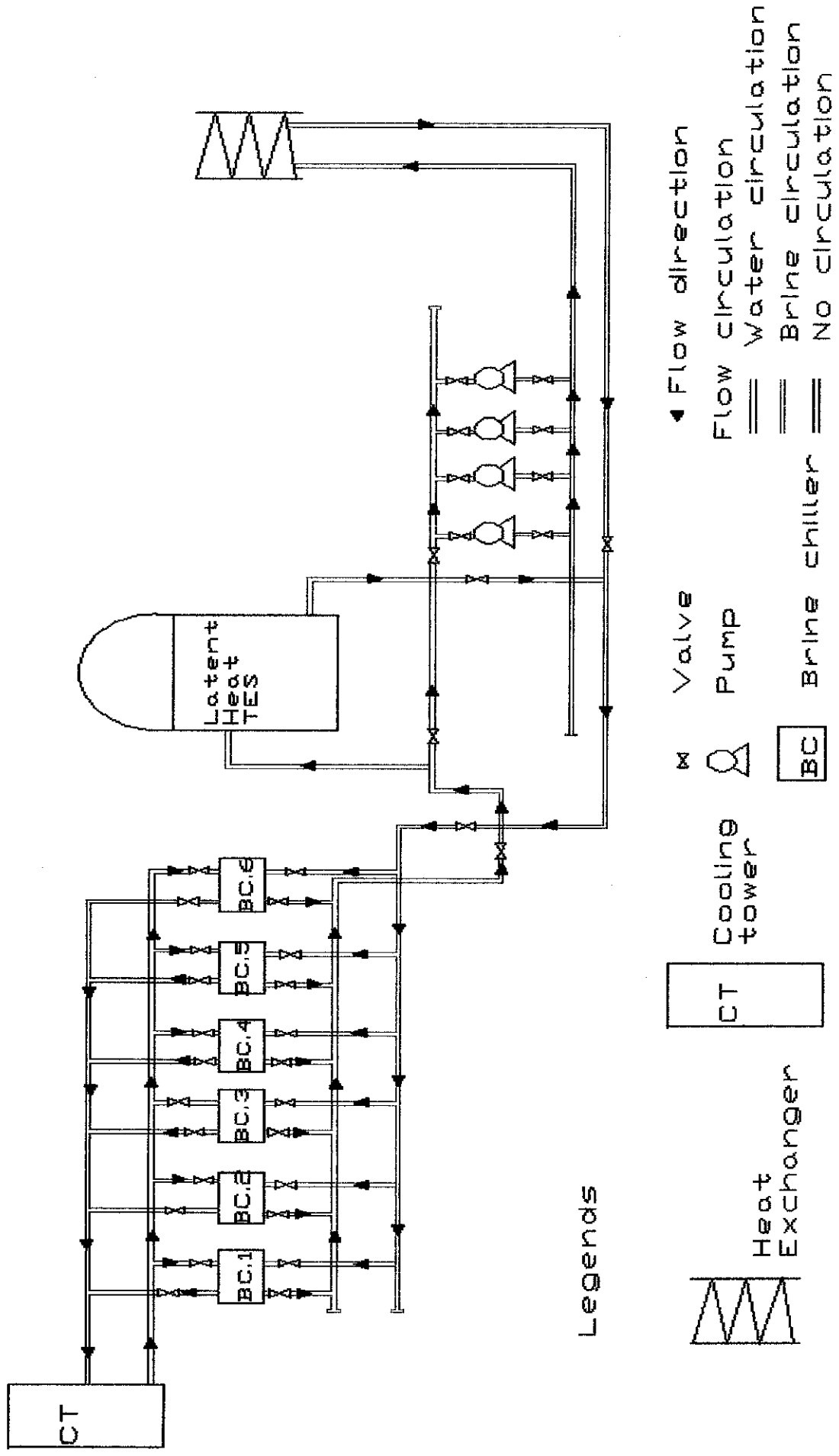
Figure 4.6: Schematic diagram for charging and direct production mode

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4.9 Temperature of Heat Transfer Fluid (HTL) and Chilled Water

In order to continue with equipment calculation, the operating temperature must be decided. To ensure the effective cooling, the temperatures required are obtained from GDC KLCC.

