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Measurements of the performance of the room integrated PCM in the new Energy Efficiency Center

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Abstract

The design of the Energy Efficiency Center, located in Würzburg, Germany, has as an overall aim to create a reference building which implements innovative techniques, serves demonstrational purposes, and is used for research and development in the field of energy optimized buildings. As the outer shell of the building as well as the interior construction is lightweight because of flexibility requirements and resource saving aspects, little heat storage capacity is available to buffer temperature fluctuation. To avoid room climates outside the comfort range without integrating too large conventional cooling power reserves, a combination of several thermal energy storage technologies is implemented to meet the cooling demand in an energy efficient way. One of the thermal energy storage technologies involves the integration of PCM in building materials, as well as an individually optimized cooling ceiling with PCM. Specifically, the prototypes of PCM cooling ceilings were investigated regarding their dynamic thermal behavior before being implemented in the EEC. In this work, the cooling concept with integrated PCM in wallboards, as well as the cooling ceiling with PCM is briefly presented. Subsequently, the first measurement results of the intense long-term monitoring of the performance of the integrated PCM are presented and analyzed.

Keywords: phase change materials (PCM); cooling ceiling; energy efficiency; thermal storage with PCM

1. The Energy Efficiency Center

Current approaches in reducing CO_2 emissions as part of international and national climate protection policies are based on people's consciousness about the increasing threat of the greenhouse effect. Likewise, ecological and economic consequences, as well as the constantly augmenting costs of fossil fuels have promoted these current policies to significantly reduce CO_2 emissions. In view of plans to increase the energy efficiency by 20% until 2020, turning old buildings into energy efficient ones as well as establishing high standards for energy efficiency of new buildings has become notably important in Germany. Besides that, with growing insights in the field of energy research several new technologies were developed in the past years which promise more energy efficiency in buildings. Anyhow, in the building sector innovations often take many years until being accepted on the market. This means that a great potential of energy savings is still unused.

The Energy Efficiency Center (EEC) is located in Wuerzburg, Germany and was finished in June 2013. Based on the above facts, the overall aim of the design of the EEC is to create a reference building which implements innovative energy efficient technologies, to optimize their interaction, to identify synergy effects and to accelerate their introduction to the market by demonstration. These ambitious goals are promoted by gathering the know-how of the involved research partners from science and industry and by exchanging experience and ideas. The new research building serves demonstrational purposes, and is used for research and development in the field of energy optimized buildings. More specifically, it involves innovative, energy efficient materials, components, and systems, all of which are to demonstrate their applicability for both old and new buildings. The EEC is designed to be easily extendable and is equally devoted to energy efficiency and aesthetically architectural design. The EEC includes offices, laboratories and a technical center as well

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as the corresponding infrastructure for the research activities of the ZAE Bayern in Wuerzburg. Furthermore, a seminar room, a conference room and a public Information Center are part of the room concept.

Figure 1: The Energy Efficiency Center

The two-storied building is characterized by a light-weight construction in combination with a highly transparent building envelope with large glass surfaces. It is covered by a translucent roof membrane which serves as weather protection and plays an important role in light and climate management of the building as it creates an intermediate climate zone which acts as a preconditioned heat-insulating layer in the cold season and can be ventilated in summer to prevent overheating. Underneath the roof membrane there is an insulating layer, partly opaque and partly translucent, using highly insulating aerogel modules in order to facilitate optimal daylight conditions for the second floor offices. The lightweight facades are triple glazed with applied low-e coatings and insulated with vacuum insulation panels in the opaque sections.

Due to the innovative, resource saving lightweight construction of the EEC including a membrane rooftop as well as the highly insulated lightweight facades, the EEC will show a highly dynamic thermal behavior. Because of high internal heat gains from measurement setups, electronic devices, solar gains and occupants high requirements especially for cooling have to be met. As the outer shell of the building as well as the interior construction is lightweight because of flexibility requirements and resource saving aspects, little heat storage capacity is available to buffer temperature fluctuation. To avoid room climates outside the comfort range without integrating too large conventional cooling power reserves, a combination of several thermal energy storage (TES) technologies is implemented to meet the cooling demand in an energy efficient way (Klinker et al., 2012, 2013). One of the thermal energy storage technologies involves the integration of phase change materials (PCM) in wallboards, as well as an individually optimized cooling ceiling with PCM. Specifically, two prototypes of PCM cooling ceilings were investigated regarding their dynamic thermal behavior before being implemented in the EEC (Klinker et al., 2014).

