A Review on Thermal Comfort of a Room

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Abstract: Humans are highly intelligent species with the ability to harness raw materials from nature to achieve remarkable feats. One such achievement of our ingenuity is the creation of massive structures that can provide us with shelter, which is a fundamental requirement for all humans, along with food and water. With the advancement in technology, various methods and devices have been used to control the temperature in indoor spaces in order to attain maximum thermal comfort. One of the most commonly used devices are air conditioners. As effective as air conditioners are at controlling the temperature indoors, they are high power consuming devices and also have a detrimental impact on the environment. Air conditioners release harmful gasses such as CFCs, HFCs and HFOs into the air. Hence, there is an urgent need to employ an alternative methods for temperature control in houses, office spaces and other commercial buildings in order to reduce our dependency on air conditioners. In this review various studies pertaining to the use of insulating materials in the wall construction of a building is discussed in detail. As they exhibit better ways to bring in thermal comfort without the use of air conditioners this is one of key research area which need to be highlighted for further studies.

***IndexTerms* – Thermal Comfort, CFCs, HFCs, Insulating Materials etc**

I. Introduction

Humans are highly intelligent species with the ability to harness raw materials from nature to achieve remarkable feats. We have transformed the world around us to fit our needs and comforts. One such achievement of our ingenuity is the creation of massive structures that can provide us with shelter, which is a fundamental requirement for all humans, along with food and water. It protects us from the external elements. From the clay and brick houses in 3100 B.C.E. to the ginormous skyscrapers from the present day, we have come a long way in the journey of human shelter. However, there's still aspects that can be improved. Once such aspect is to maintain comfortable temperatures in these massive structures. Temperature is the degree of hotness or coldness measures on a definite scale. It is a measure of heat. Heat is defined as the energy that is transferred from one body to another as the result of a difference in temperature. If two bodies at different temperatures are brought together, energy is transferred (i.e, heat flow from the hotter body to the colder one). Although the variables that determine a comfortable temperature are subjective, building environments typically use static temperatures from the range of 20 degrees Celsius to 25 degrees Celsius (this may vary depending upon the climatic conditions a particular area). With the advancement in technology, various methods and devices have been used to control the temperature in indoor spaces in order to attain maximum thermal comfort. One of the most commonly used devices are air conditioners. In the past decade, the demand for air conditioners has increased exponentially. According to the International Energy Agency, as of the year 2018, over 1.5 billion air conditioning units were installed. This trend is expected to continue and it is estimated that by the year 2050, over 5.6 billion units would have been installed. As effective as air conditioners are at controlling the temperature indoors, they are high power consuming devices and also have a detrimental impact on the environment. Air conditioners release harmful gasses such as CFCs, HFCs and HFOs into the air. These gasses are responsible for the depletion of the ozone layer, which results in adverse climatic conditions. However, with the rise in global temperatures, temperature control is more important than it has ever been, and air conditioners have become a necessity. Even places like Bangalore, which is at a relatively higher altitude, experiences harsh summers where the temperatures rise upto 35 degree Celsius. Hence, there is an urgent need to employ alternative methods for temperature control in houses, office spaces and other commercial buildings in order to reduce our dependency on air conditioners. Over the years, numerous methods have been researched, developed and employed for the same. One such method is the use of insulating materials in buildings. Insulators are materials which have a low value of thermal conductivity. Due to this property, they conduct heat poorly and hence, they can be used to prevent the transfer of heat from the outside environment to the indoor spaces. There are many such insulating materials that can be used.

II. LITERATURE ON Insulating Materials

Materials are classified as conductors, semi-conductors and insulators. A material that reduces or prevents the transmission of heat or sound or electricity is known as an insulating material. When insulating materials are used in buildings, they help limit the flow of heat between the building spaces and the outside environment. This is because of their thermal properties.

Thermal conductivity - Thermal conductivity, or 'K', is a constant for any given material at a given temperature, and is measured in W/mK (watts per kelvin meter). Thermal conductivity can be defined as the rate at which heat is transferred by conduction through a unit cross-section area of a material, when a temperature gradient exits perpendicular to the area.The higher the value of thermal conductivity, the better the thermal conductivity. Good insulators therefore, have very low values of 'K'.