Table 4.1: Temperature of heat transfer fluid and chilled water

	Temperature
Temperature HTL entering storage from chiller, T_1	-6°C
Temperature HTL leaving from the storage to the chiller, T_2	-2°C
Temperature HTL entering the heat exchanger, T_3	3°C
Temperature HTL leaving the heat exchanger, T_4	10°C
Temperature Chilled water supply to UTP	5°C
Temperature Chilled water return from UTP	13°C

4.10 Heat exchanger

Heat exchanger is important equipment to cool chilled water return from UTP. In heat exchanger, chilled water return from UTP is cooled by ethylene glycol. The capacity of heat exchanger is depend on cooling load from UTP and temperature of chilled water that supply or return to UTP.

By using calculation, the capacity of heat exchanger should be 29700 kW. Since the heat transfer fluid has low temperature, the material used is stainless steel S 316 L. The type of heat exchanger is brazed heat exchanger. The suggested model is Thermal Solution Inc, Model BPL 300. See Appendix H for the sample calculation.

4.11 Piping

Polyethylene or PE pipe is often used for the supply of hot and cold water. It can be joined using barb-fittings with clamp rings, or it can be heat-fused (sections can be melted together) using an appropriate tool. Because PE pipe is flexible, it can be curved through a radius to make turns, and thus avoid the complexity and expense of fittings required to make turns with other types of piping [3].

4.12 Fittings

Fittings are important in piping system. The fittings also can cause frictions to the flow. So from the fitting, we need to know K value to calculate minor pressure loss. The fittings used are valves, elbows and Tee-branches.

4.12.1 Valves

Valves are very important components in mode of operation system. There are 3 modes of operations, so some line need to be isolated and some valves are needed to ensure the direction of the flow. So the types of valves used are:

i. Ball Valve

The ball valve provides an efficient on/off operation. The valve is ideally suited to automation because of the short distance that the actuator has to travel to effect full operation. Loss coefficient, K_l is 0.05 [2]. Number of ball valves are 37.

ii. Check Valve

Check valves may also be described as non-return, backpressure, retaining and clack valves. The purpose of a check valves is to permit flow in one direction and to prevent it in the reverse direction. Loss coefficient, K_l is 2 [2]. Number of check valve is 1.

4.12.2 Elbows and Tee branch

This is a fitting device which is bent in such a way to produce 90 degree change in the direction of flow of the content in the pipe. An Elbow is used to change the direction in piping and is also sometimes called a "quarter bend". The friction coefficient for flanged 90° bend is 0.3.

A tee is used for changing the direction of pipe runs. A common type of pipe tee is the STRAIGHT tee, which has a straight-through portion and a 90-degree takeoff on one side. All three openings of the straight tee are of the same size. ". The friction coefficient for Tee branch is 2.0.

A Pipe Flange allows two pipes to be mechanically connected together, or a pipe to be mechanically connected to a valve, tee, choke or other piece of equipments.

The design and specification of a flange relates to the size and pressure capacity of the equipment to which it is fitted. All flanges are sized according to their nominal bore size.

Head loss for pump is based on piping and fittings. The calculation for head loss is in Appendix I.

4.13 Pumps

A pump moves liquids from lower pressure to higher pressure, and overcomes this difference in pressure by adding energy to the system (such as a water system). In this system the pump is for heat transfer fluid distribution. For this distribution pump, the capacity of pump should overcome the head pressure loss and the height of tank.

This system is going to use 4 pumps. By using 4 pumps like existing system, the number of pumps can be run based on the cooling load per hour. So there will no waste of energy. The capacity of pump is 210 kW. Sample calculation is in Appendix J. The type of pump is End Suction Centrifugal Pump. The suggestion model is Ebara 300 x 400 113 CN13.

