Design of Ice Thermal Energy Storage System for GDC (UTP) Plant

by

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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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NORLINA MOHD SARKAWI

ABSTRACT

Thermal Energy Storage (TES) is considered one of the most important advanced energy technologies which the thermal applications ranging from heating to cooling in buildings. The Ice Thermal Energy Storage is more efficient in terms of amount of energy over storage size compared to chilled water. This project is to analyse and design the Ice Thermal Energy Storage (ITES) system for Gas District Cooling (GDC) plant in UTP. The design specification of ITES system is based on the current setting of TES. The method used involves designing the district cooling system configuration for ITES system to supply the cooling capacity of 10,000RTh, determining the equipment specifications and then comparing with the current TES system to validate the design. From the findings, the designed ITES system consists of 4 units of 520 RT brine chillers and 4 units of encapsulated ice tanks that provided the cooling storage of 10,000 RTh. The ITES system is capable to reduce the charging hours of 14.3 % of the current TES system.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Thermal Energy Storage (TES) is considered one of the most important advance energy technologies that currently receives increasing attention to the utilization of this essential technique which the thermal applications ranging from heating to cooling in buildings [1]. A typical use of TES in Universiti Teknologi PETRONAS (UTP) is chilled water system which is produced in Gas District Cooling (GDC) plant and supply to UTP. Among the facilities served in UTP are UTP main campus and hostel. The plant initially produced the chilled water of 4000 RT and electricity generation of 8.4 MW in April 2003. There is a plan to increase the cooling capacity to 11,000RT and 20MW to meet higher demand as the population of student increases to 11,000 [2]. The current chilled water system is equipped with 2 units of 1,250 RT Steam Absorption Chiller (SAC), 4 units of 325 RT Electric Chiller (EC) and TES tank with storage capacity of 10,000 RTh. The tank is a vertical cylindrical vessel, 22.3 m in diameter and 15 m height and is capable of storing 5,400 m^3 of chilled water. The plant configuration can be viewed in the Appendix. The EC operate for 24 hours while the SAC operate from 7a.m. until 12 (midnight). The tank is charged by electric chillers at night and discharged during the day to support the cooling load requirements [3]. The system provides cooling capacity of proven effectiveness and reliability as well as environment-friendly [4].

1.2 Problem Statement

Ice storage is more efficient than chilled water storage in terms of amount of energy stored over weight and volume. ITES system uses the latent heat of fusion of water (335 kJ/kg) to store the cooling capacity. Therefore, the size of ice tank is smaller than that of chilled water for the same capacity.

Ice Thermal Energy Storage could be one of the alternatives to meet the requirement by applying partial ice storage as a substitute to the chilled water storage.

1.3 Objectives

- To study the TES and ITES and analyze the available chilled water data
- To design the ITES system equivalent to the current TES system

1.4 Scope of Study

The study involved fundamental of TES system, types of TES and their system configurations, mode of operations and system components as well as available TES plant in Malaysia. An in-depth study of GDC (UTP) chilled water system was made in order to ascertain the feasibility of the project. The available chilled water data was a baseline of the design requirements.

The design covered ITES system configuration that have capacity equivalent to the current TES system; TES tank and electric chillers system were being focused on. The specifications of the equipment were redesigned to fit the ITES requirement. Other additional components such as glycol pipeline were included in the designed system configuration.

CHAPTER 2
LITERATURE REVIEW

2.1 Thermal Energy Storage

Thermal energy storage (TES) is considered as a mature technology that currently receives increasing attention to the utilization of this essential technique, particularly in commercial and institutional building applications. Many cities throughout the world face the increasingly high energy cost, not that it directly incurred due to energy used, but rather associated with the overall demand for electricity. One way to avoid the construction of new expensive power plants is to level the electrical demand over time by shifting the electrical loads to period of lower overall electrical usage.

TES appears to be the only answer to correct the mismatch between the supply and demand energy. The use of TES provides an effective way to take advantage of low electricity rates in effect during the night and other off-peak periods, one type of which is ice thermal energy storage (ITES). The principle behind ITES is simple; during the night, low rates off-peak electricity is utilized to create large ice storage, and during the day, the ice is melted by absorbing the heat from buildings needing cooling. ITES is proved applicable to any plant that has a chilled water system [1]. There are various types of ITES available such as ice-on-coil, static ice tank, ice harvester, and encapsulated ice store. In this regard, encapsulated ice storage is considered because of its simplicity compared to other systems. Moreover, most ITES plants in Malaysia utilize this type of ice storage such GDC (KLCC), GDC (KLIA), and Bangsar.

2.2 Latent Heat Storage

Latent heat storage is an exceptionally attractive technique because it provides a high storage density and stores latent heat of fusion capacity at a constant temperature corresponding to the phase transition temperature of the phase change materials (PCM). For instance, 80 times as much energy is needed to melt 1 kg of ice as to increase the temperature of 1 kg of water by 1°C. This means that a certain amount of energy storage requires a much smaller weight and volume of the material [5].

A latent heat energy storage must contains three components: (a) a heat storage substance that undergoes a solid-to-liquid phase transition in the required operating temperature range and where the bulk of heat added is stored as the latent heat of fusion, (b) a container for holding the storage substance and (c) a heat exchange surface for transferring heat from the heat surface to the PCM and from the latter to the heat sink [6].

2.2.1 Encapsulated PCM

A method of using the latent heat storage is through encapsulation of PCM in spherical containers inside a storage tank. The spherical geometry offers a number of advantages and is preferred due to their best performances, favourable relation of volume of energy stored to the area for heat transfer as well as easiness of packing into the storage tank with good bed porosity [7].

Encapsulated PCM storage can use open non-pressurized tanks, or pressurized tanks. According to the nature of the PCM, a wide range of thermal storage temperatures (from 0°C to -33°C by steps of 2 or 3°C) are suitable for many industrial, commercial and even domestic applications. Figure 1 represents the schematic diagram of an encapsulated ITES system.

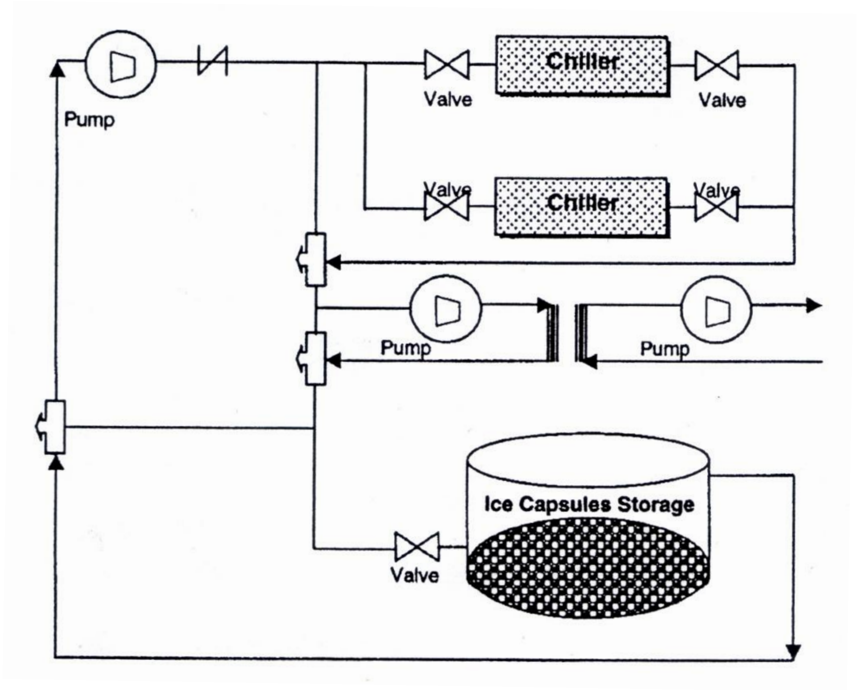


Figure 1: Schematic diagram of an encapsulated ITES system [8].

During the charging process, the brine solution is circulated through the tank at a subzero temperature (i.e. -4 degree C) and freezes the water to form ice store. When cooling is needed, the store is discharged using the same brine solution circulated through the tank, but at a temperature above the freezing point of water. The water in the capsules then melts, cooling the brine solution and subsequently circulated to the air-conditioning unit.

The charge mode and discharge mode are not symmetrical because of the undercooling phenomenon. Any substance does not crystallize, upon cooling, at the melting temperature T_F (liquid solid equilibrium) but at a lower temperature T. The difference $\Delta T = T_F - T$ is called *undercooling.* The most important parameter influencing ΔT is the sample size. ΔT increases when the sample size decreases [8].

