Thermal Energy Storage in Building Using Phase Change Materials (PCMS)

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Abstract - *This object presents anew analysis of peak load shifting for air conditioning system using PCM (phase changematerial) in a room. The gentle range of the used PCM is from 20 to 25°C. The amount of the PCM is resoluteaccording to the cooling load of the room during the peak time. The hourly cooling load is considered. A low-power fanis used to drive air over the PCM capsules, which are decided in a chamber above the room. Auxiliary cooling unit isused to suspension the PCM when the night temperature is higher than 18°C. The temperatures of the PCM are restrained by9 thermocouples inserted inside a capsule. The different degrees of temperature of the air at the inlet, at the middle, and atthe outlet of the air-passing chamber as well as at the room are dignified during day and night. In addition to that, theclimate conditions are measured. As a result, during the peak load shifting time, which is within 2 hours, the decrease ofthe room temperature is between 7-10 °C by using PCM ceiling system. Accordingly, it can be concluded that the PCMsystem is effective for the peak load shifting.*

Keywords-*peak load shifting - PCM thermal storage- air-conditioning.*

I. INTRODUCTION

As the demand for air conditioning enlarged greatly throughout thelast decade, there has been a large demand of electric power. Inaccumulation, the limited reserves of fossil fuels have led to a surgeof interest in efficient energy application. Electrical energyfeasting varies suggestively during the day and nightaccording to the demand by industrial, commercial andresidential activities. In hot climate countries, the major part ofthe load variation is due to air conditioning. Better powermanagement and momentous economic benefit can be accomplished if some of the peak load could be shifted to the off-peak loadperiod. This objective can be achieved by thermal energy storagefor cooling in residential and commercial buildingestablishments. Phase change materials (PCMs) have beendeliberated for thermal storage in buildings since 1980.There are several promising developments are taking place inthe field of application of PCMs for heating and cooling of building. Experimental study of two real size concrete cubiclesdecided that the energy storage in the walls by summarizingPCMs and the comparison with conventional concrete withoutPCMs led to an improved thermal inertia as well as lower innertemperatures. Performance of a hybrid heating-system, combined with PCMthermal storage was examined numerically. The resultsindicated that the thermal storage of PCM plates improved theindoor thermal comfort level and saved about 47% of normal and-peak-hour energy and 12% of total energy consumption inwinter in Beijing.

The wallboards are inexpensive and widely used in a variability ofapplications, making them very suitable for PCMencapsulation. To improve the wallboard efficiency, a vacuuminsulation panel (VIP) was allied to the PCM panel.An empirical model for a real-scale prototype of a PCM-airheat exchanger was built from experimental results, aimed atstimulating the thermal behavior in the tested heat exchanger indiverse cases. The use of the granular PCM can lead toimprovement of the indoor thermal environment in comparisonwith that in conventional systems due to thermal radiation fromthe floor surface area, which can be maintained around thephase change temperature.Studies of the free-cooling potential for different climatic locations were investigated. It was found that the optimumPCM had a sentimental temperature that was roughly equalto the average ambient air temperature in the hottest month,and that the free-cooling possible was proportional to theaverage daily amplitude of the ambient air's temperatureswings. For all the analyzed climatic conditions, the PCM witha wider phase change temperature range (12 K) was found tobe the most efficient. In tests, a PCM wallboard roomwas constructed by attaching PCM wallboards, developed byincorporating about 26% PCM by weight into gypsumwallboards, to the surface of an ordinary wall.

0mcomparedwith an ordinary room, it was found that the PCM wallboardroom could greatly reduce the energy cost of HVAC systemsand transfer electronic power peak load to valley. Experimentalanalysis of cooling buildings using nighttime coldaccumulation in paraffin with a melting point of 22 ºC as thePCM was investigated.The effects of a peak shaving control of air habituationsystems using PCM for ceiling boards in an office buildingwere examined.

In this study investigational analysis of peak load shifting for airacclimatizing system using coconut fatty acid as PCM in a roomunder climate of Cairo is investigated. In order to accomplish theoptimum design for the selected location the average ambientconditions for all the months are studied. Coconut fatty acid isselected due to its encouraging melting and freezing temperaturerange as well as its low price.

