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Electricity cost saving comparison due to tariff change and ice thermal storage (ITS) usage based on a hybrid centrifugal-ITS system for buildings: A university district cooling perspective☆

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ABSTRACT

In this paper, the case study of a district cooling system of a university located in a South East Asia region (lat: 01°29′; long: 110°20′E) is presented. In general, the university has high peak ambient temperature of around 32–35 °C coupled with high humidity of about 85% during afternoon period. The total electricity charge for the Universiti Malaysia Sarawak Campus is very high amounting to more than $314,911 per month. In this paper, a few district cooling schemes are investigated to provide "what-if analysis" and in order to minimize the overall electricity charges. Few scenarios designed for the application of centrifugal with and without ice-thermal storage (ITS) systems on the buildings were investigated. It was found that, due to the local tariff status, marginally saving can be achieved in the range of 0.08–3.13% if a new tariff is adopted; and a total of further saving of 1.26–2.43% if ITS is operated. This marginally saving is mainly due to the local tariff conditions and lower local temperature range (ΔT) which are less favorable as compared with those reported in the literature elsewhere.

1. Introduction

The building industry involves two kinds of energy applications, i.e., building construction application, and post-constructions (occupants) application. The latter consumes much of the energy use due to the energy consumption over a period of much longer time [1]. For modern buildings, one of the notable energy usages is due primarily to the electrical-driven air conditioning systems, either for heating or cooling. For bigger system such as district cooling systems (DCS) application, higher capacity of the cooling systems are necessary due to the higher cooling or heating demand which necessarily incur enormous electrical energy costs. The advantages of DCS systems in huge building areas compared with individual air-conditioning unit systems are many, among others:

- *Economical advantages*: The DCS have overall lower total capital cost compared to the split cooling that require their own cooling equipment(s) [2,3].
- *Space conservation*: The space required for cooling equipment(s) can become vacant for other purposes for a district cooling systems [2,3].
- *Noise reduction*: The noise that produced by the cooling machines can be avoided in the consumer buildings [2].
- *Flexibility*: The DCS systems also flexible to employ a wide range of inter-related thermal storage technologies such as co-generation, tri-generation, and thermal energy storage (TES) [2,3]. The present paper is primarily concerning with the TES storage technique.

In respect of energy usage, it was reported that thermal energy storage (TES) not only dramatically reduces the use of peak-period high cost energy; it can also reduce the total energy usage by as much as 13% [4,5]. The United State Department of Energy reported that many ice storage applications can result in lower first cost and/or with higher system efficiency as compared to non-storage system [6]. This is because ice-storage allows downsizing of the conventional chiller system [3,7], the resulting cost savings may substantially or entirely cover the added incremental cost of the storage system [7]. MacCracken [8] pointed out that since thermal

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Nomenclature

C1	commercial 1
C2	commercial 2
C3	commercial 3
CAIS	Centre Academic and Information Services
CH	chiller
DCS	district cooling system
FCST	Faculty Resource Science and Technology
MEP	mechanical and electrical plant
MIS	main intake supply
N/A	not available
S1	Scenario 1
S2	Scenario 2
S3	Scenario 3
SESCO	Sarawak Electricity Supply Corporation
UNIMAS	Universiti Malaysia Sarawak
ΔT	ambient temperature difference

Measurement units

°C	degree Celsius
m^2	meter square
RM	Ringgit Malaysia
%	percent
RT	refrigerant ton
unit	kWh (kilowatt-hour)
$	US dollar (USD)

storage method operate at full load during the night time, the fuel cost for powering the ITS plant during the night (non-peak hours) will be reduced, as the cooling demand is shifted from peak hours to non-peak hours. The two main reasons for the saving are thus: (1) in the night, the base load plants are much more energy efficient than daytime plants; and (2) line losses are less during the night time because much less power is transmitted at night.

Results from the study by the California Energy Commission [9] shows an even higher energy saving potential figures, for two typical major California utilities with energy usage reduction as much as 10% and can up to 30% has been reported [9,10].