2.3 Operational Strategies for ITES

There are several strategies available for charging and discharging the ice storage depending on cooling demand during peak hours including full-storage and partial storage (load levelling and demand limiting).

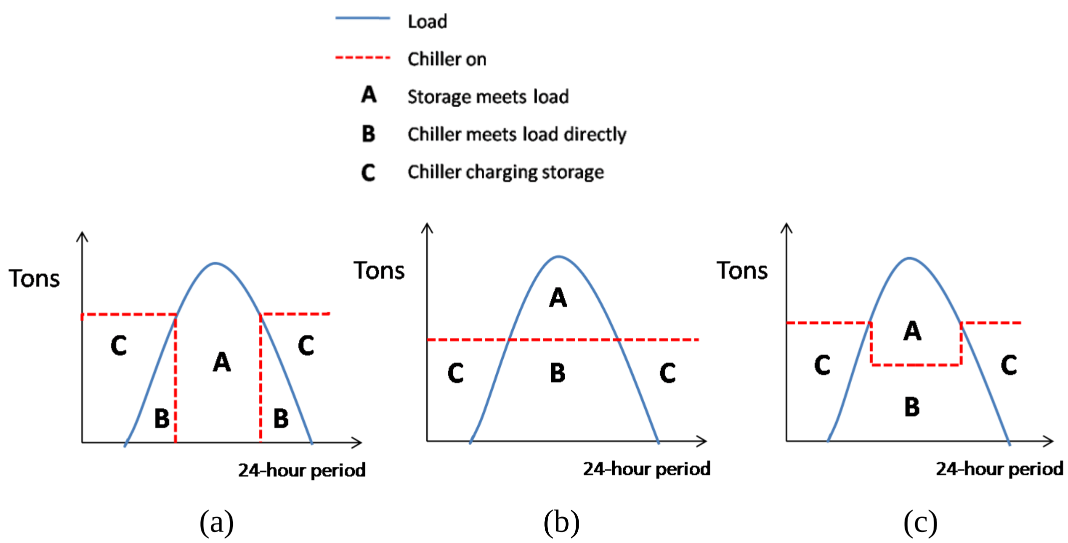


Figure 2: Operating strategies. (a) full storage; (b) partial storage load-levelling and (c) partial-storage demand-limiting [1].

2.3.1 Full storage

The concept is to shift the peak load entirely to off-peak hours (Figure 2a). The storage is designed to operate at full capacity during the hottest anticipated day and utilize all the non-peak hours for charging. The operation of heating and cooling generating equipment is de-coupled from peak heating or cooling during storage discharging. This way, the chiller is meant to charge the storage only and not to provide direct cooling to the buildings. The strategy is most effective when peak demand rates are high or the peak-period is short. However, the system requires massive ice storage and increased sized of chiller to meet the demand, therefore increases the initial cost of installation and consumes more space [1].

2.3.2 Partial storage load-levelling

In partial storage, the chiller and the storage operates together to satisfy the demand. The size of the chiller is at smaller capacity than that of the design load, which gives advantages over full storage strategy in terms of capital cost. Although the strategy does not shift the load as much as full storage, the small equipment installations can have lower initial cost that make the partial storage the most economic option [1]. The umbrella profile of partial storage can be subdivided into two distinct categories, which are chiller priority control and store priority control.

Chiller priority control

The principle of chiller priority control strategy is to run the refrigeration plant continuously through both the ice production and the storage discharge periods. During daytime, the chiller provides the base-load cooling while the rest is drawn from the storage which the refrigeration plant is unable to cope with the peak demand. The strategy is potential to achieve reductions in the region of 50% chiller capacity compared to the conventional refrigeration installation [9]. Thus, the capital cost of storage installation can be counterbalanced with the capital cost saving arising from the chiller reduction capacity.

Store priority control strategy

The principle of store priority control strategy is a contrast to the chiller priority strategy, in which the storage is given priority over the chiller during the daytime. The objective is to reduce the operations of refrigeration plant during periods when the electric tariffs are high [9]. The chiller is only used to cover the refrigeration energy discharged by the storage.

2.3.3 Partial storage demand-limiting

Under demand-limiting system, the chiller runs continuously but the capacity is reduced during peak hours (Figure 2c). It is always controlled to limit the peak electrical demand [9]. The capital cost and demand savings are higher if applied for a load-levelling system and lower for a full-storage system.

2.4 Chiller and Storage Capacity

Since all the cooling originates with the chiller, the chiller capacity needs to be calculated first by equating the full load chiller operating hours to the total cooling load. There are possible modes of operation for any particular time including charging (ice-making), charging with cooling, cooling with a combination of storage and chiller, cooling with chiller only, cooling with storage only, and system off [10,11].

$$\textit{Total ton hours} = \textit{Chiller day capacity} + \textit{Chiller ice capacity} \tag{1}$$

The approach in this project is partial storage, which is to operate the chiller throughout the day, producing ice at night and directly contributing the load during the day. This results in the smallest possible of chiller capacity at its limit.

The required chiller capacity is usually described in terms of its conventional rating and therefore the ice-making operating hours include a factor of 0.7. This is a capacity modifier, not efficiency adjustment. The efficiency during charging hours, whether it is the same, better or somewhat worse will depend on number of factors, such as night time condenser temperatures, arrangement and type of components [10]. The electric chiller charges the TES from 12 (midnight) to 7a.m. in the morning [3], which is 7 hours and provides direct cooling from 7.a.m. until 12 a.m. therefore, Equation (1) becomes

$$\textit{Total ton hours} = (NC \times 12hr \times 1) + (NC \times 7hr \times 0.7)$$

Where NC is nominal chiller size.

The amount of storage becomes:

$$\textit{Storage ton hours} = NC \times \textit{ice-making hours} \times \textit{Capacity factor} \tag{2}$$

Note that this partial storage chiller is only 49% of the peak load and 41% of the full storage selection. Storage capacity is reduced to 41% of full storage requirement [10].

Choosing the right size recirculating chiller adds to the economies of its use. The optimum size needed is based on the amount of heat the application is generating, plus additional power to maintain temperature under varying loads [12].

$$BTU/hr = (T_1\text{-}T_2) \times gpm \times 60\ min/hr \times \rho \times C_p \qquad (3)$$

Where

T_1 = temperature of coolant leaving the equipment, °F

T_2 = temperature of coolant entering the equipment, °F

gpm = gallons per minute of coolant flowing through the equipment

ρ = density of coolant, lb/gal

C_p = specific heat of coolant, BTU/lb-°F

Additional Considerations:

1. If ambient temperature of the cooling location is above 20°C, add 1% to the calculated wattage for each 0.5°C above 20°C.
2. If operating at 50Hz, add 20% to the calculated wattage.
3. If line voltage is consistently below rated voltage, or if work at high altitude, add 10% to the calculated wattage.
4. Future growth cooling needs or variability of heat output of existing unit.

One of the disadvantages of ITES is the increased pressure drop of the moving fluid (glycol) from the storage tank and electric chiller to the heat exchanger since it has a very low temperature (0°C), causing certain amount of energy loss. Therefore, certain adjustment should be made to maintain the fluid temperature thus increases the system efficiency. Larger pipeline and pump size is necessary in order to make the pressure drop less significant.

2.5 Current TES Setting

2.5.1 TES pattern at GDC (UTP)

The function of thermal energy storage is to support the requirement to supply the chilled water. The type of thermal energy used is sensible, whereby the sensible heat capacity is used to store cooling load through naturally stratified type storage. In the chilled water storage tank, warm and cool water are stored together with the warmer, less dense water is stored at the top of the tank while the cooled water is stored at the bottom. There is no physical barrier between the contacts.

4 units of 325 RT of EC were used to charge the TES by introducing cooled water from the bottom of the tank and withdrawn the hot water from the top. The hot water was cooled by the electric chillers and returned into the storage in cooled volume during charging mode. The main valve was shut-off during the charging process in order for all the chilled water produced by the electric chillers to flow into TES. The process cycle was done during off-peak hours, which was from 12.00 midnight until 7 a.m. in the morning.

