DISTRICT COOLING POTENTIAL FOR MEGA DEVELOPMENTS IN SRI LANKA

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Abstract

This paper presents the study related to existing buildings from a perspective of a district cooling system and its feasibility forthe projected mega developments in the country. This study is focused to show the District Cooling System (DCS) conversion suitability for a cluster of existing buildingsin the city of Colombo.Nine large scale buildings in Colombo having central air conditioning systems and having different cooling load patterns are selected for the study. The estimated cooling demand profile shows that the maximum cooling demand of the system is around 6,000 TR.

Five suitable chiller options are considered for the cooling production based on the total capacity of the district cooling system and profile of the overall cooling demand.The maximum and minimum electrical energy savings that can be achieved by switching to the DCS from the existing individual systems are 6.42 and 5.67 million kWh per year. This energy savings is expected to result in a reduction in coal usage (assuming 60% of electricity generating by coal and oil, and rest by hydro) by about 1420 and 1240 tons per year respectively and reduction in CO_2 emission of about 4,990 and 4,365 tons per year respectively.Discounted Cash Flow Analysis indicates that the best option has a NPV of LKR 396 million, IRR of 13.5% and benefit to cost ratio of 1.35. The sensitivity analysis of the best option reveals that even with the worst combined effect of the various parameters, the DCS is viable as it has a NPV of LKR 87 million, IRR of 11.8% and benefit to cost ratio of 1.07.

Consequently, DCS is viable to implement in Colombo under the conditions and assumptions employed. It could be concluded that DCS could be a viable option for the forthcoming Colombo Port City Project and MegapolisDevelopment Projects since they can be implemented smoothly by planning the piping distribution network into the master plans of the projects.

Keywords: Central chiller plant, district cooling, cooling load profile, energy savings, discounted cash flow analysis, sensitivity analysis.

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Introduction

Sri Lanka is currently achieving rapid development after the civil war. Consequently, large scale commercial buildings are being built in the country. Most of existing large scale commercial buildings (hotels, commercial and office complexes etc.) is located in Colombo and main cities. In addition, a large multi-functional business city named "Colombo Port City" is under construction.Megapolis projects are on discussion stage and would be to build in near future. Almost all these buildings will have their own electrical driven central air conditioning systems incurring 40-60% of building electrical energy consumption tocater the building cooling requirements for comfort and health aspects of the occupants. Under certain conditions, these air-conditioning systems would operate at poor part load conditions leading to more than the necessary electrical energy & power consumption. This may have a major impact on the national grid and would result in unnecessary out flow of foreign exchange from the country since electricity is generated mainly from imported coal and oil. DCS is a central cooling production and distribution system instead of individual central air conditioning plant of buildings and it could minimize installed equipment capacities, environment pollution, space usage, vibration & noise due to equipment, repair and maintenance cost, investment cost, inventory and related cost to the user. Such systems could eliminate poor part load operation of individual chiller plants and will definitely maximize the system efficiency.

Literature

The first DCS in the world was established in Denver's Colorado Automatic Refrigerator Company in 1889 (AREA, 2014). Large scale district cooling systems were built in the Rockefeller Centre in New York City and the United States Capitol buildings in the early part of 20th century (AREA, 2014). Even though the first district cooling system was established in early part of the 20th century, commercial district cooling systems were established in the USA in commercial areas near cities after mid-20th century. However, district cooling is nowadays spreading over the world. When considering regional counties, Singapore and Malaysia also are now using district cooling technology and India is looking at the feasibility of district cooling. The trend for district cooling is enhancing over the world due to urbanisation, rapid development of some countries, climate change and sustainability.

District cooling system is a central cooling production and distribution system instead of individual central air conditioning plantsat buildings. District Cooling System (DCS) minimizes installed air-conditioning equipment capacity, environment pollution, space usage, vibration & noise due to equipment, repair and maintenance cost, investment cost, inventory and related cost to the user.There are several techniques to generate district cooling such as free cooling (local sources such as ocean and lakes etc. using natural temperature gradient), with heat exchangers, compression (electrical) chillers (grid electricity or electricity generated from municipal solid waste or a combination of aforementioned sources), absorption chillers (conventional waste heat etc.) and heat pumps.Areas with high density of large size buildings are suitable for cost effective district cooling systems. The most suitable technology or combination of technologies is selected considering economic and other factors like; local energy systems, availability of natural resources, environmental constraints and local authority rules & regulations.