The EEC will undergo an intense long-term monitoring phase starting summer 2014. For the needs of this monitoring there are eight test rooms, four on the south and four on the north side of the building, equipped with all the necessary sensors and measuring equipment. Three of these test rooms are used as reference cases and they have only regular materials, without PCM in the wall or in the ceiling. A floor plan of the EEC, with the test-rooms and the positions of PCM wallboards highlighted is presented in figure 2. In this paper, an overview of the cooling concept with integrated PCM in wallboards, as well as the cooling ceilings with PCM is presented. Subsequently, the first measurement results of the intense long-term monitoring of the performance of the integrated PCM are presented and analyzed.

Figure 2: Part of the EEC second floor plan with the test-rooms and the positions of PCM wallboards highlighted

2. Cooling concept with PCM

During the last 15 years, ZAE Bayern has collected extensive experience in the field of PCM in buildings in several public funded projects (Mehling, 2014 and Weinläder, 2011). PCM undergo a reversible phase change between the solid and the liquid state in a material specific temperature range. By the phase change PCM are able to store a large amount of heat in a narrow temperature range as all absorbed heat is required to break up the bonds of the crystal lattice. Therefore the implementation of room-integrated PCM has a temperature stabilization effect and allows the buffering of temperature peaks without the need of energy consuming conventional cooling systems. Experiences show that especially PCM in building materials like wallboards are reacting quite slow to temperature fluctuations of the room air due to low heat transfer coefficients to the room air in the case of free convection. This is problematic during the charging process (passive cooling in daytime) as well as for regeneration of the PCM.

In the EEC, phase change materials melting around 23°C are incorporated in building wallboards as well as in the cooling ceilings. Specifically, wallboards with PCM as well as the prototype cooling ceiling with PCM are located in all the offices on the second floor, except in the three reference rooms - a schematic design of the cooling concept with PCM is presented in figure 3. Natural ventilation takes place during nighttime in order to enhance the regeneration of the PCM. If needed, a ventilation system can provide forced convection to overcome the problem of low heat transfer coefficients leading to an acceleration of the charging and discharging process.

The two prototypes of cooling ceilings address the improvement of thermal contact between PCM, cooling fluid and the ceiling surface, but each with other priorities. Two types of PCM cooling ceilings were initially investigated for their dynamic behavior (Klinker et al., 2014), the main difference of which is the positioning of the PCM layer. In cooling ceiling - type I - macroencapsulated PCM is put on top of a conventional cooling ceiling panel including water pipes. The PCM containers are thermally connected via a pressed graphite matrix. In cooling ceiling – type II - the PCM containers are between the ceiling panel and the water pipes which are directly connected to the backside of the PCM containers. Subsequent to this investigation, both cooling ceiling prototypes received further optimization and are meanwhile integrated into the newly built Energy Efficiency Center.