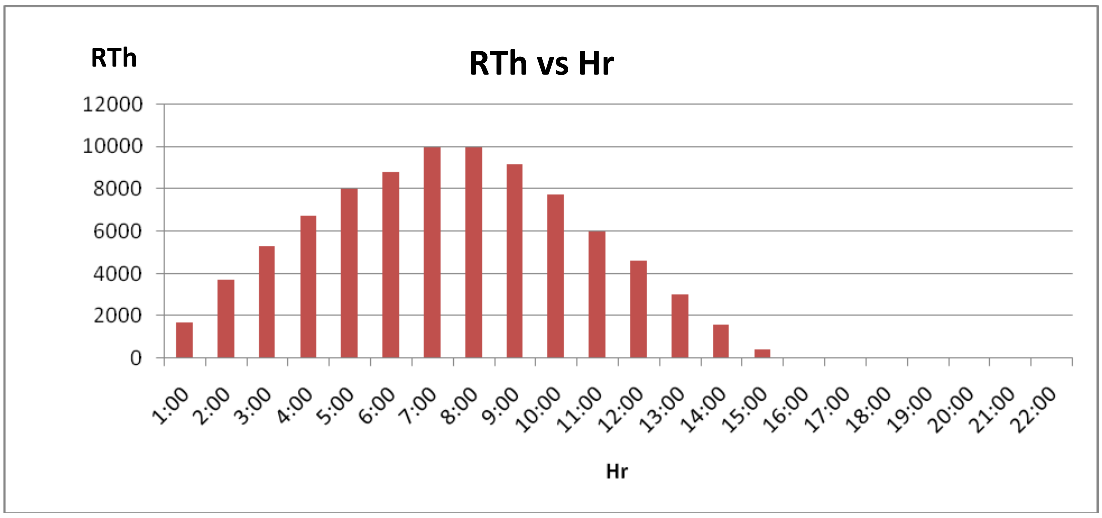


Figure 3: Hourly holding capacity of current TES [3].

From the profile of current TES on 4th July 2006, the cooling capacity reached maximum of 10,000 RTh at 7 p.m. during charging mode. The cooling capacity gradually reduced in 8 hours duration from 7 a.m. to 3 p.m. to supply the chilled water [3].

2.5.2 Electric chiller pattern

The current TES system adopts chiller priority control strategy, at which the chiller is set to run 24 hours. The electric chiller charges ITES from midnight until 7 a.m. and provides direct cooling to the facility in the following hours until midnight. During the discharge mode of ITES, the operation of electric chiller is reduced to save the electricity usage. The following figure represents the operation of 4 units of electric chiller.

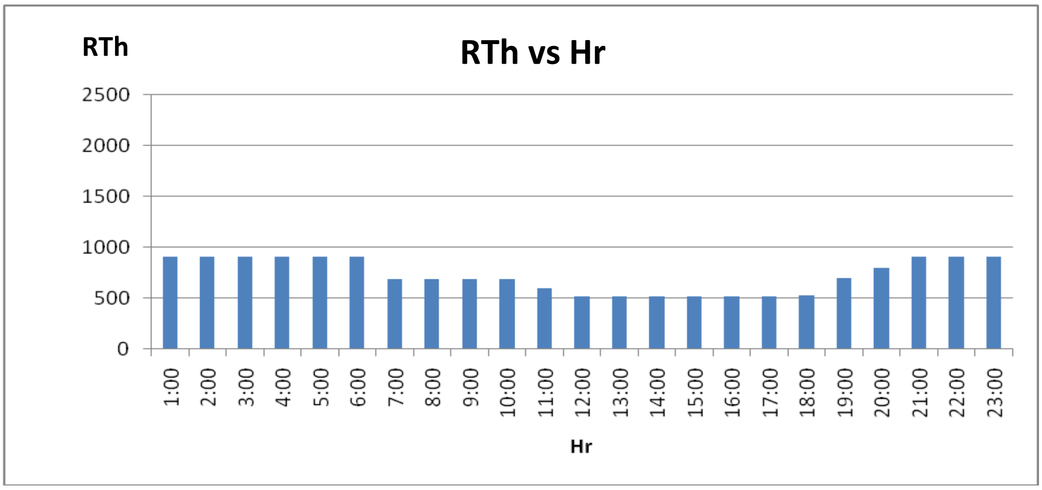


Figure 4: Hourly generation of chilled water by electric chillers [3].

Table 1 below represents the system performance of electric chillers at various capacities.

Table 1: System performance of electric chillers.

RTh	kWh/RTh	% C.O.P.
288	1.04	3.4
280	1.06	3.3
33	1.50	2.4

CHAPTER 3
METHODOLOGY AND PROJECT WORK

The study of ITES and current TES was done during FYP I. In FYP II, the system configuration was designed.

3.1 Available data analysis

During initial phase, all the requirement such as current cooling load and load profile were determined based on the chilled water data. The ITES plant at KLCC was selected to be a guideline to design the new ITES system for UTP. The information would be compared with the designed system in order to validate the project.

3.2 Modelling

A rough system configuration was created to determine the component and system flow required in ITES facility. The specifications of each equipment were calculated to meet the requirement. Some equipment data were retrieved from the manufacturer of readily available model in the market which has been certified. A load profile of designed system was drafted to imply the operation of these equipments.

3.2.1 Storage Capacity

The current chilled water tank at GDC plant was designed to store a cooling capacity of 10,000 RTh. This capacity was selected for the ITES capacity. The charging and discharging pattern of the TES profile was used as the baseline to develop the pattern for ITES.

3.2.2 Component Specifications

The selection of nodule was based on the availability in the market.

For the specifications of storage tank, the design of encapsulated ice storage tank [10] was based on the following assumptions:

- The tank is horizontally divided into sub-volumes where the water temperature in the spheres is assumed uniform;

- During the charging phase, the water temperature in the spheres of each sub-volume decreases till 0°C before freezing occurs. The temperature remains then equal to 0°C during the freezing of all the water in the spheres. After that, the water temperature can become negative. During the discharging phase, the opposed evolution is considered;

- In charging phase, the increase of the heat transfer coefficient due to partial crystallization is not accounted for;

- During freezing, the presence of water between the sphere wall and the ice is neglected ; the development of ice is assumed to be symmetric (from the sphere wall to its center) ; the effect of air in the sphere is neglected ; the increase of sphere volume during the freezing is neglected; the resistance through the liquid water in the sphere is neglected;

- During melting, the natural convection in water is neglected; the decrease of sphere volume is neglected; the effect of air in the sphere is neglected.

There are various chillers available in the market. Thus the research was selecting the required chiller capacity from the available chiller and the specifications were based on the data provided by the manufacturer.

3.3 Validating

The most critical part of the project was to evaluate whether the ITES complied with the current TES. Comparison was made between the existing chilled water data and the designed system. From there, the system performance was determined to prove whether ITES was an improved system compared to chilled water.

3.4 Tool

The AutoCAD 2008 was used to design the system configuration. The proposed system was produced.

3.5 Documentation

Designed system analysis was documented for references. Reports were fully documented and hard bounded as requirement.