Cold thermal energy storage systems can be incorporated for load levelling, minimizing operation cost and to improve the reliability of a district cooling system. Using a benchmark on market demand per meter of distribution (kW/m of piping) will give an indication whether it is economically feasible to deliver district cooling to a certain area (RESCUE,2015).Current annual district cold deliveries can be estimated to be around 300 PJ per year, thereof around 200 PJ in the Middle East, 80 PJ in USA, 14 PJ in Japan, and 10 PJ in Europe (Werner S, 2017).District cooling is becoming increasingly relevant as cooling demand surges worldwide. Energy consumption for space cooling increased 60% globally from 2000 to 2010 (IEA, 2014b). Today, district cooling is relatively common in North America, Europe, the Middle East (GCC - Gulf Cooperation Council), and Asia Pacific & Africa have 43%, 5%, 33% and 19% share respectively in the world district cooling market (Marafeq Qatar, 2015).

Data and Analysis

The proposed district cooling system was considered for nine selected existing large buildings (hotel, office and commercial) operated with central air-conditioning systems in the Colombo central area. Required data was collected and comprehensively analysed to obtain the individual building cooling load profiles. Subsequently, the individual building cooling load profiles were analysed to project the total cooling load profile of selected building for the district cooling system.

For the buildings which had data from energy audits, the cooling load was estimatedfollowing equation 1.

$$\boldsymbol{BCL} = \mathbf{1.19} \times \boldsymbol{CHWFR} \times (\boldsymbol{CHWRT} - \boldsymbol{CHWST}) \text{----------------------- (1)}$$

Where;
BCL - Building cooling load, (TR)
CHWFR - Chilled water flow rate, (l/s)
CHWRT - Chilled water return temperature, (°C)
CHWST - Chilled water supply temperature, (°C)

For the buildings which did not have data from energy audits, the cooling load was estimated following equation 2.

$$\boldsymbol{BCL} = \boldsymbol{MOCL} \times \boldsymbol{CF} \text{------------------------ (2)}$$

Where;
BCL - Building cooling load, (TR)
MOCL - Maximum operating chiller load, (TR)
CF - Loading factor

This equation was used to generate the cooling load profile and was compared with the cooling load profile which was estimated during a detailed energy audit and results are approximately same (see Fig.1).

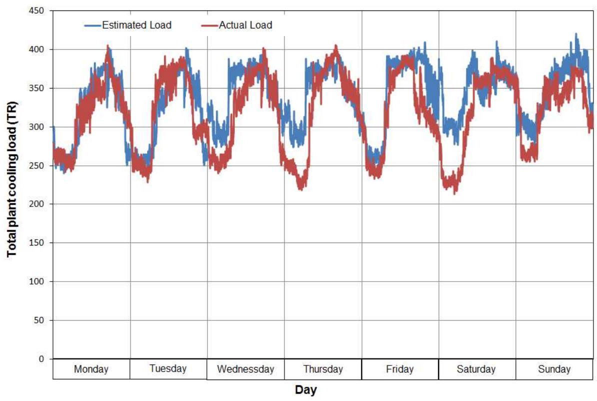

Fig. 1 :Cooling load profiles from two methods

The demand of the DCS was analysed using these individual building loads by using equation 3.

$$\boldsymbol{Demand\ of\ DCS\ (TR)} = \sum \boldsymbol{Individual\ Building\ Cooling\ Load, (TR)} \text{-------------- (3)}$$

Analysis of demand of the DCS is summarised as shown in Fig. 2 and 3.

The maximum cooling demand for the DCS is 6,000 TR and occurs during the day time on weekdays. The cooling demand of the DCS during day time on weekdays ranges from 5,400 to 6,000 TR. The minimum cooling demand of the DCS is 1,800 TR and occurs after late night on week days. The cooling demand of the DCS from 7:00 to 14:00 on Saturday ranges from 4,800 to 5,200 TR and is probably due to office hours on Saturdays. The cooling demand of the DCS during the weekend after 14:00 on Saturday ranges from 2,200 to 3,600 TR.

