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Laboratory Testing of Different Melting Temperature Phase Change Materials Under Four Season Conditions for Thermal Energy Storage in Building Envelope

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ABSTRACT

In the light of an urge for conceptually new ideas for raising energy efficiency to meet 2050 EU decarbonisation plans, building thermal envelopes could be given new functionalities. Thus, to compensate the irregularities in the availability of solar energy, phase change materials might serve as the energy storage medium in the building envelope. Paper presents the comparison of two phase change materials with different melting temperatures 21 ˚C and 28˚C for application in building thermal envelopes. Conditions of four seasons in Northern Europe climate are simulated in laboratory testing. The average temperature in phase change materials and small-scale indoor space are compared.

Keywords: Building envelope, solar thermal energy storage, melting temperature, latent heat, small scale PASSLINK test

1. INTRODUCTION

EU Green deal calls for decarbonized building stock till 2050 and promotes the use of RES and smart technologies in buildings to reach that [1]–[3]. Nearly zero-energy buildings as one of the instruments in the way to decarbonized building stock suggests using renewable energy sources available on-site to cover the energy demand. However, the availability of renewable technologies (in contrast to conventional fossil energy) exhibits inconsistencies compared to the energy demand – at peaks, it may exceed the demand and at lows, it may not cover the energy needed. It has diurnal and seasonal or meteorological swings depending on the type of renewable energy technology. Thermal energy storage (TES) is a technique for storing thermal energy by heating or cooling a storage medium, which can then be used for heating and cooling applications at a later time. The use of TES in an energy system has many advantages, including increased overall performance and reliability, as well as improved economics, lower maintenance and operating costs, and less contamination of the atmosphere, such as less carbon dioxide emissions due to the reduced energy demand for heating [4]. There are passive and active TES techniques that are used for various applications – in HVAC systems, in building structures, or in systems in close vicinity to buildings [5]. TES systems can be based on sensible, latent, and thermochemical heat storage. The first two are suitable for applications in buildings. Sensible heat thermal energy storage systems are commercially available and less complex, but latent heat thermal energy storage systems (LHTES) provide higher storage capacity per unit volume [6].

Phase change materials (PCM) serve as a medium for energy storage in LHTES systems. Solid-liquid PCMs are the most common to use in building applications and are divided into three main categories: organic, inorganic, and eutectics [7]. The most commonly used organic PCMs are based on paraffin, fatty acid, and sugar alcohols. Paraffin's advantage for application in buildings is the phase change temperature range from 10^{o}C to 100^{o}C [8]. Various studies are carried out on phase change material enriched building components: boards, bricks, shading devices [9], [10], [11]. However, PCM enhanced building components have not yet reached the mass production level, and there lies a potential for optimization and innovation. Scientific knowledge of PCM behaviour and characteristic details strengthens the path for technological innovations.

The melting temperature of phase change material is one of the parameters that define its suitability for application in particular building application with defined

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performance goals. Paper illustrates the thermal behaviour of two phase change materials in four seasons – winter, spring, summer, and autumn – under defined conditions in laboratory testing.

2. METHOD

The experiment is launched to compare in laboratory testing the thermal behaviour of two phase change materials – one with melting temperature 21˚C (Rubitherm RT21HC) and the other with melting temperature 28˚C (Rubitherm RT28HC) – under different climatic conditions imitating different seasons of the year.

The experimental setup is performed in the small-scale replica of PASSLINK test. Two test boxes are used to compare materials. Plywood test box in the size of 557x577x577 is lined with 50mm insulation (XPS) to gain an “indoor” compartment. PCM container is built in one of the walls in each test box (Fig.1.).

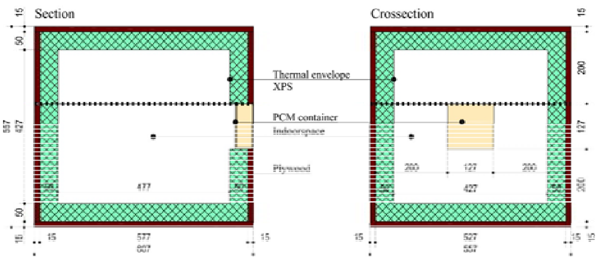

Figure 1. Test box. Small scale PASSLINK type test cell

For monitoring purposes set of thermocouples are placed in the experimental setup (Fig. 2.). For each test box, there is a set of 11 thermocouples installed – six are placed in PCM container at different heights to observe temperature changes in different layers of phase change materials, and five thermocouples are located in the “indoor space” of the test box at different heights. The provided set of thermocouples will allow comparing changes in PCM temperature and “indoor space” temperature among two setups under defined conditions.