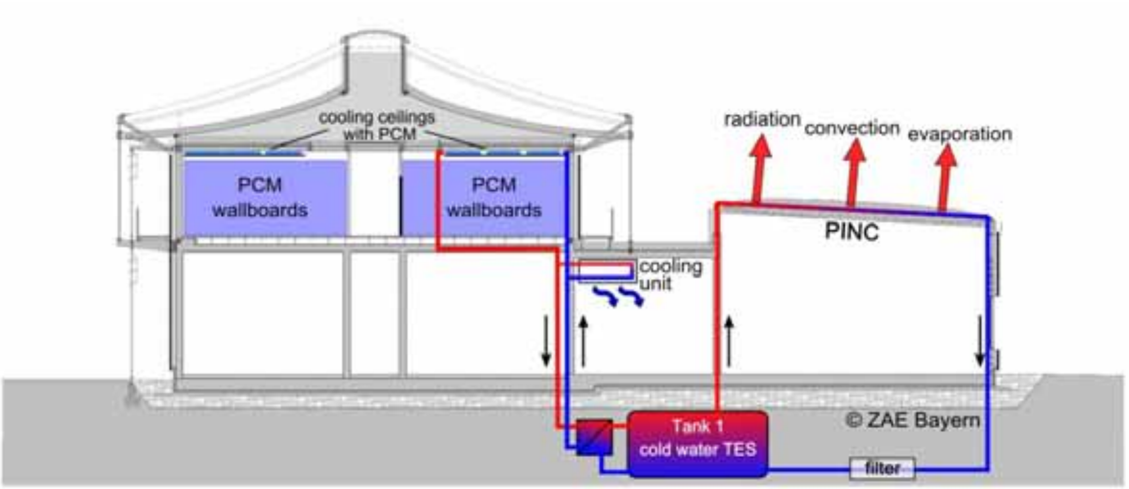

Figure 3: Schematic design of the cooling concept with PCM

3. Materials and method

3.1. General measurement setup

For the needs of this study the south facing test rooms, R110, R111, R112 and R113, are used (figure 2). The reference room (R110) is constructed with regular gypsum boards and ceiling without PCM. The other three test rooms have incorporated PCM on the wallboards and on the cooling ceiling. Specifically, R111includes PCM integrated on the wall and ceiling, the details of which are not needed for this work and therefore not described, while R112 and R113 have Knauf comfortboards with PCM integrated in the walls and different types of cooling ceilings with PCM. R112 has a cooling ceiling - type I - with the PCM situated on top of the cooling pipes and R113 has a cooling ceiling - type II - with the PCM directly attached to the cooling ceiling.

The measurements are performed during the weekends, when the users are not present and the internal loads of the rooms can be controlled. During the first measurement the blinds are open and the lights are turned on in order to achieve high solar and internal gains in the rooms. During the measurements, the operative temperature and the surface temperatures of the walls and ceilings are recorded. During this first measurement, it was observed that the operative temperatures of test-rooms R110 and R113 are lower compared to test-room R112 as shown in figure 4. This difference can be explained by the proximity of these test-rooms with rooms R109 and R114 which had the lights switched off and blinds openwhile the ventilation was on. Furthermore, between R109 and R110 as well as between R113 and R114 there is only a concrete wall and no insulation. Given these facts, the temperature in R109 and R114 is lower than in test-rooms R110 and R113 respectively and therefore affecting the operative temperature of the latter. Based on this observation, it was considered that the two adjacent rooms R109 and R114 should also be controlled and monitored in order to have the same conditions as the test-rooms.

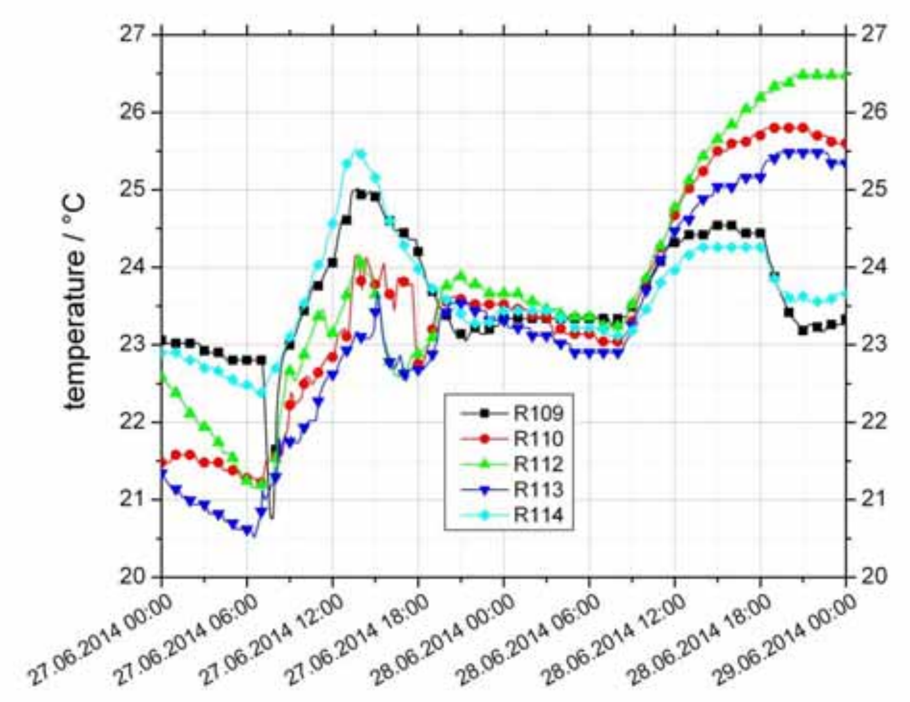

Figure 4: Comparison of operative temperature in the test-rooms 110, 112 and 113 and air temperature in the adjacent rooms 109 and 114 during the first measurements

3.2. Sensor positions

During the measurements the room and surface temperatures and also the heat fluxes are monitored. In figure 5 the position of the temperature sensors on the comfortboards are presented, while in figure 5 and figure 6 are presented the sensor positions in the cooling ceilings type I and type II respectively. Specifically, temperature sensors are located on both surfaces of the comfortboards at three different heights; 0.5m, 1.4m, and 2.3m. Regarding the cooling ceiling - type I, temperature sensors are located on both sides of the PCM modules and also at the ceiling cavity and at the sheet metal roof, while a heat flux sensor is located at the bottom of the cooling ceiling panel. Regarding the cooling ceiling - type II, temperature sensors are located on top of the PCM modules and on top of the cooling ceiling panel. Additionally, the temperature at the ceiling cavity and at the sheet metal roof is recorded, while heat flux sensors are located on both sides of the PCM panel.

