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Modeling and simulation to determine the potential energy savings by implementing cold thermal energy storage system in office buildings

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ABSTRACT

In Malaysia, air conditioning (AC) systems are considered as the major energy consumers in office buildings with almost 57% share. During the past decade, cold thermal energy storage (CTES) systems have been widely used for their significant economic benefits. However, there were always doubts about their energy saving possibilities. The main objective of the present work is to develop a computer model to determine the potential energy savings of implementing CTES systems in Malaysia. A case study building has been selected to determine the energy consumption pattern of an office building. In the first step the building baseline model was developed and validated with the recorded data from the fieldwork. Once the simulation results reach an acceptable accuracy, different CTES system configuration was added to the model to predict their energy consumption pattern. It was found that the overall energy used by the full load storage strategy is considerably more than the conventional system. However, by applying the load leveling storage strategy, and considering its benefits to reduce the air handling unit size and reducing the pumping power, the overall energy usage was almost 4% lower than the non-storage system. Although utilizing CTES systems cannot reduce the total energy consumption considerably, but it has several outstanding benefits such as cost saving, bringing balance in the grid system, reducing the overall fuel consumption in the power plants and consequently reducing to total carbon footprint.

1. Introduction

People have taken advantage of natural cooling for thousands of years. Caves, holes dug in the ground, springs, ice, snow and evaporative cooling have all been used to cool food and drinks. However, natural cooling has limitations. Nowadays, as the cool generator systems are becoming more developed, the existence of the storage devices is unavoidable. Generally, thermal energy storage (TES) systems help reserving the energy in thermal reservoirs for later usage. They are designed to store either the higher (heat) or the lower (cold) temperature in comparison with their environment [1]. The energy might be charged, stored and discharged daily, weekly, yearly or in the seasonal cycles [2]. The cold energy is usually stored in the form of ice [3], chilled water [4,5], phase change materials [6–8] or eutectic solution during the low electricity demand hours [9,10].

In Malaysia the temperature fluctuates between 20 °C and 32 °C all year round [11]. The total number of air conditioning (AC) systems augmented from around 13,000 units in 1970 to more than 250,000 units in 1991 and the number is predicted to exceed over 1.5 million units by the year 2020 [12]. Consequently, the reported electricity consumption of the AC systems increased from 1200 GW h in 1999 to more than 2200 GW h in 2009 and it is predicted to exceed more than 3000 GW h in 2015 [13]. Generally, AC systems operate in their full load for only a few hours per day. Storage is the key to bring balance between demand and production level in the cooling system. The technology is called cold thermal energy storage (CTES). The potential demand reduction and stability of the electric grid has made it a valuable technique that is now widely used in different applications for the buildings that are mainly occupied during the working hours, such as office buildings [14–16], hospitals [17], schools [18,19], churches and mosques [20].

CTES is a technology whereby cold energy is stored in a thermal reservoir during off-peak periods for later use [1,2]. Consequently, shifting electrical demand to off-peak hours has a major "Green" benefit of decreasing fuel consumption in the power plant [21,22]. Moreover, electricity production and distribution during the night hours, when the ambient temperature and line losses are lowest, is significantly more efficient than those for daytime.

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Nomenclature

AC	air conditioning
C_p	thermal conductivity
CTES	cold thermal energy storage
FCU	fan coil unit
h_{fg}	latent heat of fusion
ITS	ice thermal storage
PCM	phase change materials
Q	heat flux

Greek symbols

ε	effectiveness

Subscripts

in	inlet
ideal	ideal
out	out
ret	return
sup	supply

Therefore, utilizing the CTES technique can significantly reduce the energy demand. The operating strategy of CTES systems is generally divided into two categories of full storage and partial storage, as shown in Fig. 1.

