DISTRICT COOLING SYSTEMS FOR MEGA PROJECTS IN SRI LANKA

Shanith Kankanamge, Nayanthara De Silva[*] and C.R. De Silva
Department of Building Economics, Department of Computer Science and Engineering
University of Moratuwa, Sri Lanka

Abstract

In marching towards sustainable development after 30 years of civil war, Sri Lanka is currently undergoing a boom time with regard to its construction industry. A number of mega projects are ongoing in the capital city of the country. Thus, managing the high operational costs of these upcoming mega facilities will become a challenging task in near future. Air conditioning is identified as a prominent building facility in terms of high operational costs. The aim of the research is to study the effect of District Cooling Systems (DCS) on the reduction of energy demand arising from the operation of mega facilities and, thus, subsequently reducing the operational costs.

A qualitative approach was selected as the research methodology to achieve the research objectives. An expert survey was carried out to identify the dominant enablers of DCS implementation in the country. The expert survey included professionals from multi-disciplinary backgrounds such as investors, HVAC contractors, DCS engineers and facility managers. Furthermore, an in-depth case study was carried out with the intention of validating the potential energy saving with the proposed DCS approach. Six existing large-scale buildings which are located close to each other were selected for the case study.

The results showed that the implementation of DCS in Sri Lanka (as an energy conservational approach) has tremendous potential. They showed a 25% reduction in energy demand when maintaining a temperature of 170C. Thus, DCS can be proposed as an effective approach to reducing the operational costs of mega facilities. Furthermore, the adaption of these advanced technologies in infrastructure developments will enhance the attraction of potential international investors to the country.

Keywords: District cooling systems, Energy management, Mega projects, Operational cost, Facilities management

---

[*] Corresponding Author: Nayanthara De Silva; E-mail- endds@uom.lk

Introduction

The construction industry can be identified as a most important industry in the development of a country (Towey, 2012). The construction industry in Sri Lanka is currently in a boom period with a number of world renowned property developers investing in the commercial capital city, Colombo. Such investments include the World Capital Centre, Colombo's Financial City and the Lotus Tower (an iconic Colombo building). The rate of growth of the construction industry is high, close to 9.94% (Department of Census and Statistics, 2017), while similar Asian countries only have a growth rate of 4.5% - 5% in construction (Burger, 2015). Furthermore, Colombo has been listed as the fastest growing city by the MasterCard Survey in 2015 due to the large volume of construction projects (Santiago, 2015). As a late comer to such development, Colombo can plan to avoid circumstances which other developed cities face currently after the major developments have been completed (Business Times, 2016). Developed cities mainly face the issues of energy demand and supply, and upgrading to newer infrastructural techniques with minimum disturbance to the present operations (Charest, Flyvbjerg, Bruzelius, & Rothengatter, 2004). Enormous constructional expansion initiates a need for more energy due to increased number of built properties (Chow et al., 2003). Sri Lankan energy production is at a point where 50% of total export income has been allocated to the importation of fossil fuels (Ministry of Power and Energy, 2015).

Air conditioning can be identified as a major service within built environments especially in tropical climates such as in Sri Lanka. Building cooling has been identified as a basic utility rather than a luxurious commodity by modern society. Energy accounting reports show that 68% of the demand for energy in Sri Lanka occurs because of HVAC applications (Sri Lanka Sustainable Energy Authority, 2014). Furthermore, the demand for energy occurring through HVAC applications has expanded by 60% universally from 2000 to 2010 (International Energy Agency, 2015). The statistics prove the significance of utilising energy-efficient HVAC systems that can bring down energy demand and, subsequently, reduce the operational cost while achieving high operational cost efficiencies.