4.14 Economic Analysis and Design Justification

This section is the section to prove that the new design is worthy to develop. There are some problems to analyze the design using economic in details because some of the capital and operational cost are confidential to the company. So the author decides to justify using the operational cost using electricity tariff and the advantages of the new design. The justification will be on operational cost, energy stored per volume of tank, save to the environment and high reliability.

4.14.1 Operational and Maintenance Cost

The operational cost will analyze the main energy consumption equipment which is chiller. Since the existing rate for chiller is confidential, the rate will be taken as same as Tenaga Nasional Berhad electricity rate. For new design, chillers only run during the off-peak rate for 11 hours. Table 4.2 will tabulate chillers run for existing design.

Table 4.2 Period of chillers running for existing design

Period of chillers running	Type of chillers running	Number of chillers Running
Peak hour(12 hours) (direct production)	1250RT Steam Absorption Chiller 350 RT Electric Chillers	2 2
Off-Peak(12 hours) (TES Charge)	350 RT Electric Chiller	4

By using economy analysis with Tenaga Nasional Berhad for both designs, the operation cost shows the new design is at lost about RM 14000 per month. It is because steam absorption chillers do not use electricity. But because of the high maintenance cost for existing design, the new design will save at least RM 100000 per month. Sample calculation is in Appendix K.

4.14.2 Energy stored per volume of tank

In order to further analyze the project viability, energy stored per volume of tank is calculated. This value will indicate how much energy can be stored per unit volume. The highest value shows that the volume of tank is used more efficient to store the energy.

Table 4.3: Different between new design, current design and KLCC design

Location	Energy Stored, RTh	Volume of tank,m^3	Unit energy per m^3,RTh/m^3
UTP GDC	10000	5400	1.85
New Design	37100	2700	13.77

Table 4.3 shows the different size of tanks in different project. Focus on UTP GDC and new design, new design has increased the value of unit energy per volume of tank by 13 times. It indicates that the new design tank can store more energy per unit volume and this shows the volume of the new tank is used more effectively.

4.14.3 Save Environment

Environment protection is an important element in the industry. Since this is for campus site which is public site, environment is an important issue. The chiller chosen for new design meets environmental regulations covering protection of the ozone layer and greenhouse gas emission. The refrigerant used is R134a which is environmental friendly. Noise level is also an important issue in today's world. Chillers used are used Low Noise Version which has noise level control.

Even if for other campus site which going to use this design, air cooled chiller can be used to eliminate the cooling tower. By eliminating cooling tower, the system will use fewer chemicals. Air cooled chiller can be used since the chiller only running during the night time where the outside temperature is low.

4.14.4 High Reliability

The new system has high reliability. Even some of equipment such as tank is maintenance free. High reliability is also proven in previous projects which indicate that the system never failed to fulfill their requirement such as in KLCC project and Bangsar project. Apart from that, as UTP may extend, this design also allow UTP to extend their cooling load for 100% increment without new tank storage.

CHAPTER 5

CONCLUSIONS AND RECOMMANDATIONS

5.1 Conclusions

The main objective of this project is to pre-design latent heat thermal energy storage using electricity from grid to replace existing UTP GDC. This project will replace chilled water TES with latent heat TES. Gas turbine as source of energy for chillers will be replaced with direct electricity from the grid. The basic principal of this project is running the chillers only during off-peak time to reduce the operating cost. After design phase is completed, economic analysis has been done to ensure the economic viability of the project. All the objectives are successfully achieved.

Total cooling loads for latent heat storage is 37100 RTh. In order to store 37100 RTh energy, the volume of tank is 2700m³. In ice tank, there should be nodules and heat transfer fluid. For the storage tank, there will be need some of modification such as insulation and tank grid. Numbers of nodules which is needed for this tank is 3297770 nodules. Each nodule consist 493 cm³. The selected nodule's diameter is 9.8 cm and AC.00 series. The capacity for this nodule to produce energy is 0.0153 kW. Heat transfer fluid for this tank is ethylene glycol which is more effective than propylene glycol.