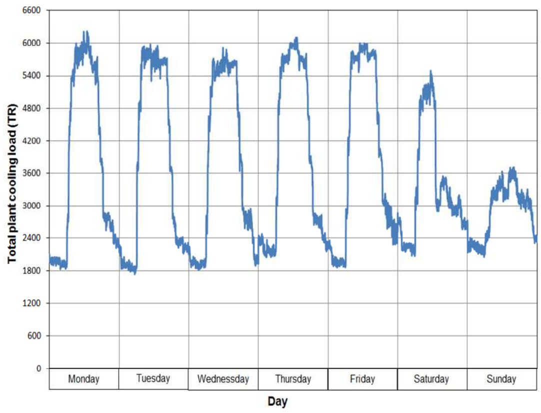

Fig.2 : Cooling load profile of DCS

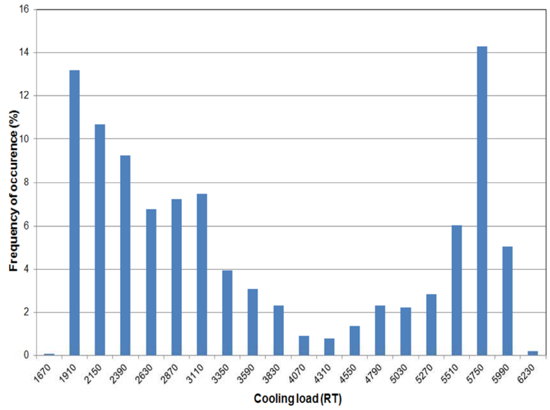

Fig. 3 :Frequency of occurrence of DCS

Frequency of occurrence of the DCS cooling load is shown in Fig.2 and it shows that the highest frequency of occurrence is 14.3% of operating time of the DCS at 5,750 TR. The second highest frequency of occurrence is 13.2% of the operating time of the DCS at 1,910 TR.

System and Benefits

The capacity of DCS was estimated as 6,600 TR with a capacity margin factor of 1.1. Five suitable chiller combination options were judiciously selected for the DCS to supply the cooling demand by considering cooling load profile {base load (1,800 TR), maximum load (6,600RT), and load step up & down levels}, frequency of occurrence, generally available chiller capacities in market, energy efficiency, investment, redundancy& past experience about chillers and shown in Table 1.

Table 11 : Chiller option for DCS

Option	Chiller combination (TR)
Option 1	2×3,300
Option 2	1×3,000 & 2×3,600
Option 3	1×1,600, 1×2,000 & 2×3,000
Option 4	1×1,400, 1×1,800 & 2×3,400
Option 5	1×600 & 6×1,200

Chilled water temperature difference greatly affects the pipe size as well as distribution system cost. Cooling production plant's chiller chilled water temperature difference was taken as 8°C (12 - 4°C) and this temperature difference was considered for the distribution pipe sizing.Plate heat exchangers are the most suitable energy transfer unit for ETS in DCS as they are effective and less in size than other types. Existing chilled water pumps in the buildings are to be used with the heat exchangers and then, the user side pressure drop of the heat exchanger was taken as equal as or less than current chiller evaporator pressure drop. Source side pressure drop of the heat exchangers also was considered minimum as much as possible to achieve lower distribution energy consumption.

Findings of the energy audits for some buildings considered for the DCS showed that the average chiller system efficiency is 1 kW/TR and average chilled water pump efficiency is 0.06 kW/TR. Therefore, the average chiller system efficiency without chilled water pumps is 0.94 kW/TR. The DCS efficiency can be estimated based on the chillers, primary chilled water pumps, condenser water pumps, cooling towers and distribution pumps in operation. Then, the energy savingswere estimated as below.

$$\boldsymbol{ES} = \boldsymbol{CL} \times \boldsymbol{OT} \times (\boldsymbol{PCSE} - \boldsymbol{DCSE}) \text{-------------- (4)}$$

Where;

ES - Energy saving, kWh/year
CL - Cooling load, TR
OT - Operating time, h/year
PCSE - Present chiller system efficiency, kW/TR
DCSE - District cooling system efficiency, kW/TR

(Note: Present chiller system efficiency was considered without chilled water pump power as the chilled water pumps are to be used for the building chilled water loop).

