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Evaluation of cooling ceilings with application of PCMs at specialized laboratory

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Abstract. In this article is covered measurements of radiant cooling ceilings (RCC) in Laboratory of Environmental Engineering at Faculty of applied informatics under Tomas Bata University in Zlin. This laboratory performing standardized tests of special HVAC equipments. Article validate measurements on newly made customization of laboratory for measurements of such RCC. Measurement was performed on RCC with application of PCMs material. This RCC was specially developed for purposes of validation and made in two dimensions. Specific application of PCMs allows achieving recovery of accumulation media in multiple cycles during one day. Outline of newly made RCC is described followed up by detail of set-up of experiment. In article is estimate cooling capacity of used RCC with applied PCMs. Discontinuous cooling cycles is covered as well with description of measured data.

1 Introduction

In European Union are buildings responsible for more than 40% of entire energy expenditure. Meanwhile, this sector continues to increase social well-being with utmost indoor environment. This trend is reflected by energy use incrementation. Energy efficiency needs to be improved as same as renewable energy sources which are noteworthy efforts in the field. [1, 2]

Energy efficient and economical ways for heating or cooling inside buildings are Thermally-activated building systems (TABSs). These systems accommodate building structures as energy storage. Floors, slabs and mostly outer walls are utilized to radiant and convective energy and act as dynamic thermal elements. The same can be said of space heating which releases stored energy. As contradict, ceiling panels equipped with Phase Change Materials (PCMs) can absorb energy and can flatten actual solar radiation peaks [3]. These ceiling panels can be used also for additional heating elements to cover peaks. Nevertheless, application for cooling is mostly in scope for this panels for their ability to improve convective patterns [4]. Meanwhile providing better thermal comfort levels than conventional HVAC system in terms of appropriate surface temperature control and reduction of air movement. This allows to minimize the draught discomfort and to develop better homogeneous temperature distribution in occupied space. [5]

Low maintenance and energy-efficient is commonly required by passive systems. Regeneration of PCMs integrated into the wall or ceiling might be a problematic when is maintained by free cooling. [6]

In hot humid climates is also possibility of condensation and thus this should be considered in design and regulation phase. Condensation in combination with radiant cooling ceiling is in scope of several researches. [7–9]

Until now is implementation of TABS control subordinate in design process. One of the reason could be specification of control algorithms are difficult which is caused by thermal inertia of the system. Otherwise, it could be caused by challenge to meet comfort requirements in each room where could be different gains. Nevertheless that these rooms are connected to the same supply. In control theory are implemented various approaches which have mostly some disadvantages caused by different approaches for cooling or heating. [10]

In article by Zhang et al. [11] is considered new type of radiant cooling ceiling with inclined aluminium fins. This inclination increase convective heat flux in opposition to same area.

Releasing latent heat is main feature of PCMs materials. The temperature range, which is needed, depends on choosing these materials for the given application and temperature conditions. In the field of environmental engineering and the buildings itself, this temperature range is 20-30 $^{\circ}C$. There are other requirements that represent technical or economical appreciation. Temperature, when phase transition occurs, is a condition where the material is able to accumulate and subsequently release thermal energy. This is a very important parameter, taking into account the highest daily room temperature of the space in summer in non-production areas of 27 $^{\circ}C$, see [12], the melting range is suitable right around this value. Another parameter is the amount of enthalpy in phase change, ie the amount of energy stored. The melting and solidifica-

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tion process may deteriorate PCMs properties by increasing number of cycles, therefore cyclic stability and reproducibility of phase transformation is important.

2 Methods

2.1 Cooling ceilings

The cooling ceiling was designed to use radiant surfaces with PCMs. The expanded contact surface tube cooler serves for cooling and is in direct contact with PCMs. The shell construction of this ceiling was made with a sheet metal of 1.5mm thickness and white matt finish. Shell was created in two lengths which was 1,4 m and 1.6 m. Other dimensions was 0.8 m and 0.02 m and was same for both boxes. The minimum thickness of this cover and the high emissivity ensure a sufficient heat transfer between PCMs and the surrounding environment. In the cooling ceiling, the heat transfer medium is water that is cooled according to the set point. The temperature of the water is kept above the dew point temperature in the room. The demand for the cold source is about 16 $°C$. The operation of this appliance is energy-efficient and, with a sufficient cooling surface, it can easily provide comfortable micro-climatic conditions inside the building.

Other advantages of this system are the ability to remove accumulated heat from PCMs. This is a recovery of the storage medium, which is very problematic for this material. The temperature range where the PCM material releases the accumulated heat is 18-22 $°C$. Previous tests with an increase in heat transfer coefficient by surface treatment or use of forced flow did not allow reaching the phase transition temperature. During these measurements, this temperature was not reached in any way. The low phase transition temperature of these materials causes problematic behaviour in terms of the use of heat-repeatability. However, the cooling ceiling device eliminates this phenomenon by virtue of its ability to cool this material below the freezing point. The Recovery Accumulator feature is one of the possible functions of this system.