The optimization design is done by choose the best option of design and comply with manufacturer specification. For the best design, it needs 3 modes of operation. During charging mode, glycol is cooled by the chiller and then circulated around the nodules in a storage tank where they are cooled to temperatures low enough to form ice in the nodules. Another mode is discharging mode which the same glycol works by circulating around the nodules in the storage tank. Nodules cool the glycol solution that is then pumped to the heat exchanger to provide air conditioning system in UTP. The last mode is charge and direct production mode. During this mode, it is almost

same with charge mode, but the glycol also flows directly to the heat exchanger instead of only flow to the storage tank.

The main equipments used are pumps and heat exchanger. There will be 4 pumps in the system. Pumps will be running depend on the cooling load from the UTP. Each pump consists of 210kW. The heat exchanger capacity is 29700 kW. For the piping system several fittings are used such as elbows, Tee-branch and valves. The pipe also needs insulation which is polyethylene insulation.

Last but not least, economic analysis and design justification are done to ensure the feasibility of the project. Based on operation and maintenance cost analysis, this project can save a lot of money for each month of operation. It is at least about RM 100000 per month. The efficiency of storage which is unit energy per volume of tank also increases 13 times from the existing system. Other design justifications are environmental protection and high reliability. All of those prove that this project should be developed.

5.2 Recommendations

The recommendations for this study are to have consistent work to continue this project to ensure it can be applied in UTP and the optimization of the design can be used Stockaid 2002 software. Besides that, to improve this project, for operator operation method, the equipment should be run only when needed and also run at the best efficiency. For new designs, it also recommends to use air cooled chiller to eliminate cooling tower. Elimination of cooling tower is good for the environment and lowering the capital cost.

For further study, detail design can be made for this system. The detail design may include pipe routing from UTP heat exchanger to the building and detail design of the tank.

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APPENDICES

APPENDIX A

COMPARISON BETWEEN ETHYLENE GLYCOL AND PROPYLENE GLYCOL

Table A.1: Comparison between ethylene glycol and propylene glycol

Property	Ethylene Glycol	Propylene Glycol	Comments
Freeze point depression	more effective	less effective	More antifreeze is needed of propylene glycol to achieve the same freeze point
Heat transfer efficiency	less	better	Ethylene glycol can't carry as much heat as propylene glycol. More fluid must be circulated to transfer the same amount of energy. Pumps volume increased.
Viscosity	lower	higher	Propylene glycol increases major head loss in the systems. Pumps head increased.
Flammability	low	low	
Chemical oxygen demand	low	higher	
Biodegrading	degrades in 10 - 30 days	needs more than 20 - 30 days to degrade	
Carcinogenic	no	no	A carcinogen is any substance or agent that promotes cancer
Toxic	High level of acute when taken orally, targets the kidneys	Lower level of acute	Ethylene glycol should never be used in any drinking water or food processing system

Source: http://www.jcna.com/library/tech/techoll.html

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APPENDIX B

MONTHLY COOLING LOAD ON YEAR 2005

Table B.1: Monthly Cooling Load on Year 2005

Month	Cooling Load, RTh	Maximum Daily Cooling Load, Rth
January	577195.3	35526.5
February	735913.4	42263.0
March	865131.5	41241.5
April	851608.3	41206.5
May	861702.5	42112.3
June	684090.1	38119.7
July	689374.6	38024.1
August	884427.6	41354.1
September	821320.2	42008.8
October	707120.6	42289.3
November	711385.2	40660.9
December	664531.0	36750.5
Maximum value	884427.6	42289.3
Additional 10% Safety Factor		46518.23