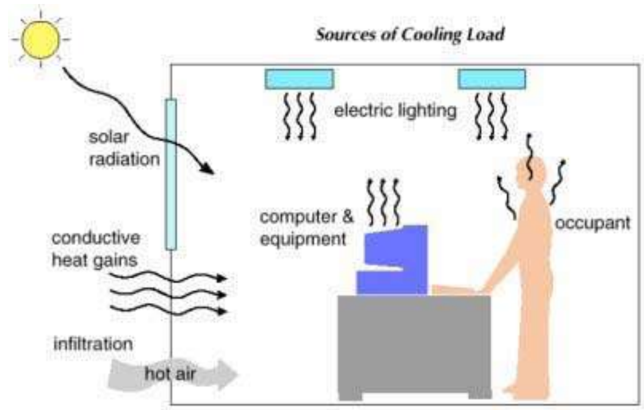

Fig. 1 The major sources of heat gain into a building

II. EXPERIMENTAL WORK

2.1. Thermal design for PCM mass calculations:

The PCM storage capacity is considered to be used in the testroom with its thermal loads during the peak time. To reachsuitable thermal comfort the room temperature should be inthe range concerning 21 and 28 °C. Accordingly, to overcomethe day/night time lag problem the thermal storage capacity ofthe PCM has to accommodate the heat gains within the spaceduring the peak time. The net heat load into a construction is calledthe cooling load. The total building cooling load consists ofheat transferred through the building envelope and heat generated by occupants,equipment, and lights. The main sources of heat gain into abuilding are shown in Fig.1. Note that groundlosses/gains are typically small and are here presumednegligible. The load due to heat transfer through the envelopeis called as external load, while all other loads are called asinternal loads.Based on energy balance, the net cooling load is calculated asfollows:

$$Q_{load} = (Q_{solar} + Q_{people} + Q_{electricity} + Q_{walls} + Q_{windows} + Q_{ceiling} + Q_{doors} + Q_{infiltration})_{in} \quad (1)$$

The hourly cooling load is calculated by using HAPsoftware version 4.04. The peak load is shown in Fig. 2.The extent of PCM is calculated rendering to thecalculation of cooling load during the peak period. The quantity of PCM is calculated as follows:

$$m_{PCM} = Q_{load} * time / (C_{Pl} * (T_l - T_m) + h_{fg} + C_{Ps} * (T_m - T_s)) \quad (2)$$

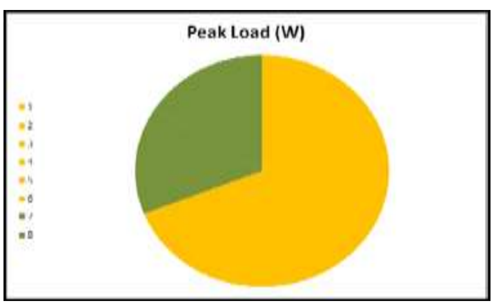

Fig. 2 Calculated peak load

2.2. Outline of the system

The result from the thermal design process is used toproduce prototype module for concealed heat thermal storagefor the laboratory test room. As shown in Fig. 3 theexperimental apparatus consists of the following:

i) Auxiliary refrigeration circuit.

ii) PCM chamber of capsules.

iii) Room space.

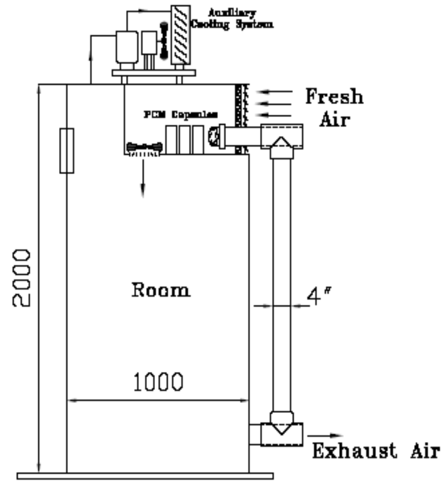

Fig 3.Schematic of the prototype

Fig 4.Photo of the prototype

The assembly is a ceiling chamber contains PCMcapsules above a room space. The dimension of the roomis 1 m in length, 1 m in width, and 2 m in height. Thewall building is a sandwich panel. The thickness ofeach wall is 52 mm. A fan opening is providing on theceiling of the room. The ceiling chamber height is 30cm. Fig 3 1nd 4 shows the outline of the system. Throughoutnight, the capsules are cooled by bathing the ambient airthrough the ceiling chamber. After that, it bathes throughthe room and then consumes from an opening at thebottom of the room. During the daytime air enters fromceiling foundational flows through the room space thenreturns to the ceiling chamber to be recycled with freshair to the room. If the temperature of the ambient air ishigher than 18°C, a temporary cooling unit is used forcooling the capsules during the night. The cooling timeby using the storage unit is two hoursduring the period from 12pm to 16pm. In this study, thethermal storage time can be done before 9am.

III. RESULTS AND DISCUSSION

3.1. Weather condition

Figure 5 shows the data of the average ambient air temperaturefor each month at the field of the experimentations in 2008. PCMMelting at 22-24oC is workable for free cooling.From May to October free-cooling cannot bemade available and electric cooling can be used for loadshifting regime. PCM melting at 22-24oC will easily givecontentedinfection during day time for rest of themonths.

