Comparative Study of Cost and Power Consumption of HVAC System Using Phase Change Material

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Abstract— Phase change materials (PCM) are materials which absorb the latent heat of the surrounding air. They usually have characteristics such as near to constant temperature operating range with high energy density of melting from solidified state. Nowadays, heating ventilation & air conditioning (HVAC) of commercial & domestic buildings, green rooms in pharmaceutical companies is necessary for maintaining desired atmospheric condition inside the building compound for optimum working environment. For doing so, lot of energy is consumed in this process. Therefore, there is a need of reduction in power consumption where PCM finds a huge market. These materials store the latent heat of the net heat available as latent heat thermal energy without increase in its temperature. Thus, there is a large scope for its usage for reducing the heat load for refrigerating effect for a specified area. This paper intends to compare the variation in heat load calculation of air refrigerated areas like that in commercial buildings, domestic purposes, industrial applications etc. with and without the use of PCM materials.

Keywords- *Phase Change Material (PCM), HVAC, Air Conditioning (AC), Power Consumption*

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I. Introduction

PCM is used for building applications since it acts as a latent thermal heat reservoir which changes the required heating and cooling loads over the air conditioning (AC) system. Mostly, PCM is used only for solid to liquid phase transformations (i.e. latent heat of fusion) whereas liquid to vapour phase transformations (i.e. latent heat of vaporization) are neglected purposefully as it accounts for a drastic change in volume of the material which is not desirable for its application in a space constrained building construction design. While building materials such as brick, concrete also absorb some of the solar heat incident on them during daytime but they themselves get heated up in doing so, whereas PCM stores more heat compared to them in significantly less mass and PCM maintains its temperature constant while melting when it absorbs the heat till it completely changes its phase from solid to liquid. Usually the melting temperature of PCM is around 70-80 degree Fahrenheit. Studies show commercial buildings having HVAC installations for maintaining their specified temperature using PCM saves potentially about 10-30% in power consumption along with reduced heat load resulting in less expensive HVAC equipment’s during new setup installation. Abhay B. Lingayat and Yogesh R. Suple [1] have presented a detailed study on PCM incorporation in building material, PCMs integration with building architecture for space heating, space cooling and in combination of heating and cooling and concluded that there is a lot of scope for usage of PCM in future as it acts as a renewable energy source in reducing global energy loads. Brian James and Paul Delaney [2] carried out energy simulations of a commercial office building in California’s climate zone (CZ) 13. They have represented temperature profiles of inside and outside wall surface temperatures along with outside dry bulb temperature graphically as a comparison with and without PCM which suggested that PCM helps in reduction cooling loads along with assisting the air conditioner to control the inner temperature of the building. Since most PCMs have low thermal conductivity, it needs to be exposed to a sufficient area of heat transfer, which is achieved with heat pipes and metallic fins was concluded by D. J. Malan et al [5]. Yueru Zhang [6] has analyzed the effect of PCM on indoor temperature control by building simple mathematic model concluding that the construction energy waste can be cut down by reasonable design and adopting suitable material. The dynamic performance and rapid charging times with low temperature differences have been discussed in [7, 8]. Harshal Gupta and P. Meenatchi Sundaram [4] had suggested of using PCM instead of diesel generators for energy backup in case of load shedding. They concluded that usage of PCM as an alternative to diesel generators resulting in less carbon footprints and energy consumption in case of developing countries. Akshata Namjoshi et al [9] carried out an experimental study to improve the performance of AC systems and concluded that there is no significant change in COP of the system along with PCM installed, whereas there is an improvement in performance in terms of energy saving. Mohammed M. Farid et al [10] have made a review on phase change material and its types with applications. They have tried to put forward recent trends in PCM technologies. Also they have suggested improvements over few common problems faced with PCM. Fig.1 shows the phase transformations of PCM when there is a difference between the melting point temperature of the material and the ambient temperature.

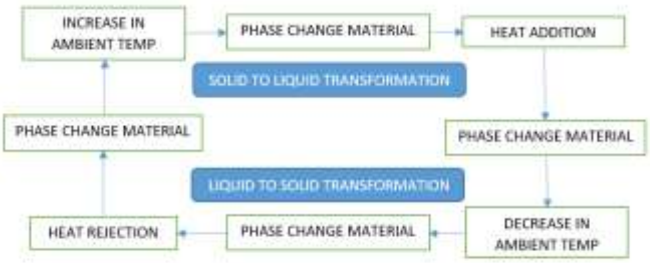

Figure 1. PCM PHASE CHANGE CYCLE

II. PROBLEM DEFINITON

For analyzing the difference between the cooling load requirement with and without use of PCM, an example of an office layout in a commercial building is taken into consideration. The office is located in Mumbai which is a metropolitan city in India with latitude of 19.07 degree north. The city has hot and humid climate during summers being situated towards the coastline of Maharashtra. The office is situated on the 5th floor of the 11 floor commercial building. Thus the ceiling is roof-shaded and is made of Asbestos-Cement Shingles. The office receives direct solar heat gain from south, east and west directions. The windows are located in east and west directions. The walls are made of common masonry bricks with cement plastering and the windows have ordinary glass panels. The office gains heat externally through direct incident solar heat through walls and windows along with internal heat generated through human bodies and through the appliances operating inside the premises. The entire layout can be sub-divided into 4 AC rooms, 1 non- AC room and hallway passage connecting them. The layout of the office is as shown in the fig. 2.