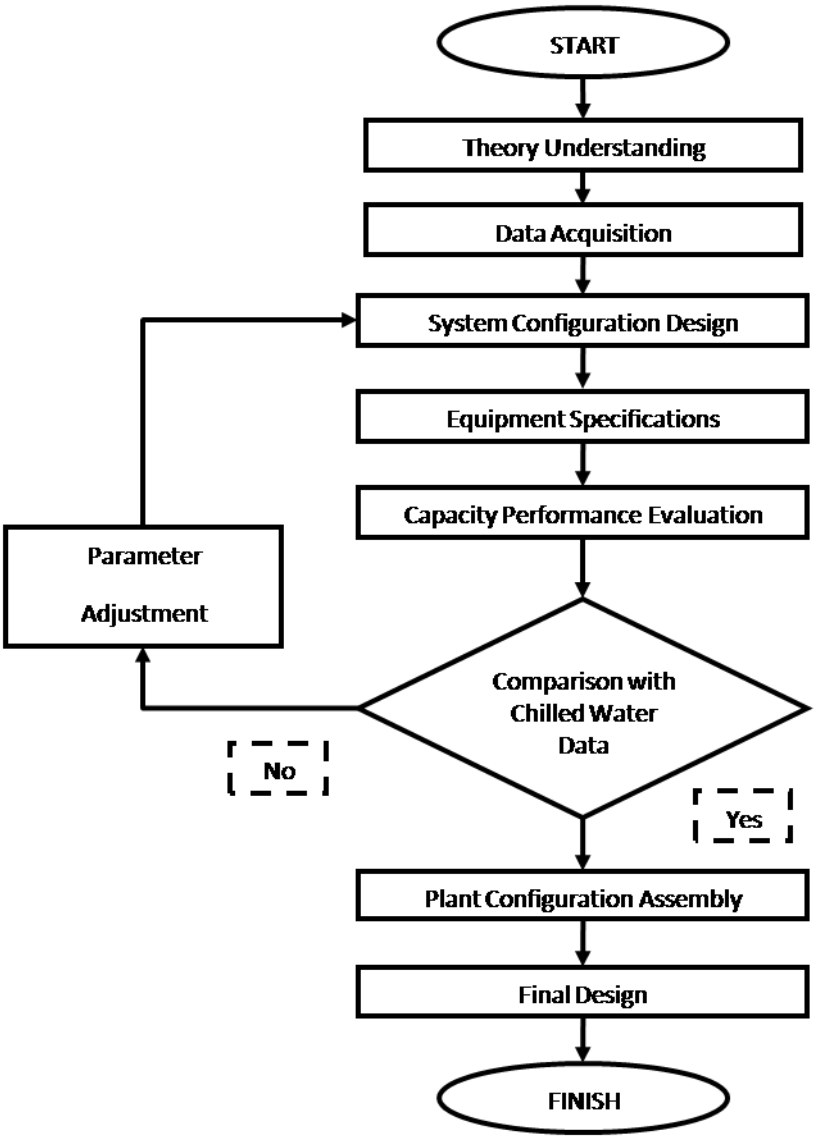


Figure 5: Overall design flow.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Proposed system configuration

The proposed ITES system that was designed is shown in Figure 6.

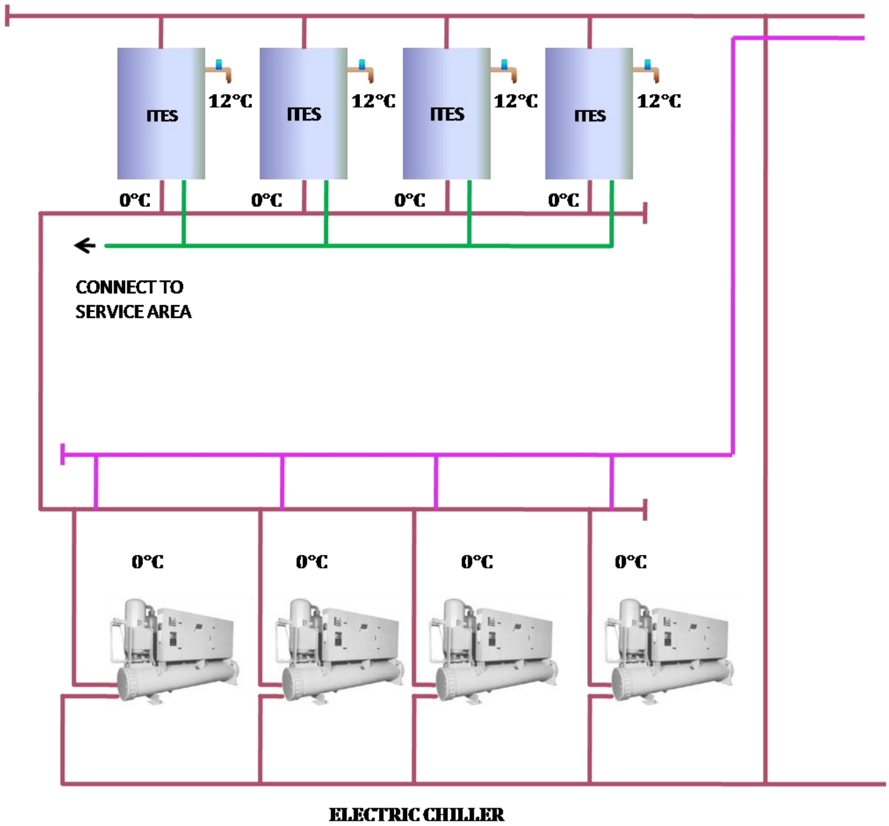


Figure 6: Proposed design of ITES system.

The system consisted of several identical brine chillers and ITES tanks. Each tank contained 60% volume of nodules and the remaining space was reserved for glycol solution. The total amount of storage capacity was similar to current TES

(10,000 RTh). The brine chiller should be capable to chill the brine solution from 12°C (return temperature) to -4 °C.

The circulation initiated where the brine solution received heat load from the returned chilled water of approximately 12°C temperature at heat exchanger unit. The chillers were used to cool down the solution to subzero temperature (-4°C). The chillers charged all the ITES simultaneously. During the charging mode, the cooled solution entered the tank and froze the deionized water inside the nodule, producing ice.

During the discharging mode, the same brine solution entered the tank and melted the ice. The cooled solution ($0°C < T < 0.5°C$) then transferred the cooling capacity from the storage to the chilled water at heat exchanger unit at the temperature of 6°C. The chilled water subsequently circulated the air-conditioning unit of campus and distributed the cooling. The cooling storage discharged would follow the pattern of current TES discharging mode. However, the charging pattern of ITES was determined based on chiller capacity.

The brine chiller would also provide direct cooling if the demand surpassed the storage capacity. Every storage tank was equipped with service line for maintenance.

The proposed ITES unit was a separate system from the current TES unit since the circulation of brine solution and chilled water could not be integrated to each other.

4.2 Equipment Specifications

4.2.1 Selection of nodule

The selection of nodule is based on the desired phase change temperature of the PCM. All the details such as latent heat capacity, size and weight are normally provided by the manufacturer. The specification of the nodule selected will determine the volume of the ice tank and glycol required to fulfil the cooling demand.

Table 2: Common types of nodule used in industry.

Nodule type	Phase change temperature	Latent heat	Sensible heat		Heat transfer factor		Nodule weight	Toxicity LD50 value	Operating temperature limits
	Tst °C	QI kWh	Solid Qss kWh/°C	Liquid Qsl kWh/°C	cristallisation Kvcr kW/°C	fusion Kvfu kW/°C	Kg	mg/Kg*	°C
SN.33	-33	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	1.2	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	
AN.12	-11.7	47.7	0.75	1.09	1.15	1.85	620	5000	-25
AN.10	-10.4	49.9	0.7	1.07	1.15	1.85	617	11000	
AN.06	-5.5	44.6	0.75	1.1	1.15	1.85	625	18000	To
AN.03	-2.6	48.3	0.8	1.2	1.15	1.85	592	58000	
AC. 00	0	48.4	0.7	1.1	1.15	1.85	560	85000	+60
AC.27	+27	44.5	0.86	1.04	1.15	1.85	867	2500	

The nodule proposed in the design is STL-AC-00 (Figure 7), a product of Cristopia [13, 14] which is commonly used in most GDC plants in Malaysia such as GDC (KLCC) [14]. In this regard, the PCM used is water which has phase change temperature of 0°C.

Figure 7: STL-AC-00.

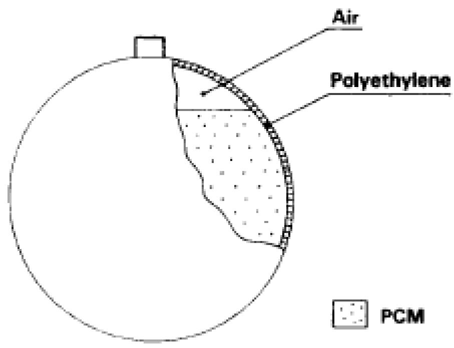


Figure 8: Nodule configuration [7].

The nodule is made by plastic [7, 8], such as high density polyethylene [7]. The nodule diameter is 98mm with thickness of 1mm and is used for conventional building air conditioning ice storage temperature (0°C). Each nodule has a latent heat capacity of 0.01126 RTh and can fill up to 1222 nodules for every 1m^3 volume (13.766 RTh). According to the manufacturer, the nodules are capable to withstand 10,000 cycles without any breakage and the lifetime is higher that the equivalent of 20 years of normal utilization [13].

4.2.2 Storage tank

Based on the cooling storage and nodule specifications, the volume of the storage tank is determined based on the following:

Total volume of nodules,

$$V_{nodule} = \frac{RTh_{requirement}}{RTh_{nodule}/m^3}$$

$$= \frac{10{,}000RTh}{13.766RTh/m^3}$$

$$= 727\ m^3$$

This volume will make up to 60% of storage tank volume. The remaining 40% is filled with glycol solution.