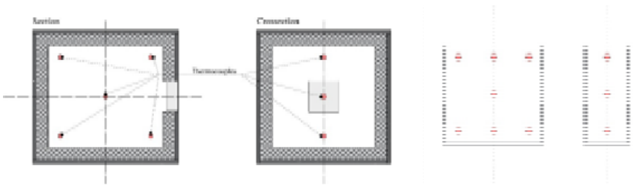

Figure 2. Thermocouples in small scale PASLINK type testing boxes (left) and PCM container (right)

Test boxes are placed next to each other in climatic test chamber TEMI 2500 (Fig. 3). There are two halogen lamps for solar radiation simulation situated right on the longitudinal axes of each test box. The desired temperature in the climatic chamber is ensured by the heating / cooling unit.

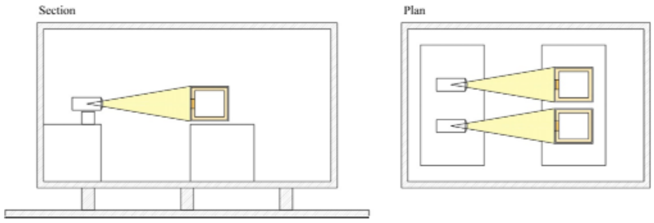

Figure 3. Experimental setup in the climate chamber

2.1 Experiment plan

There are two test boxes placed in the experimental test stand as described above. Each test box contains a PCM container with different melting temperatures. To gain insights on the thermal behaviour of PCMs with different melting temperatures testing conditions are set to imitate 4 seasons in the year – spring, summer, autumn, and winter. Three identical 24-hour cycles are repeated for each season. For each season conditions are chosen as follows:

1) The initial state is the outdoor temperature. All solar wall module setups and climate chamber itself is cooled to initial state before the start of the experiment;
2) Outdoor temperature is the same in heating and cooling phases – the average temperature of one day in a particular season;
3) Duration and intensity of solar radiation.

All together testing takes 72 hours. Testing conditions are summarized in Table 1.

Table 1. Conditions of the experiment

Season	Condition	Value
	Irradiance (solar simulator) duration	12 h
Spring	Irradiance (solar simulator) intensity	690 W/m^2
	Outdoor temperature	7 ˚C
	Irradiance (solar simulator) duration	12 h min
Summer	Irradiance (solar simulator) intensity	750 W/m^2
	Outdoor temperature	19 ˚C
	Irradiance (solar simulator) duration	10 h
Autumn	Irradiance (solar simulator) intensity	440 W/m^2
	Outdoor temperature	10 ˚C
	Irradiance (solar simulator) duration	9 h
Winter	Irradiance (solar simulator) intensity	230 W/m^2
	Outdoor temperature	0 ˚C

Characteristics of materials used in modules and PASLINK test cell is summarized in Table 3 and Table 4.

Table 3. Components of the solar facade model

Component	PCM1	PCM2
	RUBITHERM RT21HC Melting area: 20-23˚C Congealing area: 21-19˚C Density 15˚C: 0,88 kg/l Density 40˚C: 0,77 kg/l Heat storage capacity ± 7,5% 190kJ/kg	RUBITHERM RT21HC Melting area: 27-29˚C Congealing area: 29-27˚C Density 15˚C: 0,88 kg/l Density 40˚C: 0,77 kg/l Heat storage capacity ± 7,5% 190kJ/kg
PCM glass container	Dimensions: 127 × 127 × 60 mm	

Table 4. Components of the small scale PASLINK test cell

Component	Characteristics
Plywood	15 mm λ = 0,13 W/mK
XPS	50 mm λ = 0,037 W/mK

2.2 Measuring equipment

During the test, measurements are registered via multipurpose data logger CR1000 Campbell Scientific. Data are logged once in a minute. Solar radiation is measured by pyranometer CMP3, Kipp & Zonen. Type K thermocouples are used to measure temperature in PCM and indoors.