APPENDIX C

HOURLY COOLING LOAD ON 24 OCTOBER 2005

Table C.1: Hourly Cooling Load on 24 October 2005

HOUR	Cooling Load, RT
0:00	0
1:00	0
2:00	0
3:00	0
4:00	0
5:00	0
6:00	327.2847222
7:00	3072.429167
8:00	4010.111522
9:00	3933.461944
10:00	3560.775555
11:00	3590.932778
12:00	3634.103889
13:00	3616.713333
14:00	3575.264444
15:00	3607.381389
16:00	3145.863889
17:00	2577.754722
18:00	1239.395277
19:00	1021.931111
20:00	947.7844447
21:00	873.0455554
22:00	796.3636108
23:00	422.713611
SUM	42289.3 RTh
AVG	1849.555127 RT
MAX	4010.1115217 RT

APPENDIX D

DATA FOR 1m³ OF TANK

Table D.1: Data for various types of nodules

Nodule type	Phase change temperature	Latent Heat	Sensible heat		Heat Transfer factor		Nodule weight	Toxicity LD50 value	Operating temperature limit
	Tst °C	QI kWh	Qss kWh/°C	Qsl kWh/°C	Kvcr kW/°C	fusion Kvfu kW/°C	Kg	mg/Kg*	°C
SN.33	-33.0	44.6	0.7	1.08	1.6	2.2	724	2600	-40
SN.29	-28.9	39.3	0.8	1.15	1.6	2.2	681	1200	
SN.26	-26.2	47.6	0.85	1.20	1.6	2.2	704	1200	to
SN.21	-21.3	39.4	0.7	1.09	1.6	2.2	653	1300	
SN.18	-18.3	47.5	0.9	1.24	1.6	2.2	706	2700	60
AN.15	-15.4	46.4	0.7	1.12	1.15	1.85	602	8400	-25
AN.12	-11.7	47.7	0.75	1.09	1.15	1.85	620	5000	
AN.10	-10.4	49.9	0.7	1.07	1.15	1.85	617	11000	to
AN.06	-5.5	44.6	0.75	1.10	1.15	1.85	625	18000	
AN.03	-2.6	48.3	0.8	1.20	1.15	1.85	592	58000	60
AC.00	0.0	48.4	0.7	1.10	1.15	1.85	560	85000	
AC.27	27.0	44.5	0.86	1.04	1.15	1.85	867	2500	

source: <http://www.cristopia.com/english/why/indwhy.htm>

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APPENDIX E

CALCULATION FOR NODULE

Cooling load: 37100 RTh

1RTh = 3.52 kWh

37100 RTh = 130592 kWh

Volume of a nodule, $\dfrac{4}{3}\pi\left(\dfrac{D}{2}\right)^3$ ---(1)

$$=\frac{4}{3}\pi\left(\frac{9.8cm}{2}\right)^3$$

$$= 492.81 \text{ cm}^3$$

Capacity of each nodule to produce energy,

$Q = \dot{m}C_p\Delta T$ ---(2)

Based on KLCC data sheet, 1 nodule Latent is 0.0396kWh. Since the nodule selected which is STL – AC – 00 same with ice storage in KLCC, Q = 0.0396 kWh.

Number of nodules in the ice storage tank is capacity of TES tank divide by capacity of each nodule to produce energy

$$= \frac{130592 kWh}{0.0396 kWh}$$
$$= 3297770 nodules$$

Based on selected nodule, 1 m³ size of tank can contain 1222 nodules. So the size of tank is

$$\text{Size of tank} = \frac{3297770}{1222}$$

$$= 2700 \text{ m}^3$$

APPENDIX F

CALCULATION FOR ICE TANK

Capacity of ice storage is 37100 RTh

1 RT = 3.52 kW

So, 37100 RTh = 30096 kWh

From Appendix D,

The volume of tank is 2700 m^3.