District Cooling Systems (DCS) have been identified as the major and significant approach to reducing energy demand and achieving cost efficiencies by the United Nations Environment programme (United Nations Environment Programme, 2015). DCS have been known for their ability to produce energy efficiencies along with environmental conservation initiatives in high dense areas where cooling is required (Gang et al., 2015). Furthermore, as per the UNEP, Gulf leaders predict that 30% of the total cooling demand of the region can be met with DCS by 2030, saving the equivalence of 200,000 barrels in the process of fuel generation (avoiding 20GW of power generation per day). Zhang et al. (2016), have stated that, for the optimum use of DCS, the designing process must utilize the available natural resources. Natural resources such as lake water and sea water can be integrated within the DCS to achieve even more energy efficiencies. Additionally, a number of different technologies have been introduced via different systems to enhance energy conservation in the production of chilled water for cooling purposes (Chan et al., 2004). Gang et al. (2015) showed that DCS can achieve significant energy savings when coupled with environmental factors.

Overview of DCS

Originally, the concept of DCS was developed as District Heating Systems (Rezaie and Rosen, 2012). Later on, with the invention of electrical air conditioning in the early 1900s the concept of

commercial cooling was utilized by industry. Furthermore, the concept of district energy entered the market with the commercialized development of larger cooling systems and heating systems (Udomsri et al., 2012). The most outstanding feature, as compared to a typical central AC system, is that DCS produces large amounts of cooling energy in a central plant and supplies cooling energy to several buildings instead of a single building (Cabeza and de Gracia, 2015).
The operational cycle of a typical DCS is given in Fig. 1. In a DCS, a coolant travels through the central cooling plant to the multiple buildings in the loop through a central distribution network to supply chilled water to buildings and other connected properties in the system (Chan et al., 2005; Kaushik and Nand, 2015).

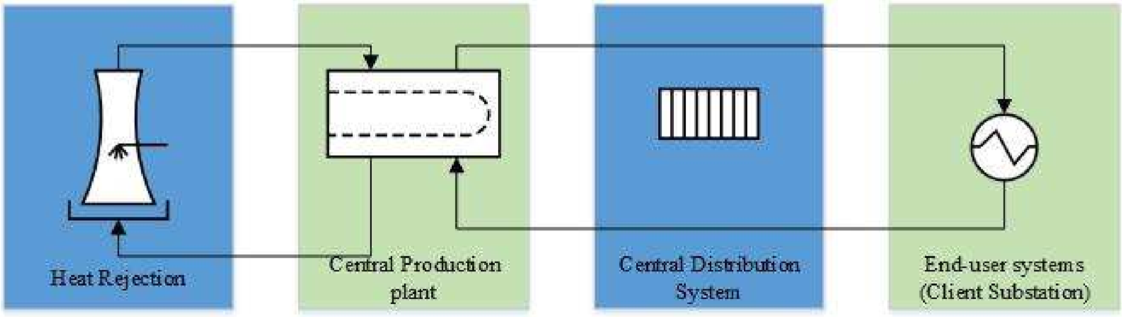


Fig 1: Typical DCS Layout
Adopted from Chow et al. (2003)

- Central production plant - Central production plant is the location where chilled water is produced to be distributed through the central distribution network and, thus, it acts as the heart of the DCS system. This consists of chiller banks, primary and secondary pumps etc. The central production plant must be located in a convenient and economical location to distribute chilled water to the entire serving area.
- Central distribution network - The central distribution network is an underground pipe network system which connects the central production plant and the client buildings. It transmits chilled water to the end user systems and brings back heat transferred water (heated water) from end user systems.
- End-user systems - Clients of DCSs are the buildings which are connected to the central distribution network. DCS will only provide chilled water to the heat transfer station of the client substation. The circulation arrangement of the chilled water inside the client building is the responsibility of the property holder.
- Heat Rejection System - Heat generated in the built environment is transferred back to the central distribution system through end-user systems and the central distribution network. The transferred heat that is received by the central system is removed to the atmosphere.

Researchers have introduced advanced DCS technologies such as renewable cooling systems and renewable heat rejection systems (Gang et al., 2015; Gang et al., 2014). In situations where there is an absence of such sources, conventional cooling towers can be employed. When compared to a traditional Individual Cooling System (ICS), DCS provides massive and collective cooling production which provides greater efficiency (Chow et al., 2003). At the same time, DCS reduces the space required to install ICS components and allows a user to utilize space more precisely (Chan et al., 2006).