Thermal resistance - Thermal resistance is the measurement of a temperature difference by which an object or material resists a heat flow. Thermal resistance is the reciprocal of thermal conductivity. Thermal resistance 'R' in kelvins per watt (K/W).

Critical thickness - The thickness upto which heat flow increases and after which heat flow decreases is termed as critical thickness. In the case of cylinders and spheres it is called critical radius.

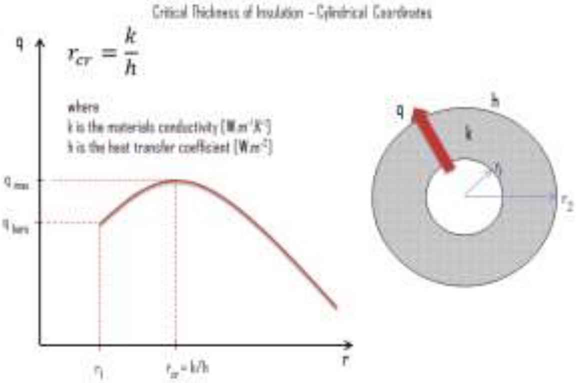

Figure 1 Graphical representation of critical thickness of insulation

III. RESULTS & DISCUSSIONS:

Insulating materials are classified into 3 categories [1] Conventional insulators (examples are glass wool, rock glass, expanded polystyrene etc.), State-of-the-art insulators (examples are aerogel, vacuum insulation panels etc.) and Sustainable insulators (Bamboo fibre, corn, rice husk etc.). It was concluded that the thermal conductivity of state-of-the-art insulation materials is the lowest while sustainable insulation materials have higher volumetric heat capacity. The lifecycle cost performance of the materials were compared and it was found that Buildings with high thermal resistance are more cost effective in cold regions. Low thermal resistance is more cost effective in hot regions. It was also found that buildings with lower operational energy consumption in a city that uses coal to produce electricity may result in higher carbon emission compared to another building with higher operational energy consumption in another city with gas as a fuel leading to the conclusion that it is not possible to establish a relationship between wall thermal resistance and carbon emissions in different climate zone. Lastly, the study found that sustainable insulation may reduce the peak cooling load and lower the risk of overheating due to their high heat storage capacity compared to other insulation types.

Super-insulated aerogel [2] was compared with expanded polystyrene, extruded polystyrene, foamed polyurethane, and fibre glass. The study found that although aerogel material has various advantages (such as the super-insulation performance, the minimum optimum insulation thickness, a larger potential of building energy conservation, etc.), the current price of aerogel materials is relatively high, which leads to a longer payback period than the other materials. Experimental results showed that aerogel had the minimum optimum thickness of 3.7 mm. When aerogel was implemented with the optimum thickness, the annual cooling and the heating load for the hollow shale brick building were reduced by 7.5% and 18.2%, respectively. Additionally, compared with the other materials, aerogel achieved a faster reduction for greenhouse-gas emissions as the thickness increased. The aerogel insulation could lead to lower carbon emissions.

Phase change materials (PCM) were used as insulating materials. PCMs [3] were incorporated into bricks in either a single layer or double layers. The PCMs used were OM35 and eicosane. It was found that a temperature reduction up to 9.5°C was achieved for dual PCM layer within the brick and a temperature reduction of 6°C was achieved for single layered PCM brick. The heat gain reduction up to 60% was observed for dual PCM layer brick and around 40% for single layer PCM brick, during the day; however, it was found that PCMs rejected heat during the night. An overall heat reduction between 16% and 20% was observed over the period of 24 hours. The study also found that the use of fins within the PCM encapsulation affects adversely as the heat transfer during the day increases substantially. It was also found that increasing the PCM thickness may not be a viable solution unless the heat rejection during the night is ensured through any auxiliary means apart from using finned configuration, for a building space conditioning. Lastly, the study concluded that a thickness of 1 cm to 1.3 cm for the PCMs was suitable in achieving a peak temperature reduction of around 6°C.