An important feature of the manufactured cooling element is the perfect distribution of surface temperature, especially for the PCM material. The tubular heat exchanger consists of chilled ceiling elements TROX WK-D-UL-KS [13], which consist of a heat conducting strip in which the pipe meanders are pressed in order to ensure optimal heat transfer. Proper heat transfer through the cooling belt to the PCM material or box is ensured by a specific patch.

For the purpose of measurement was important to modify laboratory to fulfil measurement procedure and standard CSN EN 14240 [14]. Based on the fact that measuring space need to have emissivity better than 0.9 it was important to cover recondition unit in indoor part of compensated calorimetric chamber. For this purpose was built tight curtain which divided indoor space into two separated parts.

An integral part of creating a cooling ceiling was also to create a measurement procedure or methodology to measure the cooling performance of this device. This methodology is based on CSN EN 14240 [14], is applied

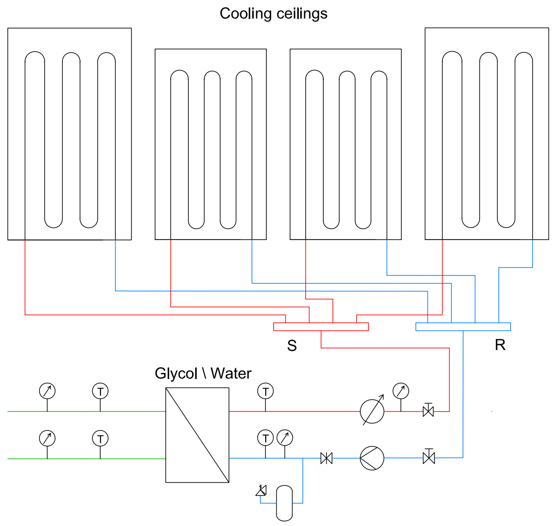

Fig. 1. Hydraulic set-up of experiment.

to the existing possibilities of the laboratory of environmental technology in the measurement space of the calorimetric chamber. This space is surrounded by compensation spaces, which are indoor space, compensation indoor space and compensation outdoor space.

During the test, the surrounding walls must ensure minimal heat losses. Therefore, the air temperature in the surrounding compensating space will be kept the same in the Outdoor part as well as inside the test space.

The heat load is secured inside the laboratory using electrically heated dummies. The electric power of these dummies is adjustable with a maximum of 180 W. The maximum internal room heat load is 200 $W\,m^2$. The placement of these dummies was therefore chosen so that the required thermal load values were maintained in accordance to normative requirements.

During the tests, the temperature and humidity of the air, the surface temperatures of the surrounding areas, including the cooling elements, the temperature of the heat transfer medium (water) inside the cooling elements are measured. The measuring room also measures the temperature of the spherical thermometer together with the exact positions of the temperature sensors as shown in the following figure.

To determine the cooling capacity of the device, it is also necessary to measure the volume flow of water flowing into the cooling ceilings. The standard furthermore provides for a residence time of at least 60 minutes during which cooling performance is measured The total cooling capacity of the cooling ceiling is given by the equation 1.

$$P = c_p\, q_m\, (\theta_{w2} - \theta_{w1}) \tag{1}$$

Where c_p is heat capacity $[-]$

And standard cooling performance is as in equation 2.

$$P_a = \frac{P}{A_a} \tag{2}$$

Where A_a is active cooling area $[m^2]$

Table 1: Cooling capacity of cooling ceiling with PCM

Measurement	1	2	3	4
Avg. effective temperature diff.	13,21	11,24	9,26	7,26
Active area cooling capacity	-116	-100	-81	-64
Cooling performance	-542	-467	-378	-302

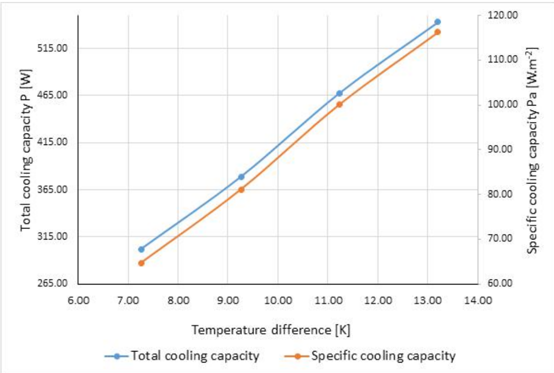

Fig. 2. Cooling capacity of cooling ceiling with PCM.

3 Results

3.1 Evaluation of cooling capacity of cooling ceilings

Cooling capacity of the cooling ceiling was measured with and without PCM application for four different temperatures of the cooling medium. The air temperature inside the laboratory was maintained at the desired air temperature range of 26 to 28 $°C$ during all measurements. Cooling medium flow rate was set to 5 $l\,min^{-1}$. Individual measurements required the necessary time to stabilize the air temperature in a room, which was controlled by electric dummies. The heat output of these dummies was inhibited by cooling. To ensure greater measurement accuracy, in the case of stabilization of PCM cooling ceilings, the settling time was about twice as high as in the case of non-PCMs cooling ceilings.

