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ENERGY STORAGE SYSTEM FOR PASSIVE COOLING, A REVIEW

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Abstract:—Thermal energy storage is one of the key technologies for energy conservation, and therefore, it is of great practical importance. Cold energy storage systems are designed to produce the necessary cooling storage during off peak time in order to utilize advantage of cheaper electric utility rates. This paper investigates the effects of various design and operating factors on the optimal controls of using the cold storage system to minimize the operating costs while maintaining adequate occupant comfort conditions in commercial buildings. The basic operating strategy of the active cold energy storage system is to charge the ice storage by operating the chiller during low electrical charge periods. During the on-peak periods, the ice storage is discharged to meet the building cooling requirements. As a result, it is possible to reduce or even eliminate the chiller operation during on-peak time. This paper is a review of the energy storage cooling techniques used in the recent past.

Keywords:—Air conditioning system, energy saving, phase change material, refrigeration system, thermal energy storage

I. INTRODUCTION

Energy storage has only recently been developed to a point where it can have a significant importance on modern technology. In particular, energy storage is critically important to the success of any intermittent energy source in meeting demand. Cool thermal energy storage plays a significant role in conserving available energy and improving its utilization, such as shifting on-peak demand to off-peak period. Many applications have been employed, for example, cool storage systems for air conditioning, natural cooling of energy efficient buildings etc. Cool thermal energy storage system is classified as sensible, latent heat and the combined storage systems. The advantages of the latent heat system in comparison with sensible storage are high heat storage density, small size of the system and a narrow temperature change during charging and discharging processes.

Cool storage technology is an effective means of shifting peak electrical loads as part of the strategy for energy management in buildings. There are principally three types of cool storage system being developed, such as chilled water storage, ice storage and eutectic salt. A chilled water storage system need the large storage tanks, but is easily compatible with existing chiller systems. During the charging mode, a tank is charged with water at 4–6^{o}C in stratified layers for later use in meeting cooling requirement. During the discharging mode, chilled water is supplied from the bottom of the tank and is returned to the top of the tank. In this type of system, chilled water is stored at night in a storage tank, and chilled water from the tank is circulated at day through the cooling coil to accommodate the required cooling for the buildings.

Ice storage systems use the latent heat of fusion of water to store cooling capacity. In this system, ice may be generated by using glycol or brine solutions that enter the ice tanks from the chiller at temperatures 3–6^{o}C below the freezing point of water. An ice-storage system is a heat exchanger with varying performance over time. The principle behind ice thermal storage is basically very simple: off-peak electricity is utilized during the night-time to create a large mass of ice. During the daytime, this ice store melts by absorbing heat from the building. The cooling capacity of the ice storage system depends on the heat of fusion and the rate at which ice can be melted to satisfy the cooling demand. Benefits can be received by both the consumer (lower energy costs, better space temperature control) and the utility (higher load factor, lower capital investment in new generating equipment). A cool storage system can meet the same total cooling load as a non-storage system over a given period of time with a smaller chiller. The chiller operates at 100% of its rated capacity throughout its period of operation in the cool storage system, therefore, the plant works at its optimum efficiency.

II. REVIEW OF WORK CARRIED OUT

Dr. GhalibY. Kahwaji, [1] experimentally studied the feasibility of utilizing thermal energy storage systems in reducing both the initial and running expenses of chiller systems in larger mosques. The basic principle of the active cold energy storage system is to charge the ice storage by operating the refrigeration system during low electrical charge periods. During the on-peak periods, the ice storage is discharged to meet the building cooling requirements. The study focused on the great mosque in the city of Mosul as a model. Two load profiles are considered, the occasional and the normal profiles with three different partial storage control strategies. The conventional strategy is also considered for the purpose of comparisons. From the results, it can be concluded that, the amount of the shifted load from the on-peak period for the occasional profile is equal to 45.2%, 24%, and 39.1% for the three control cases respectively. Up to 74% reduction in the on-peak power consumption can be achieved with a total shifted power, (from the on peak to the off-peak periods) of up to 47.2%, which will add significantly to the total cost reduction. For the normal profile, the amount of the shifted load from the on-peak period is equal to 9.8%. The peak power consumption is reduced by 33.1%, and about 10% of the consumed power is shifted to a low price period.

