Membranes with thermo-regulating properties for architectural application

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1 Introduction
Membrane materials used for roof structures of buildings provide a relatively low thermal insulation capacity compared to the classic building materials. Therefore, a large amount of heat penetrates daily through such roof structures into the building especially during the summer months leading to an overheating of the building’s interior. On the other side, the nightly heat loss through these roof constructions, specifically during the winter months, is significantly high. The low thermal insulation capacity of conventional architectural membranes can be strongly improved by using a membrane material with thermo-regulating properties. The thermo-regulation properties of the membrane material are provided by the application of phase change material (PCM) - a highly productive thermal storage medium.

2 Phase change material (PCM)
Phase change material (PCM) possesses the ability to change its physical state within a certain temperature range. When the melting temperature is obtained in a heating process, the phase change from the solid to the liquid state occurs. During this melting process, the PCM absorbs and stores a large amount of latent heat. The temperature of the PCM and its surroundings remains nearly constant throughout the entire process. In a cooling process of the PCM, the stored latent heat is released into the environment in a certain temperature range, and a reverse phase change from the liquid to the solid state takes place. During this crystallization process, the temperature of the PCM and its surroundings remains also nearly constant. The absorption or release of a large amount of latent heat without any temperature change, is responsible for the desire to use PCM as heat storage mean.
In order to compare the amount of latent heat absorbed by a PCM during the actual phase change with the amount of sensible heat absorbed in an ordinary heating process, the ice-water phase change process will be used for comparison. When ice melts, it absorbs an amount of latent heat of about 335 J/g. When the water is further heated, it absorbs a sensible heat of only 4 J/g while its temperature rises by one degree Celsius. Thus, water needs to be heated from about 1 °C up to about 84 °C in order to absorb the same amount of heat which is absorbed during the melting process of ice.

In addition to ice (water), more than 500 natural and synthetic PCMs, such as paraffins or salt hydrates are known. These materials differ from one another in their phase change temperature ranges and their latent heat storage capacities.

3 Thermo-regulating effect

In its roof application, the PCM starts to absorb the heat provided by the solar radiation during the day in form of latent heat as soon as the membrane material’s temperature exceeds a given value. During the latent heat absorption by the PCM, its temperature and the temperature of the surrounding membrane material remains nearly constant. Therefore, the heat absorption by the PCM limits the heat flux into the building during the day. Especially on hot summer days, the thermal comfort inside the building will be enhanced significantly as a result of the PCM’s latent heat absorption feature. The PCM releases the stored latent heat overnight in a reverse cooling process, which also limits the heat flux out of the building and, therefore, results in a significant reduction of the nightly heat loss through the membrane roof.

It is not intended that the PCM absorbs all of the heat provided by solar radiation during the day which would penetrate through the membrane roof into the building. By the latent heat absorption of the PCM starting at a given trigger temperature an overheating of the interior space shall be avoided and the interior temperature should be kept on a comfortable level without the use of additional air-conditioning capacity. Therefore, high peak demand energy requirements are prevented in hot climates.

4 Membrane material design

In an architectural membrane application, the PCM needs to be properly contained in order to prevent dissolution while in its liquid state. Although PCMs are often difficult to contain, silicone rubber was found to be an appropriate carrier system. In order to fulfill their requirements in various geographical areas and in different applications, several PCMs have been selected for the use in the membrane fabrics. The melting points of the selected PCMs range from 30 °C to 60 °C. All of the chosen PCMs are non-combustible salt hydrates. They possess high latent heat storage capacities of up to 340 J/g. Based on a PCM content of 40 % in a one millimeter thick silicone rubber layer latent heat storage capacities of up to 150 kJ/m² are obtained. This is a substantial increase in the heat storage capabilities of architectural membrane structures. In order for an ordinary membrane material made of PVC coated polyester with a similar weight to absorb the same amount of heat, its temperature would need to be raised by about 100 degrees Celsius.

The newly-developed membrane materials with PCM-treatment possess similar weights compared to common membranes made of PVC coated polyester fabrics, PTFE coated fiber glass fabrics, and silicone coated fiber glass fabrics. However, the thickness of the newly-developed membrane material is slightly higher than the thickness of the membrane materials used for comparison (Table1).
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### Table 1: Weight and thickness of selected membrane materials

<table>
<thead>
<tr>
<th>Membrane material</th>
<th>Weight/area, g/m²</th>
<th>Thickness, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PES / PVC</td>
<td>1245</td>
<td>1.0</td>
</tr>
<tr>
<td>Fiber glass / PTFE</td>
<td>1550</td>
<td>0.9</td>
</tr>
<tr>
<td>Fiber glass / silicone</td>
<td>830</td>
<td>0.7</td>
</tr>
<tr>
<td>Fiber glass / silicone rubber with PCM</td>
<td>1210</td>
<td>1.3</td>
</tr>
</tbody>
</table>

5** Thermal performance**

The PCM application in architectural membrane materials provides a substantial improvement of their thermal performance by thermally controlling the heat flux through them. This thermo-regulating feature has a significant influence on the thermal management of the entire building. As a result, the thermal comfort of the enclosure will enhance, the overall heating and air-conditioning demands of the facility will decrease and the construction becomes more energy efficient.

