A REVIEW ON ENERGY EFFICIENT BUILDINGS - USING PHASE CHANGE MATERIALS, GREEN ROOFS AND HEAT REFLECTIVE COATINGS

Vyshakh E.J[1], **Bennet Kuriakose**[2]

[1] *PG Scholar, St Joseph's College of Engineering and Technology, Palai, Kerala, India*
[2] *Associate Professor, Dept. of civil engineering, St Joseph's College of Engineering and Technology, Palai, Kerala, India*

***

Abstract - *Global energy demand is rapidly increasing and elevated fossil fuel consumption leads to depletion of ozone layer, global warming etc. In some countries the major sector of energy usage is buildings. Considering the reports from International Energy Agency (IEA), building sector accounts for more than 30 percent of total consumption of energy and is the producer of 30% of the total* CO_2 *emissions. Buildings being energy efficient is of primary concern recently. PCM (Phase Changing Materials) is an efficient solution to the issue. Its capable to reduce temperature variations by changing their state from solid to the liquid when temperature increases via absorbing energy, and can release the absorbed energy, and change from liquid to the solid state when temperature drops and obtain thermal comfort inside the building. Green roof tops are another superior example of a concept for reducing consumption of energy and improving business and residential building comfort levels. Furthermore, because it is obviously known that white colour has the highest solar reflective performance, white or light colour coatings have been frequently placed on the building's posterior walls or roofs so as to reflect the incident sunlight and thus reduce energy consumption for interior cooling.*

Key Words: **Thermal comfort, Phase change material, Heat reflectance, Thermochromic films, Green roofs.**

1.INTRODUCTION

In buildings, majority of energy is utilized to preserve a comfortable ambient environment in terms of comfort on thermal basis (heating or cooling) and the quality of air (ventilation). According to the report by World Bank on power consumption in residential sector, 40% of the energy demand is required to meet the electricity demand for such structures that are built to bring down the amount of energy required for heating and cooling are known as energy efficient buildings. The energy consumption for maintaining thermal comfort can be reduced by the use of Phase Changing Materials. Phase Changing Materials (PCM) are substances which release or absorbs sufficient energy at phase transition. These materials store thermal energy during the time of melting and in turn liberates thermal energy in the time of freezing. They are mainly employed for obtaining thermal comfort inside the building.

The phase transitions via produced latent heat is used to store thermal energy in phase change materials (PCMs). sssPCMs can be employed to acquire cooling (below ambient transition temperatures), building thermal swings (below ambient transition temperatures), and short-term storage of solar thermal energy. The capacity to store energy in a consolidated form can provide a supply of heat that is quickly accessible when thermal energy comes from a recurring and periodic source, such as radiation from sun. Phase changing materials that posses the ability to change state from solid state to liquid and vice versa are utilised in construction to achieve control over temperature changes. They melt by absorbing heat during daytime and then keeps the room temperature constant until the phase changes. The PCM then turn back to solid state at night. Thus, the phase change cycle repeats.

Green roof tops are another superior example of a concept for reducing energy consumption and improving the comfort of business and residential buildings. Green roofs have always been studied as a bioclimatic method for improving building energy efficiency. Green roofs provide undeniable thermal advantages. When opposed to an exposed naked roof, the indoor and roof temperatures of a structure with a green roof are much lower. The most important environmental element affecting the green roof's cooling capability is relative humidity. Because Infrared energy makes up almost half of all solar energy, increasing the infrared reflectivity of the outside wall or roof has recently been investigated and used to minimise energy usage. As it is commonly known that white has the highest solar reflective performance, white or light colour coatings have been frequently used on the posterior of building walls or roofs till date. However, white or light colours are always susceptible to pollution, and a single hue seldom meets human desire in practical building decorating. Furthermore, novel deep colour pigments with excellent infrared reflecting properties have been discovered in recent years.

2 THERMAL EFFICIENT BUILDINGS - USING PHASE CHANGE MATERIAL (PCM)

Evidently every field including transportation, buildings and industry, requires energy as a vital component in smooth functioning. All these sectors need massive amounts of energy so as to carry out their tasks leading to an energy usage of roughly 50%, 25% and 20% respectively. The consumption of energy in the building sector accounts for cooling, ventilation, heating, lighting, etc. Among these splits, the energy consumption for meeting goals of heating, ventilation, and air conditioning (HVAC) is the most considerable. Further, energy usage for HVAC purpose directly relates to the heat flow between the building and its surrounding, which in turn means that, less heat exchange can result in less HVAC energy usage. Higher thickness and lower thermal conductivity of the building materials can help in lowering the heat exchange. Storing energy is an alternate way to lower the heat exchange. Phase change materials (PCMs) are a strong candidate for the purpose as they are well known for its property of thermal energy storage capability from numerous previous studies. If the building envelope incorporates a layer of PCM, taking into consideration its energy storing capability, the effective heat exchange will significantly reduce.

In a study carried out by Kheradmand et al[3] fluctuations in temperature of façade wall with the addition of PCM was investigated. It was found that the use of PCM devitalized temperature fluctuations, as PCM inhibited any temperature fluctuations during the phase change. Su et al[4] carried out a comparable study in which layers of microencapsulated PCM having different melting temperature (Tm) were incorporated into drywall to investigate the thermal behavior. It was found that as the thickness of the PCM increased, its efficiency also increased. Considering the conditions supposedly ideal, the temperature was brought down by 6.7◦C. In an experimental study, Chou et al. [5] augmented PCM to the roof and concluded that the gain of heat lowered by 52.7% accounting to the usage of PCM.

Al-Rashed et.al [1] in his study, so as to lower the rate of heat transfer, incorporated PCM in the sidewalls and rooftop of a building in Kuwait City, which has a very hot and humid climate. To examine the relationship among heat gain and melting temperature, PCM variants RT-31, RT-35 and RT-42 (with 20 mm thickness) are investigated. By inducing sol–air temperature, the influence of solar radiation on vertical walls and roofs are investigated. Additionally, the annual rate of energy-saving and avoidance of CO_2 emission are investigated. In this study, the change in heat gain rate of rooms by installing PCM inside the walls and roof are examined. The walls of the building are augmented with a PCM layer of 20 mm thickness as shown in Fig 1. The base wall is made out of face brick (102mm thickness), gypsum board (19mm thickness), lightweight concrete block (102mm thickness) and the roof is made with acoustic tile (19mm thickness), felt-membrane (10mm thickness), heavy-weight concrete (51mm thickness) and slag-stone (13mm thickness).