Based on the application of DCS, three main technical approaches for DCSs can be identified: (1) District cooling systems with electric chillers, (2) Thermal Energy Storage, and (3) Tri-generation technology (Yik, et al., 2001). Among them, Thermal Energy Storage (TES) is widely used due to its energy conservational approach and cost reduction through load transferring. TES is a mechanism introduced with the ambition of reducing energy costs by shifting operation hours and promoting the storage of energy (Augusto et al., 2015). Furthermore, it also reduces peak time load on the national electricity grid (Nuytten et al., 2013). Fig. 2 demonstrates the power consumption pattern and the shifting loads of the national electricity system with TES.

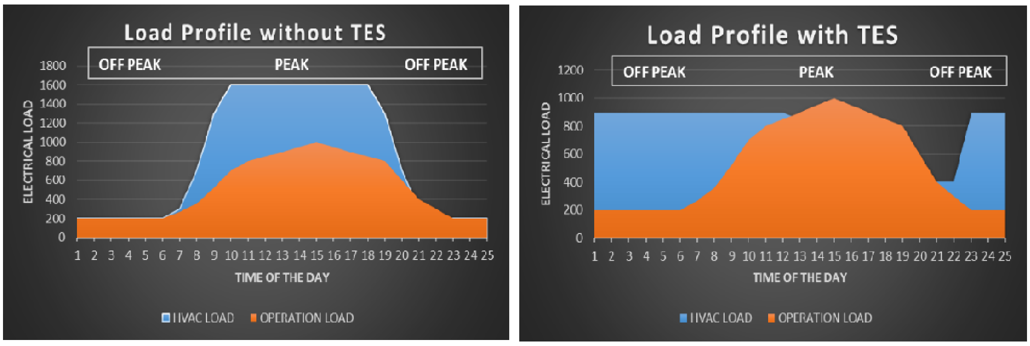


Fig 2: Power Distribution with TES

Adapted from Valappil (2015)

As stated by Paksoy (2007), TES can reduce energy costs by 20% - 30% when compared with a conventional AC system (Cabeza et al., 2015). However, due to high temperature ranges in tropical countries, the benefits that could be gained from TES can be reduced. Alternatively, cold seawater has been used in advanced systems to cool down the returned warm water from the end user systems (Atilhan et al., 2011).

Research Methodology

This research is exploratory in nature. It uses a case study approach to study the perception of individuals toward the implementation of DCS in Sri Lanka. Two case studies were used for two different objectives as follows.

Case study I: A prototype DCS connecting six high rise buildings was developed. The objective of case study 1 was to analyse the economic feasibility of DCS. The framework shown in Fig. 3 was used to select buildings for case study 1. Energy bills, sub meters' records and the data logs from the building management system (BMS) (taken from September to November 2016) were used to obtain data for the case study.

An expert survey was carried out to validate the prototype DCS for case study I. Details of the participants in the expert survey are shown in Table 1.