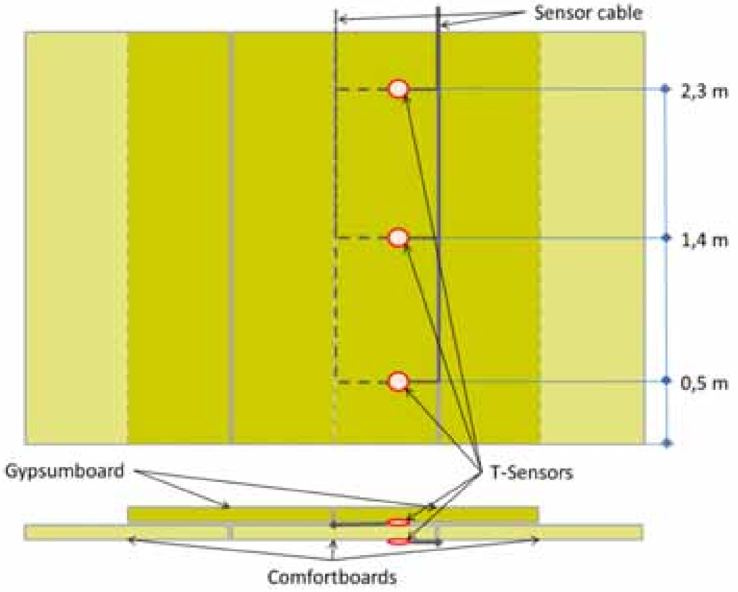

Figure 5: Sensor position for the integrated comfortboards

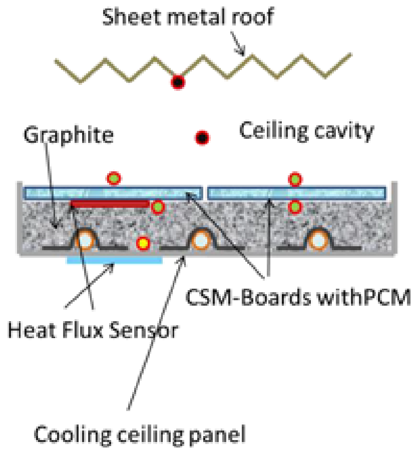

Figure 6: Sensor position for cooling ceiling type I – PCM on top

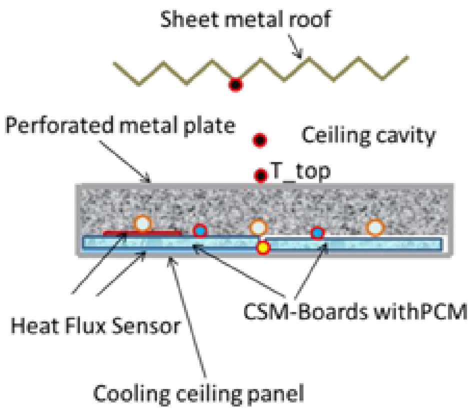

Figure 7: Sensor position for cooling ceiling type II – PCM at the bottom

3.3. Measurement control strategy

The control strategy of the measurement presented in this paper is described in detail in this section. The test-rooms on the south side, as well as the adjacent rooms R109 and R114, are cooled before the measurement. The cooling started on Friday evening, in order to achieve the regeneration of the PCM in the ceiling and the walls. This way the heating behavior of the PCM materials can be observed over the course of the day. It should be mentioned that this measurement takes place during a warm weekend where the outside temperature was about 25°C.

In order to have as little interference as possible during cooling the test-rooms on Friday, the ventilation is closed on Friday at 18:00h while the rooms were not allowed be entered. The blinds are open to ensure sufficient heat into the rooms and the lights are turned on. For this purpose, the “presence” in the adjacent rooms R109 and R114 is placed firmly on 'on' at the building automation system and the blinds ascend manually. In addition, the “Economy mode” is activated at the building automation system in order to prevent the daytime cooling despite the presence of users. ”Regeneration mode” is activated by timer in the building automation system; from Friday at 14: 00h to Saturday 06: 00h, from Saturday at 22: 00h to Sunday at 06: 00h and from Sunday at 22: 00h to Monday at 06: 00h. During these times, the cooling ceiling is actively cooled by cold water to regenerate the PCM during the night.