3. RESULTS

Fig. 4 reflects the comparison of average PCM temperatures in the Autumn setup. Three similar waves reflecting three days are visualized in this and other following graphs as three days of the experiment. Higher temperature is reached in PCM RT28HC, Temperature increase "plateau" after 23˚C and steep temperature drop after solar radiation simulation is switched of indicates partial melting of RT28HC. The temperature in RT21HC is lower than in RT28HC in the charging phase but higher in discharging phase. Contrary to RT28HC, temperature decreases at a slower rate after the solar simulation is switched off. It indicates, that RT21HC as well is not fully melted, but the melted fraction is bigger, therefore temperature drop takes place at a slower rate in RT21HC compared to RT28HC and the overall area under RT21HC daily temperature change is larger. At the end of each day, the average temperature in both PCMs returns to the initial temperature.

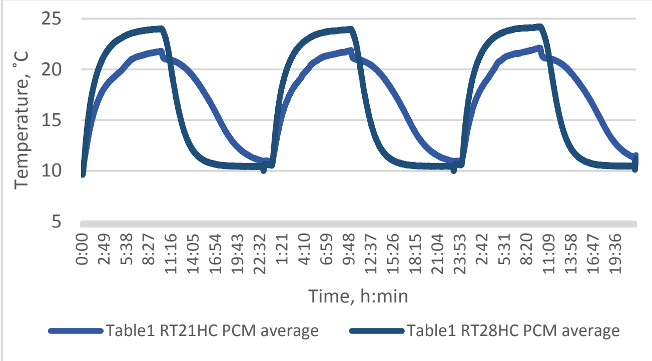

Figure 4. Average temperatures in two PCMs - RT21HC and RT28HC. 72h cycle. Autumn

The advantage of latent heat storage allows the indoor temperature in the test box containing RT21HC to raise higher compared to RT28HC test box indoor temperature despite the temperature in phase change material itself being higher in RT28HC during the charging phase. The peak temperature is achieved higher and cooling takes place at a slower rate in the test box with RT21HC (Fig. 5). At the end of each day, indoor temperature returns to the initial state in both test boxes.

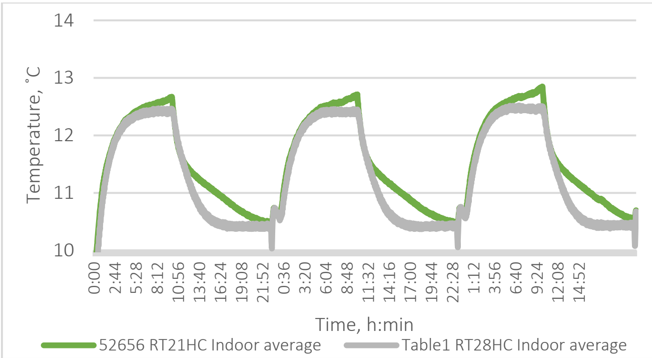

Figure 5. Average indoor temperatures in test boxes. 72h cycle. Autumn

Fig. 6 reflects the comparison of average PCM temperatures in the Spring setup. The solar radiation level in spring is higher, but the "outdoor" temperature is lower compared to autumn conditions. Such testing conditions have enhanced the temperature increase rate in the charging phase and in both phase change materials partial melting can be observed. Higher peak average PCM temperature is reached in PCM RT28HC. Temperature decrease "plateau" appears in both phase change materials and in RT28HC plateau sits at a higher temperature level - 25 vs 21˚C compared to RT21HC. Plateau is more inclined in RT28HC which indicates that the melting fraction might be lower in this phase change material. Temperature increase "plateau" after 23˚C and steep temperature drop after solar radiation simulation is switched of indicates only partial melting of RT28HC. The temperature in RT21HC is lower than in RT28HC in the charging phase and at the beginning of discharging phase. In the last 7 hours of 24-hour duration temperature in RT21HC is higher. Immediate temperature drop after the solar simulation is switched off indicates that both phase change materials are not fully melted, but the melted fraction in RT21HC might be bigger, therefore and due to the different solidification processes in particular phase change materials, temperature drop takes place at slower rate in RT21HC. Temperature graphs in the charging phase were closer for RT21HC and RT28HC compared to the Autumn test.

