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Feasibility Study of A District Cooling Systems: A Case Study

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Abstract

This paper contains the design aspects of District Cooling System (DCS) for the New Engineering Complex and Technology (ECT) Building of University Putra Malaysia (UPM). The purpose of the DCS plant is to provide air-conditioning to all buildings around ECT that consists of eight laboratories and a 11 storey Building. The study was carried out to determine the required total cooling load, the cooling load profile, the main chiller and TES (Thermal Energy Storage) tanks capacities as well as to estimate suitable base load. The designed value was then compared with those obtained from simulation using the STOCKAID 2000 software. The results show that the main chiller capacity in direct chilled water production, P_r is 413 RT and base chiller is 100 RT. The required TES tanks volume is 164 m^3, while chiller capacity in charge of the TES, P_c is 277 RT. Total energy that can be stored in TES Q_{st} is 3042 RTh (10697 kWh). Total cooling load for the ECT of UPM is 14.2 x 10^6 Btuh. Annual saving in energy costs for the designed DCS is RM 930,667. Even though, the initial investment is about 2.8 times more than Split Unit System (SUS), but the payback period of additional investment of RM 4.85 million is only 6.2 years and with an incredible internal rate of return (IRR) of 17.4% per year. In comparison between DCS and Conventional Centralised Cooling System (CCCS) using sensitivity analysis, CCCS always has higher payback period and lower IRR than DCS. However, this study also showed that the CCCS may save energy costs of RM 674,500 with a payback period is 8.7 years.

Introduction

District Cooling System (DCS) uses a single cooling plant to produce and distribute chilled water to several buildings for air-conditioning as well as other purposes like electricity and steam distribution within a specific area. Basically, DCS is also part of CCCS that are commonly found in many commercial premises and high-rise buildings, which need air-conditioning, supply. But in DCS, the cooling plant will serve several buildings rather than one in CCCS. The plant is centralized control so that the produced chilled water can be distributed effectively to district premises. Besides that, it is common to incorporate the DCS cooling plant with an-energy storage. Energy storage is a conservation system for strategic energy-load management that takes advantage of discounted, off-peak electricity tariff offered by the national power grid supplier, Tenaga Nasional Berhad (TNB) [1]. Some types of common cooling system and their suitable area of applications are shown below in Table 1.

It is wise to implement DCS in areas that need high cooling load. Examples are business and commercial centres, hospitals and universities where there are several buildings, which need plenty of air-conditioning. It is because DCS gives reliable and uninterrupted supply of air-conditioning that makes it ideal for operations that need 24-hour supply. [2].

The target area for this project is the New Engineering Complex and Technology (ECT) of University Putra Malaysia (UPM). The UPM Engineering Faculty complex consists of a 11 storeys administrative building and eight laboratories for eight different engineering disciplines at UPM equipped with lecture theatres and tutorial rooms. Total space area for air-conditioning is assumed to be 16084 m^2. [Source: Engineering Complex and Technology of UPM]

Table 1 common cooling system and their suitable area of applications

Types of Air-conditioning System	Commonly Used Area
Centralized Cooling System	Cooling a huge area like the shopping complexes, cinema, buildings etc.
Conventional Split Unit Air-conditioning	Cooling a specific area like office rooms and residential areas. It is most commonly found also in shop houses, lecturer theatres / rooms etc. where the cooling load is not high.
District Cooling System	It can be used to cool a down town business districts (Putrajaya, Cyberjaya, and Kuala Lumpur City Central KLCC) and also institutional settings like airport (KLIA) and college campuses (UNITEN)

Methodology

Cooling load profile is essential in determining chiller and TES tank capacity. An estimated loading profile was plotted based on data from electric meter readings for a week. The Base Load, Thermal Ice Storage and Brine Chiller Capacity were determined by using the software STOCKAID 2000. Matrix Evaluation method was used to evaluate and ease the selection types of DCS and its major components like chiller, thermal energy storage tank, heat exchangers, motor and pumps. For the financial analysis the methods of payback period and internal rate of return (IRR) was used. The system that has the shortest payback period and highest IRR is most preferred.