As depicted in Fig.1, the building is heated up by the surroundings through the walls along with the roof. Assumption is undertaken that the ambient temperature of the room does not variate over time and stalls at 24 ◦C constantly.

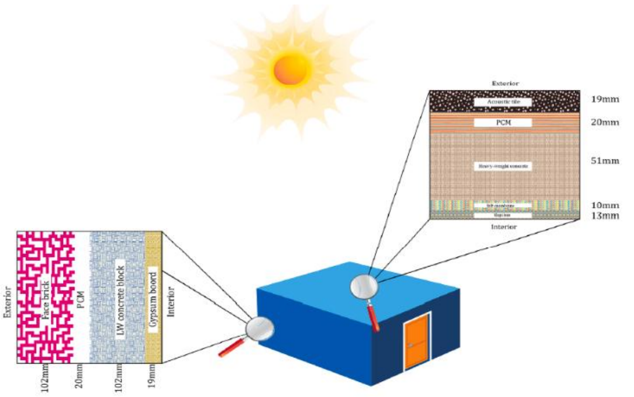
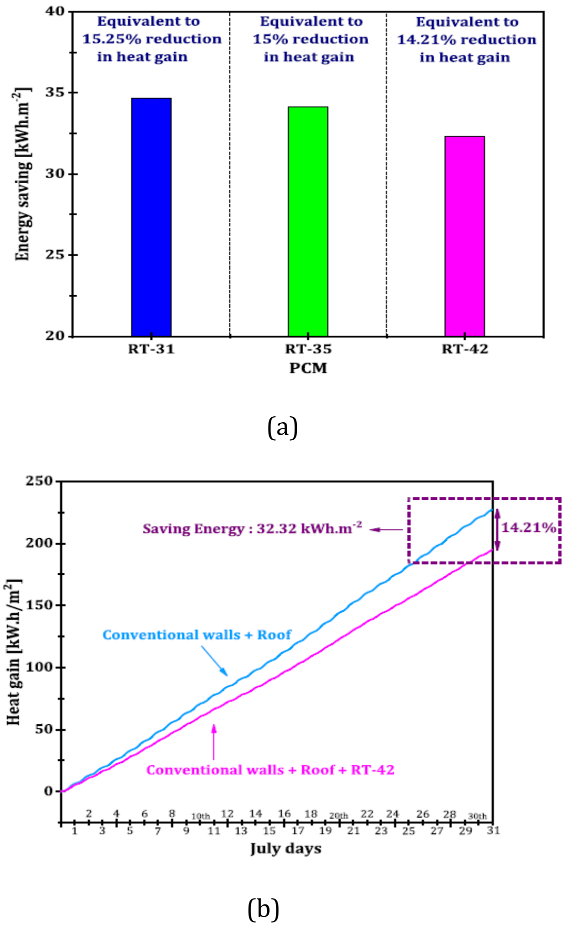


Fig.1. Overview of proposed method - Al-Rashed et.al [1]

The incident rate of sunlight depends upon the geographical direction to where the wall faces and hence the incident solar radiation in different directions is considered. The hourly fluctuations in ambient temperature along with solar radiation in all geographical directions were acquired using Meteonorm software. Since the Kuwait City temperature will be at its peak value in the month of July the heat gain difference obtained by incorporating PCM in walls and roofs were examined for July. Further, the hourly variations in the temperature for the month of July were also examined.

In this study, the reduction effect in the total heat exchange inside a building by the installation of PCM inside the walls and roof of the building were analysed. Computations on CO_2 saving rates were also carried out. Three kinds of PCMs of standards RT-35 (29–36 ◦C) , RT-31 (27–33 ◦C) and RT-42 (38–43 ◦C) were involved in the investigation regarding the effects of melting temperatures of the PCM in the effective variations in heat transfer. The experiments and overall analysis were performed upon two scenarios. In the former scenario, the heat transfer variation due to the effect of usage of PCM was examined for the month of July which was found to be the hottest month at the city. In the latter one, PCMs were installed and analysed throughout a whole year so as to evaluate and conclude about the overall effectiveness of augmenting PCM inside the walls.

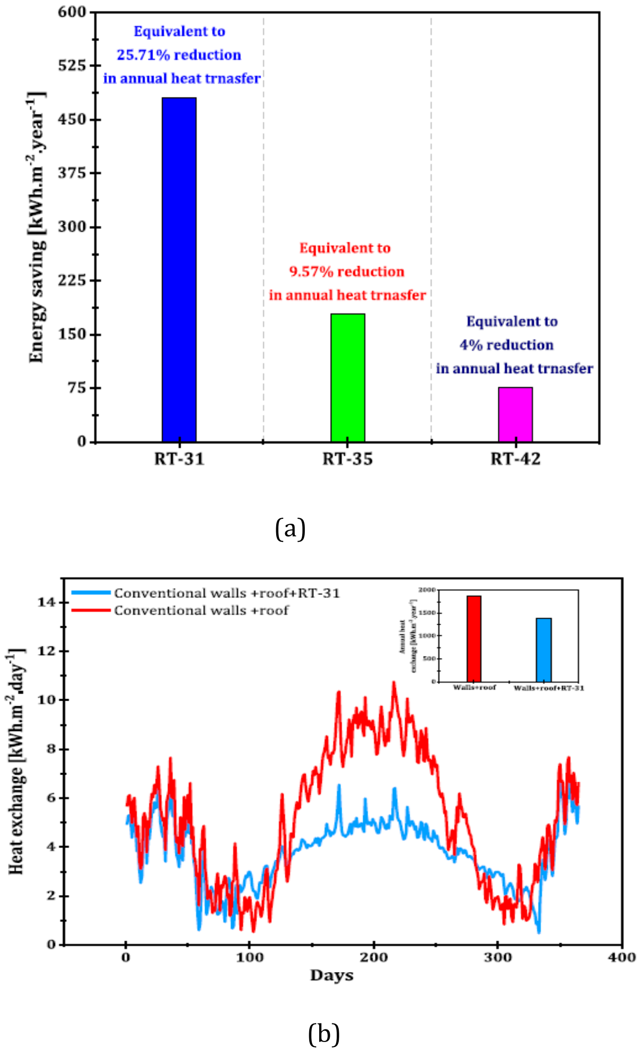


(a)

(b)

Fig. 2. (a) Energy saving rate comparisons of different PCM variants. (b) heat gain rate comparison[1]

From the results acquired in the month of July, it was concluded that, installing PCM into the roof and walls of the building , reduced the overall rate of heat gain by 15.25%, 15% and 14.21% for RT-31, RT-35 and RT-42 respectively. Fig. 2 (a) shown above confirms that energy saving due to having wall augmented with RT-42 is significantly lesser when compared to the other variants of PCM wall and roof. Fig. 2 (b), shows the overall heat gain for the month of July. It was concluded that for this month, the heat exchange through the conventional roofs and walls without PCM is 227.3 kWh/m2, while the rate fell to 194.98 kWh/m2 when RT-42 variant of PCM was augmented to the roof and walls, which is approximately a 14.21% heat gain reduction. In addition, the energy-saving was computed to be 32.32 kWh/m2. Fig 3 shown below reports the annual heat transfer reduction rate. The roof and walls augmented with PCM variants RT-31, RT-35 and RT-42 induce an effective reduction of heat exchange at the rate of 25.71%, 9.57%, and 4%, respectively, over the whole year.