Quantity of nodules required,

$$= V_{nodule} \times Nodules / m^3$$

$$= 727\ m^3\ x\ 1222/m^3$$

$$= 888{,}394\ nodules$$

Total volume of storage tank,

$$V_{total} = V_{nodule} \times 1/60\%$$

$$= 727\ m^3\ x\ 1/60\%$$

$$= 1212\ m^3 \approx 1/5\ of\ 5{,}400 m^3$$

Note that the volume of ice storage was about one-fifth of current chilled water storage. It was estimated that ITES saved 80% of the space in comparison with the conventional TES.

In this regard, a rectangular vessel was selected to build ITES tank based on its atmospheric systems [13] at the ground level. According to Cristopia, the thickness of 1 m should be allocated for tank insulation. Using this basis, a thickness of 1 m was selected for project. The diameter selected for inlet and outlet was identical to evaporator outlet diameter.

4.2.3 Circulating solution

Another element that differentiates the characteristics of ITES from chilled water is the type of discharge fluid. While current TES uses water to store and circulate the cooling capacity, the ITES uses secondary coolant (brine solution) to freeze the water inside the nodule. In this regard, ethylene glycol was selected to be the coolant. The glycol solution is odourless, colourless, syrupy, and sweet tasting fluid. The antifreeze capability of ethylene glycol has made it commonly used in cooling applications. The properties of ethylene glycol were represented in the following tables.

Table 3: Freezing point of ethylene glycol based water solutions [15].

Freezing Point								
Ethylene Glycol Solution (*% by volume*)		0	10	20	30	40	50	60
Temperature	(°F)	32	23	14	2	-13	-36	-70
	(°C)	0	-3	-8	-16	-25	-37	-55

Table 4: Dynamic viscosity of ethylene glycol based water solutions [15].

Dynamic Viscosity - *μ* - *(centpoise)*								
Temperature		Ethylene Glycol Solution *(% by volume)*						
(°F)	(°C)	25	30	40	50	60	65	100
0	-17.8	1)	1)	15	22	35	45	310
40	4.4	3	3.5	4.8	6.5	9	10.2	48
80	26.7	1.5	1.7	2.2	2.8	3.8	4.5	14
120	48.9	0.9	1	1.3	1.5	2	2.4	7
160	71.1	0.65	0.7	0.8	0.95	1.3	1.5	3.8
200	93.3	0.48	0.5	0.6	0.7	0.88	0.98	1.4
240	115.6	2)	2)	2)	2)	2)	2)	1.8
280	137.8	2)	2)	2)	2)	2)	2)	1.4

1) *Below freezing point*
2) *Above freezing point*

Table 5: Specific gravity of ethylene glycol based water solutions [15].

Specific Gravity- *SG* -								
Temperature		Ethylene Glycol Solution *(% by volume)*						
(°F)	(°C)	25	30	40	50	60	65	100
-40	-40	1)	1)	1)	1)	1.12	1.13	1)
0	-17.8	1)	1)	1.08	1.10	1.11	1.12	1.16
40	4.4	1.048	1.057	1.07	1.088	1.1	1.11	1.145
80	26.7	1.04	1.048	1.06	1.077	1.09	1.095	1.13
120	48.9	1.03	1.038	1.05	1.064	1.077	1.082	1.115
160	71.1	1.018	1.025	1.038	1.05	1.062	1.068	1.1
200	93.3	1.005	1.013	1.026	1.038	1.049	1.054	1.084
240	115.6	2)	2)	2)	2)	2)	2)	1.067
280	137.8	2)	2)	2)	2)	2)	2)	1.05

1) *Below freezing point*
2) *Above freezing point*

Table 6: Specific heat capacity of ethylene glycol based water solutions [15].

Specific Heat Capacity - c_p - (Btu/lb.°F)								
Temperature		Ethylene Glycol Solution (% by volume)						
(°F)	(°C)	25	30	40	50	60	65	100
-40	-40	1)	1)	1)	1)	0.68	0.703	1)
0	-17.8	1)	1)	0.83	0.78	0.723	0.7	0.54
40	4.4	0.913	0.89	0.845	0.795	0.748	0.721	0.562
80	26.7	0.921	0.902	0.86	0.815	0.768	0.743	0.59
120	48.9	0.933	0.915	0.875	0.832	0.788	0.765	0.612
160	71.1	0.94	0.925	0.89	0.85	0.81	0.786	0.64
200	93.3	0.953	0.936	0.905	0.865	0.83	0.807	0.66
240	115.6	2)	2)	2)	2)	2)	0.828	0.689
280	137.8	2)	2)	2)	2)	2)	2)	0.71

1) *Below freezing point*
2) *Above freezing point*

The following calculation represents the refrigerating effect received by glycol solution from 12°C to -4°C during 7 hours charging period. The specific heat capacity, *c* for glycol at 40% volume can be referred from Table 6.

$m = \rho V \qquad \rho = 1{,}113.2\ kg/m^3$

$c = 0.86\ BTU/lb.°F = 3{,}600.648\ J/kg.K\ (1\ BTU/lb.°F = 4{,}186.8\ J/kg.K)$

$Q = mc\Delta T = \rho Vc\Delta T \qquad \Delta T = 285\ K - 269\ K = 16\ K$

$= 1{,}113.2\ kg/m^3 \times (1{,}212 - 727\ m^3) \times 3.60065\ kJ/kg.K \times 16\ K$

$Q = 31{,}103{,}970\ kJ$

$\dot{Q} = 31{,}103{,}970\ kJ/7hours = 4{,}443{,}434.31\ kJ/hr$

The above value implies for a single storage tank. This could increase the capital cost of maintenance and complexity. The author decided to optimise the design i.e. to reduce storage space and chiller usage. The research made on GDC (KLCC) and other ITES plants have shown a common industrial practice to have several smaller equivalent tanks rather than a large one. Therefore, several alternatives were considered by multiplying the number of tanks with equal storage requirement. The following table represents 4 alternatives for design optimization.

Table 7: Design alternatives.

Alternative	No. of tanks	Volume/tank, m^3	No. of nodules	$\dot{Q}$, *kJ/hr*	RTh/tank
A	1	1212	888,394	4,443,434.31	10,000
B	2	606	443,843	2,224,369.05	5,000
C	3	303	221,927	1,112,138.72	2,500
D	4	152	110,958	560,696.02	1,250

The author considers up only 4 tanks because of space availability at GDC plant. From the table, since all the alternative uses the same brine chillers, Alternative D is much preferred because it has the least tank size and rate of discharge and therefore reduces the operating and maintenance cost. Alternative D also has the highest storage efficiency compared to other alternatives.

4.2.4 Chiller

The current electric chiller can support the cooling capacity of

$$4 \text{ x } 325 \text{ RT x } 0.7 \text{ x } 7 \text{ hrs} = 6{,}370 \text{ RTh}$$

According to Cristopia, the factor of 0.7 during storage was estimated because a loss of 3% cooling capacity occurred for every degree cooling. This capacity is insufficient to charge the ice storage since the heat fusion of ice is greater than that of chilled water. Therefore, the chiller should be resized in order to meet the charging requirement. 4 brine chillers were considered in the project based on the current setup of electrics and plant space.

The project considered to use 510 RT X 4 units of brine chillers for charging the ITES. The selection is also based on the current setup of electric chillers and plant space to ease the installation of the equipment.

The brine chiller type used at GDC (KLCC) is R123 Duplex centrifugal (3 Trane Chillers) with the capacity of 2,000 RT and power input of 1.4 MW each [14]. The project considered to use the DUNHAM-BUSH® water-cooled chiller with semi-hermetic screw compressors. The physical specifications are as follows:

Table 8: Physical characteristics of water-cooled chiller [16].

Unit Model	**HXWC 520-5NR**
Nominal Tons	520
Minimum Unit Capacity Reduction (%)	8.33
Compressor Model (Quantity)	**HX1816 (3)**
RPM	2900
Evaporator Model	**X5R**
Water Connection (Inch)	10
Nominal Water Flow (gal/min)	1047
Nominal Pressure Drop (kPa)	26.1
Condenser Model	**Z5R**
Water Connection (Inch)	8
Nominal Water Flow (gal/min)	1255
Nominal Pressure Drop (kPa)	27
Approximate Refrigerant Charge (kg) R-134a	570

Based on Table 8, the closest nominal tons for chiller capacity are 520 RT (model HXWC 520-5NR).