Determining the Dcs Configuration

The Cooling Load can be calculated by multiplying the space area of ECT and the Grand total factor, F_{GT}. The Refrigeration Load is the space areas of ECT multiply by the Refrigeration factor, F_R (4). The calculations was performed by using the methodology described by MOGC Engineering Consulting Sdn. Bhd. and the total cooling load was found to be 1185 Refrigeration Ton

Implementation Method:

Water is cooled at a central location and pumped through insulated pipelines directly to consumers. The main plant components are Chiller, TES, Heat exchangers, Motors and Pumps. Chiller and TES capacity was determined from the total cooling load. An estimation of cooling load demand profile for the UPM engineering Complex and Technology is plotted as shown in Fig. 1.

The demand ranges from 1040 RT to 1200 RT at 11.00 a.m. until 2.00 p.m. The minimum cooling load demand profile occurs from 9.00 p.m. to 10.00 p.m., which is approximately 27 RT. The cooling load demand profile varies every hour. The total daily demand was found to be 8000 RTh.

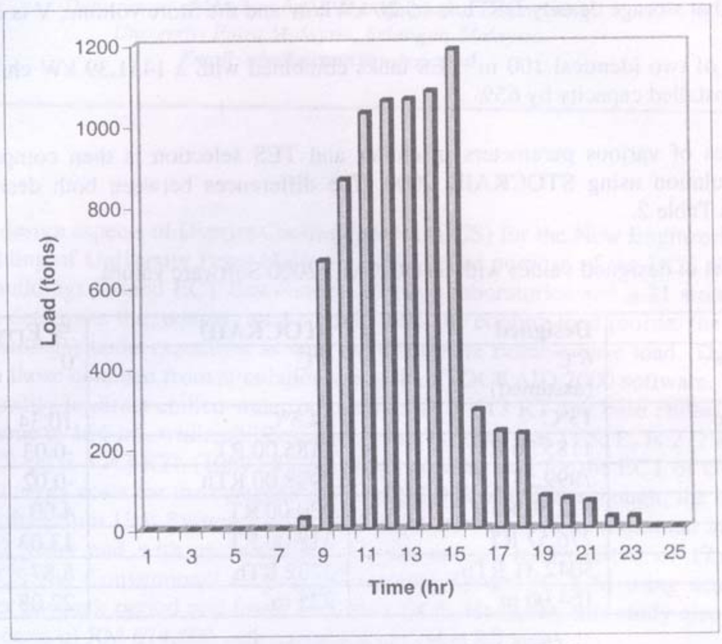

Fig.1 Cooling load Profile for the ECT

The assumptions are:

- The maximum demand temperature is at +6 8C / +13 8C and the storage temperature, Tst at 0 8C.
- P_r denotes the chiller capacity in direct production at +6 8C (the chiller runs 10 hours at this rate) and P_c denotes the chiller capacity in charge at -5 8C (the chiller runs 14 hours at this rate).
- Next, f is the capacity reduction coefficient between the two modes (charge and direct production). According to data for chillers available on the market [Cristopia Energy System], we typically have a 3% capacity reduction per degree Celsius.
- Direct chiller production time, x = 10 hours.
- Chiller charging time, y = 14 hours

The storage density DSTL was calculated using the formula provided by Cristopia Energy Systems:

$$\text{DSTL} = \{Q_{ss} \times (T_m - T_{st})\} + Q_l + [Q_{sl}(T_d - T_{st})] \text{ where}$$

where,

Qss – Sensible heat solid, kWh / °C

Tm - Maximum demand temperature, 13°C

Td - Difference between the maximum demand temperature range

Tst - Phase change temperature, 0°C
Qsl - Sensible heat liquid, kWh / °Cm^3
Ql - latent heat, kWh / m^3

Calculation shows that storage density DSTL is 65.20 kWh/m^3 and the Store volume, V is 164 m^3

Thus, the selection of two identical 100 m^3 TES tanks combined with a 1451.39 kW chiller (413 RT) will be able to reduce the installed capacity by 65%.

The designed values of various parameters in chiller and TES selection is then compared with the values obtained from simulation using STOCKAID 2000. The differences between both designed and simulation values are shown in Table 2.

Table 2 Comparisons of designed values with STOCKAID 2000 Software values.