(a)

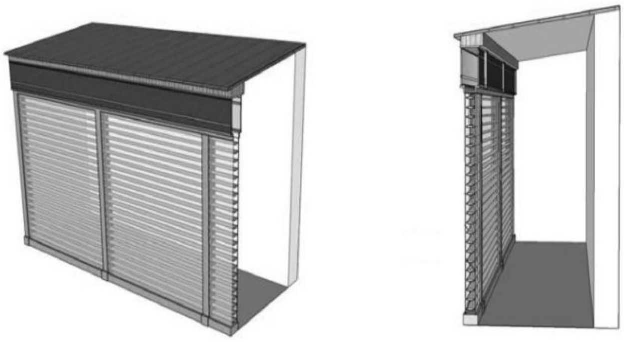
(b)

Fig. 3. (a) Annual heat transfer reduction comparison (b) Daily heat transfer variation comparison[1]

The maximum CO2 saving throughout the year was also calculated to be 198.65 kgCO2/m2.year which was recorded for the RT-31 PCM variant.

Thermal comfort does not merely converge to the aspect of cooling the indoor ambience during hot temperatures, rather widens its coverage of the concept of heating up the indoor temperature so as to obtain a comfortable temperature compared to the harsh cold climate outside. Inculcation of PCM into building components through multiple applications is an efficient passive way that many researchers are considering. Ceron et al[6] created a new tile system that uses PCM as a passive thermal conditioner and put the prototype to the test. They came to the conclusion that the system can balance the ambient temperature in the winter and lower the amount of energy necessary to ensure thermal comfort at night. Zhang et al.[7] created a thermally improved frame wall with the goal of lowering peak air-conditioning demands in residential buildings. Mourid et al[8] evaluated the effects of PCM inclusion on conventional walls in an experiment, and found that PCM integrated walls can reduce energy consumption by up to 20%.

China, as a specific place, is at the pinnacle of urban construction, and this fast growth of urban, village, and town construction has assisted the construction sector and the advancement of building supplies. The need for building heating and cooling has developed, resulting in an elevation in the use of fossil fuels and, as a result, a shoot up in building-sourced greenhouse gas emissions, which account for around 40% of total global greenhouse gas productions. Thus, Qing Li et.al [2] in his study, regarding a rural house in China's one of most cold location (Heilongjiang), researchers investigated the effectiveness of a sunspace and also a sunspace incorporating PCM louvres on usage of energy. The tests were conducted out for four various indoor temperatures (14, 16, 18, and 20 °C) during a seven-month period, from October to April the following year.



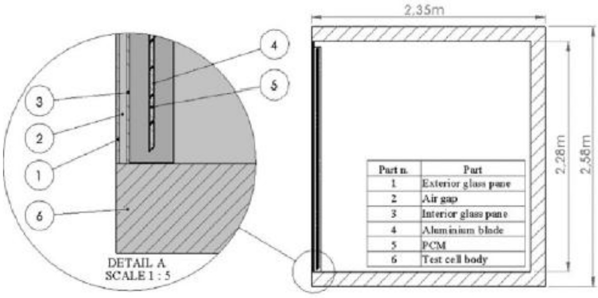
(a) (b)

Fig 4: The schematic view of (a) front view (b) lateral view of the PCM louvers[2]

Three instances, precisely the original rural dwelling, rural residence with only sunspace, and also sunspace alongside PCM louvres, were developed to illustrate the impact of sunspace and PCM louvre combinations on the rural residence energy saving. Sketchup and the Openstudio plug-in were used to create a basic model of a rural home with sunspace. The rural dwelling with sunspace features a 1.5-meter-deep space adjacent to the residence's south façade. A big (11.4 m wide and 2.5 m height) glass window faces the south. The PCM louvres are inserted into the sunspace's glass envelope, and a simplified model is created to display the front and side views of the studied structure, as seen in Figure 4 (a) and (b) given above respectively. The phase transition features a paraffin-filled shuttle-shaped aluminum alloy casing. The louvres are 1.9 metres long, 0.1 metres wide, and 0.02 metres thick at their thickest point. The louvres are installed in the interlayer of glass layer, with a 150 mm spacing between them and a 25 mm gap between them and the glass on both sides. The building also gets heat from a variety of sources, including the bodies of the occupants (five people), lighting (three incandescent bulbs with a total power of 190 W), and electrical equipment (kettle, TV, etc. with a total power of 190 W).

The aluminum alloy enclosure and paraffin wax make up the PCM louvre. The louvre pieces are 100 mm wide and are uniformly distributed within the glass structure at an angle of 0° during the day and 90° at night. EnergyPlus, which uses the finite difference approach, does the analysis for evaluating the impact of PCM louvres used in the sunspace. A strong tool for assesing building energy which has been used extensively by researchers is EnergyPlus. The model is verified using experimental work on PCM shutters, taking into account the interior temperature and heat flux measurements collected in the room with PCM shutters on August 4 to check the correctness of the EnergyPlus model simulation. Figure 5 below depicts the test cell composition in PCM shutter study.

(a) Test room



(b) Plan of test room with PCM

Fig 5: Test cell composition in PCM shutter study[2]

Multiple comparison evaluations were carried out for the energy consumption for heating of a traditional rural dwelling in peak level cold region of China, taking into account the installation of a sunspace and extra PCM louvres. The computations are conducted in this context for three distinct construction types: the original rural dwelling, the rural residence having sunspace, and the rural residence having the PCM louvres in the sunspace. Throughout the study, 4 distinct interior temperatures (14, 16, 18, and 20°C) are incorporated in the simulations. Furthermore, the simulations are run for a period of seven months (from 18th October to 5th April) in which the weather in the region is classified as cold. Furthermore, the 21st of January is chosen as the typical day for an hourly evaluation as the weather is comparitively colder on this day than others examined in the analyses. Summer air-conditioning energy use, on the contrary, is not involved in this assessment. The monthly energy usage simulation results for the three examined types of structures are shown in Figure 6 below.