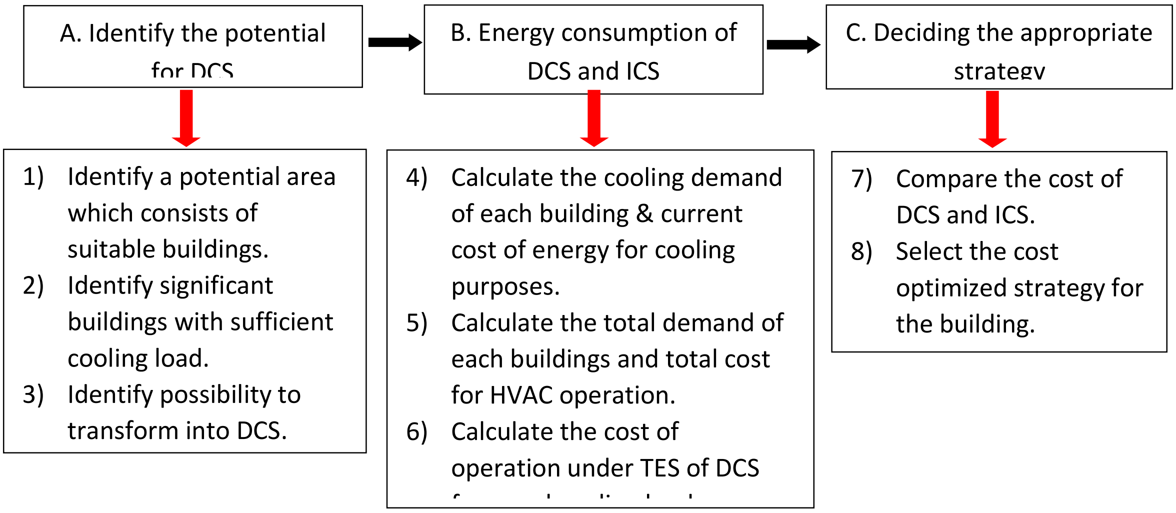
Table 1: Expert survey-1 interviewee information

Interviewee code	EI-1	EI-2	EI-3
Industry Experience	+15 Years	+15 Years	+15 Years
Current Employer	Hotel	Hotel	Sri Lanka Energy Managers Association
Designation	Hotel Engineer	Hotel Engineer	Executive committee
Max. Level of Education	B.Sc. Holder	B.Sc. Holder	M.Sc. Holder

Case study II: Case study II was used to propose an energy savings' DCS application for a current on-going mega project in Sri Lanka.

Analysis and Discussion

The framework shown in Fig. 3 was used to design the prototype DCS and analyse its economic feasibility.



A. Identify the potential for DCS

B. Energy consumption of DCS and ICS

C. Deciding the appropriate strategy

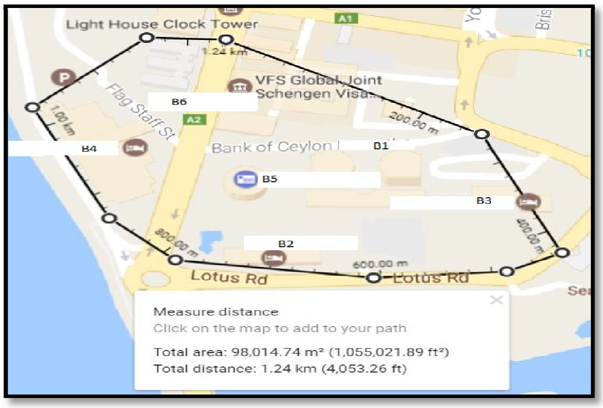
1) Identify a potential area which consists of suitable buildings.
2) Identify significant buildings with sufficient cooling load.
3) Identify possibility to transform into DCS.

4) Calculate the cooling demand of each building & current cost of energy for cooling purposes.
5) Calculate the total demand of each buildings and total cost for HVAC operation.
6) Calculate the cost of operation under TES of DCS

7) Compare the cost of DCS and ICS.
8) Select the cost optimized strategy for the building.

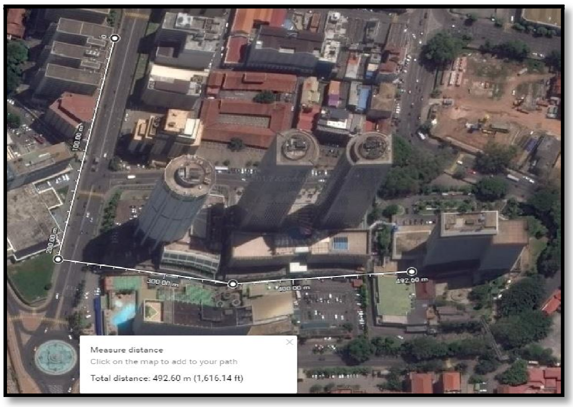
Fig 3: Framework of prototype DCS

Step 1: An area covering 98.01 Km^2 was selected (Fig. 4) as several large scale buildings are located within close proximity.