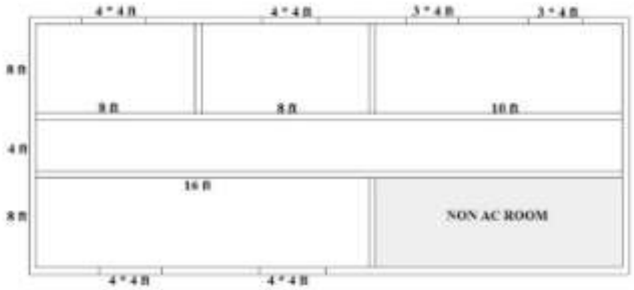

Figure 2. LAYOUT OF THE OFFICE IN COMMERCIAL BUILDING

Phase change material (PCM) is employed over the gap between the false ceiling and the bottom of the ceiling slab for reduction in latent heat inside the working area.

For analytical cost calculation, the following two cases are considered-

A. Power consumption without PCM

In this case, the AC is considered to be working for entire 12hours of office timing

B. Power consumption with PCM

In this case, the AC is considered to be working around 8 hours out of 12 hours office timing. For the remaining 4hours during peak load time the AC is turned off and PCM operates during this time.

The AC considered for both the cases is of the following specifications,

- DDC series 6 tonne AC with 13 SEER and 11 EER.

III. DATA PROCESSING

Area of the room to be air conditioned =Length of the room * Breadth of room in ft (1)

Volume of room air to be air conditioned = Area in sq.ft * Height of the room in ft (2)

Ventilation= No of people * Cfm/person (3)

Ventilation= Volume of room to be air conditioned * No of air charge/hr (4)

Ventilation= Area in sq.ft to be air conditioned * Cfm/sq.ft (5)

Sensible heat storage-

$$Q = \int_{T1}^{T2} m * Cp * dT = m * Cp * (T2 - T1) \quad (6)$$

Latent heat storage-

$$Q = m * LH \quad (7)$$

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Heat generated by occupancy= No of person * Sensible heat/person (8)

Heat generated due to lighting= 1 watt/sq,ft * Ballast factor(i.e. 1.25) (9)

Outside air infiltration= Cfm*Temperature in degree Fahrenheit * B.F * 1.08 (10)

ESHF= ERSH/ERTH (11)

RSHF= RSH/RTH (12)

Dehumidified rise= (1 - B.F) * (Room Temp – ADP) (13)

Dehumidified Cfm= (RSH)/(1.08 * Dehumidified rise) (14)

TR= (grand total heat)/ (12000btu/hr) (15)

IV. METHODOLOGY

A. Methodology used in calculating the cooling load is as follows

1) Basic data collection
   a) Calculate the area to be air conditioned in Sq.ft using (1).
   b) Calculate the total volume of place in cu.ft using (2).
   c) Analyse the geographical location of room.
   d) Analyse the outside & inside air properties, such as DBT, WBT, %RH, Dew Point, Gr/Lb, Enthalpy.
   e) Calculate the difference between of DBT inside & outside, specific humidity and Gr/Lb
2) Calculate Ventilation volume (cfm)
   a) Depending upon No. of people in the room using (3)
   b) Direct exhaust from air conditioned area if Or if number of people not known then consider volume of room/hr using (4)
   Consider max of above values
3) Calculate the entire sensible Heat load available in room using (6).
   a) Heat flow through the exterior walls, ceiling floors, glass of windows
   b) Infiltration and outside air using (10).
   c) Occupancy
   d) Electrical appliances
   Calculate total space sensible heat by adding all the factors above
4) Calculate the entire latent heat load available in room using (7).
   a) Infiltration
   b) From Occupants
   Calculate total space latent heat by adding all the factors above
5) Calculate grand total space heat in BTU/hr
6) Calculate tonne of refrigeration using (15).