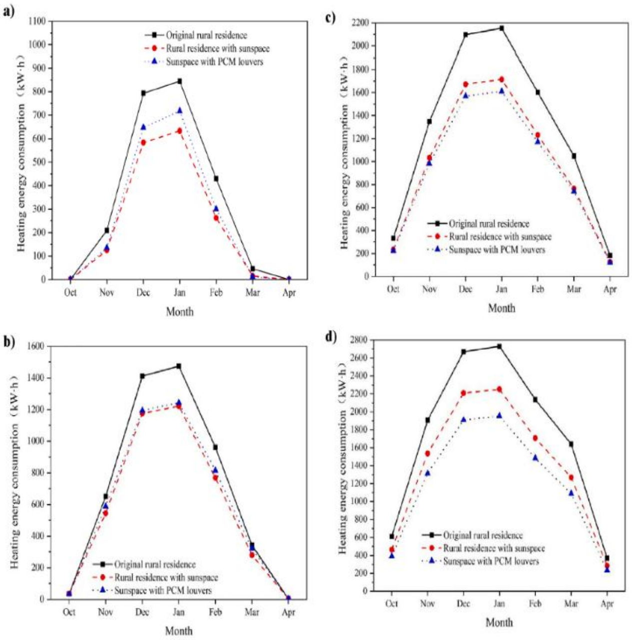
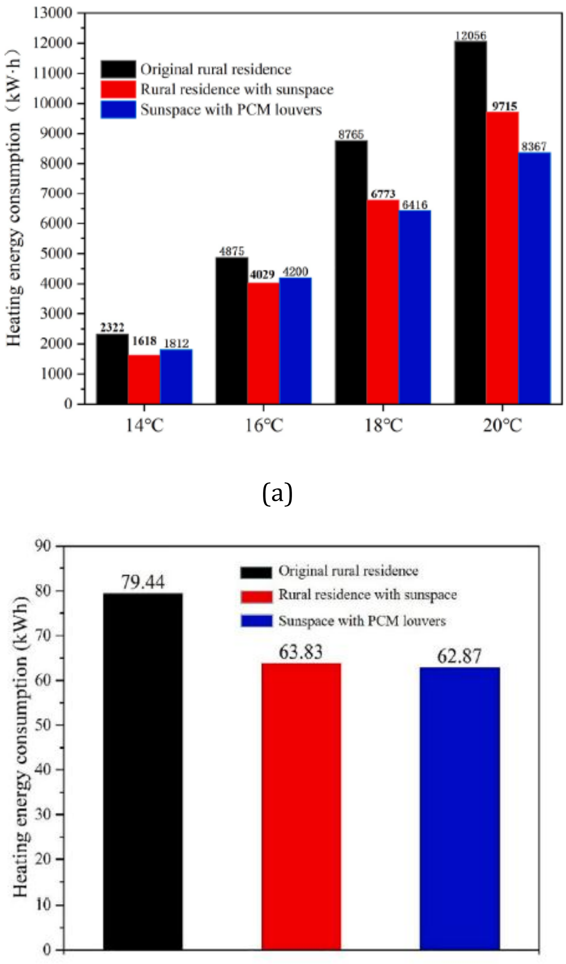


Fig 6: Energy consumption on monthly basis for the temperatures a) 14˚C, b) 16˚C, c) 18˚C, d) 20˚C (indoor)[2]

Apart from the month-by-month study, the overall consumption and savings data during the heating season give a comprehensive picture. Figure 7 (a) given below depicts the overall energy use in relation to interior temperatures during the course of the heating season. It is evident that when the desired internal temperature rises from 14 to 20 degrees Celsius, the total energy consumed for the building heating in the estimated cold time rises dramatically. To more accurately assess the impact of sunspace, it should be noted that its inclusion can lower overall energy consumption throughout the time by 704, 846, 1992, and 2341 kWh for internal design temperatures of 14, 16, 18, and 20 degrees Celsius, respectively. The findings clearly show that using the sunspace has a significant influence on reducing heating energy usage throughout the year.



(a)

(b)

Fig 6 (a)Total consumption of energy. (b) Consumption of energy on January 21 (at 18°C indoor)[2]

An extension of the study is undertaken for a model day, 21st January, which happens to be the coldest day of considered period regarding the rural dwelling, in order to investigate the impacts of sunspace alongside PCM louvres on energy usage on hourly basis. Despite the fact that the consumption values of the rural dwelling with sunspace and the sunspace with PCM louvres are fairly close during the day, the one with PCM louvres consumes somewhat less energy, as shown in Figure 7 (b) above, which depicts total energy consumption on January 21. Thus, from this study it was concluded that, the addition of a sunspace to a typical rural dwelling in a cold climate considerably decreases energy usage for all of the internal temperatures and months were evaluated. When the building is connected to a sunspace and the inside design temperature is adjusted to 18°C, the monthly along with overall energy savings can be as high as 439 kWh (20.40%) and 1992 kWh (22.73%), respectively.

3 ENERGY EFFICIENT ROOFING SYSTEM USING - TiO_2 ENHANCED THERMOCHROMIC FILMS

Space heating and cooling, which are related with the features of the building enclosure, such as windows, sidewalls, and rooftops, account for a large amount of energy consumption. The roof is responsible for 70% of total heat gain in a structure. Due to its high sensitivity to solar radiation, it accounts for a significant portion of a building's total energy requirements for cooling. A cool roof with increased solar reflectivity and high thermal transmissivity is one of the greatest passive methods for reducing a building's cooling demand. The increased solar reflectance reduces solar radiation absorption, while the high thermal emittance improves the capacity of the roof top to dissipate any absorbed solar energy. When a building needs to be cooled, the roof should be highly reflecting, and when the building needs to be heated, the roof should be extremely absorptive [17] Till date, materials types have been investigated to attain this: one is heterogeneous directional reflective material [18] which is ruled by sun's angle during different points in time of the year; and thermochromic material [19], which is capable to change its own colour in response to temperature variation. Furthermore, due to their reactivity being high, nontoxicity, cheap cost, and easy availability, titanium dioxide (TiO2) powders offer enormous promise as perfect and strong photocatalysts for a variety of crucial processes. Because TiO2 particles do not absorb light in the visible spectrum, they have a white hue. They are also effective UV absorbers that are integrated into polymer coatings to increase their overall life. As a result, photocatalytic, self-cleaning, and long-lasting coatings incorporating TiO2 particles are predicted [20].