4. Results

A comparative graph of the operative temperature of test-rooms R112, R113, as well as the air temperature of the adjacent room R114, from August 8th to August 10th, is presented in Figure 8. The outside temperature, as well as the illumination in these rooms is also illustrated. The difference in the performance of the two cooling ceiling types is observed in this graph; R112 has a cooling ceiling – type I with the PCM on top and R113 has a cooling ceiling – type II with the PCM at the bottom. The operative temperature in R112 with the cooling ceiling – type I is cooling down faster during regeneration mode than in R113 due to the better contact of the water pipes to the room air.

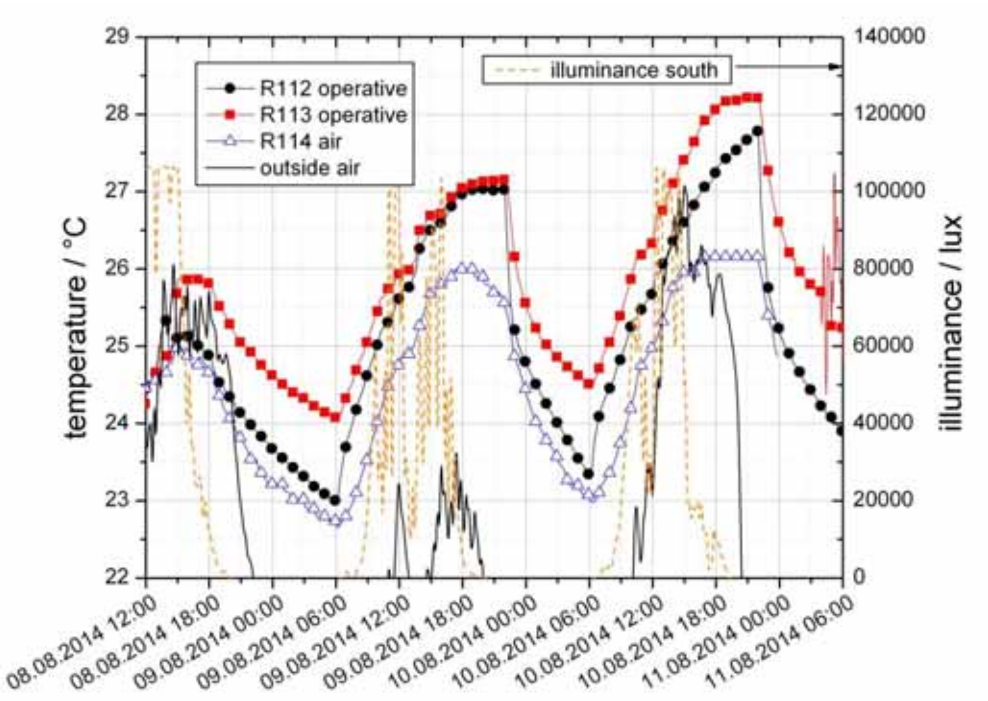

Figure 8: Comparative graph of the operative temperature in test rooms R112 and R113

The operative as well as the ceiling temperatures of R112 and R113 are respectively presented in Figure 9. It is observed in this graph that the PCM in R113 is melting quicker than in R112 often leading to higher surface temperatures. Especially, on August 9th the PCM in R113 seems to melt around 18:00h leading to a temperature increase of the cooling panel, while in R112 the PCM is not completely melted until the end of the day. On August 10th on the other hand the PCM in R113 melts around 12:00h compared to R112 which melts around 18:00h.

