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# Comparison of energy performance and economics of chilled water thermal storage and conventional air-conditioning systems

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ABSTRACT

During the summer of previous years, Kuwait faced a series of power shortages emphasizing the need for urgent commissioning of power generation projects. It is estimated that the demand for electricity is growing at an average of 5.4% per year, encouraged by government subsidies and driven by the rapid and continual expansion in building construction, urban development, and heavy reliance on air-conditioning (AC) systems for the cooling of buildings. The chilled water thermal storage (CWTS) system is one of the available techniques that can be utilized to reduce peak electricity demand of buildings when national electricity consumption is at its highest level.

This paper demonstrates that the implementation of CWTS system reduces the peak power demand of AC systems for design day conditions by 36.7–87.5% and annual energy consumption by between 4.5% and 6.9% compared with conventional systems, where chillers and pumps significantly contribute to this reduction. In addition, the Life Cycle Cost (LCC) was estimated for both the Ministry of Electricity and Water (MEW) and the consumer. Results show that CWTS operating with a load leveling strategy gives the lowest LCC compared to 50% demand limiting and full storage strategies, and is, therefore, considered as the most cost effective option for both MEW and consumer.



## 1. Introduction

MEW, the sole supplier of electricity in Kuwait, is facing huge increase in demand year on year. This increase in power demand is due to rapid growth in constructions of residential buildings, modern offices and large commercial buildings which lead to high energy consumption for the operation of AC systems. Based on statistical data supplied by MEW [1], the peak power demand has significantly increased from 6.45 GW in 2000 to 10.90 GW in 2010 with annual average increase of 5.3% which is well above the world average of 2.7% [2]. Peak power demand is important because MEW is faced with investing in new generation capacity to cope with expected increase in peak demand. In addition, it has been estimated that AC systems of buildings annually consume about 45% of the exported electrical energy from the power plants and contribute about 63% of the peak power generation [3].

Cool thermal storage system is one of the well known technology that can be implemented to significantly reduce the electric peak power demand of the AC systems in buildings. The primary benefit of implementing of this technology is to shift the power consumption of the AC systems from the daytime to nights when both the demand of electricity and temperature are considerably lower [4]. In addition, some systems configurations and designs may result in lower capital and operating costs [5]. Depending on the system configuration, the chiller may be smaller than would be required for direct cooling, leading to smaller auxiliaries such as the cooling tower, the condenser and the chilled water pumps [6]. Pumping energy can be reduced by increasing the chilled water temperature range, and fan energy can be cut with colder air distribution as the case when ice thermal storage is used [7]. Al-Rabghi in Ref. [8] argued that thermal energy storage could be one of several technological methods for lowering energy consumption of buildings if it were incorporated within their AC systems.

Moreover, Henze et al. [9] showed that the adoption of cool thermal storage system within chilled water plant for a group of buildings in Germany provide economic benefits, operational merits by avoiding numerous safety measures necessary for a cooling plant without storage and a cost effective addition of supplemented cooling capacity. In another application, Ehyaei et al. [10] studied the effect of utilisation of cool thermal storage system on the selection of micro gas turbine for electricity generation for a residential building located in Tehran. Their study showed that cool thermal storage reduces the micro gas turbine units from 21 to 11 and cost by 29.5% due to reduction in maximum cooling demand of the building. In addition, further case studies of implementing cool thermal storage have been presented by Yau and Rismanchi [4] as

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**Fig. 1.** The clinic building.

well as successful implementation for other applications given by Dincer and Rosen [11].

Cool thermal storage system is accepted by many as a proven energy conservation technology since it reduces the energy consumption and hence results in conservation of fossil fuels and reductions in green house gases and CFC emissions [12]. The advantages of a cool thermal storage system over a conventional AC system are summarised below [13]:

- The refrigeration capacity can be substantially reduced.
- The chiller plant operates at its optimum efficiency.
- The chiller efficiency can be improved and a constant generating load can be maintained.

However, there are some practical difficulties in implementing the technology. These difficulties arise from errors in the sizing of the system which result in higher payback period, failure in the operation of the system due to mechanical malfunction of equipment and control system and an inexperienced operator causing inefficient operation of the system [13].