Jianying et.al.[16] in his study, by integrating thermochromic materials alongside nano-TiO2 particles into a polymer matrix, created, multipurpose films with increased optical characteristics across the solar spectrum and possible self-cleaning capability. The technique of hot-pressing was chosen to make films since it is simple to utilize and cost-effective for covering huge areas. To develop the unique roofing system, traditional roofing substances (wood, aluminium, asphalt concrete, etc.) were coated with these films. A UV-VIS-IR spectrophotometer was used to evaluate the optical characteristics of both multipurpose films and the novel roofing system. Because of its outstanding physical and optical qualities, as well as its resistance to oxidation, polyvinyl chloride (PVC) was chosen as the polymer matrix. In this research, 3 types of thermochromic materials with black, blue, and red hues were used. The temperature at which the changeover occurs is roughly 31 degrees Celsius. A Cary 6000i UVVis-IR spectrophotometer was used to analyse the spectra of reflectance of nano-TiO2 and thermochromic powders. Furthermore, the microstructure of both these components were studied using an electron microscope and image analysis was performed to determine the particle size distribution.

Using a hot-pressing process, multipurpose films that itself contain nano-TiO2 and thermochromic powders were created. Individual powders were put into PVC film at a rate of 5% and 10%. PVC film was doped with mixtures of 0.5 percent blue-3 percent TiO2, 1 percent blue-3 percent TiO2, 2 percent blue-3 percent TiO2, and 4 percent blue-6 percent TiO2 powders. Figure 7 illustrated below, depicts a typical multifunctional film manufacturing process through hot pressing. PVC powder was first thoroughly mixed with nano-TiO2 and black, blue, and red variants of thermochromic powders for approximately 5 minutes, as being illustrated below. As the next step, the uniformly dispersed mix of powder was kept between two parallel plates after being put between two substrates. Before loading the samples, the plates were warmed to 200°C.

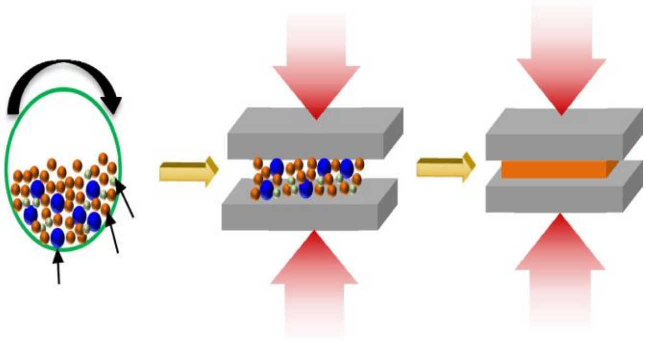
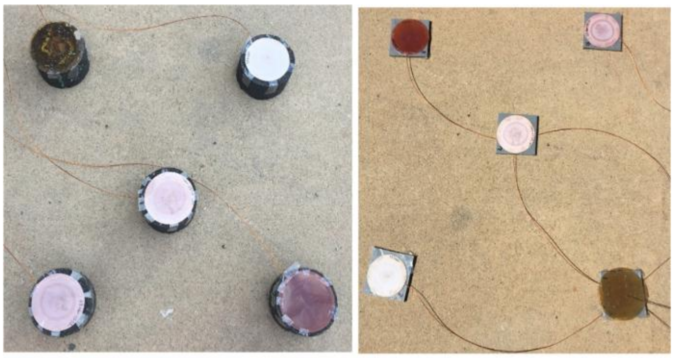


Fig.7. Illustration of hot - pressing Process[16]

The stack was then warmed for 10 minutes at 200 degrees Celsius before being pressed for 5 minutes at 5 MPa. After that, the film was created and allowed to cool to room temperature. After then, the film was peeled away from the substrates. The control sample was made of pure PVC film without any functional additions. The temperature of roofing sample surfaces that are being coated with various films was monitored to examine both the thermal performance and the comparative cooling impact of the films having multiple add-ons. Figure 8 shows how the experiment was set up. Sensors for surface temperature (thermocouples type K) are coupled to a system for data recording in the basic experiment setup. Sensors with a 0.1°C precision were installed in the centre of each sample's surface. The experiment was carried out in, Cleveland, Ohio, where the samples considered were exposed to direct sun radiation. During the summer days in July and August 2016, the surface temperature of each sample was measured at 1min intervals for a period of 24 hours. Temperature measurements were taken and kept every 60 seconds.



(a) (b)

Fig.8. Experimental set-up for (a) asphalt concrete; (b) plastics[16]

When doping 5 percent and 10 percent individual powders, the multipurpose film had SR of 7–18 percent and 11–20 percent, respectively, compared to 7 percent for the control film. Compared to other powders, the addition of blue thermochromic powder and TiO2 microparticles, increases the solar reflectance of the film by 148 to 211 percent. Furthermore, combining both blue thermochromic powder and nano-TiO2 particles significantly enhances the SR values of PVC film from 7% to 24 - 35%. The SR values of the films with the addition of functional particles are raised up to 33 - 50 percent in the infrared spectrum. 5 percent TiO2/PVC film, 5 percent blue/PVC film, 1 percent blue-5 percent TiO2/PVC film, and 2 percent blue-3 percent TiO2/PVC film were used to create novel roofing systems based on cost and efficacy. As shown in Fig. 9 below, the reflectance spectra of the system of roofing planned were computed over multiple range of wavelengths from 300 to 1800 nm using spectrophotometry and were then compared to each other. The new roofing solutions are more reflective in the infrared range than they are in the UV and visible ranges, as can be observed from the figure. Furthermore, multifunctional coatings on aluminium and wood have a greater reflectivity than asphalt concrete and polymers.