Measure distance
Click on the map to add to your path
Total area: 98,014.74 m² (1,055,021.89 ft²)
Total distance: 1.24 km (4,053.26 ft)

Fig 4: Selected area for prototype DCS



Measure distance
Click on the map to add to your path
Total distance: 492.60 m (1,616.14 ft)

Fig 5: Length of the DCS distribution network

The total length of the central distribution network for the prototype DCS was 492.60m in its shortest route (Fig. 5). A double line of pipes must be laid for the supply of chilled water and the return of warm water which makes the length of the pipe line 985.2m. Since the return pipeline needs not to be insulated the cost of the distribution network can be further reduced. The piping cost cannot be quantified due to the un-defined location of the TES plant in the system. The location of the TES plant was difficult to decide without an in-depth study of underground infrastructure provided for building services. Therefore, only the total cost of ice production was considered for calculation purposes.

Steps 2 and 3: Six buildings in which the energy consumption is greater than 1000TR were selected (refer to Table 2). The possibility of transferring existing ICS into DCS was elicited from the experts.

Table 2: Description of the buildings in the prototype DCS

Building Code	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**
Building Category	Office building	Hotel building	Hotel building	Hotel building	Office building	Office building
Current AC strategy	Central AC	Central AC	Central AC	Central AC	Central AC	Central AC
Total cooling load (average)	1800TR	1100TR	1400TR	1300TR	1700TR	2000TR
Total space for cooling (m^2)	27235	5336	5980	4140	11500	13340

Step 4: The cooling demand of the selected buildings were calculated based on three months' energy consumption. Table 2 shows the maximum cooling load values of all the buildings.

Step 5: Total energy demand:
The maximum cooling load of the prototype DCS was calculated using the following equation.

$$CDN_{max} = \left(\sum_{i=1}^{6} CBi\right) \times 1.25$$

where,

CDN_{Max} = Cooling load of the prototype DCS for maximum demand
CB_i = Cooling load of i^{th} building

The maximum cooling load of the prototype DCS was calculated through accumulating individual cooling loads. Furthermore, 25% of additional margin was taken from the individual cooling loads to calculate the current maximum cooling load of the DCS (Hauer, 2013). The additional margin was allocated to compensate for losses in wastage and the occasional over-demand which could arise from the buildings in the DCS. The percentage factor for the additional margin was derived from literature which has presented similar projects in other countries such as Singapore and UAE (Gang et al., 2015). Therefore, the total cooling demand of the prototype DCS is 11625 TR, according to the cooling load of buildings shown in Table 2. Thus, the DCS has been designed to meet the total demand of 11625 TR of cooling demand. Temperature difference (ΔQ) was calculated considering three temperature set points as shown in Table 3, in order to calculate the required ice quantities. The proposed system used ice TES due to its longer energy storage capacity under tropical conditions.

Table 3: Designed different temperature sets

Set point combinations	**Return temperature**	**Supply temperature**	**Temperature difference (ΔQ)**	**Ice Quantity (t)**
1	13°C	4°C	9°C	1,639,645
2	12°C	4°C	8°C	1,457,462
3	13°C	6°C	7°C	1,275,279

In Sri Lanka, electricity charges are categorized into three classes such as day time, peak time and off-peak time and Table 4 shows respective unit prices (i.e. cost per kwh). Table 5 shows the energy consumption of the ICS in each class. Records of chiller logs/BMS were utilized to obtain the energy consumption of the chillers. Higher consumption during the day time occurs due to working hours within office buildings.