One common classic wall made of grey brick [4] and three modern walls made of Hollow clay block, LECA block (light weight aggregate concrete) and AAC block (autoclaved aerated concrete) were considered to determine optimal thickness of insulation, energy saving, and payback period for various classic and modern exterior wall structures in all climate zones of Iran with respect to four cardinal wall orientations. It was found that for grey brick wall, optimum thickness varies between 1.5cm and 3.5 cm. For hollow clay bricks the thickness varied from 1cm and 4 cm. A lower range of optimal thickness between 0.5 and 2.5 for LECA block wall and between 0 and 2 cm for AAC block wall was found. The study notes that energy cost in Iran is very cheap compared to global price, so optimal thickness of insulation is typically lower in many countries. Depending on wall types, orientations, and climates, the optimal insulation thickness varied between 0 and 4 cm. These results have remarkable differences with data that have een reported in the literature for other countries. This pattern is due to the low energy cost, high discount and inflation rates as economic features of Iran.

Thermal comfort in the buildings with thermal energy storage (TES) [5] technology is achieved in two ways: with passive cooling, and with active cooling. The passive cooling in the building with TES technologies is carried out by imposing PCM in the roof and in the walls without any external air circulation devices. The experiment was carried out with two model building units that were constructed with identical dimensions (1m×1m ×1.25m) and identical constructional features. One model unit was constructed with the implementation of PCM in the roof, and another one was constructed without PCM in the roof. Polyethylene glycol MW 600 was chosen as PCM as is chemically stable and biologically safe. This PCM has a low melting temperature around 27° C to 30° C and has the high latent heat of fusion 148 kJ kg^{-1}. It was concluded that the implementation of PCM in the building roof reduces the average peak temperature rise in the room and also reduces the fluctuations of temperature in the room which is about 1° C to 2 °C.

The first brick (Brick 1) was a regular brick with no PCM incorporated [6]. The second brick (Brick 2) was carrying the PCM eicosane and the third brick (Brick 3) was carrying the PCM OM35. It was found that the temperature on the inner surface of Brick

1 (i.e. without PCM) increases faster as compared to the PCM embedded bricks. An inside surface temperature difference of 4.5–6℃ was observed between Brick 1 and other PCM embedded bricks (i.e. Brick 2 and Brick 3) during peak hours. However, during the night it is observed that, brick 3 having OM35 cools relatively faster compared to Brick 2 carrying Eicosane. This is due to the higher thermal capacity of Eicosane. It is noticed that median and mean temperature for brick 2 is higher as compared to that of brick 3 even though it has higher thermal capacity. This is due to the higher melting temperature range of Eicosane than OM35.The heat flow during the day is higher in case of brick 1, compared to brick 2 and brick 3. During the night, the inside surface temperature of brick 1 reduces faster as compared to the PCM bricks due to lower thermal capacity, thus it has higher rate of discharge. Both Eicosane and OM35 showed a sub-cooling of 2.1℃ and 2.2℃, respectively. These PCMs were found to discharge during the off sun-shine hours, ensuring effective utilization of these PCMs. The results show a substantial reduction (up to 10℃) in temperature fluctuation with PCM incorporated bricks. An inside temperature reduction between 4.5℃ and 7℃, during the peak hours of the day, with respect to the conventional bricks, is observed. The results show that heat gain is reduced by 8% and 12% with incorporation of Eicosane and OM35, with respect to the conventional bricks.

The phase change heat storage foamed cement blocks [7] that were prepared with paraffin, expanded graphite, and Portland cement. The physical structure, thermal conductivity and thermal energy storage performance of foamed cement were studied through experiments. It was observed that there was no paraffin leakage when adding the paraffin/expanded graphite (mass ratio is 80%:20%) composite PCM into the foamed cement. Thereby concluding that paraffin can effectively improve the thermal energy storage performance of the foamed cement blocks. It was also found that the thermal conductivity of the pure cement block was similar to the foamed cement block with 20%–25% composite PCM. 30% is an ideal mass ratio for the foamed cement blocks with composite PCM. The study concludes that the proposed foamed cement blocks with paraffin/ expanded graphite composite PCM are suitable for the climate region with peak temperature lower than 42.5 °C and can effectively improve building energy efficiency when applied in building envelops, such as walls, roofs, and floors.