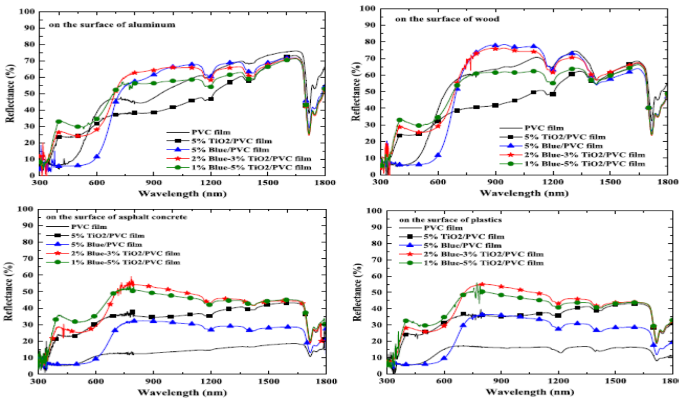
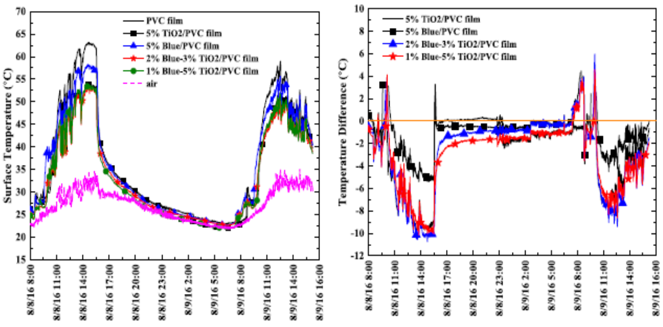


Fig.9. Spectral reflectance comparison[16]

Experimental outcomes on polymers covered with different films are shown in Figure 10 below. For plastics inculcated with film of PVC, 5 percent TiO2/PVC film, 5 percent blue/PVC film, 1 percent blue-5 percent TiO2/PVC film, and 2 percent blue-3 percent TiO2/PVC film, the air temperature was up to 35.0 C, and the temperature was at a range of 63.1° C, 53.7°C, 58.3°C, 53.8 °C, and 53.1°C, respectively on the surface. Furthermore, while using 5% blue/PVC film, the highest cooling efficacy was determined to be 5°C, and 10°C when using other smart films. The findings of the experiments show that using multifunctional coatings comprising powders having thermochromic nature and particles of nano-TiO2 can bring down the temperature of roof surface, significantly lowering building interior temperatures.



(a) (b)

Fig.10. Surface temperature (a) difference of temperature (b) for plastics covered with various films.[16]

The roof is immediately presented to sunlight and receives the most heat during a bright day in the building, adding significantly to heat gain and boosting the structure's energy consumption. As a result, the reflectance value of a building's roof has a major impact on solar heat uptake and consumption of energy. The reflectance of a conventional roof typically ranges between 20% and 30%. It is evident from the experimental outcomes that, in comparison to standard cool roofs, the novel roof proposed in this study, with thermochromic films has the potential to provide both cooling and warming effects during the summer and winter respectively. Innovative roofing techniques have been shown to lower building surface temperatures, in turn, potentially lowering heating demands.

4 INVESTIGATION OF - THERMAL PERFORMANCE OF GREEN ROOF

Global warming has now become a modern-day threat. It threatens the existence of everything on the planet and has had a significant influence on water and energy usage. A rise in ambient temperature, which raises the inside and external temperature levels of structures, catalyses the use of energy-intensive and costly systems for air-conditioning. Green roof tops are an example of a concept for reducing usage of energy and improving the comfort of business and residential buildings. In 2001, Onmura et al[11] researched the evaporative cooling impact from rooftop lawn beds in a 3-story structure in Japan, and it was established that the average temperature of the roof reduced from 6°C to 30°C throughout the day, resulting in a 50% reduction in heat flow. Niachou et al. [12] conducted a comprehensive investigation of thermal characteristics and an energy performance assessment using a mathematical technique in 2001. This research was carried out in a hotel in Greece. According to his conclusions, non-insulated buildings saved the most energy over the course of a year with 37%, followed by moderately insulated buildings at 4% and buildings that were well-insulated, exhibited savings rate at 2%.

Kumar, et al. [13] produced a computation of the cooling capacity of green roofs alongside solar thermal shading in 2005. The comparison was done using the case of a similar roof-top garden at Haryana, and he observed that inculcating a green roof brought down average inside temperature by 5.1°C when compared to a bare roof. Green roofs have recently been studied as a bioclimatic method for improving building energy efficiency. Parizotto et al. [14] examined the green roof heat efficiency of a casual residence building in Brazil. The research was carried out during the warm and moderate warm seasons. During the hot season, the green roof brought down heat gain by 92–97% when compared to other roofing options, according to his research. Permpituck et al. [15] conducted an experimental study in Thailand on the energy consumption variation by employment of roof lawn gardens. He experimented with different soil depths to see how they affected the overall thermal performance.

V Kumar et al. [10] computed the effect of green roofs on thermic performance and capability of cooling in India's climate that is moderately warm. Tests were conducted on two identical models measuring 1.5 m m x 1.5 m x 2.2 m, each having a 19 cm thick concrete slab and a brick wall that is hollow and has 15 cm thickness. As illustrated in Fig.11 below, two rooms were built in a manner so that shadows will not cover the walls and obstruct sunlight.

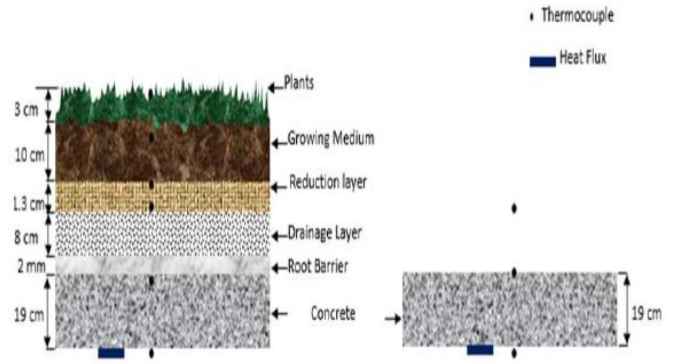
Fig.11. Experimental Set-up[10]

The test rooms were similar, except that one had a simple roof of concrete and the other one had a so called, "Green roof," which generally consist of five layers from the bottom to top, as indicated in Table 1 given below. Polystyrene insulation with a thickness of 5 cm (U value of 0.408 W/m2K) was employed.`

Layer	Thickness	Type
Root Barrier	3 millimeters	Sheet of Polyethylene
Medium of Drainage	8 centimeters	Moderate Size
Medium of Retention	1.3 centimeters	Composite
Medium for Growing	10 centimeters	Soil
Plants	2-4 centimeters	Paspalum Notatum

Table. 1. Green roof system layers[10]

Two distinct types of roofs were put up to compute the effect of using green roofs on cooling potency: exposed roof (concrete slab) and one with green roof layer. The measurements were taken between December 17th and December 24th, 2015. Figures 12(a) and 12(b) given below, illustrate the measurement points taken on the green roof layer and the conventional roof, respectively. The thermocouple was positioned in such a way that it could be used to monitor both the temperature of the canopy of plant on the green roof and the retention medium effectively. The temperature of the surface and heat flow measurements were obtained in both indoor and outdoor situations. All temperature data was taken every 10 minutes, while heat flux was taken every 15 minutes.



