CHAPTER 5

CONCLUSION AND SCOPE FOR FUTURE WORK

5.1 Concluding remarks

The building sector is responsible for 1/3rd of the world energy consumption and more than 50% of this consumed energy is utilized for space heating and cooling. Thermal energy storage in the form of sensible heat and latent heat has been identified as the only effective methods in regulating the indoor temperature, shifting the peak load to the off-peak hours and reducing the energy need for space cooling and heating in the buildings. Latent heat storage using PCM can store 5-14 times more heat in comparison to the materials used for sensible heat storage. Therefore, integrating the PCM in the building envelope will effectively improves the indoor thermal behavior of the building in terms of peak temperature reduction, minimizing daily temperature swing, and increasing time lag. However, PCM suffers with two major drawbacks, i.e. leakage during phase transition and poor thermal conductivity, when embedded in the building envelope. Indirect incorporation technique has the ability of overcoming these drawbacks of the PCM. Among all the indirect incorporation techniques, MPCM founds more suitability with the building element. It will not only minimize the leakage and enhances the heat transfer of PCM, it is also a cost effective and simplest method in comparison to other techniques used to incorporate the PCM in buildings. Therefore, a wide range of available PCM and composite PCM can be used in buildings as MPCM. Additionally, commercial manufacturers of PCM can provide readymade MPCMs which are encapsulated in sheets, tubes, cylinders, pouches, plastic panels, polymers and etc.

To evaluate the effectiveness of MPCM in regulating the indoor thermal behavior of the building in the tropical climate of India, real outdoor short duration (24 hour) and long duration (annual) field testing was conducted. The commercially available PCM is macro-encapsulated in tubular shape containers made of aluminum alloy 8011. The MPCM is incorporated in the walls and the roof of the cubicle during construction and was tested for the indoor thermal response. Following conclusion are made based on the short duration field testing results:

1. The experimental cubicle has achieved a peak temperature reduction for all the orientations and indoor ambient ranging from 7.19 % to 9.18 %.
2. Integrating MPCM in the experimental cubicle will reduce the thermal amplitude of all the walls and the roof ranging from 40.67 % to 59.79 %.
3. A time delay, in peak temperature, of 120 minutes for the east wall, north wall and inside ambient of experimental cubicle was observed. Whereas, west wall, south wall and the roof of experimental cubicle show 60 minutes of time delay in peak temperature.
4. The east wall of the experimental cubicle shows a maximum peak heat flux reduction of 41.31 %. The total peak heat flux reduction was 27.32 %.
5. The integration of MPCM will reduce the cooling load to 38.76 %, which leads to 28.31 Rupees/day (~0.40 US $/day) cost saving on the electricity bill.
6. The thermal images obtained from thermography also revealed that the inside surface average temperature of a section of the south wall of the experimental cubicle is low in comparison to the south wall of reference cubicle.

7. In yearly analysis experimental cubicle shows a reduction in the indoor peak temperature round the year, ranging from 0.2°C to 4.3°C along with a percentage reduction in the indoor thermal amplitude ranging from -2.43% to 51.3%.
8. The experimental cubicle has obtained an annual average time delay of 97.5 min and percentage reduction of 24.69% in the annual average decrement factor.
9. Months falling in the summer season have effectively utilized the latent heat storage capacity of the embedded PCM in comparison to the months of the winter season because of better charging and discharging of the PCM.
10. Effective improvement in the time lag and reduction in the decrement factor was observed for the summer season/months compare to the winter season/months of both the cubicles.
11. The enhanced latent heat storage capacity of experimental cubicle reduced the daily average peak heat flux by a maximum of 29.09% for the month of June to a minimum of 0.15 % for the month of December.
12. A yearly average percentage reduction of 17.37% in peak heat flux was obtained by the experimental cubicle compare to the reference cubicle. Consequently, annual average cost saving of 1.47 rupees/kWh/m^2/day on the peak cooling load could be obtained.

To evaluate the thermal energy performance of the PCM series of composite PCM using EG and EV was prepared through vacuum impregnation technique. The PCM/EV/EG ss-CPCMs containing 3%, 5%, and 7% of EG was successfully prepared. Thermal energy storage behavior, thermal stability, thermal conductivity, thermal reliability, and leakage-proof performance of ss-CPCM was investigated. Following are the conclusions based on thermal energy performance characterization of the commercially available OM37 PCM:

1. The latent heat of melting and freezing of ss-CPCM-1, 3, 5, and 7 was monotonically decreased with increase in the loading of EG due to decrease in the wt% of PCM and negligible energy storage capacity of EG. However, ss-CPCM-1, 3, 5, and 7 has shown good values for latent heat storage capacity of 114.23 J/g, 111.56 J/g, 105.08 J/g, 99.32 J/g for melting process and 112.82 J/g, 108.22 J/g, 102.56 J/g, 97.62 J/g for freezing process respectively. Also, the calculated values of latent heat energy storage were in good agreement with measured value latent heat of ss-CPCMs.
2. The thermal conductivity of the ss-CPCM was significantly affected by the presence of EG and is increases with the increase in wt% of EG. The maximum value of thermal conductivity of 0.311 W/mK was obtained for ss-CPCM-7. Increment of 33.1%, 79.3%, and 114.4% was observed for ss-CPCM-3, ss-CPCM-5, and ss-CPCM-7 in comparison to PCM.
3. The melting and freezing behavior of ss-CPCM changes with change in the weight fraction of EG. Increase in the weight fraction of EG reduces the time of ss-CPCM to completely melt and completely freeze. The ss-CPCM-7 shows 25.9% and 19.2% faster heating and cooling time in comparison to PCM.
4. The leakage proof performance tests suggest that ss-CPCM-3, 5, and 7 have excellent leak-proof behavior. Additionally, ss-CPCM have high thermal stability and thermal reliability. Therefore, PCM/EV/EG ss-CPCM could be used as a potential material for thermal energy storage in building applications.

5.2 Recommendation for future work

Following are the suggestions for future research on integrating MPCM in the building envelope for improving indoor thermal behavior.

1. In the tropical and equatorial climate, because of the large temperature difference in the summer and winter season, one PCM is insufficient to provide latent heat storage in the buildings for both the summer and winter seasons. In the winter season the maximum temperature remains below the transition temperature range of the PCM resulting in no utilization of the latent heat of the PCM. Therefore, the possibilities of using hybrid PCM must be explored for these types of climates.
2. Sufficient active ventilation systems must be provided in the building to discharge the heat released by the PCM during the nights to the outside environment otherwise, it may cause thermal discomfort because of overheating. Additionally, a separate study is to be conducted to analyze the effect of active, passive, and no ventilation on the building structure embedded with MPCM.
3. Further research on Life Cycle Costing (LCC) and the Pay-back period of using PCM in the building envelope should be conducted to understand the economic and commercial viability of the technology.
4. A standard code of using a specific PCM with a particular type of container must be developed to easily identify the compatibility of the PCM and the container for a diffrent types of building envelope across the globe.
5. Optimal size and optimal location of the macroencapsulated PCM need to be further investigated for the effective utilization of the heat storage capacity of the PCM.

6. Mechanical properties like strength, toughness, and corrosion can also be analyzed to find out the effect of integrating M PCM in the walls and roof of the building.
7. This study opens a new direction of using OM37 PCM as ss-CPCM. Since, ss-CPCM has shown excellent thermal energy storage performance therefore, a study must be conducted to evaluate the effect of embedding ss-CPCM in light weight building element in indoor thermal behavior of the building.