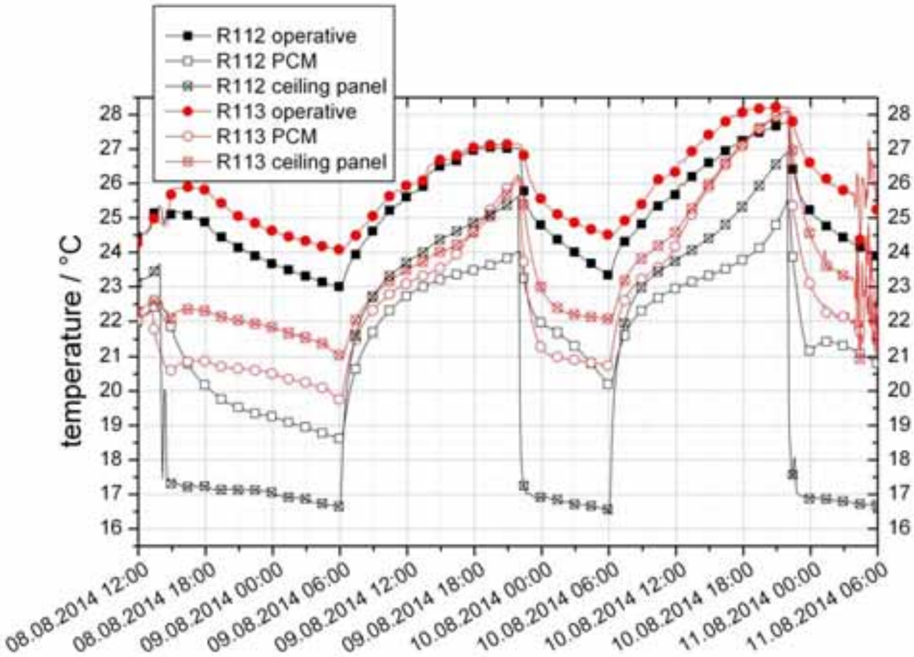

Figure 9: Comparative graph of the operative and ceiling temperatures in R112 and R113 for the weekend of August 9th – 10th.

This fact is also illustrated in Figure 10 where the temperature of the cooling fluid of both systems is illustrated and in Figure 11 where the heat flow of both systems is depicted. The cooling ceiling – type I in R112 shows much higher water temperatures during the regeneration mode because the water pipes cool not only the PCM but also the room air. Both systems seem to perform better during the first day of the measurement, August 9th, while in R113 the fluid temperature increases more than in R112 due to the PCM melting as mentioned earlier. It seems, that the PCM in R113 could not be regenerated completely during the night from 10th to 11th, thus having not the full storage capacitiy on 11th. Regarding the heat flow, it is observed in figure 11 that the heat flow of the two systems is very similar during passive cooling from August 9th 6:00h to 16:00h and August 10th 6:00h to 12:00h when the PCM is not completely melted. Although the two ceiling types have different constructions regarding the position of the PCM, the cooling power in passive mode seems to be quite similar.

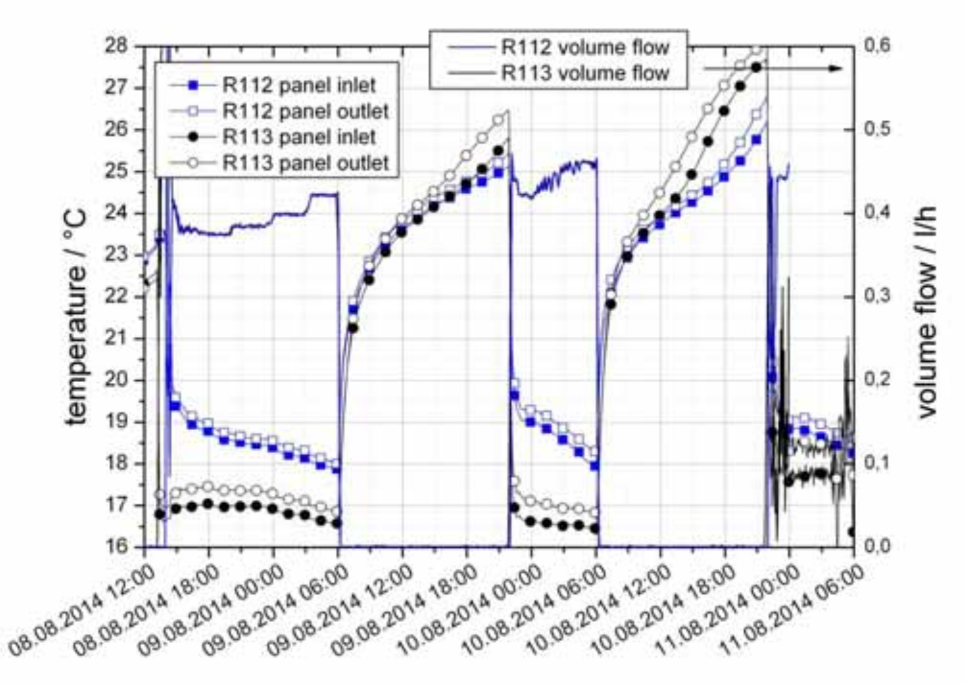

Figure 10: Cooling fluid temperature in R112 and R113 for the weekend of August 9th - 10th.