For this project the diameter of tank is based on current set up. Diameter of tank is 22.3 m.

$$V = \frac{\pi D^2 h}{4} - (1)$$

$$h = \frac{4V}{\pi D^2}$$

$$h = \frac{4(2700)}{\pi 22.3^2}$$

The height of tank is 7 m.

$$\text{Volumetric flowrate, } \dot{V} = \frac{V}{t} - - - - - - - - - - - - - - - - - - (3)$$

$$\dot{V} = \frac{2700 m^3}{12 hours}$$

$$\dot{V} = 225 m^3 / h$$

$$\dot{V} = 0.0625 m^3 / s$$

Volumetric flowrate is 0.0625m^3/s

Mass flowrate, $\dot{m}_{TES} = \rho \dot{V}$ ---------------(4)

Density of 25% ethylene glycol in water solution at 14.5°C is 1019.40 kg/m^3.

$$m_{TES} = (1019.40 \frac{kg}{m^3})(0.0625 \frac{m^3}{s})$$

$$\dot{m}_{TES} = 63.69 kg/s$$

Mass flowrate for heat transfer fluid come out from TES is 63.69 kg/s.

Booyancy force also needs to be calculated for tank grid.

$$F_{net} = V_{submerge} \times \rho_{fluid} \times g - Weight_{Object}$$ --------------------------------------(5)

where $V_{submerge}$ = total volume of nodules, volume each nodule is 490cm^3.

ρ_{fluid} = density of ethleyne glycol, 1019kg/m^3

g = gravity acceleration 9.81 m/s^2

W_{object} = total weight of the nodules in Newton, weight one nodule is 0.46 kg.

So total force is 113kN.

APPENDIX G

DESIGN OF TANK

Perlite concrete roof
deck insulation(100mm)

Polyethylene piping
insulation

tank grid

glycol in

grid support

14000

100

Ø400

12751

Man Hole

Ladder Inside Tank

Ladder Outside Tank

Polyurethane foam
insulation (100mm)

Ø400

glycol out

7000

tank base support
(100mm cellular glass support)

concerate slab

Ø22300

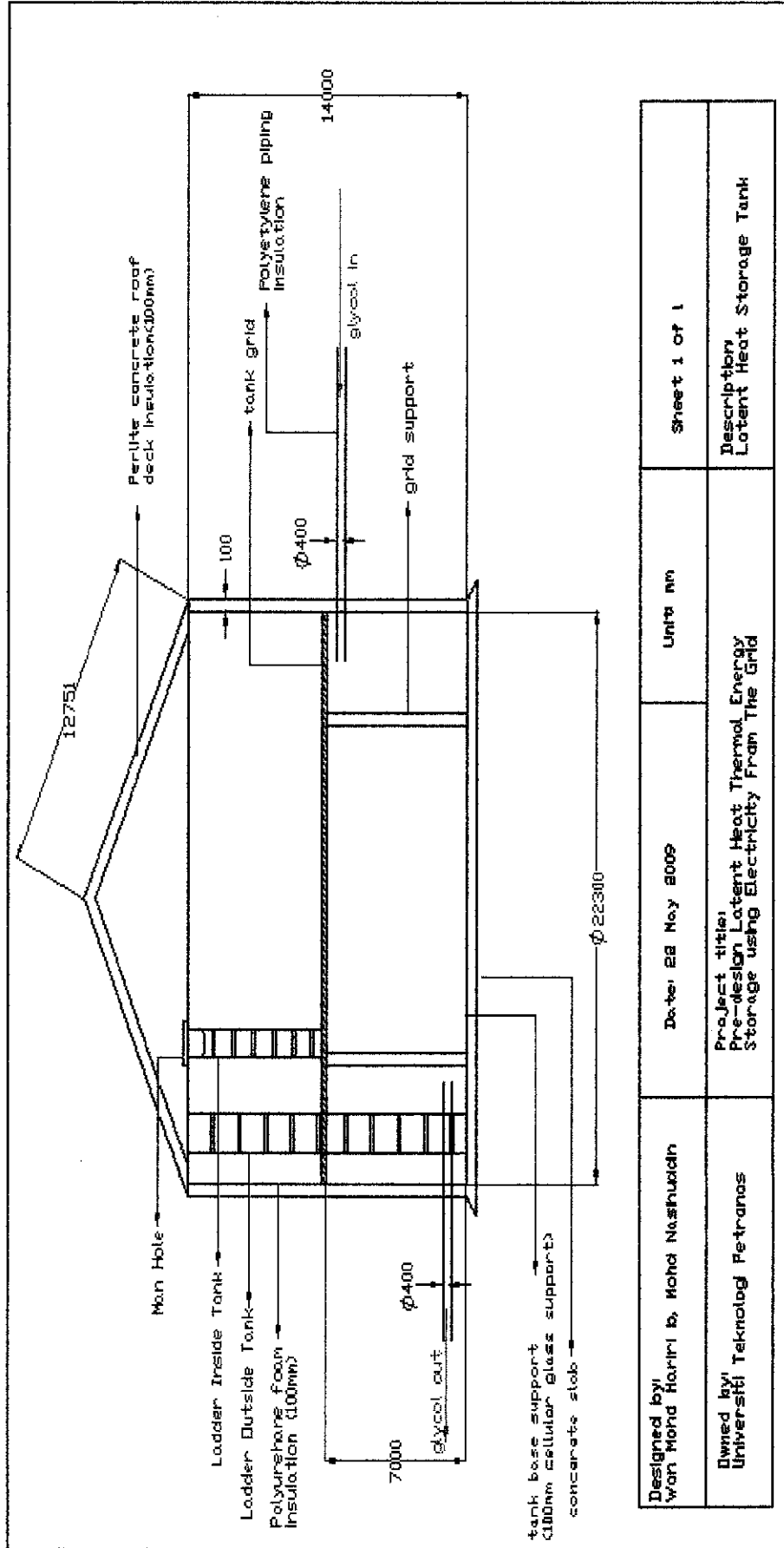| Designed by: Wan Mohd Hariri b. Mohd Nashuddin	Date: 28 May 2009	Units: mm	Sheet 1 of 1
Owned by: Universiti Teknologi Petronas	Project title: Pre-design Latent Heat Thermal Energy Storage using Electricity From The Grid		Descriptor: Latent Heat Storage Tank