(a) (b)

Fig 12. Measurement points of (a) Green roof layer. (b) Conventional roof[10]

The temperature of both the green roof and the exposed concrete slab were recorded using a temperature data logger (TC-08). Type T thermocouples were made use of to measure temperature. Heat flux data recorder (LI19) were employed for measuring heat flux in W/m2. Heat flux sensors (Hukseflux HFP01) were made use of to monitor the flow of heat through rooms. The thermal-energy simulation was performed on moderately warm days, considering the climate boundaries of southern India. Design Builder software (Version 5.00 BETA) was used to analyse the influence of Green Roof on the building considered for the study in comparison to various flat roof coverings. The roof coating and insulation properties were varied throughout the process. The office building model simulated, was implemented within the Energy Plus simulation environment with flat roof plan and experimentally observed parameters to analyse the Green Roof performance on the two buildings. As illustrated in Fig. 13, the architectural design of the building was first executed by specifying interior thermal zones, geometry, etc.

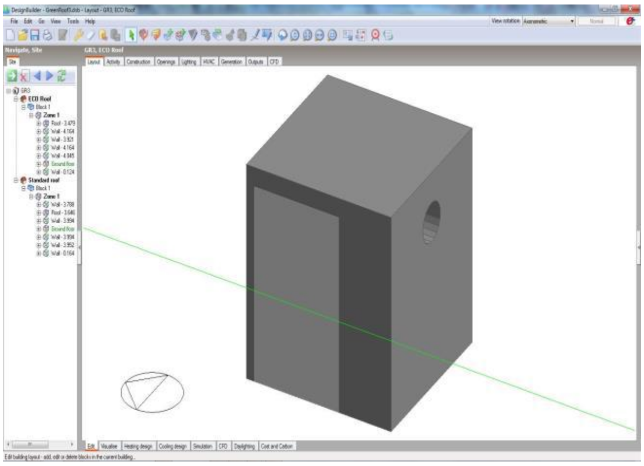
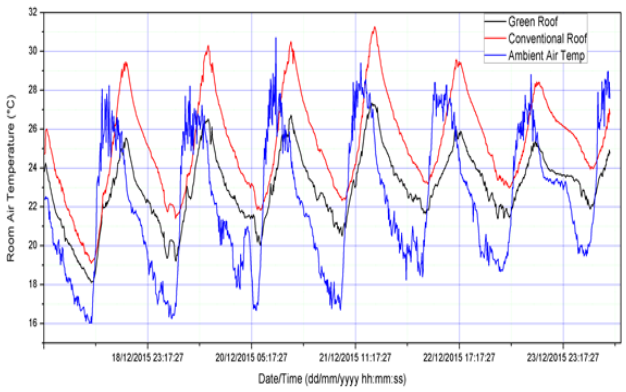
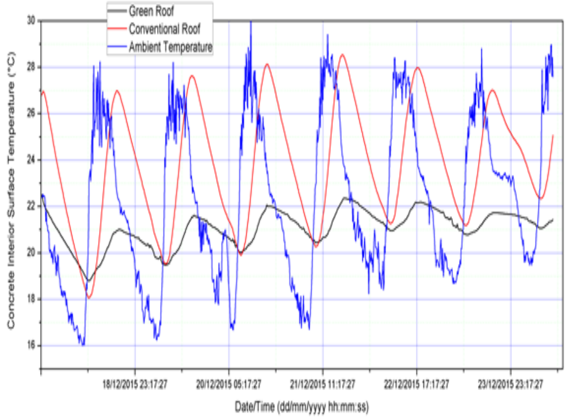


Fig.13. The building model building simulated employing Design Builder[10]

The maximum internal surface temperatures of the traditional concrete slab and that of green roofs were 28.53ºC and 22.39ºC, respectively. Fig 14(b) gives a comparative illustration of the internal surface temperature of both the exposed roof and the green roof. The peak gain of heat of the exposed roof compared to a green roof was discovered to be 6.14ºC. The green roof's internal surface temperature exhibits a profile that is attenuated throughout the experiment. The findings indicate that the green roof is beneficial. Due to the prevalence of, plants and soil layers, the temperature dropped dramatically. When compared to the traditional roof, the room equipped with the green roof had a lower temperature throughout the trial. On hot days, the temperatures for the traditional and green roofs ended up at 31.5ºC and 27.1ºC, respectively, at mid noon as shown in Fig.14(a). Throughout the trial, the maximum green roof room temperature appears to be consistently lower than the traditional roof, having a maximum comparative difference of 4.4ºC.



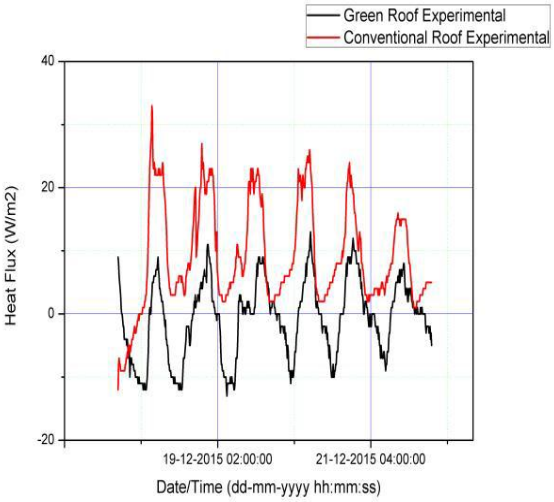
(a)



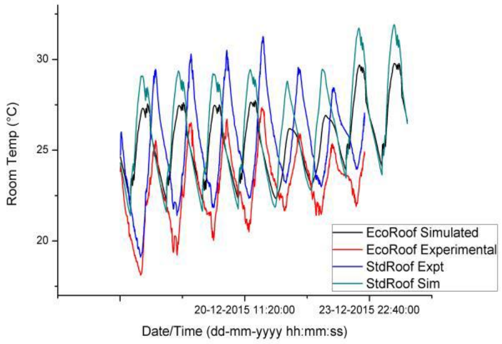
(b)

Fig 14. Comparison of (a) Room air temperature (b) Interior surface temperature[10]

The quantity of heat flow via the two roofs is measured using heat flux sensors (HFP01) attached to the internal concrete slab surface. A data logger LI19 was used to capture heat flow data at 15-minute intervals. Figure 15(a) shown below depicts the heat transfer history over the course of six days. Green roofs had lower heat flux peaks than conventional roofs, as could be seen in the figure. The simulations of green and conventional rooms demonstrate a high level of consistency with the experimental data as being illustrated in fig 15(b). In the experimental data, the temperature reduction in using green roof is depicted as an average of 4°C, but the simulation reveals a significantly smaller difference of 3.1°C degrees. It must also be mentioned that the temperatures associated with green roof represent a significant temporal difference from the traditional roof temperature trends.