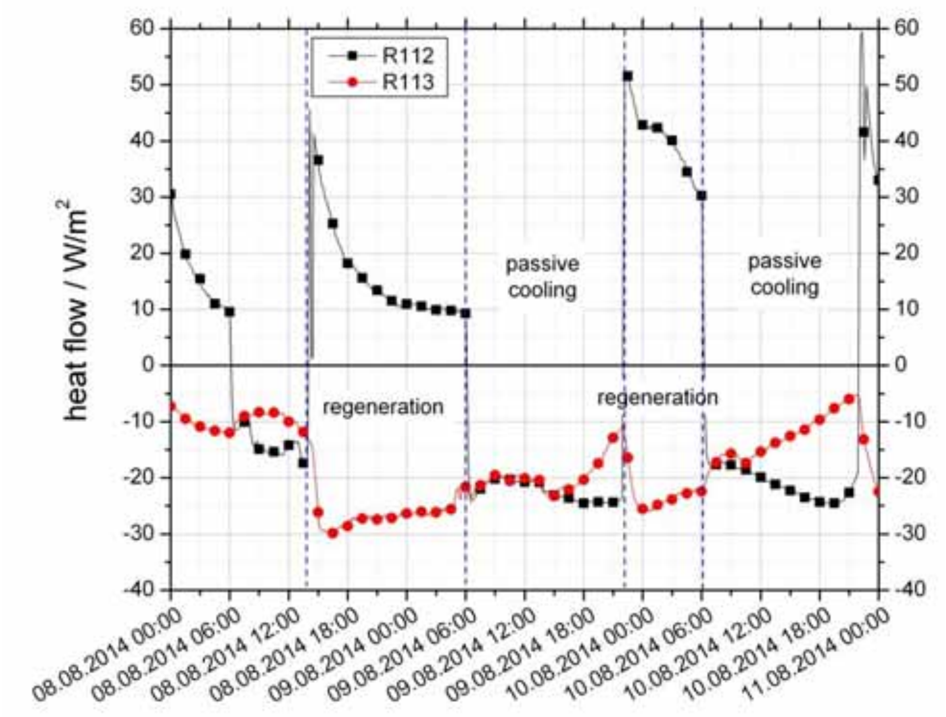

Figure 11: Heat flow in R112 and R113 for the weekend of August 9th – 10th.

Finally, the wallboard temperatures in R112 and R113 are presented in Figure 12. Based on this graph, there is no significant difference in the wallboard performance in the two rooms. Specifically, there is no wallboard PCM effect observed given that the temperature is above the PCM melting range (19ºC-23ºC) and therefore the PCM is liquid during this measurement. R113 has slightly higher wallboard temperatures throughout the weekend due to the typically slightly higher room temperatures in this test room. Both rooms show a stratification of the wallboard temperatures; the temperature increases with the height of the sensor position on the wallboard.