Several investigations and case studies about CTES technology and related strategies are available in the literature [23–25]. One of the most accurate methods to predict and determine the effect of utilizing CTES systems, is computer modeling. In this study, the building modeling was performed by using TRNSYS simulation software. TRNSYS is well suited to detailed analyses of any system whose behavior is dependent on the passage of time [26]. During the past decade, many researchers have used this simulation software to simulate and predict the building behavior in different climates from passive cooling [27], night cooling [28,29], radiant cooling [30], seasonal cool storage system [31] to the complicated solar thermal and electric desiccant cooling systems [32]. Soltan and Ardehali [33] has numerically simulated an ice-on-coil TES system to determine the approximate duration of water solidification around a circular cross-section coil.

According to statistical data in Malaysia, office buildings consume almost 20% of the total electricity consumption [13]. Therefore, there is a great potential to reduce utility costs as well as energy expenditure and carbon emissions in this sector. The main objective of the present work is to develop a computer model to determine the potential energy savings by implementing CTES system in office buildings based on the Malaysian climates.

2. Methodology

In order to model the building in TRNSYS simulation software, numbers of inputs and parameters are required such as; meteorological data, building characteristics (orientation, thermal characteristics of components etc.), AC and ventilation requirements, and internal thermal gains.

2.1. Field work study

The fieldwork study was conducted to evaluate the energy consumption of an operating AC system in an office building in Malaysia. A newly built 10 story office building located in Kuala Lumpur was selected as the case study for this project. The total electricity consumption of the chiller plant room and the building was measured and recorded during the fieldwork period. The electricity consumption pattern was then used as the baseline for the system calculation and simulation. The following steps were considered during the fieldwork study.

- The existing HVAC system design has been studied through the mechanical and electrical (M&E) drawings as well as architectural drawing of the building.
- The fieldwork measurement was conducted by using equipment such as power analyzer, thermometer, hygrometer, anemometer, electronic Micromanometer, luxmeter and indoor air quality meter.
- The fieldwork was started on Friday February 24th, 2012, 5:15 PM and continued for almost half a year until Sunday August 12th, 2012 8:00 AM (170 days).

2.2. Building modeling equations

The building model used in this simulation is the typical multi-zone building component (Type 56). Detailed theories about this component is presented in TRNSYS user manual [26]. Herein a fundamental mathematical frame is presented through a series of

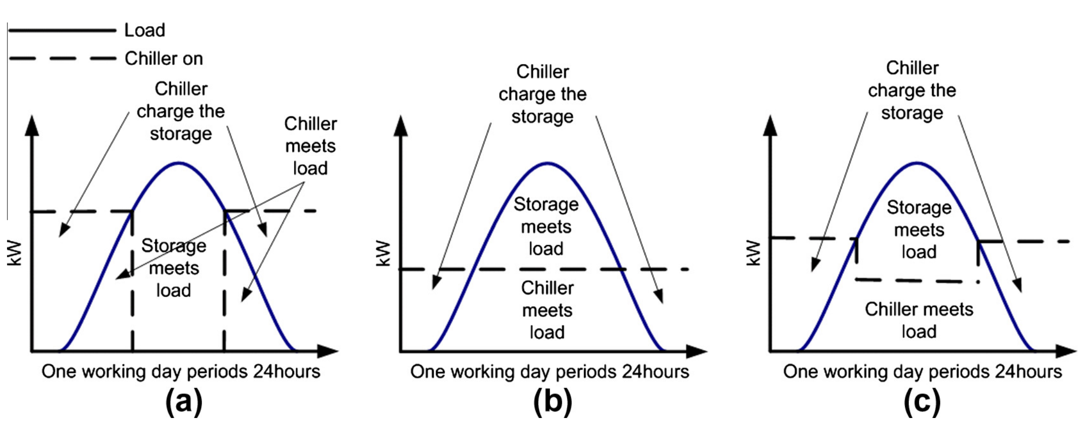

Fig. 1. Schematic drawing of different storage strategies. (a) Full-storage, (b) partial-storage load-leveling and (c) partial-storage demand-limiting.