(a)



(b)

Fig 15. (a) Heat flux study (b) Comparison of experimental and simulated values[10]

Moreover, it must be stated that the proposed model is extensively validated using a large collection of test data for air inside the room and plant canopy temperatures. According to a numerical study, the soil depth must be greater than 10 cm for being effective. The study discovered that roofs with a depth of 20 cm, 30 cm, and 40 cm (soil depth) were all able to succeed in lowering the temperature of the room to a similar extent.

5 CONCLUSION

On the current scenario of ever-increasing energy demands, the proven need for large quantities of energy for maintaining thermal comfort of building ambience is not negligible. In this paper three among the most innovative solutions to the mentioned issue is being discussed, namely, PCM, Reflective coatings and green roofs. Here, two case studies have been considered to prove for the efficiency and benefits of PCM. From the first case study it can be understood that PCM can be utilized as an effective method to reduce energy spent for cooling the indoor ambience in extreme hot climate. While the second case study exhibits the fact that PCM is equally efficient in extreme cold climate as it helps to gain control over the energy consumption for maintaining indoor temperature and meeting thermal comfort at the same time. Thus, considering the facts acquired hereby, we can conclude that employing PCM can help to cut short the total energy usage in a building regarding the achievement of thermal comfort. While examining the possibility extents of reflective coatings on building posterior, by conducting comparative trials on typical summer days, the overall performance of new roofing systems using thermochromic sheets was also studied. The surface temperature was found to be lower as a result of the findings. Considering the studies regarding green roofs examines, it can be ascertained that on hot days, green roofs have been shown to have a significant impact on room air temperature as well as the interior and the roof's external surface temperature. The overall heat in the two rooms is revealed to be vastly different i.e., rooms incorporating green roofs exhibited much lower temperature than that of a bare roof.

REFERENCES

[1] Al-Rashed, Abdullah AAA, Abdulwahab A. Alnaqi, and Jalal Alsarraf. "Energy-saving of building envelope using passive PCM technique: A case study of Kuwait City climate conditions." Sustainable Energy Technologies and Assessments 46 (2021): 101254

[2] Li, Qing, et al. "Effect of sunspace and PCM louver combination on the energy saving of rural residences: Case study in a severe cold region of China." Sustainable Energy Technologies and Assessments 45 (2021): 101126.

[3] Kheradmand M, Azenha M, de Aguiar JLB, Castro-Gomes J. Experimental and numerical studies of hybrid PCM embedded in plastering mortar for

enhanced thermal behaviour of buildings. Energy 2016;94:250–61.

[4] Su W, Darkwa J, Kokogiannakis G. Numerical thermal evaluation of laminated binary microencapsulated phase change material drywall systems. Build Simul 2020;13(1):89–98.

[5] Chou H-M, Chen C-R, Nguyen V-L. A new design of metal-sheet cool roof using PCM. Energy Build 2013;57:42–50.

[6] Cer´on I, Neila J, Khayet M. Experimental tile with phase change materials (PCM) for building use. Energy Build 2011;43(8):1869–74. https://doi.org/10.1016/j. enbuild.2011.03.031.

[7] Zhang M, Medina MA, King JB. Development of a thermally enhanced frame wall with phase-change materials for on-peak air conditioning demand reduction and energy savings in residential buildings. Int J EnergyRes2005;29(9):795–809.

[8] Mourid A, El Alami M, Kuznik F. Experimental investigation on thermal behavior and reduction of energy consumption in a real scale building by using phase change materials on its envelope. Sustain Cities Soc 2018;41:35–43.

[9] Chenxi Zhu, Jian Lv, Lingdong Chen, Weiqiang Lin, Jing Zhang, Jintao Yang, Jie Feng, Dark, heat-reflective, anti-ice rain and superhydrophobic cement concrete surfaces, Construction and Building Materials,Volume 220,2019,Pages 21-28,ISSN 0950-0618

[10] Kumar, Vinod, and A. M. Mahalle. "Investigation of the thermal performance of green roof on a mild warm climate." *International Journal of Renewable Energy Research (IJRER)* 6.2 (2016): 487-493.

[11] S.Onmura, M. Matsumoto, S.Hokoi, Study on evaporative cooling effect of roof lawn gardens, Energy and Buildings, Vol 33, pp.653-666, 2001

[12] A.Niachou, K Papakonstantinou, M Santamouris, A. Tsangrassoulis, G.Mihalakakou, Analysis of green roof thermal properties and investigation of its energy potential, Energy and buildings vol 33, pp 719-729, 2001

[13] Rakesh Kumar, S.C Kaushik, performance evaluation of green roofs and solar shading for thermal protection of buildings, Buildings and Environment, Vol.40, pp.1505-1511, 2005

[14] S.Parizotto, R. Lamberts, Investigation of green roof thermal performance in temperate climate: A case study of an experimental building in Florianopolis city, Southern Brazil, Energy and Buildings vol.43, pp 1712-1722, 2011

[15] Sittipong Permpituck, Pichai namprakai, the energy consumption of roof lawns in Thailand, Renewable energy, Vol. 40, pp.98-103, 2012.

[16] Hu, Jianying, and Xiong Bill Yu. "Design and characterization of energy efficient roofing system with innovative TiO2 enhanced thermochromic films." Construction and Building Materials 223 (2019): 1053-1062.

[17] C. Gray, Application of Adaptive Albedo Roofing Coatings in the Southeastern United States Dissertation, The University of Alabama at Birmingham, 2015.

[18] H. Akbari, A.G. Touchaei, Modeling and labeling heterogeneous directional reflective roofing materials, Sol. Energ. Mat. Sol. Cells 124 (2014) 192–210.

[19] T. Karlessi, M. Santamouris, K. Apostolakis, A. Synnefa, I. Livada, Development and testing of thermochromic coatings for buildings and urban structures, Sol. Energy 83 (4) (2009) 538–551.

[20] T. Kamegawa, Y. Shimizu, H. Yamashita, Superhydrophobic surfaces with photocatalytic self-cleaning properties by nanocomposite coating of TiO2 and polytetrafluoroethylene, Adv. Mater. 24 (27) (2012) 3697–3700.