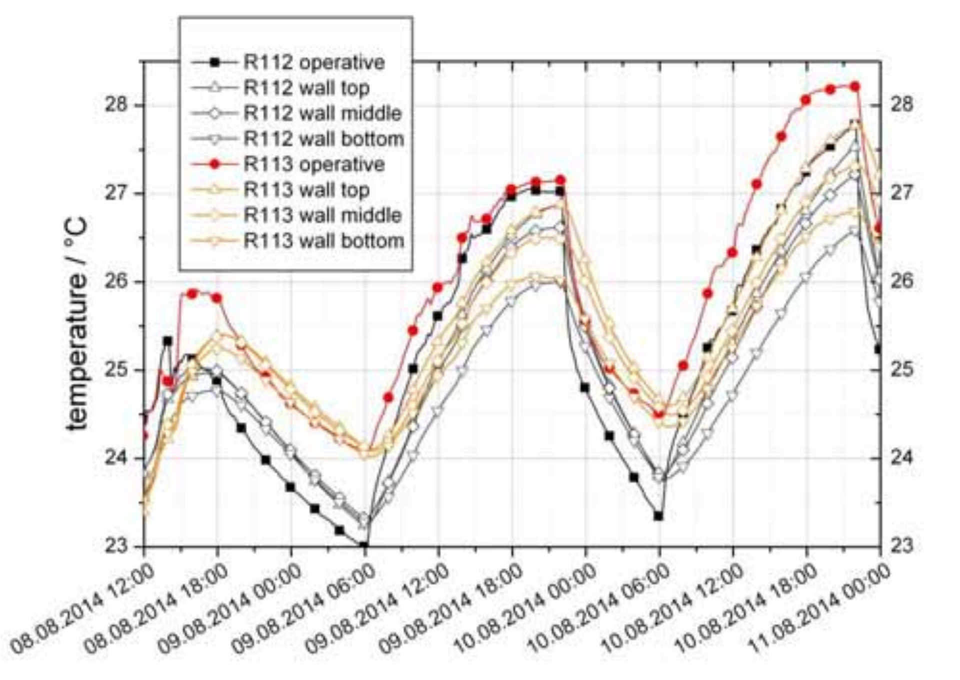

Figure 12: Operative and wallboard temperatures in R112 and R113

A graph of the wallboard temperatures and the operative temperature in test room R112 from July 12th to July 13th is presented in Figure 13. The temperature curves of the comfortboards in R112 show the typical bend of a PCM reaching the end of its melting (see red arrow).

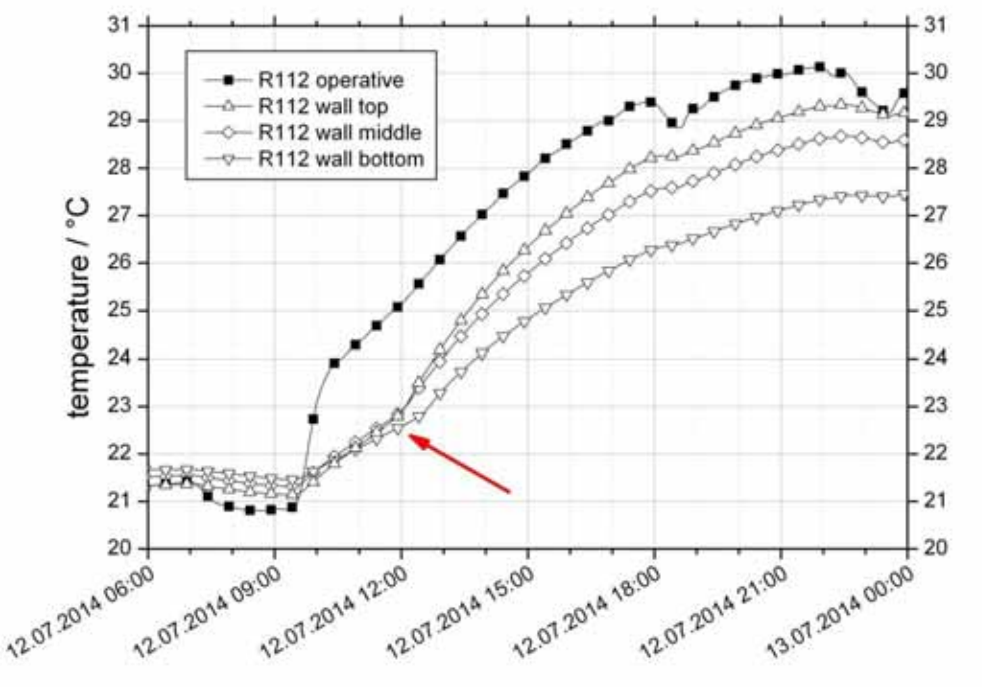

Figure 10: Operative and wallboard temperature in R112

5. Conclusions

A number of test measurements are performed using four different test rooms on the south side of the building - one reference room without PCM and three test rooms with integrated PCM on the ceilings and on the wallboards - comparing the behavior of two prototype cooling ceilings and also the performance of wallboards with integrated PCM in the rooms. Based on these initial measurements it is observed that the two types of cooling ceilings – type I where the macroencapsulated PCM is put on top of a conventional cooling ceiling panel including water pipes and type II where the PCM containers are between the ceiling panel and the water pipes which are directly connected to the backside of the PCM containers – behave similarly. This is not exactly expected based on the better thermal contact between PCM and room air in cooling ceiling type II. Ceiling type II is also expected to show shorter regeneration times of the PCM as the cooling fluid mainly takes up the heat from the PCM instead of the heat of the room air.

The wallboard temperatures that are observed in test rooms R112 and R113 show the effect of the integrated PCM quite clearly. More detailed measurements are expected to be performed in the near future in order to show the effect of the integration of PCM wallboards in the building elements and also the different behavior of the two prototype cooling ceilings.

6. Acknowledgements

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