Evaporator/condenser features includes:

- Cleanable and Removable Integral Fin Copper Tube
- Removable Water Heads
- Victaulic Groove Water Connections
- Vessel designed and constructed according to American Society of Mechanical Engineers (ASME) Code
- Relief Valve's standard – ¾" Female Pipe Trade (FPT)
- Full Pump Down Capacity in Condenser

Figure 9: HXWC 520-5NR.

According to DUNHAM-BUSH®, the power required for the chiller depends on customer requirement. A power input ratio of 520 RT chiller to GDC (KLCC) brine chiller was estimated.

Power input	*= 1.4 MW x 520 RT / 2,000 RT*
	= 0.36 MW
Total power input	*= 0.36 MW x 4 units*
	= 1.44 MW

The power generated by Gas Turbine Generator (GTG) at current GDC (UTP) was 4.2 MW x 2 units. Only one unit of GTG was needed to generate the power required to run the current electric chillers [2]. Thus, the proposed system could be feasible with the current power supply.

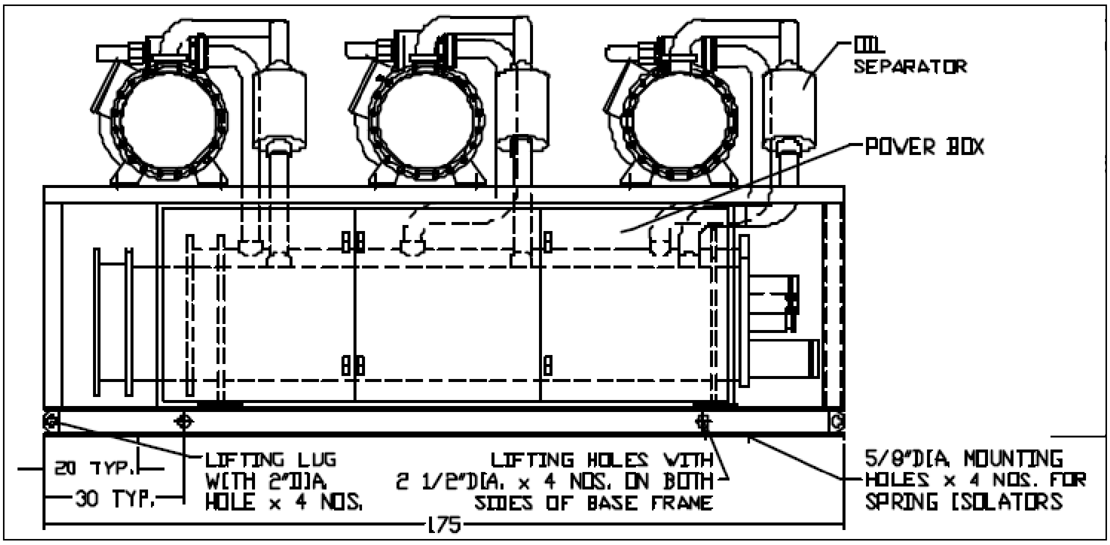
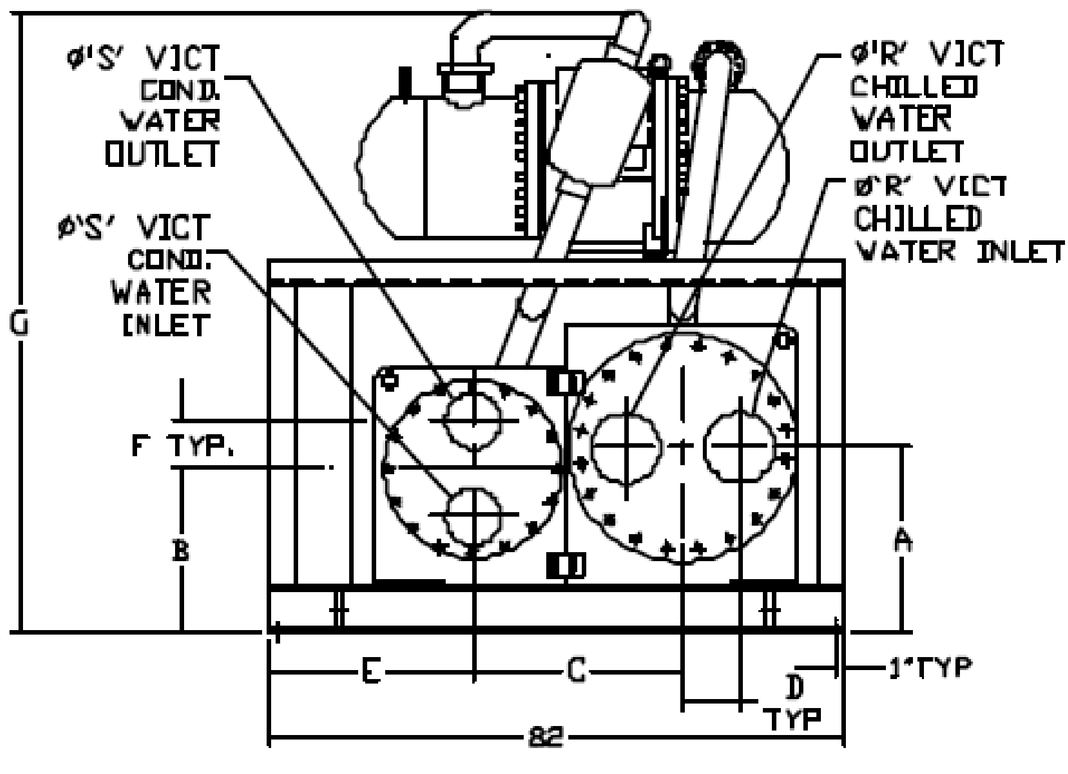


Figure 10: Side view of chiller.



MODEL HXVC	A	B	C	D	E	F	G	R	S
400-5NR	25 1/4	22 1/4	27 7/8	7 3/8	32 1/4	6 1/8	96 1/2	10	8
440-5NR	25 1/4	22 1/4	27 7/8	7 3/8	32 1/4	6 1/8	96 1/2	10	8
480-5NR	26 1/4	23 1/4	29 7/8	8 1/8	31 1/2	6 7/8	96 1/2	10	8
520-5NR	26 1/4	23 1/4	29 7/8	8 1/8	31 1/2	6 7/8	96 1/2	10	8
530-5NR	26 1/4	23 1/4	29 7/8	8 1/8	31 1/2	6 7/8	96 1/2	10	8
560-5NR	26 1/4	23 1/4	29 7/8	8 1/8	31 1/2	6 7/8	96 1/2	10	8

Figure 11: Front view of chiller.

The flow rate of evaporator was determined from the manufacturer's data (Table 8). The same flow rate was applied to a pump circulating the glycol solution from evaporator into the storage. According to the specifications, the recommended drain valve and storage inlet diameter is 10" (254 mm). The flow velocity was determined as follows:

Flow rate, $Q = 1{,}047\ gal/min = 28.58\ m^3/hr$

$$Q = V \times A$$

$$V = Q/A = (28.58\ m^3/hr) / [\pi \times (0.254m)^2/4]$$

$$V = 564\ m/hr = 0.16\ m/s$$

The following calculation of flow velocity applied to condenser-cooling water connection. The recommended diameter for condenser is 8" (203mm).

Flow rate, $Q = 1{,}255\ gal/min = 34.26\ m^3/hr$

$$Q = V \times A$$

$$V = Q/A = (34.26\ m^3/hr) / [\pi \times (0.203m)^2/4]$$

$$V = 1{,}059\ m/hr = 0.29\ m/s$$

4.3 Charging pattern from the designed ITES

The objective of this analysis is to set the design requirement of cooling capacity after all the specifications of equipment were justified. A profile of current TES operation on 4th July 2009 was taken as a baseline to determine the requirement.