Items	**Designed**	**STOCKAID**	**% Error**
Leaving temperature	6°C (assumed)	6°C	0
Return temperature	13°C	14.5°C	10.34
Maximum Load	1185.36 RT	1185.00 RT	-0.03
Daily Demand, Q_l	7999.54	7998.00 RTh	-0.02
P_r	412.80 RT	430.00 RT	4.00
P_c	276.57 RT	318.00 RT	13.03
Q_{st}	3042.31 RTh	3232 RTh	5.87
Volume	164.06 m^3	225 m^3	27.08

The gaskets-plate type heat exchanger was selected because it is commonly used in central cooling compare to other plate heat exchangers [E.A.D. Saunders]. In central cooling, a closed circuit of high-quality water, which is used to cool a process, is passed through it where heat is removed from the closed circuit water of a lower quality, such as sea or river.

The heat source for this plant is electricity due to its convenience and cleanliness. Although natural gas is definitely more efficient but the small cooling capacity of this plant limits the use of gas cooling. Other, heat sources are not chosen due to problems like pollution, inefficiency and storage area. Table 3 and 4 show the technical highlights for the DCS plant of UPM'

Table 3 Technical Highlights for the DCS Plant of UPM

Configuration			
Item	**Characteristics**	**Qty**	**Price, RM**
Centrifugal chiller	Pr = 1451. 39kW +6 °C / +13 °C Pc = 972.43 kW -5 °C / -2.3 °C Brine chiller = 400 RT Base chiller = 100 RT	 1 1	2,200,000
TES tank	Volume, V = 100 m^3 External diameter = 3000 mm Total length = 14770 mm External insulation = 147 m^2	2	1,200,000

	Surface area Inlets & outlets = 250 mm Connections Number of cradles = 6 Empty weight = 12700 kg Heat transfer fluid vol. = 38.8 m^3 Storage density, = 61.1 kWh / m^3 DSTL Energy stored, Q_{st} = 11572 kWh		
Nodules (Balls inside TES tank that use to store energy by mixing with heat transfer fluid)	Tst = 0 °C Ql = 48.4 kWh / m^3 Qss = 0.7 kWh / °C m^3 Qsl = 1.1 kWh / °C Kvcr = 1.15 kW / °C m^3 Kvfu = 1.85 kW / °C m^3 Nodule weight = 580 kg Diameter = 96 mm	43173 4	
Heat Exchanger (Gasketed-plate)	Temperature: -40 °C to 180 °C Pressure: 30 bar Typical surface area Range for a single unit: 1-1200 m^2	6	

Table 4 Technical Highlights for the DCS plant of the UPM

Item	**Characteristics**	**Qty**	**Price, RM** [1]
Centrifugal chiller motor	Ne = 7.96 kW N = 1200 RPM	1	
Centrifugal chiller compressor	Ne = 1.91 kW N = 5000 RPM	1	
Tertiary Plant 1. Chilled water pump (a) Lab. (b) Chiller to substatn. (c) Storage (d) Main building (e) Ground source 2.Electrical works, metering equipment	 P = 2.0 hp; Q = 100 GPM P = 2.0 hp; Q = 300 GPM P = 3.0 hp; Q = 400 GPM P = 9.0 hp; Q = 100 GPM P = 200 hp; Q = 700 GPM	 11 4 2	300,000

Pipe works	800,000
Air handling / fan coil units	600,000
Duct works	250,000
Grilles and diffusers	100,000
Chiller plant control system	250,000
Anchillary equipments	100,000
Vibration & Acoustic Control System	250,000
Testing & Commisioning	50,000
Painting & Labelling	50,000
Building Automation System	700,000
Spare & Accessories	150,000
Total Capital Costs	7,000,000
Preliminaries / Construction costs	500,000
Total initial investments (approx.)	**7,500,000**

INSTALLED CAPACITY	
Heat source	Electricity
Capacity (Cooling load)	1185.36 RT
Chilled water	1200 RT (Refrigeration Tonnes)
CHILLED WATER TEMPERATURE	
Supply	3 °C - 7 °C
Return	12 °C – 15 °C

Performance Analysis

Economical Aspects

The following assumptions were take for the calculation of the Payback Period:

Direct power consumption per day is 14 hours,
Days per month = 20.
TES Tariff is used, i.e. RM 0.118 / kWh for 10 hours from 2100 to 0700. While RM 0.208 / kWh is used from 0700 to 2100.