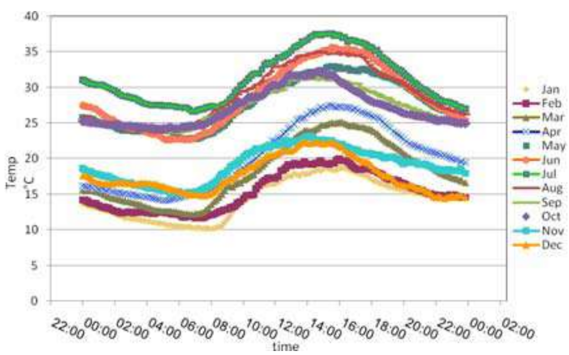

Fig. 5 Average ambient air temperature

3.2. Cooling load and PCM quantity

Radiation heat gainfrom sources such as sun, lights and even people revenues time tobecome a load. The radiant heat must first heat up the constructionand contents and then be showed and released over time tothe room air by convection processes. This sources a delaybetween the time a heat gain occurs and the time its full effects as a cooling load appear. The peak load is shown in Fig. 6. Thequantity of PCM is calculated as explicated before in equation(2) from Fig. 6, which is the area under the cooling load curveat the period of time from 15 pm till 17 pm. This area isalmost equal to 30% of the total cooling load. These resources that 30% of the energy used for air habituation can besaved by using free cooling of PCM. The calculated quantity ofthe PCM for the 30% of the cooling load of the assumed prototype is 38kg of coconut fatty acid.

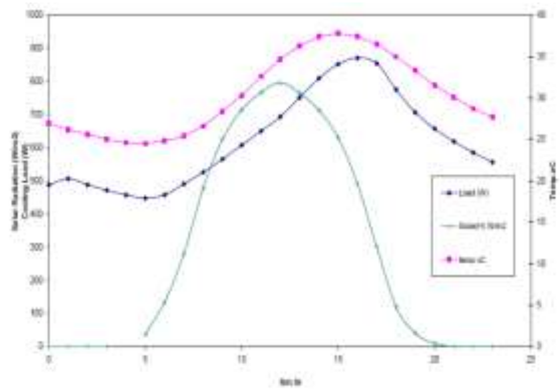

Fig. 6 Hourly cooling load, solar radiation, and the ambient air temperature

3.3 Temperature profiles

The radial temperature profiles of the PCM at three dissimilarheights that is 30 mm, 60 mm and 90 mm throughout the charge anddischarge periods are shown in Fig 7. The situations of the thermocouples areat the center of the PCM capsule and at radii of 25mm and50mm. The temperature curvatures illustrate the temperaturecirculation in three regions during the charge and theemancipation processes. The liquid region is above the upper limitof the melting range. The phase evolution region is within themelting range. The solid region is below the lower limit of themelting range. The visible variation in temperature is perceived during the chargeand discharge processes. During the charge process, theconduction through the bottom wall of the capsule causes rapidcooling at the bottom. At the liberation process, thetemperature increases rapidly until melting occurs thenbecomes constant.

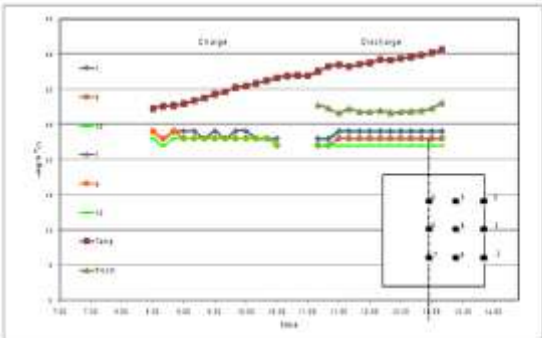

Fig. 7 Temperature profiles of the PCM

IV. CONCLUSIONS

In this research, the properties of the peak shaving control usingPCM capsules in a ceiling-chamber for a room are examined. The subsequent results were obtainedby exploratory the designed model experimentally,

1. In summer the cooling load peak is at 4 p.m. due to the time that heat takes to be directed throughthe walls.

2. PCM melting at 22-24^{o}C is workable for freecooling for 6 months. For the rest 6 months thepeak shaving control can be applied by a nightelectric cooling unit.

3. Within 2 hours of peak load unstable time, theroom can be kept cooled at a comfort temperatureby cooling with off-peak energy.

4. Using free cooling of PCM can save 30% of theenergy used for air conditioning.

5. Using permitted cooling of PCM can preserve thetemperature within the room between 20 to 26°C.

6. The change in the air temperature in storagechamber is comparative to the change in the PCMtemperature inside the capsules.

7. The change in the air temperature in the room isproportional to the change of ambient airtemperature.

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