B. Methodology for power consumption with and without PCM installed

TABLE I. COST & POWER CONSUMPTION

Parameters	Without PCM	With PCM
Working hours	12hrs	12hrs
AC running time	12hr	8hrs
Unit consumption per hour	1.909kw	1.909kw
Power consumed in 12 hours	22.908kw	15.272kw
Power consumed in 1 month	687.24kw	458.16kw
Cost of unit consumption	Rs 15	Rs 15
Total monthly bill	Rs 10308.6	Rs 6872

C. *Abbreviations*

Symbol	Description
Q	Amount of heat stored or released as sensible heat in kJ
m	Mass of the material used to store the sensible heat in kg
T1	Initial temperature of the material in K
T2	Final temperature of the material in K
Cp	Specific heat capacity of the material in kJ/kgK
LH	Latent heat of fusion in kJ/kg
Cfm	Cubic feet per minute
BTU/hr	British thermal units per hour
SEER	Seasonal energy efficiency ratio
EER	Energy efficiency ratio
DBT	Dry bulb temperature
WBT	Wet bulb temperature
RH	Relative humidity
Gr/lb	Grains per pound
B.F	Bypass factor
ESHF	Effective sensible heat factor
ERSH	Effective room sensible heat
ERTH	Effective room total heat
RSHF	Room sensible heat factor
RSH	Room sensible heat
RTH	Room total heat

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V. RESULT

A. Cooling Load

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Using the methodology (A) for calculating the values for cooling load for various timings all along the day, we get the following results as in table II

TABLE II. COOLING LOAD AT DIFFERENT TIMINGS

Time	9am	10am	11am	12pm	1pm	2pm	3pm	4pm
TR	4.1824	4.2186	4.3798	4.158	4.6063	4.8458	5.0943	5.2445

Using the table II, the graph plotted is shown in fig. 2

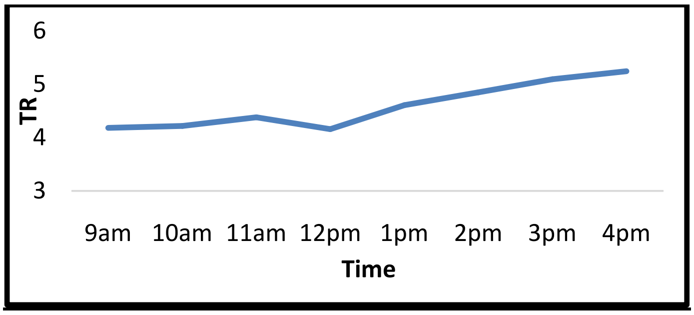

Figure 2. VARIATION OF COOLING CAPACITY WITH TIME

Figure 2. Shows that the cooling load required in the morning when the office timing starts is the lowest since the intensity of solar radiation is the least during this period. The graph also suggests that cooling load has an increasing tendency from 9am to 11am and also about a steep drop in at noon. This is because at noon time the maximum sun rays act on the roof of the building and less heat is incident on the walls of the building. Since the office has roof-shaded ceiling it absorbs less heat during this time and thus there is decrease in cooling load. The trend in increase of cooling load during morning time and afternoon time can be directly interpreted as the intensity of the slant solar heat absorbed during morning is less while during afternoon is more. Also during 4pm, the cooling load required is highest as the intensity of heat in the form of solar heat is the highest during this time.

B. Power Consumption

Using the two cases displayed in table I of power consumption following results can be suggested

From the data in table I, the graph plotted is shown in fig. 3.

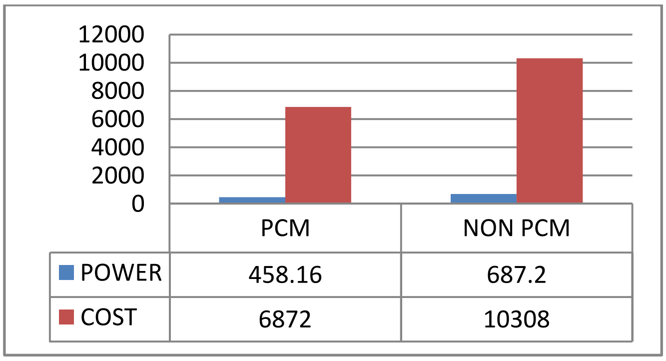

Figure 3. COST AND POWER COMPARISON

The total monthly power consumption without PCM in the system is 687.24kw and with PCM is 458.16kw. The percentage savings in energy consumption is found to be 33.33%. The cost associated with power consumption 687.24kw is Rs 10308.6 and for 458.16kw is Rs 6872. This results in savings of Rs 3436.6 in monthly electricity bill. These results are obtained by considering the AC compressor to be working full time without employing thermostat or any kind of control attachments. If controls are provided in AC system the compressor won't work for full time, thereby decreasing overall power consumption.

VI. CONCLUSION

- Thus by employing PCM for air conditioned rooms a savings of about 33.3% can be achieved and this value can be increased by increasing the duty cycle of PCM above 4hrs.
- With development of PCM material energy consumption can be decreased even further by employing it in various forms for construction of green buildings.
- If PCM is used to cool the inside of a building during peak load during daytime rather than air conditioning there is a scope in reduction of energy consumption. For cooling the PCM during night time less energy is consumed because of the difference in the atmospheric temperature. Thus cooling is achieved with a relatively less energy consumption.
- Also, installation of PCM is one time investment and it does not cost additional maintenance cost till the it completes its duty cycle which is approximately 5000 cycles after which it needs to be replaced. One PCM cycle means phase transition from either solid to liquid and then again from liquid to solid.
- It significantly helps in reducing carbon footprint of a country if it's utilized at a national level for commercial, domestic and industrial level.

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