Table 4: Electricity cost per unit in different categories

Category	**Time frame**	**Office buildings**	**Hotel buildings**
Day time	0530h – 1830h	LKR. 20.70	LKR. 14.35
Peak time	1830h – 2230h	LKR. 25.50	LKR. 23.50
Off-peak time	2230h – 0530h	LKR. 14.35	LKR. 8.14

Table 5: Electricity consumption based on building category

Building Category	**Electricity consumption (Kwh)**			**Month**
	Peak	Day	Off peak	
Hotel	434,561	679,669	407,915	September
Office	426,994	2,769,386	353,831	
Hotel	430,508	698,336	393,087	October
Office	439,133	2,752,708	358,125	
Hotel	416,575	600,099	400,203	November
Office	430,738	2,701,090	341,349	
All buildings	859,503	3,400,229	751,503	Average

The total cost of ICS was computed to compare with the energy consumption of the prototype DCS. Table 6 shows the average energy costs of all six buildings computed based on the consumption from September to November 2016.

Table 6: Annual energy cost of current systems (ICS)

Case code	**Cost of avg. annual electricity consumption for ICS (LKR)**
B1	362,695,050.40
B2	87,551,205.20
B3	102,654,841.48
B4	84,131,147.52
B5	210,930,487.00
B6	299,994,034.80
Total Cost	**1,147,956,766.40**

Step 6: Energy cost of prototype DCS
The required ice quantity for the TES was designed to be produced during the off-peak time due to low energy costs at that time. The unit costs of both industries were considered to calculate the energy cost of DCS. Furthermore, to justify the operational cost at different temperature set point combinations, as shown in Table 3, the operational cost of different set point combinations was used.

Step 7: Cost comparison
Table 7 shows the energy costs of both systems under three selected temperature differences. The results showed that average of 19% cost saving over three temperature conditions can be expected through DCS implementation.

Table 7: Annual energy cost reduction through the implementation of DCS

Annual energy cost (LKR)				
Temp Diff	Cost of Current ICS	Cost of proposed DCS	Annual saving	Saving percentage
9°c	1,147,956,766	1,041,104,682.69	199,752,083.71	9.31%
8 °c	1,147,956,766	925,426,384.62	315,430,381.78	19.38%
7 °c	1,147,956,766	809,748,086.54	431,108,679.86	29.46%

Apart from the energy costs, the operation of ICS causes significant complementary cash flows. They include cost of annual service contracts, breakdown repairs, cost of space allocation, cost of labour, which amounts to a large added operational cost for an individual ownership. Thus, the total cost of operation of the buildings considered for the developed DCS can be shown in Table 8.

Table 8: Total annual operational cost ICS of selected buildings

Case code	Ave. annual electricity consumption (LKR)	Annual maintenance budget (LKR)	Value of space consumed (LKR)	Total operational cost (LKR)
B1	362,695,050.40	5,000,000.00	37,200,000.00	404,895,050.40
B2	87,551,205.20	3,750,000.00	2,500,000.00	93,801,205.20
B3	102,654,841.48	6,500,000.00	3,500,000.00	112,654,841.48
B4	84,131,147.52	1,850,000.00	2,000,000.00	87,981,147.52
B5	210,930,487.00	3,850,000.00	10,000,000.00	224,780,487.00
B6	299,994,034.80	3,250,000.00	13,500,000.00	316,744,034.80
Total Annual Operational cost				**1,240,856,766.40**

Case Study II

The mega project for which a DCS was proposed is the on-going Colombo Financial City (CFC) project. The offshore land development is 578 acres in size and the project expects to add LKR 3.5 million of rentable space to the real estate market of Sri Lanka making the city an “Asian centre of finance”.
Table 9 portrays the energy impact and the potential reduction of cost from the implementation of the proposed DCS.

Table 9: Potential operational cost efficiencies using TES to CFC

Predicted number of m^2	Annual Cost under ICS	Annual Cost under DCS
278709.12	4,691,921,389	4,255,196,251
325160.64	5,473,908,287	4,412,796,112
371612.16	6,255,895,185	4,412,796,112

Through the analysis, it was evident that the use of DCS in case study II can achieve large cost reductions and operational efficiencies in both operational and capital investments.

Conclusions and Recommendations

The construction industry in Sri Lanka can be identified as an area that is attracting international real estate companies. The introduction of DCS within its basic infrastructure facilities could boost the attraction in addition to boosting the value of the land available. However, the greatest market handicap faced by DCS is that it requires front-loaded investment.