5.1** Thermal comfort**

In order to quantify the thermal comfort improvement by the PCM application, the temperature development inside membrane structures with and without PCM have been studied. For instance, a comparison test was carried out using two model buildings. One of the model buildings was equipped with a roof structure made of the PVC coated polyester fabric described in Table 1. The roof of the second model building consisted of the fiber glass fabric with a silicone rubber coating with PCM (Table 1). In both test configurations, only a single layer membrane construction was applied. The two membrane materials used in this test possess similar weights and show only slight differences in their thickness. Temperature measurements were carried out at the same distance underneath the two membrane structures. The temperature developments obtained for the two model buildings on the same day are shown in ‘Fig. 1’.

![Fig. 1: Temperature development inside the model buildings](image)

The test results indicate that there is a substantial delay in the temperature increase during the day due to the latent heat absorption by the PCM. The latent heat absorption by the PCM leads to temperature differences of up to 9 degrees Celsius between the two buildings. Furthermore, there is also a delay in the temperature decrease overnight due to the latent heat release of the PCM. The overall daily temperature fluctuations measured under the specific climatic conditions were reduced by about 10 degrees Celsius due to the thermo-regulating feature (latent heat absorption and latent heat emission) of the PCM.
5.2 Energy savings

In order to quantify energy savings, a computer modelling procedure has been carried out. For these calculations, a spherical membrane structure with a floor space of about 115 m² was used as a model building. The fabric structure consists of approximately 300 m² of the fiber glass fabric with a silicone rubber coating with PCM covering a volume of about 660 m³. The latent heat storage capacity of the PCM applied to the roof totals 45 000 kJ. This latent heat storage capacity leads to a significant reduction in the air-conditioning demand on hot summer days resulting in energy savings of up to 35%.

6 Material aging

The decrease of the daily temperature fluctuations leads to another benefit of the PCM application in membrane structures. The material aging is usually accelerated by high material temperatures and significant temperature fluctuations. Reducing the temperature increase in the afternoon and minimizing the daily temperature fluctuations, therefore, will enhance the service lifetime of a membrane structure which is equipped with PCM substantially.

7 Light transmission

The newly-developed membrane material shows an interesting feature regarding light transmission. The translucency of the membrane material with PCM exceeds the translucency of the common membrane materials summarized in Table 1 significantly. The test results are shown in ‘Fig. 2’.

![Translucency of the selected membrane materials](image)

Fig. 2: Translucency of the selected membrane materials

Furthermore, the translucency of the membrane material equipped with PCM changes in the course of the day. The silicone rubber layer with the PCM becomes transparent as soon as the PCM is completely melted. On the other side, when the PCM crystallizes, the silicone rubber layer with the PCM becomes opaque. The difference in the light transmission between the two states of the PCM incorporated into the silicone rubber which is coated onto the fiber glass fabric totals 15 %.
8 Additional material features

The newly-developed membrane material can be used under ambient temperatures between -50 ºC and 200 ºC. Tested in accordance with the standard method DIN 4102, it meets the requirements of the fire-protection classification B1. The membrane material possesses excellent mechanical properties, a high dimensional stability and an exceptional resistance to UV radiation and humidity.

In contrast to common silicone coated fiber glass, the dirt repellency of the surface of the newly-developed membrane material consisting of silicone rubber with PCM coated onto a fiber glass fabric is very satisfactory. In a recent lab trial, dirt particles on the surface were easily removed with a cloth. In a building application, the dirt particles will be washed away by rain due to their low adhesion to the membrane's surface.

9 Applications

The new membrane material is most suitable for applications in architectural roofing structures. However, the membrane material can be thermally beneficial when integrated in facade systems. Further possible applications include sun shades, blinds and greenhouse coverings.

10 Summary

The newly-developed membrane material with PCM treatment offers a unique set of improved thermal performance capabilities previously unattainable in an architectural membrane fabric. These capabilities will allow for a substantial improvement of the thermal management of buildings with membrane enclosures. The enhanced thermal management reduces the buildings air-conditioning and heating demands, and, therefore, makes the building more energy efficient. The reduced temperature fluctuations the membrane material is supposed to buffer during the day may influence the materials aging behaviour in a positive manner which will lead to a longer service life. A unique feature of the new membrane material is the change in its light transmission as a result of temperature changes, which might be especially interesting for architectural applications. The thermal effects provided by the PCM application in membrane structures are durable. The thermal solution is maintenance free, cost effective and does not require any external energy supply.

11 References