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Sustainable indoor comfort concepts with PCM containing building materials

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Abstract
Insulating buildings is now an accepted measure and is relatively simple to achieve, commonly used and embedded in European and national legislation. However, an additional severe problem is rising: more and more energy is used for cooling of buildings. The big problem with regard to regulating temperatures in buildings becomes apparent in summer when unintentional internal and external heat loads cause rooms to get hotter by the hour. Here the building's mass plays an important part in determining the resulting indoors temperature. Lightweight buildings do not possess enough mass to avoid heat build-up and can therefore overheat rapidly – even north of the Alps in Europe.
Phase change materials (PCM) are a sustainable solution to this problem in that they offer a convenient means of adding thermal mass into lightweight buildings such that they behave more like a heavyweight structure. It will be explained how the principle works, how to calculate the effect by means of dynamic computer simulation and mobile tools, how cooling concepts can be optimized, and which product solutions are presently available.
In a detailed case study of a passive house school in Diekirch in Luxembourg the concept is demonstrated. The new building, which is based on steel frame construction, was monitored by Fraunhofer ISE / Freiburg according to EN 15251.
The lightweight building has proven to fulfill the criteria of comfort class A.
The technology has proven to work properly. Therefore this means for better energy efficiency should be embedded in future EPBD calculation methodologies.

Keywords - Phase change materials, PCM building materials, construction, cooling energy reduction, PCM

1. Future Energy Supply Needs Storage Technologies

Europe is seeking new ways to meet the goals of the Kyoto protocol and it is accepted that in buildings there is a huge potential for reducing energy consumption. Insulating buildings is now an accepted measure and is relatively simple to achieve, commonly used and embedded in European and national legislation. However, a more severe problem is rising: it is expected that in Europe the demand for electricity for mechanical cooling of chilled spaces will expand by a factor of 4 in 2020 compared to the figures in 1996 [1]. So energy demand for cooling is getting more and more into focus.

The big problem with regard to regulating temperatures in buildings becomes apparent in summer when unintentional internal and external heat loads cause rooms to get hotter by the hour. Here the building's mass plays an important part in determining the room temperature. Lightweight buildings just do not possess enough mass to avoid heat build-up and can therefore overheat [2].

2. Thermal Storage With PCM Building Materials

Phase change materials (PCM) are a sustainable solution to this problem in that they offer a convenient means of adding thermal mass into lightweight buildings such that they behave more like a heavyweight structure. This increased "virtual" thermal mass interacts with the indoor temperature situation and as a logical consequence flattens temperature fluctuations.

Phase change – what exactly does this mean? When ice, to use a popular example, is heated, the temperature stops rising at the onset of the transition to liquid. As long as two phases (solid – liquid) exist simultaneously, the temperature does not increase; instead, the inflowing energy is used up in the phase transition. Since the energy consumption takes place without any detectable rise in temperature it is called "latent."

A good solution for safely inserting latent heat stores into building materials of all kinds is microencapsulation. Tiny globules of wax 2 to 5 microns in diameter are coated with a layer of hard plastic. These microcapsules are completely sealed, safe to process and free of formaldehyde. In addition, the resultant materials are well suited for further treatment – they are impervious to grinding, drilling, cutting, etc. since their small size makes them virtually indestructible. Measurements at the Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg have confirmed this [3]. In order to establish a method for a proper quality proof, dedicated test methods and criteria have been developed and published by RAL Quality Association e.V. in Germany. [4]

In order to answer the question about thermal benefits in housing application, a free to download software tool "PCMexpress" was developed in 2008 [5]. The dynamic computer model allows quantitative estimation of any the PCM benefits in building application. In addition a second calculation tool "Micronal PCM App" has been presented to the public early 2015 [6], which is able to estimate the saving potential in cooling energy and size of chiller capacity in office application, school environments and residential situation. Answers on comfort are delivered as well as clear economic figures about cash back time and reduction in cooling power.

Case study Nordstad Lycée, Diekirch, Luxemburg

The school building in Luxembourg is owned by Administration des Bâtiments publics Luxembourg. Ernst Basler + Partner AG in Zürich as architects were asked to develop the thermal concept which is mainly based on good insulation properties, big windows, and sufficient thermal mass to trap excess heat from pupils and sunlight in winter and to prevent from overheating in summer. The cooling strategy is based on naturally night purge by manual opening of windows.

Since the building is built by metal frame modules, there was a need to bring in thermal mass by lightweight PCM building materials. Knauf Gips KG delivered their PCM gypsum wallboards "SmartBoard™" (20% PCM in gypsum, 23°C-25°C melting range, 300 kJ/m² enthalpy) for the lightweight construction erected by ALHO Systembau GmbH. By consequently following a modular concept it was possible to rise the whole building in a very short period of time. It took only 9 months from the planning phase until moving into the finished building.

Monitoring and model based evaluation by Fraunhofer ISE, Freiburg [7]:

Part A of the study has the aim to evaluate the potential for increasing thermal comfort in summer by using PCM building materials.

Thermal room comfort: In order to evaluate the influence on the indoors climate two selected class rooms direction East have been equipped with several temperature sensors, contacts for opening of windows/doors and use of outside shading. Furthermore a weather station outside reported all relevant climatic data. The measurement was performed in June and July 2008 over a 6 weeks period. All registered data was transferred online to Fraunhofer ISE in Freiburg.