Investment for the DCS was estimated considering cooling plant building, cooling plant equipment, distribution piping with excavation & concreating, heat exchangers with accessories as they are the main components of the DCS. Currently, individual buildings incur maintenance cost for their own chiller plant. However, after implementing the DCS, it would be necessary to maintain the chiller system only in the DC production plant. Therefore, maintenance cost savings were estimated consideringproposed DCS and individual plants in buildings.Discounted Cash Flow Analysis (DCFA) was carried out with estimated cost saving through energy saving, investment and maintenance cost saving for the considered options of DCS by considering appraisal period, discount rate, incremental rate of electricity tariff, performance depreciation rate and incremental rate of maintenance cost were taken as 26 years, 10 %, 5%, 0.5% and 5 % respectively. Summary of the DCFA for all five options of the DCS is shown in Table 2.

Table 12: Summary of DCFA

Description	Option 1	Option 2	Option 3	Option 4	Option 5
Total energy savings (million kWh/year)	6.38	6.42	5.88	6.22	5.67
Present value of costs, (million LKR)	1,124	1,133	1,114	1,140	1,041
Present value of benefits, (million LKR)	1,519	1,532	1,405	1,479	1,347
Net present value (NPV), (million LKR)	395	396	291	339	305
Benefit to cost ratio	1.35	1.35	1.26	1.30	1.29
Internal rate of return (IRR), (%)	13.5	13.5	12.6	13.0	12.9

Cumulative cash flows for all five options are shown in Fig. 4.It can be clearly seen by analysing results of DCFA for all five options of the DCS that the Option 2 is the best option since it offers the highest NVP, benefit to cost ratio and IRR which is greater than discount rate.

Then, the sensitivity analysis (SA) of the best option (Option 2) is carried out by considering single parameter influence with 10% of increment (INVI) and drop (INVD) of investment, 5% of improvement (SPI) and drop (SPD) of system performance and 1% of improvement (DRI) and drop (DRD)of discount rate.The sensitivity analysis is also carried out by considering simultaneous influence of the parameters for the best option was analysed by considering best and worst combined effect of parameters. The best was considering drop of investment by 10%, improvement of system performance by 5% and drop of discount rate by 1%. The worst was considering increment of investment by 10%, drop of system performance by 5% and increment of discount rate by 1%. Findings of the sensitivity analysis is summarised in Table 3, and cumulative cash flows are shown in Fig. 5.

Table 13: Summary of sensitivity analysis for the best option (Option 2)

Description	INVI	INVD	SPI	SPD	DRI	DRD	WORST	BEST
Present value of costs, (million LKR)	1,246	1,019	1,133	1,133	1,133	1,133	1,246	1,019
Present value of benefits, (million LKR)	1,532	1,532	1,601	1,462	1,397	1,688	1,333	1,765
Net present value (NPV), (million LKR)	286	513	469	330	264	555	87	745
Benefit to cost ratio	1.23	1.50	1.41	1.29	1.23	1.49	1.07	1.73
Internal rate of return (IRR), (%)	12.3	14.9	14.0	12.9	13.5	13.5	11.8	15.5