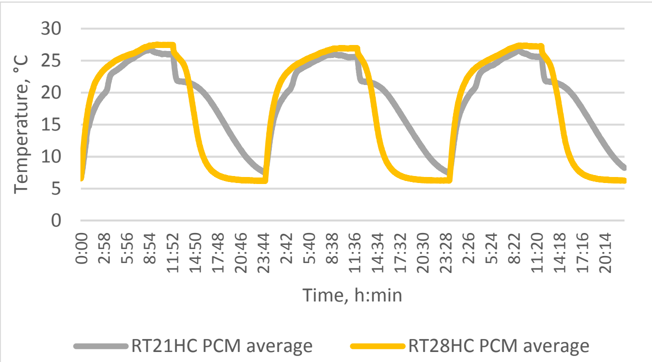

Figure 6. Average temperatures in two PCMs - RT21HC and RT28HC. 72h cycle. Spring

Despite average temperatures in phase change materials were reached higher in both samples, spring testing conditions higher compared to autumn testing, lower "outdoor" temperature in climate chamber has not allowed achieving higher indoor temperatures in test boxes. In The Spring setup still indoor temperature is reached higher in the test box containing RT21HC, despite the PCM average temperature is higher in RT28HC (Fig. 7). It might be related to the amount of melted fraction – a bigger fraction that has received sensible heat transfers it to the room behind it. Indoor space temperature is 2˚C higher in the RT21HC test box.

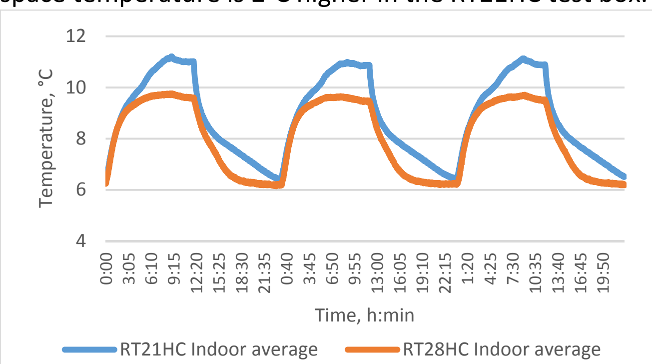

Figure 7. Average indoor temperatures in test boxes. 72h cycle. Spring

Figures 8 and 9 illustrate winter conditions. It can be seen similarly that the average temperature in RT21HC is reached higher than in RT28C, and room temperature as well is reached higher in test stand with RT21HC. Compared to spring and autumn seasons temperature differences in PCM and indoor space are smaller and in both setups follow a similar tendency because neither RT21HC nor RT28HC reaches melting temperature under winter conditions. Neither in the charging nor discharging phase distinguishable temperature "plateau" (melting/solidifying) can be observed.

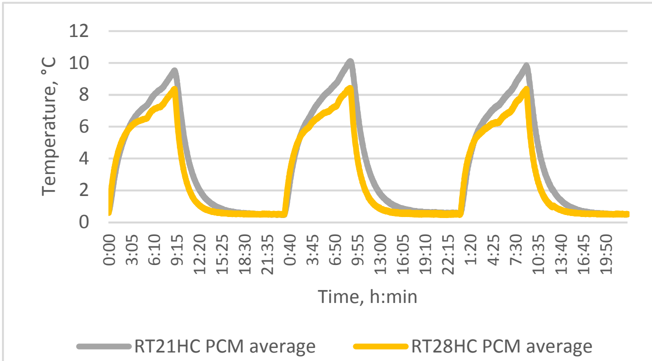

Figure 8. Average temperatures in two PCMs - RT21HC and RT28HC. 72h cycle. Winter

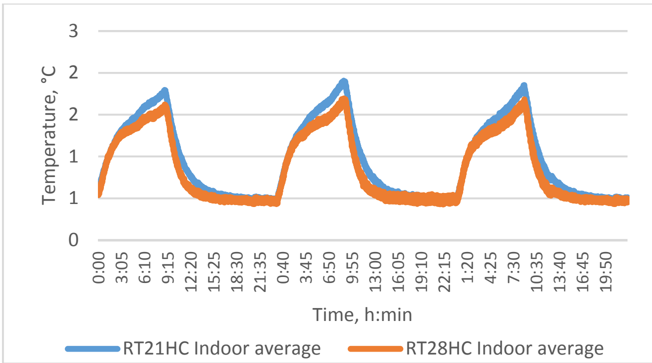

Figure 9. Average indoor temperatures in test boxes. 72h cycle. Winter

In the Summer testing round situation is different (Fig. 10 and 11). Under defined summer conditions RT28HC exhibits a wider "plateau" period in the solidification phase compared to all other seasons. The average temperature in RT21HC in a short time after solar radiation is switched off drops to solidification temperature and keeps this temperature over the night period. This indicates that phase change material has not returned to the initial – solid state.