In Kuwait, there is no cheap rate electricity tariff and there is no direct cash incentive offered by MEW for demand management measures. However, the cool thermal storage system may be attractive for both MEW and consumer if peak power demand and energy consumption are both reduced. Many types of cool thermal storage technologies are available in the market; however, CWTS is the most promising storage technology due to its lower initial cost and electrical energy when compared to other ice storage technologies [14]. In addition, CWTS does not need special equipment, can be incorporated with existing conventional AC systems and reliable with good track record [15]. Therefore, in this paper the energy performance and economics of using CWTS assisted AC system against conventional AC system are studied for Centre for Speech and Audio Therapy (CSAT) building in the climate conditions of Kuwait.

The CSAT building which represents typical medium sized building (see Fig. 1) was selected to assess the impact of cool thermal storage on the electrical power and energy consumption of the air cooled chillers. The building comprising of two blocks, referred to as A and B, connected by a small corridor. Block A is a single story construction located at the rear part of the building. Block B has ground and first floors in addition to a tall reception with a large glassed area including a skylight. This building is occupied from 07:00 a.m. to 02:00 p.m. for five days a week, and has a total floor area of 3180 $m^2$.

In CWTS AC system, large storage tank is used to store chilled water at a temperature between 4.0 and 6.7 °C [15]. This temperature is compatible with most conventional AC systems and allows the use of a conventional chiller. Higher operating efficiency of the AC system can be realized with CWTS, because the AC system operates to store chilled water during the night when ambient temperatures is low hence, improving the performance of heat rejection equipment. Moreover, CWTS operates under the same conditions as for conventional AC systems and does not require any changes in the design of piping configuration or in the Air Handling Units (AHUs) therefore, it simplifies the design consideration [16].

The main objective of this study is to compare the energy performance that is, peak power demand and annual energy consumption of CWTS assisted AC system with conventional AC system CSAT building in very hot climate such as Kuwait. The LCC analysis is conducted for both AC systems including different operating strategies for CWTS to determine the most cost-effective design. The operating strategies considered in this study are partial and full storage. Partial storage strategy is divided into load leveling (with chiller priority) and 50% demand limiting strategies. The chiller in the partial storage strategy meets the cooling demand as much as possible and when the cooling demand exceeds the chiller capacity, the additional cooling is supplied from the storage tank. In the full storage strategy, the chiller is switched off completely during peak cooling demand and the stored chilled water is used to meet the cooling demand.

## 2. Proposed design of central cooling plant and chilled water distribution system

In this study, the cooling production for the central cooling plant of the conventional AC system is shown in Fig. 2. It is assumed to consist of a single electric-driven air-cooled chiller and one working (plus one standby) primary constant flow chilled water pump. The cooling production of CWTS systems is the same as conventional system but with additional stratified chilled water tank (see Fig. 3). Chillers and storage tanks capacities in CWTS AC systems operating with 50% demand limiting and full storage strategies are estimated based on four hours discharging time, from 11:00 a.m. to 3:00 p.m. It is also assumed that storage charging starts at 6:00 p.m. and ends when the storage tank is fully charged.

The chilled water distribution systems for conventional and CWTS are arranged with primary-secondary piping designs as shown in Fig. 4 [17]. This design is considered today as the most popular chilled water system because it separates the chiller (i.e. the chilled water production zone) from the distribution piping system (i.e. the chilled water transportation zone) thereby reducing the differential pressure drop across the control valves of the cooling coil [18].

Design volumetric flow rate in the primary circuit is met by a single centrifugal pump with a second standby pump of the same size. The primary pump is assumed to be running 24 h a day irrespective of the load on the chiller. In the CWTS systems, the primary pump is sized to overcome the pressure drop of the extra control valves that are associated with the chilled water tank and the pressure drop in the piping network of the diffusers within the tank. The primary pump is assumed to deliver the required flow rate during both the charging and discharging cycles to the secondary circuit.

The secondary chilled water distribution piping system for both conventional and CWTS systems is arranged with a direct return piping arrangement as shown in Fig. 4. This piping arrangement is strongly recommended by most designers for variable flow distribution and control of flow rate through the cooling coil with a two-way temperature control valve. The chilled water in the secondary piping system is circulated by three parallel constant flow secondary pumps (plus on standby). Each pump takes its suction from a common header and discharges into another common header, thus sharing the flow while operating at the same head. This pumping arrangement allows the pumps to be switched on and off as required to meet the varying demand. Each pump operates at the same head, but shares the flow rate with the other pumps. Multiple