Guiyin Fang et al, [2] experimentally studied the operational performance of an ice storage air conditioning system with a separate helical heat pipe during charging and discharging. The experimental system of ice storage air conditioning system with separate heat pipe is set up. The performance parameters such as the evaporation pressure and the condensation pressure of refrigeration system, the refrigeration capacity and the coefficient of performance of the system, the ice packing factor and the cool storage capacity in the cool storage tank during charging period, the cool discharge rate and the cool discharge capacity in the cool storage tank, the outlet water temperature in the cool storage tank and the outlet air temperature in room unit during discharging period are investigated. The experimental results show that the ice storage air-conditioning system with separate helical heat pipe can stably work during charging and discharging period. This indicates that the ice storage air conditioning system with separate helical heat pipe is well adapted to cool storage air-conditioning systems in buildings.

Syed Mahmood Hasnain and Naif Mohammed Alabbadi, [3] experimentally studied the performance of ice storage air conditioning system. In their experimental study they coupled thermal energy storage system with a conventional air conditioning system. Electricity consumption, chiller performance, favorable conditions for thermal energy storage system, saving on energy cost, saving on the maintenance cost etc. are analysed. They concluded that thermal energy storage system is a best suitable method for electric load leveling purposes. The experimental result shows that thermal energy storage system reduced peak cooling load demand by approximately 30-40% and peak electrical demand by approximately 10-20%.

A. Shanmuga Sundaram et al, [4] developed a new passive cooling system for telecom shelters installed in desert and tropical regions using thermo syphon integrated with PCM based TES and experimented to study the feasibility of its application. The newly developed thermal system absorbs the equipment dissipated heat during the hottest part of the day, stores it as latent heat and releases it through thermosyphons during the night to the ambient. During the discharging mode of operation, the ‘day time’ stored heat in TES is utilized to operate the thermo syphon. However, with the passage of time, the condenser and evaporator reach an equilibrium state corresponding to the ambient temperature. Then the TES are said to have stored sufficient cool energy which would be available to absorb heat from electronic equipment during daytime operation. They concluded that a passive cooling system incorporating PCM based TES system and thermo syphon heat exchangers for cooling telecommunication enclosures is viable and reliable for shelters installed in desert and tropical regions. It has the following advantages:

• The present system does not require power; therefore it is a highly efficient system for remote areas where there is no power grid and the maintenance is minimized.
• The enclosed air is totally isolated from the atmospheric air thus ensuring a dust free and salt free atmosphere.
• It is a low cost cooling system and eco-friendly.

Gregor P. Henze et al, [5] experimentally investigated a commercial cooling plant with an ice storage system. Various ice storage systems, chiller compressors, and building types were analysed under four different control strategies. They concluded that good efficiency of the cooling plant in the ice making mode and rate structure with strong load-shifting incentives are prerequisites for making cool storage successful. Chillers with poor performance at subfreezing evaporator temperature require significant onto off peak differentials in the energy and demand rates to yield substantial savings. The relative performance benefit of optimal control over conventional controls increases when the rate based load shifting incentives is weak. With cooling related electrical loads being large compared to non-cooling loads, all conventional controls improve their performance when slowly recharging during off peak periods to contain off peak demand. On peak demand reduction of storage priority is near optimal for many cases.

B.Rismanchi et al, [6] experimentally analysed the application of cold thermal energy storage system for an office building in Malaysia. A macroscopic thermodynamic analysis of the application of five different cold thermal energy storage systems is presented. In order to obtain the actual energy consumption of the building in this case study, the electricity expenditure was recorded over a period of two months with 15-min intervals. The temperature and humidity fluctuations of ambient were recorded over the fieldwork period. The results obtained from the field work were used to evaluate energy and exergy efficiencies. The building energy usage is recorded and the average pattern applies for chiller selection, storage tank sizing and finally energy and exergy evaluation. The results show that all the systems are highly efficient in terms of energy with the minimum of 93% for ice harvesting and a maximum of 98% for encapsulated technique. However, the exergetic evaluation implies a totally different scenario of the study. The maximum exergy efficiency is for ice on the coil (internal) technique with an amount of 18%. It was also found that increasing the room set-point temperature by 5 ◦C can reduce the exergy efficiency by 4%.