Internal Rate of Return (IRR), i'%

Present Worth, W = - ACI + (S – M) (P/A, i'%, N) = 0 [3]

where,

ACI - Additional Capital Investment
S - Total Savings / year
N - No. of years (Payback period)
M - Maintenance
P/A - Find present worth if given annual worth
Assume i'% is between 10% - 15 %.

Sensitivity Analysis

From previous calculation the total costs of energy saving for DCS and CCCS compared with SUS are RM 989,372 and RM 647,618 respectively. The major annual expenses for the three systems are the maintenance costs. The annual maintenance costs for the SUS is approximately RM 121,800 while for DCS and CCCS the maintenance costs are about 3 % of their total initial investments / plant costs that range from RM 123,289 to RM 243,289. However, in general DCS and CCCS are more economical than SUS simply due to their saving energy costs.

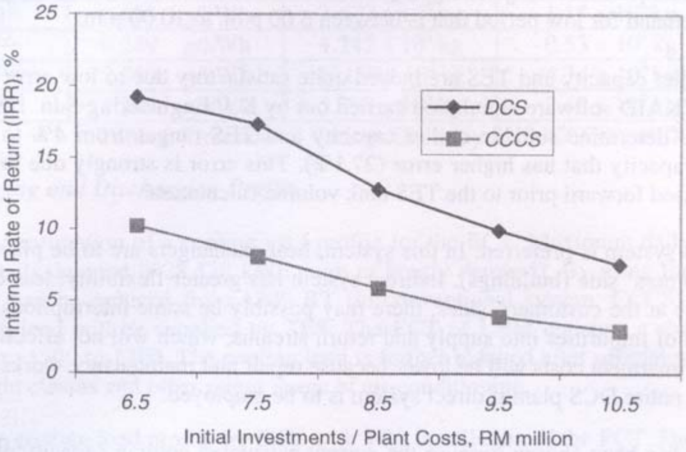

Fig. 2 Internal rate of return vs. initial investments/plant cost

Table 5 below shows the economics comparison between the DCS and CCCS. The payback period for both systems increases as the total plant costs increases. The internal rate of return (IRR), which is the most widely used rate of return method for performing engineering economic analyses for both systems decreases as the total plant costs increases. It clearly shows that DCS has a shorter payback period and higher IRR value compare to CCCS. Therefore, DCS is more viable and more economical compare to CCCS.

Besides that, the calculation shows that the estimated total DCS plant costs for the UPM Engineering Complex and Technology is RM 7500,000 with an approximate maintenance costs of RM 150,000 / year. It has a payback period of 6.21 years and IRR of 17.36 %. However, if CCCS is chosen it will has a payback period and IRR of 8.7 years and 8.1 % respectively. So, DCS should be preferred than CCCS and SUS for the UPM Engineering Complex and Technology. The sensitivity analysis of DCS and CCCS is shown in Fig. 2.

Table 5 The economics comparison between the DCS and CCCS

INITIAL COSTS, RM	MAINTENANCE COSTS, RM	PAYBACK PERIOD (YRS.)		IRR (%)	
		DCS	CCCS	DCS	CCCS
6,500,000	130,000	4.81	7.84	19.25	10.23
7,500,000	150,000	6.21	8.67	17.36	8.07
8,500,000	170,000	7.69	13.16	12.80	5.90
9,500,000	190,000	9.25	16.37	9.94	3.94
10,500,000	210,000	10.89	20.06	7.54	2.22

Discussion

Design Aspect

Total area to be cooled in UPM new ECT is 16084 m^2. The corresponding cooling load is 14.2 x 10^6 Btu/h (4167.7 kW), which is equivalent to 1185 RT. From calculation, the direct chiller capacity was 413 RT. The amount used to charge the ice in the thermal energy storage (TES) by the chiller is 276 RT. The charged ice is used to cool the water passing through it, which will be distributed to buildings during daytime as chilled water to meet the air-conditioning demand. Total volume of TES tank needed is 164 m^3. Therefore, two TES tanks of capacity 100 m^3 have been chosen. The storage energy, Q_{st} is 3042 RTh. In addition, base chiller of capacity 100 RT is to used supplement demand for low period that is between 6.00 p.m. to 10.00 p.m.