A prototype DCS was designed to analyse its economic viability. It showed that 19% cost savings can be achieved through the implementation of DCS into mega projects in Sri Lanka. Furthermore, the total operational cost of the ICS was calculated as LKR 1,240,856,766 which included annual maintenance costs and the space used for chillers. Thus, it can be recommended to implement DCS within mega projects in Sri Lanka. Furthermore, the government should initiate a process of partnering with the private sector to encourage the infrastructure development of DCS. However, there is also a need to study how to set up a legal platform for such an implementation and to manage any affairs relating to the DCS.

References

Atilhan, S., Batchelor, B., Linke, P., Abdel-Wahab, A., El-Halwagi, M., & Mahfouz, A. B. (2011). Optimal scheduling of biocide dosing for seawater-cooled power and desalination plants. *Clean Technologies and Environmental Policy, 13*, 783–796. doi:10.1007/s10098-011-0352-6

Burger, B. (2015). *Asian construction market forecast 2015 - 2020.* Retrieved from https://buildingradar.com/construction-blog/asian-construction-market-forecast-from-2015-2020/

Business Times. (2016, May 05). SL should avoid mistakes done by other South Asian cities when developing Megapolis: CCC Chair. *Daily Mirror*. Retrieved from Daily Mirror: http://www.dailSL should avoid mistakes done by other South Asian cities when developing Megapolis CCC Chair

Cabeza , L., Martorell, I., Miró, L., Fernandez , A., & Barreneche, C. (2015). Introduction to thermal energy storage (TES) systems. *Advances in Thermal Energy Storage Systems*, 1-28. doi:10.1533/9781782420965.1

Cabeza, L., & de Gracia, A. (2015). Thermal energy storage (TES) systems for cooling in residential buildings. *Advances in Thermal Energy Storage Systems*, 549-572. doi:10.1533/9781782420965.4.549

Charest, P., Flyvbjerg, B., Bruzelius, N., & Rothengatter, W. (2004). Mega projects and risk: An Anatomy of Ambition. *Anthropologica, 46*(1), 99-100. doi:10.2307/25606171

Chow, T., Fong, K., Chan, A., Yau, R., Au, W., & Cheng, V. (2004). Energy modelling of district cooling system for new urban development. *Energy and Buildings, 36*(11), 1153-1162. doi:10.1016/j.enbuild.2004.04.002

Department of Census and Statistics. (2017). *Sri Lanka GDP from construction*. Retrieved from Trading Economics: http://www.tradingeconomics.com/sri-lanka/gdp-from-construction

Du Plessis, G., Liebenberg, L., & Mathews, E. (2013). The use of variable speed drives for cost-effective energy savings in South African mine cooling systems. *Applied Energy, 111*, 16-27. doi:10.1016/j.apenergy.2013.04.061

Fu, L, Zhao, X, Jiang, Y, Li, H, & Yang, W. (2009). Laboratory research on combined cooling, heating and power (CCHP) systems. *Energy Conservation and Management, 50*(4), 977-982. doi:10.1016/j.enconman.2008.12.013

Gang, W., Wang, S., Gao, D., & Xiao, F. (2015). Performance assessment of district cooling system coupled with different energy technologies in subtropical area. *Energy Procedia, 75*, 1235-1241. doi:10.1016/j.egypro.2015.07.166

Gang, W., Wang, S., Gao, D., & Xiao, F. (2015). Performance assessment of district cooling systems for a new development district at planning stage. *Applied Energy, 140*, 33-43. doi:10.1016/j.apenergy.2014.11.014

Hauer, A. (2013). *Thermal energy storage, storage capacities and economics.* London: Archetype Publications Ltd.