Figure G.1: Design of Tank

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APPENDIX H

CAPACITY OF HEAT EXCHANGER DURING DISCHARGE MODE

All the formulas are based on [15].

$$P_{dst} = V \times kvfu \times lmtd_2 \text{ --(6)}$$

P_{dst} = Power for discharge

V = Total volume of tank

Tst = 0 $^{\circ}$C

T3 : Supply temperature, 5°C

T4: Return temperature, 10°C

Lmtd$_2$ = log mean temperature during discharge

$$= \frac{(T4 - Tst) - (T3 - Tst)}{\ln \frac{T4 - Tst}{T3 - Tst}} \text{ ------------------------------------(7)}$$

= 5.814

Kvfu = Heat transfer coefficient during fusion, 1.85 kW/$^{\circ}$C/m^3

Insert the value into the equation (6),

Pdst = 29000 kW

APPENDIX I

CALCULATION FOR HEAD LOSS

All the formulas are based on [2].

To find the velocity,

$$V = \frac{\dot{V}}{A} \tag{8}$$

where diameter of pipe = 400mm.

velocity = 0.25 m/s

To find the Darcy friction factor f,

First, need to find Reynold number,

$$RE = \frac{\rho g D}{\mu} \tag{9}$$

where ρ = 1019.4 kg/m³   μ = 16.1 x 10⁻²

So RE is 1023 and it is laminar.

$$f = \frac{64}{RE} \tag{10}$$

f = 0.101

To find loss coefficient for fittings,

Type of fittings	Unit	K value	Total K value
Ball valve	7	0.05	2.1
Check valve	4	2	8
90° elbow	3	0.3	0.15
Tee branch	1'	2	2
			12.25

So the K value is 12.25

Total head loss,

$$h_{L.total} = h_{l,major} + h_{l.minor}$$

$$= \Sigma f \frac{L}{D} \frac{v^2}{2g} + \Sigma K \frac{v^2}{2g} \text{--(11)}$$

$$= 0.183m$$

V = velocity

f = Darcy friction factor

K = coefficient loss

L = length = 180 m

D= diameter = 400mm

g = gravitational acceleration = $9.81 m/s^2$

To get the head of pump,

$$h_{pump.u} = z_2 - z_1 + h_l \text{---(12)}$$

$$= 4 + 0.183$$

$$= 4.183 \text{ m}.$$

APPENDIX J

CALCULATION FOR PUMP

All the formulas are based on [2].