Comparing test box`s indoor temperatures in summer testing conditions, it can be noticed that in contrary to other seasons during charging phase temperature is higher in test box with RT21HC, but during discharge phase temperature is higher in test box containing RT28C.

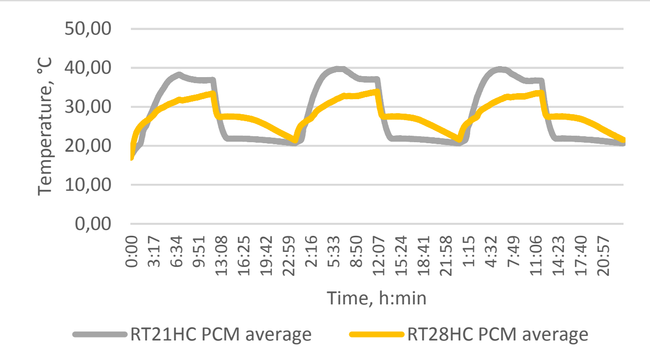

Figure 10. Average temperatures in two PCMs - RT21HC and RT28HC. 72h cycle. Summer

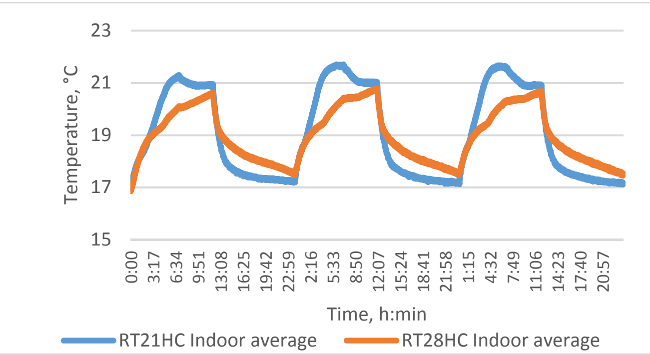

Figure 11. Average indoor temperatures in test boxes. 72h cycle. Summer

Figures 11 and 12 illustrate the average RT21HC and RT28HC PCMs average temperature in four seasons. These graphs allow us to compare charging and discharging behaviour for each PCM in different seasons.

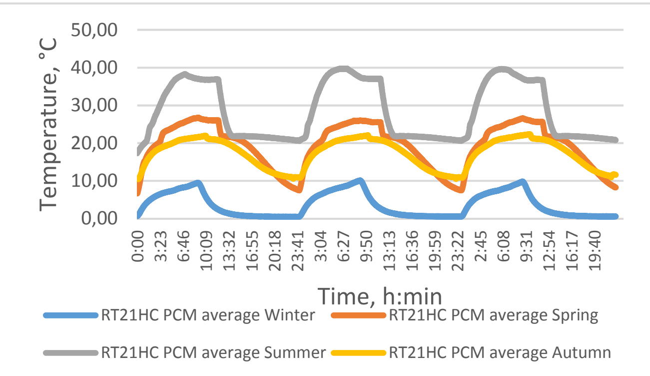

Figure 12. Average PCM temperatures in RT21HC test boxes. Winter, Spring, Summer, Autumn conditions

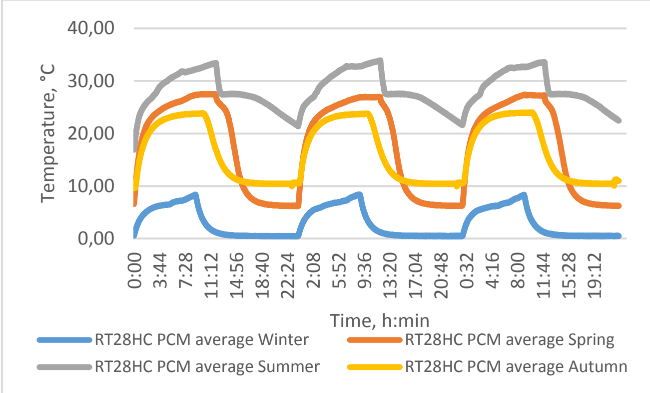

Figure 12. Average PCM temperatures inRT28HC test boxes. Winter, Spring, Summer, Autumn conditions

Full and partial melting of phase change materials is visualized in figures 13 and 14.