A base wall made up of of plaster (2 cm), clay brick (15 cm), and cement (3 cm) were studied [8]. The effect of PCM position inside the wall on the heat transfer was assessed in two scenarios, one was close to the interior of the wall and and the other was close to exterior of the wall. The PCMs selected were Enerciel and calcium chloride hexahydrate. The results show that the performance of PCM-based wall is strongly influenced by the thermal conductivity, phase-change enthalpy and melting temperature of the PCM. A PCM can more efficiently reduce the heat transfer to the interior space in case it has a lower thermal conductivity higher latent heat of phase-change, and its phase-change temperature is closer to the room temperature. Moreover, the thermal conductivity has priority over other PCM thermo-physical properties. It was found that the heat transfer reduction by Enerciel 22 was within the range 15.6% to 47.6%, while this range was 2% to 7.8% for Calcium chloride hexahydrate.

To develop a heat storage gypsum-cement board (G/C board) by using vacuum impregnation method [9] and to evaluate its physical and thermal properties. Two different types of organic PCMs were applied to the G/C board and its thermal properties were investigated. The PCMs were n-octadecane and beeswax. The study confirmed that PCM containing heat storage G/C boards had time lag effect. Such heat storage G/C board could be used to reduce energy consumption of buildings. It was found that the energy reduction effect is greater in the G/C boars with n-octadecane. This is because n-octadecane has more suitable phase change temperature than beeswax. The thermal performance was improved by using G/C boars with both the PCMs. However, application of G/C board with n-octadecane performed better ans was able to effectively reduce the cooling load.

A comprehensive analysis was carried out based on energy, environment, and economy criteria where the energy, environment, and economic costs of producing insulations are also taken into account [10]. Accordingly, material and optimum thickness of insulation for the external wall of an office building were determined. The results showed that Polyurethane with the thickness of 8 cm, EPS (expanded polystyrene) with the thickness of 20 cm, and rock wool with the thickness of 7 cm were optimum. Finally, a novel function, which considered all three parameters simultaneously, were defined. Consequently, 3E (energy, environmental, and economic) analysis was carried out and led to the presentation of the Mineral wool insulation with the thickness of 11 cm as the optimum state of investigated cases according to the 3E criterion.

An experimental investigation of phase change materials being integrated in layers within concrete block for thermal management. The experimental setup consists of two identical concrete blocks of dimensions [11] 30 cm*30 cm*2 cm. One block is deployed with PCM and the other is not. The PCMs have been deployed in the concrete block at a distance of 10 cm below the top surface inside the concrete block. The encapsulation of PCMs is done with grip seal bag (GSB) in order to prevent the PCMs from leakage. The GSB of the size 10.5mm*7.2mm and having a mass of 48.3g was used as PCM encapsulation due to its availability, low cost. An organic chemical called Calcium chloride Hexahydrate is used as the PCM to study the effects of latent heat energy storage inside the room space in terms of temperature reduction. The results show that temperature reduction up to 3°C was observed in the concrete block with PCM, compared to block without PCM. This was observed that the addition of PCM resulted in a flattened temperature profile within concrete block. Further, the effect of varying PCM thickness was also evaluated and results reveal that thickness of 12 mm was the optimum thickness.

IV. CONCLUSION

The demand for energy conservation has led to the investigation of various methods that can effectively achieve thermal comfort while consuming as little energy as possible. In order to use insulating materials for thermal insulation in buildings, the thermal properties must be studied thoroughly. Carbon emission and cost of energy must also be factored while selecting insulating materials.

Phase change materials, deployed in composite bricks have better thermal insulation and can reduce the temperature significantly, thereby achieving greater thermal comfort. One drawback of using PCM is the potential for leakage and this must be further investigated.

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