V. V. Tyagi et al, [7] designed and experimentally studied a thermal management system for cool energy storage. A prototype test room was designed to investigate the performance study of the thermal management system (TMS) with different operation conditions to maintain the temperature in under comfort range. The room air temperature, ambient temperature and Phase change material temperature at different locations were measured continuously. The thermal management system has sixty Phases change materials based high density polyethylene panels. The experimental room temperature was maintained between 22 and 24 ◦C during the cool energy storage in thermal management system. The different heat loads were used to know the real performance of the thermal management system for maintaining the experimental room temperature. The results of the study showed that there is a significant variation in the time duration to exceed the thermal comfort temperature with different heat loads. The experimental room temperature was maintained at 9 h, 3:30 h and 2:30 h in the presence of the thermal management system with different heat loads. In other words, the temperature profile of the test room with room heater of 1 kW is found to be longest when it is used in the presence of thermal management system, while it is found to be the shortest in the case of 3 kW room heaters without thermal management system. Thus it can be concluded that the Time management system can maintain the room air temperature for a long time even with an active heating load and hence, the thermal management system used in this study is a good alternative for both passive and active building space conditioning applications.

K.H. Yang & T.C. Yeh ,[8] renovated an ice storage air conditioning system in an aquarium for energy conservation and experimentally analysed the performance of the renovated system. At first, the chiller coefficient of performance and power consumption of the plant was recorded as base line comparison secondly the the ice storage system was renovated. The base system consists of three centrifugal chillers with 500TR cooling capacity each, and a 400 TR screw chiller for ice making. The ice chiller was designed to operate during the night, taking advantage of the low cost of night time off-peak power. The heat exchanger loop, chiller evaporator, ice storage tank etc. is modified. After modification, the system is experimentally analysed. They concluded that during the summer, 25% of the cooling load was successfully shifted to off-peak hours. During spring and fall, the load shifting significantly increased to 50%. During the winter, whilst the ice storage system takes the cooling load entirely without the need to run a chiller, 100%of the load has been shifted to off-peak hours. The system runs at around 80% of its full capacity, and provides a steady, reliable and energy efficient operation. In this renovated system, both reliability and redundancy have been improved.

Fakeha Sehar et al, [9] analysed the chiller energy consumption of conventional non-storage and ice storage cooling systems for large and medium-sized office buildings in the diverse climate zones. Demand Response Quick Assessment Tool (DRQAT) has been used to model and simulate large and medium-sized office buildings. The construction and weather files in Demand Response Quick Assessment Tool have been modified to incorporate construction standard and weather data for the cities representing the diverse climate zones. Results indicate that the chiller energy consumption for non-storage and ice storage systems depends highly on climatic conditions. Climate zones with hot summers as well as small day and night temperature variations show higher chiller energy consumptions. The marine climate zone has the lowest chiller energy consumption. The cold/humid climate zone has higher chiller energy consumption than the cold/dry and very cold climate zones. The cold/dry and very cold climate zones have comparable chiller energy consumption.

Torsten Koller et al, [10] developed a novel solar powered absorption chiller which has been integrated into a cooling system for the institute’s building. For the perfect working of the absorption chiller, an ice store with a nominal volume of 0.5 m^3 was developed. For the design of this ice store several experimental and theoretical investigations have been completed. Part of the experimental work was the examination of the ice store behavior under different charging and discharging temperatures. The effect on charging and discharging behavior of different heat transfer areas was also examined. In case of discharging internal and external discharging was tested. Internal discharging is used in the operation of the cooling system for the institute’s building. For theoretical investigations a simulation program was developed and validated. Based on the results of these investigations a final heat exchanger design was established. In a further step the ice store was integrated into the building’s cooling system. Long term measurements of the cooling system have shown good in-service behavior of the ice store which fits the specific requirements of the coolings stem in combination with the absorption chiller quite well.

III. CONCLUSION

Thermal energy storage system coupled with a conventional air conditioning system is a suitable energy saving method. Thermal energy storage systems reduce peak time energy consumption. Energy is stored during off peak time and during peak time, this stored energy is reused. Thus considerable amount of peak time energy consumption can be achieved. The adoption of energy storage based air conditioning systems will be more economic and cost effective in the consumer’s perspective, if different electricity tariffs are available for the on peak and off-peak time.

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