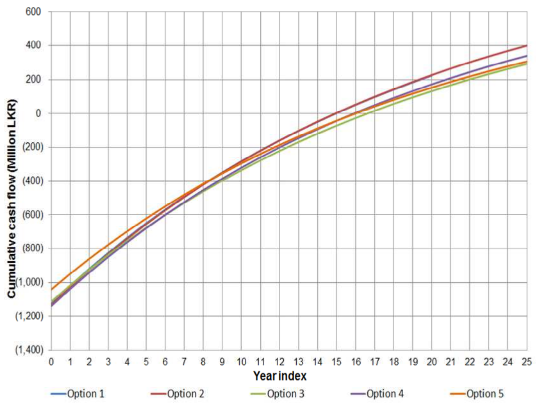

Fig. 4: Cumulative cash flow of DCFA

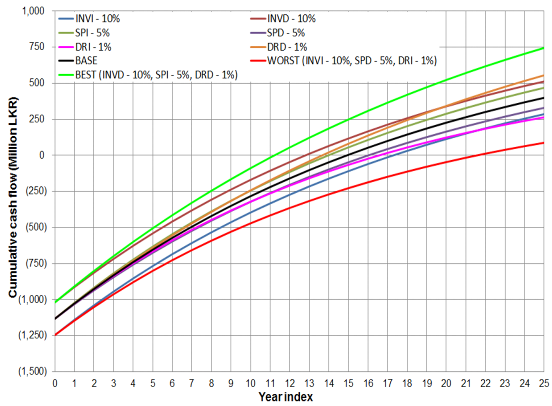

Fig. 5: Cumulative cash flow of SA

Discussion

This study focused on viability of a district cooling system for existing large commercial buildings(hotel, office and commercial) in Colombo central area. The individual building cooling load was estimated and used to estimate the total capacity of the district cooling system. The total cooling demand of the buildings is about 6,000 TR and the capacity requirement of the district cooling system was taken as 6,600 TR with a capacity margin factor of 1.1. Five suitable chiller options were considered for the cooling production based on the total capacity of district cooling system and profile of the cooling demand. Distribution system was analysed with the total plant capacity and individual building cooling demand. Heat exchangers for the buildings were sized considering the individual building cooling load profile, redundancy and maintenance needs. Performance and price of chillers, pumps, cooling towers, piping and heat exchangers were obtained from internationally and locally reputed companies and manufactures. Energy and cost savings were estimated for all five options. Investment for each option was estimated and maintenance cost saving was also estimated.

Then, discounted cash flow analysis was carried out for all five options and Option 1 & Option 2 are more attractive out of all options and Option 2 is the best option for the DCS. Thereafter, a sensitivity analysis of the best option was carried out by considering investment, system performance and variations in discount rate and combination of aforementioned parameters such that best and worst parameter combinations towards the DCS implementation. Result of other combinations of the parameters lies between the best and worst combinations and are viable as the worst combination is also found to be viable (since NPV is positive and IRR is greater than respective discount rate).

Chilled water pipe laying is the major concern when implementing the DCS in Colombo due to complexity in the city. Therefore, a comprehensive survey on DCS pipe laying is required to carry out before implementing the DCS for existing buildings in Colombo.

Conclusion

The maximum and minimum energy savings that can be achieved by switching to the DCS from existing individual systems are 6.42 and 5.67 million kWh per year and are for Option 2 and Option 5 respectively. These energy savings translate to maximum and minimum energy cost savings of LKR 106 and 93.5 million per year respectively. This energy savings will also result in a reduction in coal usage(assuming 60% of electricity generating by coal and oil, and rest by hydro) by about 1420 and 1240 tons per year respectively and reduction in CO_2 emission of about 4,990 and 4,365 tons per year respectively.

The maximum and minimum maintenance cost savings that can be achieved by switching to the DCS from existing individual systems are LKR 10.35 and 8.8 million per year respectively. The maximum maintenance cost saving is from both Option 1 and Option 2 while the minimum maintenance cost saving is for Option 5. The maximum and minimum investment costs for implementing the DCS are LKR 1,140 million and LKR 1,041 million respectively and are associated with Option 4 and Option 5 respectively.

DCFA indicates that Option 1 & Option 2 are more attractive, but the best option out of all five options is Option 2 which has a NPV of LKR 396 million, IRR of 13.5% (> discount rate of 10%) and benefit to cost ratio of 1.35.The sensitivity analysis of the best option reveals that even with the worst combined effect of the various parameters, the DCS is viable as it has a NPV of LKR 87 million, IRR of 11.8% (> discount rate of 11%) and benefit to cost ratio of 1.07.

Therefore, based on the findings of the study, it is viable to implement a district cooling system for commercial buildings in Colombo under the conditions and assumptions employed in the study.Further, including the buildings currently under construction in Colombo and integrating a cold thermal energy storage system would make the DCS more viable. Since the new buildings are much close to the proposed district cooling system, more energy saving can be achieved while the investment cost would reduce. Although cold thermal energy system will not result in energy savings, it will lead to cost savings due to current electricity tariff structure in the country.The district cooling system in Colombo central area would be furthermore attractive if the electricity required for the DCS is produced fully or partially by the municipal solid waste (MSW) as Colombo Municipal Council is responsible for the highest MSW management in the country and it is currently a serious issue.

As it is revealed that DCS is viable to implement in Colombo under the conditions and assumptions employed, it could be concluded that DCS is as a viable option for the forthcoming Colombo Port City Project, Airport Expansion Project and Megapolis Projects since they can be implemented smoothly by planning the piping distribution network into the master plans of the projects. Hence, an early intervention for a detail feasibility study for the said projects is recommended.

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