In order to calculate the capacity for pump,

Based on Appendix H,

To get the power of pump,

$$W_{pump} = \frac{\rho g h_{pump.u} \dot{V}}{\eta} \text{---(13)}$$

$$= 836kW$$

$\dot{V}$ = volumetric rate

η = efficiency of the pump = 0.8

hpump.u = head pump = 4.183

Since we are using 4 pumps, each pump is 210 kW.

APPENDIX K

ECONOMIC ANALISYS ON OPERATION COST

In order to analyze the operation cost of the new design and existing design, the author decides to investigate the usage of energy by chillers since chillers are the main of energy consumption in the system. Table K.1 and table K.2 will tabulate the usage of the chillers for existing design and new design.

Table K.1: Period of chillers running for existing design

Period of chillers running	Type of chillers running	Number of chillers Running
Peak hour(12 hours) (direct production)	1250RT Steam Absorption Chiller 350 RT Electric Chillers	2 2
Off-Peak(12 hours) (TES Charge)	350 RT Electric Chiller	4

Table K.2: Period of chillers running for new design

Period of chillers running	Type of chillers running	Number of chillers Running
Off-Peak(11 hours) (TES Charge)	850 RT Brine Chiller	6

Table K.3 will tabulate the rate of electricity for peak and off-peak rate.

Table K.3: Rate of electricity starting March 2009

Tariff Category	Unit	1st March 2009
Medium Volatge: Thermal Energy Storage For each kilowatt of maximum demand per month during the peak period	RM/kW	35.60
For all kWh during the peak period	sen/kWh	28.8
For all kWh during the off-peak period	sen/kWh	16.2
The Minimum Monthly Charge is	RM	600.00

Based on Table K.1, Table K.2 and Table K.3, the operation cost for both designs are calculated. The calculation is based on assumption both design using electricity from grid. It is because the current rate is confidential. Then, the difference of both design show that which design is less the operation cost.

Table K.4: Operating cost per month

Operation cost per month(TES)					
New design			Existing design		Saving
	kW used	RM	kW used	RM	RM
Off-peak	197472	31990.5	54912	8895.74	
Peak		0	29736	8563.97	
		31990.5		17459.7	-14531

Table K.4 shows us that new design can save per month. The design shows negative number. This is because Steam Absorption Chiller is not in the calculation since it does not use the electricity.

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But, the existing has high maintenance cost. It is almost RM 2 000000 per year [16]. So it is RM 167 000 per month. Table K.5 shows the maintenances in the existing design.

Table K.5: Preventive Maintenance

Equipments	Activities
Steam Absorption Chillers	Monthly servicing by OEM (Carrier)
Electrical Chillers	Monthly servicing by OEM (Dunham Bush)
Gas Turbines	Every 4000 running hours, servicing, parts replacement, instrumentation calibration and boroscope inspection.
Boiler	Servicing every 15 month for CF renewal.

This is only preventive maintenances. It is not including unexpected maintenances such as corrective maintenances. By comparing the existing design, only brine chillers need to be maintained from time to time. It will take only 30% of the maintenances cost [13].

Total saving = Different Operation Cost + Different Maintenances Cost

Total saving = -14531 + (Maintenances Existing Design – Maintenances New Design)

$$= -14531 + (167000 - 42000)$$

$$= RM\ 100000.$$

So the new design will save about RM 100 000 per month. It is the minimum saving since it is assumed that no breakdown maintenance is needed for this system.