Figure 2 shows the overall and standardized cooling power measured at a given flow and temperature difference. Total cooling power is the power of all measured units with an active area of 4.67 m^2. The results of cooling performance are shown in the table 1.

From the measurement results, the cooling power of the functional sample itself, which has been manufactured in two dimensions, can be determined. For cooling ceiling 1.4 m wide is cooling power 97 W and for 1.6 wide is 112 W.

3.2 Evaluation of measurement results

From the results of the cooling power measurement, a difference is seen when using the PCM heat-accumulating material. The cooling capacity was reduced by about 25% when inserted. Decreasing the cooling power of PCMs is due to the application of this material to the contact layer of the heat conducting bands of the cooling units. Cooling is limited by this layer, which takes a large part of the cold that is used to stabilize the solid phase of PCMs in a room with high air temperature. Although the PCMs layer is only 5mm thick in the cooling ceiling, the heat conduction is limited so that the surface temperature of the cooling unit is noticeably lower than in the case of a unit without applied PCMs material.

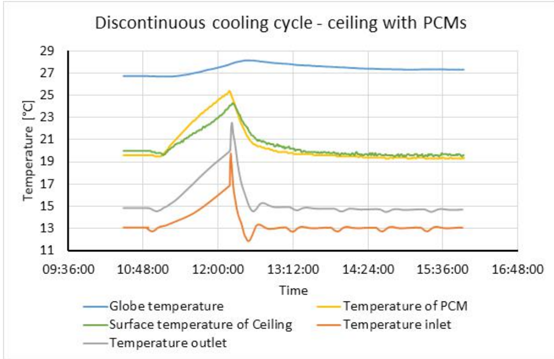

Fig. 3. Discontinous cooling cycle with PCMs.

3.3 Discontinuous cooling cycle of cooling ceiling with PCM

The measurement conditions were the same as in the previous measurements, the air temperature inside the laboratory 26 $°C$ all surrounding spaces had air temperature 26 $°C$, inlet water temperature was 10 $°C$.

Application of PCM material within cooling ceilings increases, in particular, its thermal storage capability. Another experimental measurement was, therefore, to verify the cooling accumulation capacity of the cooling ceiling during the intermittent cooling operation. The flow of coolant media was turned off during the test, but the heat load with electric dummies was in operation. Inside the room was, therefore, an increase in air temperature. The object of this measurement was to determine the thermal inertia of the cooling system using PCMs material.

After reaching the steady state of all air temperatures, the cooling source was interrupted for one hour. The measurement results show the behavior of the system, which causes a very gradual increase in the temperature of the air inside the conditioned space. After the cooling has been switched on, the room temperature has been stabilized almost immediately. Reaching the original air temperature by cooling down to 1 $°C$ lasts in this case almost 4 hours. Thermal inertia is a very lengthy process due to PCMs.

Intermittent cooling using a cooling ceiling with PCMs has made it possible to estimate the approximate amount of accumulated energy during cooling off. In steady state, as shown in the figure 3, the cooling operation was switched off at 14:00. The temperature of PCMs material significantly increased faster than the air temperature, which is indicated by the temperature of the ball thermometer. In the region of 21 to 22 $°C$, a change in the heating rate of PCMs is apparent, due to phase transition and latent heat accumulation. During the cooling operation, the heat load of 586 W was in operation. Time when the cooling was switched off was 90 minutes. The room air temperature was heated by 2.4 $°C$ while the PCMs increased by 6.9 $°C$. The temperature of all the surrounding areas of the laboratory was controlled. Thus, the minimum heat losses of the room can be assumed and the total heat energy supplied to the laboratory was consumed for heating the air and, above all, was accumulated by the cooling units. Mathematically, the total energy delivered during the cooling interruption was 3165 kJ. The cooling units contain a total of 22.95 kg of PCMs, which, during heating from 16.6 $°C$ to 23.5 $°C$, consumed approximately 3120 kJ of heat. For surface conversion, the heat absorption is up to 669 $kJ\,m^{-2}$. The PCMs manufacturer has a value of 515 $kJ\,m^{-2}$, however, for a temperature range of 18 to 24 $°C$.

Experimental intermittent cooling measurements confirmed the appropriate application of PCMs in a lower temperature range, as verified in the DTA analysis. The PCMs material has a very high specific heat capacity value just in the lower temperature range, as confirmed by the absorption of heat energy during intermittent cooling

4 Conclusion

The experimental measurement was conducted to investigate the cooling ceiling with application of PCMs. The article first describes the measurement results then show the cooling power of the ceiling units thus produced. Another part of the paper covers experimental intermittent cooling measurements where the effect of thermal accumulation is described and the amount of accumulated energy used by PCMs is determined. The results also show a significant increase in the thermal inertia of the cooling system using a heat storage medium, which can increase its thermal storage properties. By this article is validated newly modified laboratory for measurements of radiant ceiling systems.

The subject of further experimental measurements will be the evaluation of the thermal inertia of these cooling ceilings under different temperature conditions with varied thermal loads.

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