International Energy Agency. (2015). *Southeast Asia Energy Outlook 2015 : World Energy Outlook Special Report.* Retrieved from https://www.iea.org/publications/freepublications/publication/WEO2015_SouthEastAsia.pdf

Kaushik, G. and Nand, S. (2015) District Cooling Conversion System: A Case Study, *International Journal of Engineering Research and General Science*, 3(4), pp. 678-683

Liew, P., Walmsley, T. G., Klemeš, J. ˇ., Varbanov, P. S., Wan Alwis, S., & Abdul Manan, Z. (2016). Integrating district cooling systems in locally integrated energy sectors through total site heat integration. *Applied Energy, 184*, 1350-1363. doi:10.1016/j.apenergy.2016.05.078

Lychnos, G., Fletcher, J. P., & Davies, P. A. (2010). Properties of seawater bitterns with regard to liquid-desiccant cooling. *Desalination, 250*(1), 172-178. doi:10.1016/j.desal.2008.11.019

Ministry of Power and Energy. (2015). *Sri lankan energy sector development plan for knowledge based economy.* Retrieved from http://powermin.gov.lk/sinhala/wp-content/uploads/2015/03/energy_empowered_nation_2015_2025.pdf

Nordell, B. (2015). Using ice and snow in thermal energy storage systems. *Advances in Thermal Energy Storage Systems*, 187-200. doi:10.1533/9781782420965.2.187

Ramanayake, S. (2011). *Energy conservation of a central chiller plant.* (Master Thesis, University of Moratuwa). Retrieved from http://dl.lib.mrt.ac.lk/handle/123/1691?show=full

Rezaie, B., & Rosen, M. (2012). District heating and cooling: Review of technologyand potential enhancements. *Applied Energy, 93*, 2-10. doi:10.1016/j.apenergy.2011.04.020

Santiago, M. (2015, June 05). *Colombo tops list of fastest growing cities in the world.* Retrieved from Newsfirst: http://newsfirst.lk/english/2015/06/colombo-tops-list-of-fastest-growing-cities-in-the-world/98450

Shimoda, Y, Nagota, T, Isayama, N, & Mizuno, M. (2008). Verification of energy efficiency of district heating and cooling system by simulation considering design and operation parameters. *Building and Environment, 43*(4), 569-577. doi:10.1016/j.buildenv.2006.03.017

Sri Lanka Sustainable Energy Authority. (2014). *Energy balance*. Retrieved from http://www.info.energy.gov.lk/

Towey, D. (2012). *Construction Quantity Surveying – A practical Guide for the contractor's QS.* Retrieved from https://books.google.lk/books?id=vYWr3lw1ZXQC&printsec=frontcover&dq=role+of+quantity+surveyor+in+construction+industry+important&hl=en&sa=X&ei=C2T9VJnaG4LrUvKjg5gB&ved=0CBsQ6AEwAA#v=onepage&q=role%20of%20quantity%20surveyor%20in%20construction%20industry

Udomsri, S., Bales, C., Martin, A., & Martin, V. (2012). Decentralized cooling in district heating network: System simulation and parametric study. *Applied Energy, 92*, 175-184. doi:10.1016/j.apenergy.2011.10.009

United Nations Environment Program. (2015). *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*. Retrieved from http://web.unep.org/energy/

Valappil, S. (2015, December). *Thermal energy storage systems*. Retrieved from https://www.linkedin.com/pulse/thermal-energy-storage-systems-tes-sajeev-valappil

Wong, Y. H., & Choong, D. (2015). *Mastercard 2015 global destination cities index.* Retrieved from https://newsroom.mastercard.com/wp-content/uploads/2015/06/MasterCard-GDCI-2015-Final-Report1.pdf

Yik, F., Burnett, J., & Prescott, I. (2001). Predicting air-conditioning energy consumption of a group of buildings using different heat rejection methods. *Energy and Buildings, 33*(2), 151-166. doi:10.1016/S0378-7788(00)00094-3

Zhang, F., Deb, C., Lee, S. E., Yang, J., & Shah, K. W. (2016). Time series forecasting for building energy consumption using weighted Support Vector Regression with differential evolutionoptimization technique. *Energy and Building, 126*, 94-103. doi:10.1016/j.enbuild.2016.05.028