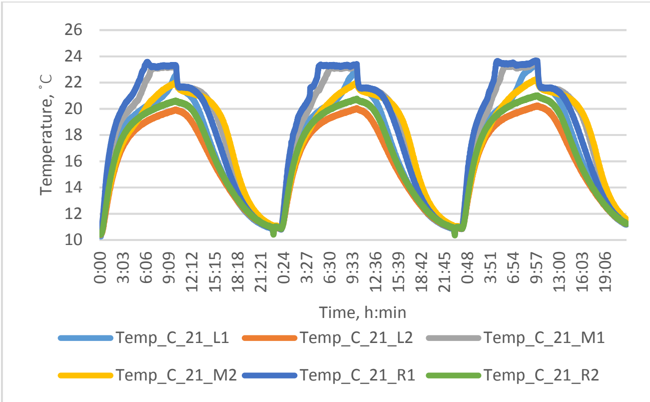

Figure 13. RT21HC PCM temperature in different layers. Autumn

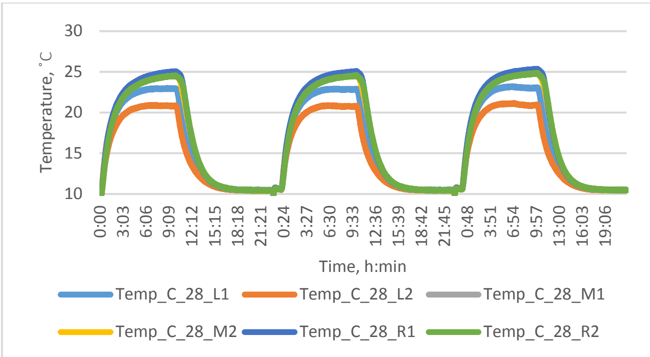

Figure 14. RT28HC PCM temperature in different layers. Autumn

In Fig. 13 it can be seen that upper layers of RT21HC phase change material have reached the melting temperature and latent heat is being stored while lower parts of PCM have not reached melting temperature. After the solar simulator is switched off, different temperature drop rates in different layers can be observed – in upper layers it is steeper compared to lower ones.

Fig. 14 depicts temperature changes in different layers of RT28HC under Autumn condition - in neither layer melting temperature is reached. After the solar simulator is switched off, different temperature drop rates in different layers are similar.

4. DISCUSSION AND CONCLUSIONS

Paper presents laboratory testing comparison of two phase change materials with melting temperature 21˚C and 28˚C under defined climatic conditions that imitate four seasons in northern Europe. In winter, spring, and autumn test rounds temperature in RT21HC test box indoor space was higher than in RT28HC during both – charging and discharging phases. Only in summer and only in discharging phase temperature in indoor space was higher in RT28HC than in the RT21HC test stand. Other valuable insight shows that the volume of RT21HC is insufficient to absorb the energy available in defined summer conditions, which indicates that the right balance between heat gains/losses/storage all around the year must be balanced when designing in detailed conceptual proposal for the particular application.

The presented study is a part of research on a PCM enriched façade system, that would take an active part in building energy balance in heating and cooling seasons contrary to the traditional construction materials that exhibit almost static thermal properties. Storing solar energy in building thermal envelopes would allow reducing energy demand for both – heating and cooling.

Since solar radiation is not always available at a constant flow all day long as in the presented experiment, in further study testing round will be performed with dynamic conditions – on and off solar simulation during the simulated day.

Gained results will be used to validate mathematical modeling results, that will allow exploring different design scenarios at different scales (from small scale PASSLINK to real size building) and under historic climate data in different locations. Based on simulation results design of the façade system will be tailored for testing under real climatic loads at an outdoor medium size testing facility.

ACKNOWLEDGEMENT

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