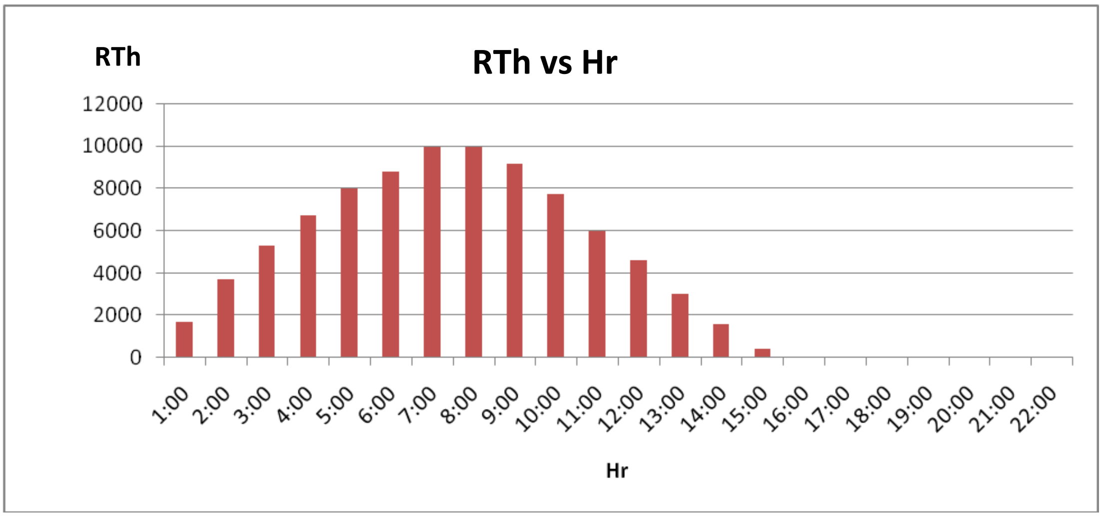


Figure 12: TES hourly holding capacity pattern on 4th July 2009 [4].

The duration for TES in charging mode was 9 hours from 8 a.m. until 4 p.m. where the student activities took place. The cooling supply gradually decreased for about 10% every hour. Therefore the discharge pattern of designed ITES will have similar characteristics of chilled water.

The duration for TES in charging mode was 7 hours from 12 midnight until 7 a.m. in the morning, which was during off-peak hours. The storage was fully charged at 8 a.m. Since the charging period varied with chiller capacity, the refrigeration-ton hour was calculated to determine how long it would take for ITES to be fully charged.

From equation (2),

Total capacity for the 1st hour

= Nominal Chiller x no. of chillers x hours of charging x capacity factor

= 520 RT x 4 x 1 hour x 1

= 2,080 RTh (assuming the chiller efficiency of 100%)

However, the efficiency of 100% was impossible in reality. Assuming the maximum efficiency of chiller was 90%, *Total capacity for the 1^{st} hour*

= 520 RT x 4 x 1 hour x 0.9

= 1,872 RTh

For the next hours, the capacity of ITES increased with the increment of 1,872 RTh. The data for charging mode was tabulated in the following table and compared.

Table 9: Hourly charging mode for designed ITES.

Hour	RTh
0:00	1,872
1:00	3,744
2:00	5,616
3:00	7,488
4:00	9,360
5:00	10,000

From the calculation, it was observed that the designed ITES was almost fully charged at the fifth hour and completely charged at the sixth hour. There was a slight variation of chiller usage at the interval between fifth and sixth hour where only a small increment of 640 RTh was needed to fully charge the ITES. Therefore, the maximum of two chillers operating (520 RT x 2) were required to suffice the cooling.

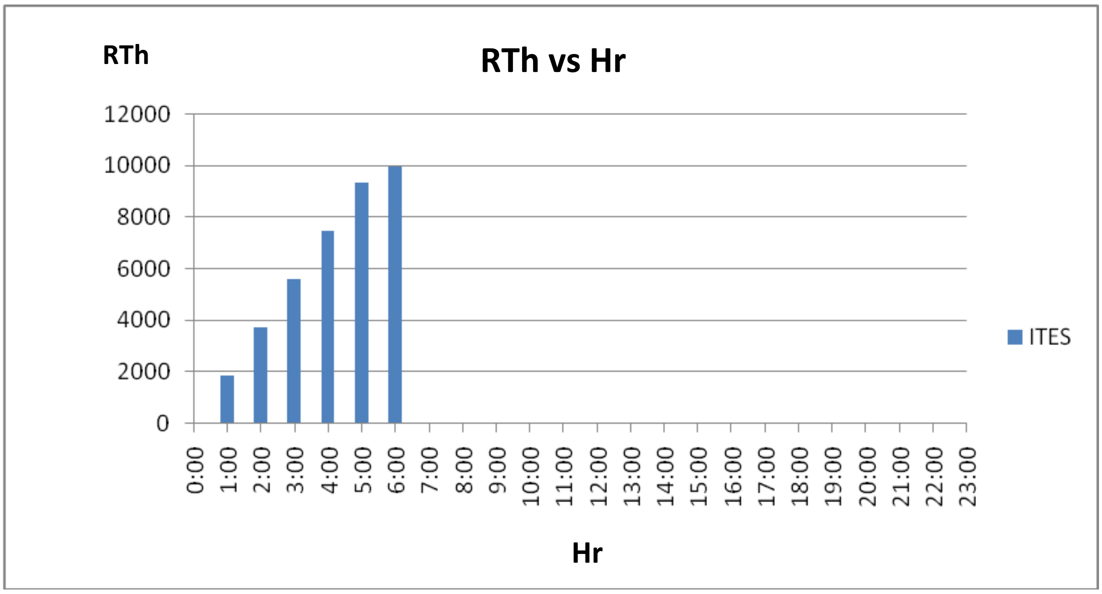


Figure 13: Hourly charging capacity for designed ITES.

The comparison was made between the designed ITES and curent TES. Since the disharging mode started at 8 a.m., the pattern for charging of ITES was shifted to match the maximum charging capacity interval between 7 a.m. to 8 a.m.

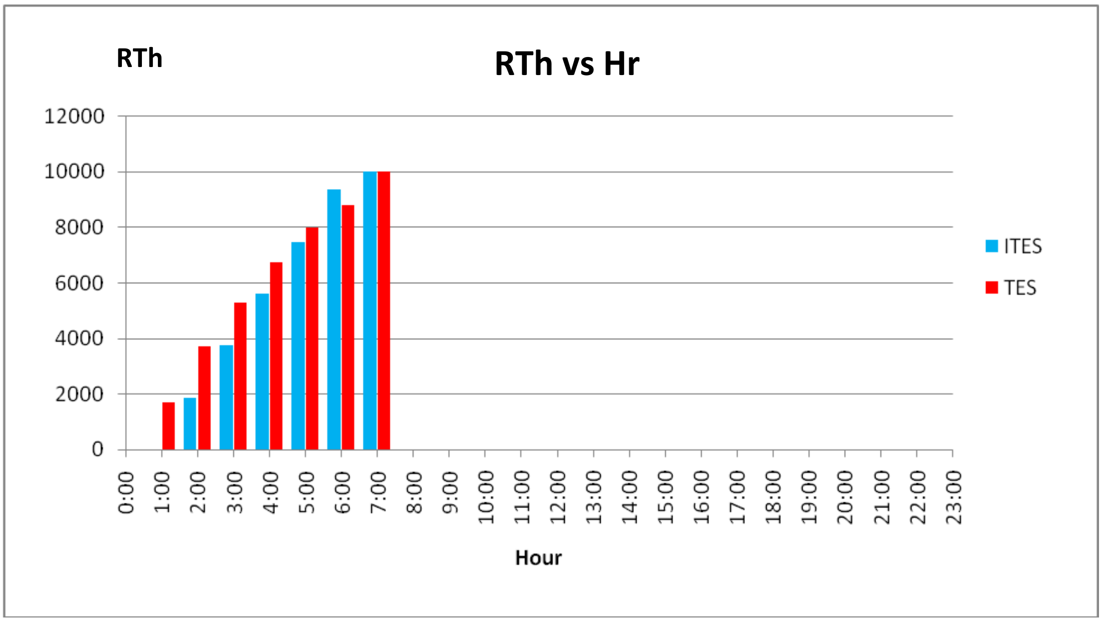


Figure 14: Charging mode between designed ITES and TES.

From Figure 14, assuming the efficiency of brine chillers was 90%, the charging duration for designed ITES was observed to take approximately 6 hours to reach maximum capacity of 10,000 RTh, less one hour than the current TES.

System performance increase,

= (Current charging hours – designed charging hours)/Current charging hours

x 100%

= (7-6 hours)/ 7 hours x 100%

= 14.3 %

Therefore, the ITES system was estimated to benefit in terms of charging period compared to chilled water system.

Figure 15 represented the whole operation of designed ITES. The charging mode started at 1 a.m. until 7 a.m., while the discharging mode took place from 7 a.m. until 4 p.m.