Sebzali and Rubini [10] had conducted an investigation in a clinic building in Kuwait, which has hot climates with long summer condition. They found out, via computational modeling analysis, that the AC systems consume around 61% of the peak electrical duty and around 40% of the total electricity consumption. The saving is due to the advantage of hot climate and huge temperature difference between day and night time, considerably long summer and low energy costs in Kuwait.

A hybrid chilled water/ice thermal storage plant for the Lucile Erwin Middle School in Colorado, United State, has been reported to able to save more than $18,000 in energy costs annually. One of the contributing saving factors reported is due to the offer of low-interest financing from the local Florida power authority, and by completely eliminating chiller demand from the utility bill. The project uses a flexible ice thermal storage management system concept with a demand limit-controlled, chiller priority, and partial storage system. This ice storage system optimized energy efficiency by carefully avoiding electrical demand peaks caused by the system, where the chiller/storage match is designed for continuous chiller operation at about −6 °C chilled water supply temperature under normal conditions [11].

Morgan and Krarti [12] reported a TES application study on a school with total small floor area of 65,000 ft^2 (6038.7 m^2). They investigated the influences of using active and passive TES systems to shift the peak cooling loads to the nights to reduce building energy costs. The set point temperature during the occupied periods from 8:30 to 17:00 was at 24 °C and 32 °C during unoccupied periods. A 50 ton scroll compressor operates during the night (from 02:00 to 08:00) and charges three ice-tanks with a total capacity of 570 tons/h using the internal melt ice-on-coil system. They found that around 47% of the annual electricity cost could be saved by employing the TES systems. This huge cost saving is due to the incentive utility rate of $0.0164 kWh^{-1} as a flat consumption rate and a demand charge of $11.24 kW^{-1}.

It is to be noted that not all the literature came up with favorable TES applications. Habeebullah [13], for instance, had conducted an economic feasibility of using the huge ITS system in the Grant Mosque of Makkah, the results of which show that as the existing electricity rate is fixed at $0.07 kWh^{-1}, the ITS system does not have any gain neither for the partial nor for the full storage strategy. However, the author indicated that by employing the energy storage system via full load storage strategy combined with an incentive time structured rate, the electricity cost could be reduced.

In order to evaluate the energy performance and cost effectiveness potential, a feasible district cooling with ice-storage system was investigated by Chan et al. [14] for a hypothetical site in Hong Kong. In their works, a parametric study employing DOE-2 and TRNSYS simulation software was conducted to evaluate the system performance at different partial storage capacities, control strategies, and under three different tariff structures. Other than the basic design factors, the results from 27 cases studies showed the importance of the tariff structure, the capital cost and electricity costs. They found out that the district cooling plant with about 40% ice-storage capacity and chiller-priority control sequence can provide better energy performance. However, the saving in electricity cost is not attractive. The authors further suggested that in order to shorten the payback period, the power supply must come from the neighboring region that provides lower electrical charges and supporting tariff structure. This also implies that there is a potential of applying the integrated technology in the South China region but only when the investment becomes favorable and with supporting tariff structure.

From cited literature and experiences obtained elsewhere, favoring conditions of TES applications can vary from country to country, and in fact region to region, due to numerous factors. Generally, the usage of ice-thermal technology has been higher in regions where a significant day and night-time differential in both temperature, in the lower price of electricity exists, and with some utility companies provide cash incentives or rebates to developers that incorporate TES schemes.

The present study is an extension of previous work reported earlier in 2007 [15]. The previous work briefly investigated some parameters influencing the DCS performance, in particular cool air distribution, chiller capacity, and occupant behavior. This paper, however, is an extension of the previous work. The current study aims to seek on the overall district cooling saving possibilities due to the following two application aspects, viz. (1) the effects of tariff change and (2) the effect of ITS usage. For that purpose, few application scenarios are given for comparison. Due to the completeness and most recent data available, the authors have chosen a typical year, i.e. 2011 for the analysis.

2. The UNIMAS' district cooling system

Universiti Malaysia Sarawak (UNIMAS) is located in Kota Samarahan of Sarawak. By completion of new campus (or known as West Campus) in the year of 2005, the total build-up area of the new campus is approximately 223,619 m^2 and keep expanding from time to time (Fig. 1). With the location at equatorial climate which provide hot tropical weather basically on 365 days per year with average