Fig. 1 left: operative room temperature, middle: reed contact door, right: wall center temperture sensor [7]

Main results out of part A, thermal room comfort measurement:

- Average operative room temperature in both class rooms was at 21,4°C.
- Maximum room temperature reached 28,2°C and 28,4°C in June/July.
- Although the outside temperatures exceed 28°C several times, the rooms exceed 26°C for totally approx.. 30 hrs in June and July during the presence of the pupils (7:00h to 17:00h).
- The measured operative room temperatures in both class rooms keep in the borders of comfort class A according to EN 15251:2007-08 during June and July.

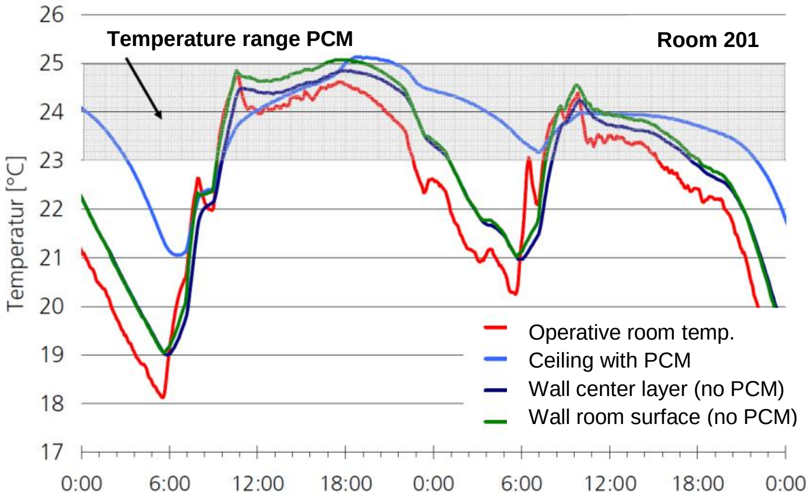

Fig. 2 Temperatur development, room 201, June 9. and 10. / 2008 [7]

In Fig. 2 the temperature behavior for different materials is shown. The flattening effect to the surface temperature of the ceiling panel with PCM compared to the standard gypsum wall panels is obvious. As a consequence to the stabilized surface temperatures, the operating room temperature also keeps lower. Additionally maximum temperatures are mainly moved outside of presence time of pupils.

<u>Part B</u> of the study validates with a model based analysis the thermal measurements and room comfort out of part A by using ESP-r simulation on a 3D building model.

Since the whole building is equipped with PCM wall boards and ceiling tiles, a simulation study was needed to be able to compare the achieved room comfort with a reference model without phase change material application. In the study this “reference model” is compared with two different scenarios: “ceiling model” and “plan model”. The “ceiling model” represents a simulation model with PCM ceiling tiles but no PCM in the walls, so to say a low PCM usage model. The “plan model” represents a simulation model where all ceilings and walls are equipped with PCM gypsum wallboards. This is equal to the maximum PCM content a room can reasonably have. The “real” building is in between these two scenarios.

1) Comparison “reference model” against “ceiling model”

If only the ceilings are equipped with PCM (= 40 m²), the room temperature is lowered by 0,5 K. The ceiling is increasing the thermal mass of the room, however this effect is not sufficient to reach the best comfort class. So this room remains at comfort class B according to EN 15251:2007-08.

2) Comparison “reference model” against “plan model”

The “plan model” is able to really improve the indoors climate compared to the “reference model”. The maximum operative room temperature is lowered by 1K. In June and July the comfort borders of class A according to EN 15251:2007-08 are not exceeded under the given ventilation behavior of the users.

3) Comparison “ceiling model” against “plan model”

If only the ceiling is containing PCM the temperature is lowered by 0,5K (achieving comfort class B) while if all surfaces are covered the temperature decrease is double (1K). Both the “plan model” as well as the “real built situation” keep in between the limits of comfort class A according to EN 15251:2007-08. So the actually built situation is close enough to the “plan model” that the aim is achieved.

It could be proven that the purely passive temperature management at 23°C to 25°C on walls and ceilings using PCM gypsum wallboard in combination with the entire climate concept is able to keep the indoor climate in a way that comfort class “A” according to European Guideline EN 15251:2007-08 could be achieved. This means that ≥ 90% of all users are satisfied with temperatures inside of the rooms.

Certainly the use of the room by the users has a significant influence on the achievable indoors climate. It turned out that especially in warmer summer nights all 3 windows should be opened in order to allow sufficient air exchange in the night. In order to achieve an even more reliable operation mode it is recommendable to let windows automatically open and close according to outside and inside temperatures.

3. Conclusions

13 years after introducing microencapsulated PCM into the market place all conceivable concepts in building application have been tested and have proven to work properly. All boundaries for a reasonable use and all necessary physical properties are known and can be calculated by means of dynamic computer modelling. After introducing several applicable PCM building products to the market place the technology is settled meanwhile and based on VDI 2164 “PCM energy storage systems in building services” [8] can also be rated as state of the art. However there is still a way to go before PCM building materials are widely accepted as a general means against air conditioning in regular construction.

Acknowledgment

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