The designed values for chiller capacity and TES are indeed quite satisfactory due to low error when compared to those values using STOCKAID software simulation carried out by K.J. Engineering Sdn. Bhd. All errors for the items that were used to determine suitable chiller capacity and TES ranges from 4% to 13%. The only exception is the TES tank capacity that has higher error (27.1%). This error is strongly due to the other items' errors, which have been carried forward prior to the TES tank volume calculation.

In most DCS plant, indirect system is preferred. In this system, heat exchangers are to be placed at the central plant as well as at the customers' side (buildings). Indirect system has greater flexibility, less disturbances and ease of control. It is because at the customers' sides, there may possibly be some interruptions like bursting of radiators and contamination of impurities into supply and return streams, which will not affect the overall DCS operation. Therefore, water treatment costs will be lower because repair and maintenance works are only carried at the users' side rather than entire DCS plant if direct system is to be employed.

Centrifugal Cooling system has been chosen because the current calculated cooling capacity of ECT is not big enough to be supplied using absorption system. Centrifugal system is powered by electricity and is much easier. With the inclusion of thermal energy storage (TES), high electricity consumption will be much reduced. Moreover, it is believed that sum of the floor areas for every building's cooling plant is much higher than the area occupied by a DCS plant to provide air-conditioning to those buildings involved [5].

The maintenance costs for each SUS is RM 200 per annum (gas insertion, cleaning, repairing and change of components) and the total maintenance costs is RM 121,800 per year. While the maintenance costs for both CCCS and DCS are comparatively lower than SUS. Besides that, it will be more economical if the plant is constructed together with the construction of the building. In terms of efficiency, DCS has the highest efficiency, followed by CCCS and SUS. It is because SUS to provide needed of cooling load will consume 17904 kWh, where as CCCS and DCS will require only 7700 kWh for the same cooling load.

Economical Aspects

From the economic point of view, although the cost of split-unit system (SUS) is three times lower than DCS, but it consumed 3.7 times more power. With quite huge energy savings costs of RM 930,667 per year, the additional investment RM of 4.85 million can be recovered quite swiftly, i.e. by 6.2 years. The CCCS also used less power and energy than SUS and this gives an annual saving of RM 674,500. Also from the sensitivity analysis, DCS has more advantage than CCCS in yielding higher IRR and lower payback period. Furthermore, by using DCS chiller, capacity is significantly lower which is 412 RT if compared to 1185 RT for CCCS. Off-course, total electricity billing in DCS is definitely less than CCCS.

Environmental Aspect

Table 6 clearly show that DCS emits the least amount of carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxide (SO_x) and nitrous oxide (NO_x) gases, followed by CCCS and SUS.

Table 6 Emission of gases from DCS

EMISSION OF GASES	EMISSION FACTOR	TYPES OF AIR-CONDITIONING SYSTEM		
		SUS	CCCS	DCS
CO_2	0.623 kg/kWh	2.677×10^6 kg	1.15×10^6 kg	1.15×10^6 kg
CO	0.289 g/kWh	1.242×10^3 kg	0.53×10^3 kg	0.53×10^3 kg
NO_X	2.350 g/kWh	10.098×10^3 kg	4.34×10^3 kg	4.34×10^3 kg
SO_X	1.349 g/kWh	5.797×10^3 kg	2.49×10^3 kg	2.49×10^3 kg

Table 5 Emission of Various Gases by SUS, CCCS and DCS.

Loading, Charging and Discharging Profile

Fig. 1 shows the estimation of a cooling load profile for the ECT. Maximum daily demand occurs at 1400 hr, i.e. 1185 RT. Daily demand is 28,128 kWh (sum of hourly demand). By using thermal energy storage (TES), chiller capacity can be reduced from 1200 RT (in conventional system, CCCS) to 413 RT. The additional required cooling load will be supplied by TES. The ECT of UPM registers a sharp declined in cooling load requirement from 1500 to 1700. The cooling load is further reduced after official working hours most probably due to some night classes and other minor usage of air-conditioning.