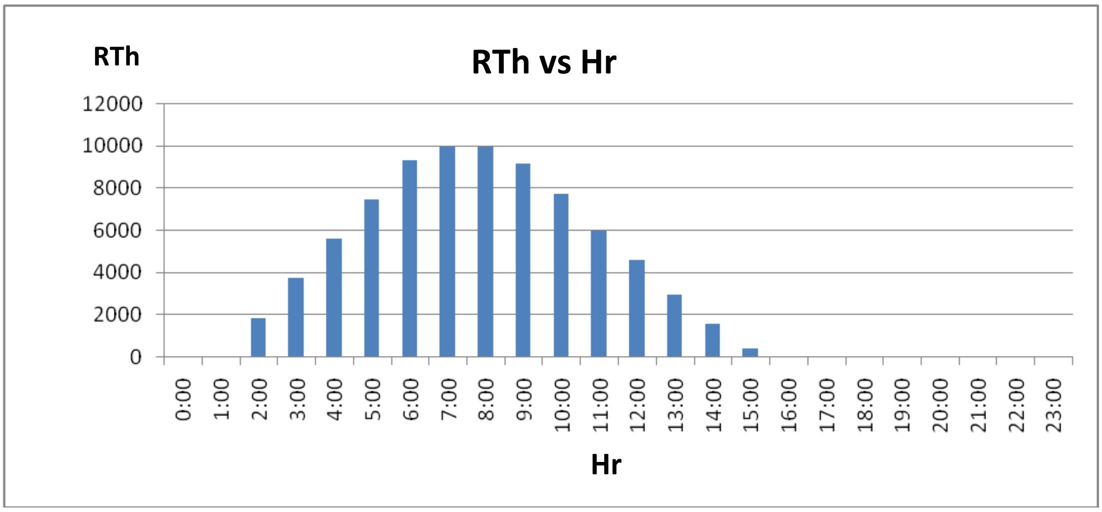


Figure 15: Hourly holding capacity of designed ITES.

4.4 Proposed tank specifications & related accessories

The proposed specifications of tank and its related accessories were therefore determined.

Useful volume = 152 m^3 *x 4 tanks*
Size = 7.4 m x 7.4 m x 7.4 m (rectangular, above ground)
Thickness = 1 m including insulation
Glycol inlet/outlet diameter = 0.254m
Pump flow rate = 28.58 m^3*/hr*
Pipeline diameter for brine circulation = 0.254m
Pipeline diameter for chiller cooling water = 0.203m

After all the specifications are justified, the configuration of designed ITES system was built. The drawing can be viewed in the Appendix.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The cooling supply requirement in the project is 10,000 RTh. The 10,000 RTh of encapsulated ITES based on the suitability that it can provide. The design of four identical tanks was chosen based on common industrial practice of available ITES plant and to achieve optimized functioning.

The volume of each tank is 152m^3, 532,616 nodules fill the 60% of the tank and the remaining is filled with ethylene glycol. The system configuration consists of 4 units of 520 RT brine chillers (DUNHAM-BUSH® water-cooled chiller with semi-hermetic screw compressors model HXWC 520-5NR) and 4 units of 1,250 RTh ice storage tanks. The power required to run the chillers is 1.44 MW.

The proposed system is capable of fully charging the 10,000 RTh within 6 hours. This is the improvement of 1 hour of current TES system. The performance increase is 14.3 %. Hence it is feasible.

5.2 Recommendation

The extension of this project could be to design heat exchanger for between glycol solution and chilled water. The objective is to meet the requirement of supply temperature (6°C) and return temperature (12°C) of chilled water for customer. This would enable the proposed system to be integrated with the current GDC.

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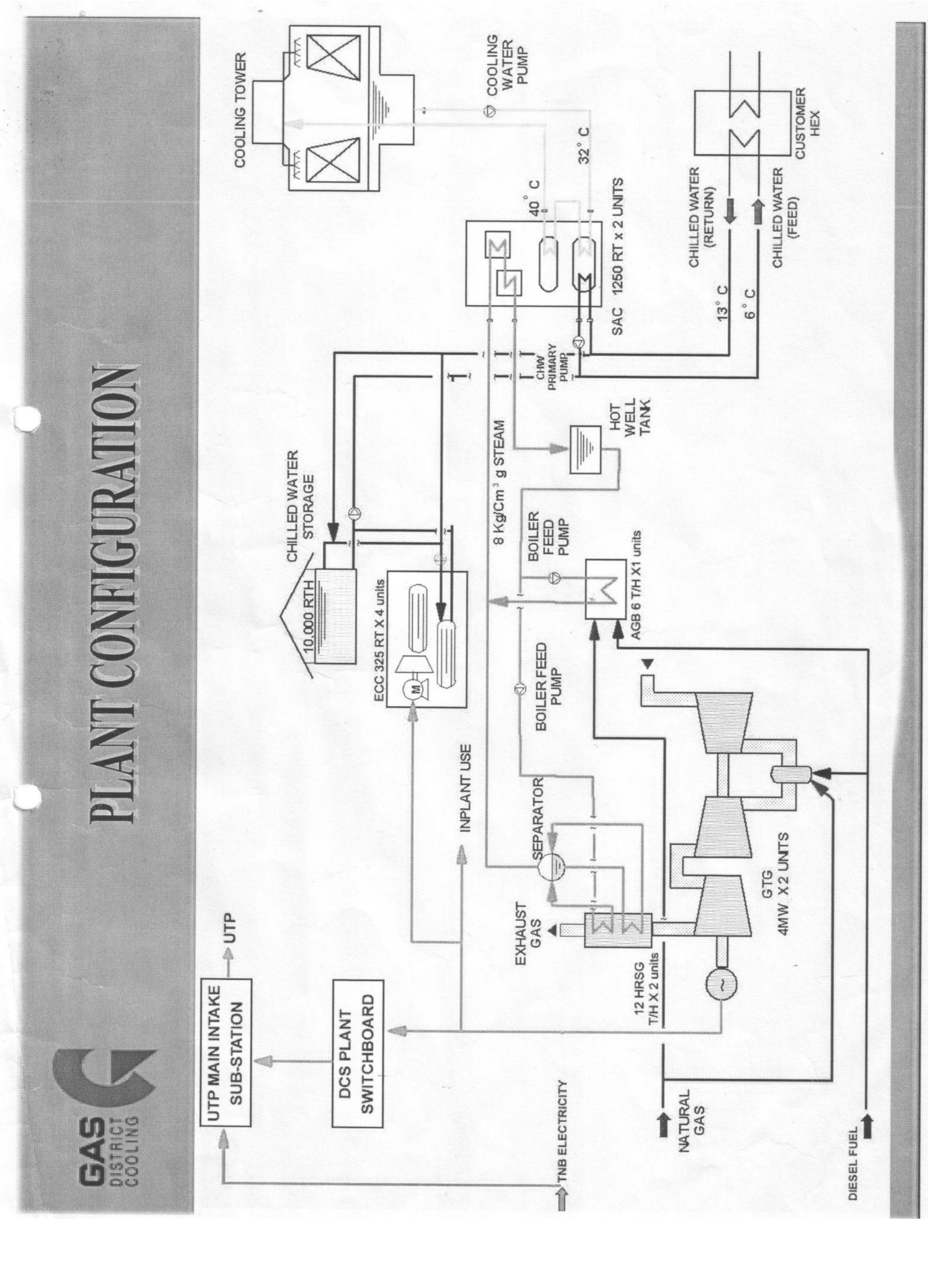
APPENDIX


PLANT CONFIGURATION
GAS DISTRICT COOLING
UTP MAIN INTAKE SUB-STATION
UTP
DCS PLANT SWITCHBOARD
TNB ELECTRICITY
INPLANT USE
CHILLED WATER STORAGE
10,000 RTH
ECC 325 RT X 4 units
8 Kg/Cm³ g STEAM
CHW PRIMARY PUMP
HOT WELL TANK
BOILER FEED PUMP
AGB 6 T/H X1 units
BOILER FEED PUMP
SEPARATOR
EXHAUST GAS
12 HRSG T/H X 2 units
GTG 4MW X 2 UNITS
NATURAL GAS
DIESEL FUEL
COOLING TOWER
COOLING WATER PUMP
40° C
32° C
SAC 1250 RT x 2 UNITS
13° C
6° C
CHILLED WATER (RETURN)
CHILLED WATER (FEED)
CUSTOMER HEX