Fig. 3 shows the cooling load profile for DCS with TES installation of the ECT. Direct chilled water production from the main chiller of capacity 400 RT is from 0800 to 1700 (10 hours). Then the direct chiller capacity of 276 RT is used to charge the TES tanks to make ice. The TES tanks are charged for 14 hours. A base chiller of capacity 100 RT will be used to supply the additional cooling load requirement from 1700 to 2300.

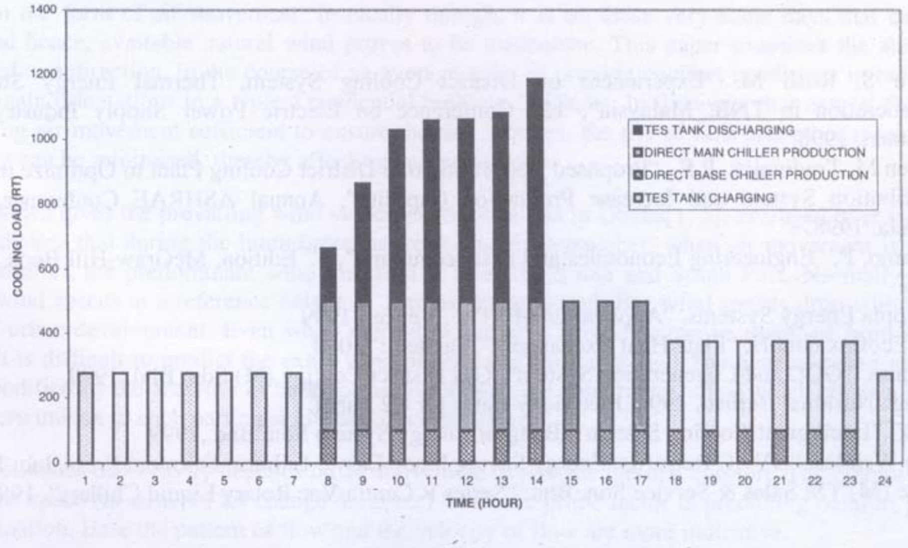

Fig. 3 Cooling load profile of ECT with TES installation

During the period from 0800 to 1700, main chiller will supply chilled water to four substations. However the main chiller capacity is only 400 RT. Therefore TES tanks and base chiller capacity will also be supplying chilled water to meet the cooling load demand. The chilled water supply temperature ranges from 3°C to – 7°C. The return cooled water from four substations will has temperature ranges from 12°C to 15°C. It enters into TES tanks, main chiller and base chiller so that chilled water can be produced and supplied again. After 1400, the TES capacity has been used up. The main chiller and base chiller will continue to provide necessary required cooling load of 291 RT to 232 RT from 1500 until 1700. Then the main chiller is used for charging TES tanks and base chiller is used to provide additional cooling load of 78 RT to 26 RT from 1700 until 2300.

In actual practice, the main chiller only starts to charge TES tanks from 2100 until 0700. It is because at this period, there is a special electricity tariffs offered by TNB. The main chiller is in resting state. Besides that, the main chiller will not supply chilled water at its maximum capacity of 412 RT from 1500 to 1700. This is because in reality there is control devices to send signals to the main plant to indicate any low cooling load areas and chilled water capacity supply to those identified areas will be reduced accordingly to their actual requirement. Therefore more savings shall be obtained in actual situation.

Conclusion

Overall designed DCS configuration of chiller and TES tank storage capacity has an error, which ranges from 4% to 13%. This is quite small compared to the actual results, which were obtained by simulation using STOCKAID software. The economical aspects of DCS are much more attractive compared to SUS such as lower power consumption.

This additional investment is recovered in just 6.2 years when DCS yields an annual IRR of 17.4% compare to CCCS with IRR 8.1 % takes 8.7 years. Moreover, with current economy slow down in the country, any investment that gives a return of 17.4% per year should be given a good consideration. DCS is more environmental friendly than CCCS and SUS. DCS and CCCS both produce 57% and 35.1% less pollutant gases than SUS. DCS will be adopted as a better way to provide air-conditioning for future developments in UPM.

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