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High temperature phase change materials for the overheating protection of facade integrated solar thermal collectors

Florian Hengstberger[a,*], Christoph Zauner[a], Katharina Resch[b], Stefan Holper[c], Michael Grobbauer[c]

[a] AIT Austrian Institute of Technology GmbH, Energy Department, Sustainable Thermal Energy Systems, Giefinggasse 2, 1210 Wien, Austria[1]
[b] Materials Science and Testing of Polymers, Department Polymer Engineering and Science, University of Leoben, Otto Glöckel-Straße 2, 8700 Leoben, Austria
[c] SFL technologies GmbH, Innovationspark 2, 8152 Stallhofen, Austria

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ABSTRACT

Maintaining the thermal comfort in buildings with facade integrated solar thermal collectors is a key criterion for the acceptance of this technology. The worst case scenario is a long period of stagnation where the solar absorber reaches very high temperatures and starts to heat up the interior wall. An appealing solution to this problem is to embed a layer of phase change material (PCM) into the absorber insulation which buffers the heat during the day and releases it in the night.

We carried out dynamic simulations of a facade integrated collector in stagnation to determine the optimum melting temperature of a thin layer of PCM at various positions between the absorber and the interior wall. We found that PCMs with a wide range of melting temperatures can be used if the PCM is correctly positioned. Placing the PCM close to the hot absorber allows using high temperature PCMs having melting temperatures of up to 85 °C in our reference scenario. The high melting point of the PCM and the proximity to the solar absorber have important technical benefits. The regeneration process in the night, where the PCM solidifies and recharges for the next day, is very efficient due to the large temperature gradients involved. In addition the solar absorber is now available to transfer heat from the PCM to ambient. The novel recharging process we propose is not only fast, it is also very reliable: the large temperature difference makes the regeneration immune to the changes in indoor or ambient conditions. This is a major advantage over the conventional usage of low temperature PCMs close to the interior wall, whose regeneration rate will strongly be affected by small changes in indoor temperature.

We complete our analysis by discussing potential materials and designs of a facade integrated solar thermal collector equipped with an overheating protection based on a high temperature PCMs.

1. Introduction

The integration of solar thermal collectors into facades is an attractive energy efficiency measure for newly constructed buildings and in retrofit [1–3]. Although the architectural appeal of the building is important for the acceptance of this technology [4], the indoor climate conditions must also be taken into account: the thermal comfort in the rooms behind the solar thermal element must be maintained under all circumstances and at all time.

During the last years we have developed prefabricated facade elements with embedded solar thermal collectors and have installed them into the facade of a multi-storey test building (see Fig. 1). The collectors operated successfully over several months and the temperatures and heat fluxes were recorded for the entire installation period [5].

When analysing the data we discovered that during periods of stagnation the thermal comfort conditions are violated. We observed that the interior wall overheats and reaches unacceptably high levels of more than 30 °C. This temperature rise is a consequence of the heat flowing from the hot absorber into the room $\dot{Q} = h\Delta T$ and leads to a violation of the comfort conditions even if the temperature inside the room is controlled by air condition. Fig. 2 shows that for optimum comfort the wall temperature must not exceed 25 °C even if the temperature of the air is maintained at 21 °C.

In our facade installation experiments we discovered that even thick layers of thermal insulation (10 cm of glass wool, which is more than twice that of regular flat plate collector) do not solve the overheating problem and it was clear that another strategy [7] is

* Corresponding author.
E-mail address: florian.hengstberger@ait.ac.at (F. Hengstberger).
[1] http://www.ait.ac.at.

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Nomenclature

α	absorptivity (–)
ϵ	emissivity (–)
λ	thermal conductivity (W/m K)
ρ	density (kg/m^3)
b	thickness of the PCM (m)
d	distance between PCM and absorber (m)
h	convection heat transfer coefficient (W/m^2 K)
L	latent heat (kJ/kg)
m	mass (kg)
t	time (h)
c_p	constant pressure specific heat (J/kg K)
$\dot{Q}$	heat transfer rate (W)
SOC	state of charge of the PCM (–)

Subscripts

abs	absorber
amb	ambient
m	melting

Fig. 1. Prototype installation of a solar thermal facade element developed in MPPF – Multifunctional Plug & Play Facade [5]. Overheating of the interior wall behind the solar thermal elements was observed when the collector was in stagnation.

required. One possibility is to reduce the stagnation temperature, either by manipulating the natural ventilation in the collector [8] or by using a less efficient colored absorber [9]. Another option would be to use thermotropic glazings, which switch into a opaque state at a certain temperature, as has been suggested for polymer collectors [10]. Unfortunately, all these solutions reduce the efficiency of the solar collector.

A very appealing passive solution is to embed a phase change material (PCM) in the insulation behind the absorber to buffer the excess heat during stagnation. Since long periods of stagnation can occur it is clear that the PCM must regularly be regenerated. Because its mass should be as low as possible, we concluded that the best design is to recharge (solidify) the PCM everyday at night.

In the last years much effort has been devoted to the development of PCM based solutions for the heat management of buildings and many different concepts for the incorporation of PCMs in building walls have been developed [11–16]. However, facade integrated solar thermal collectors are clearly a special case due to the high temperatures involved in stagnation and we had to work out our own thermal concept. We have been guided by recent work

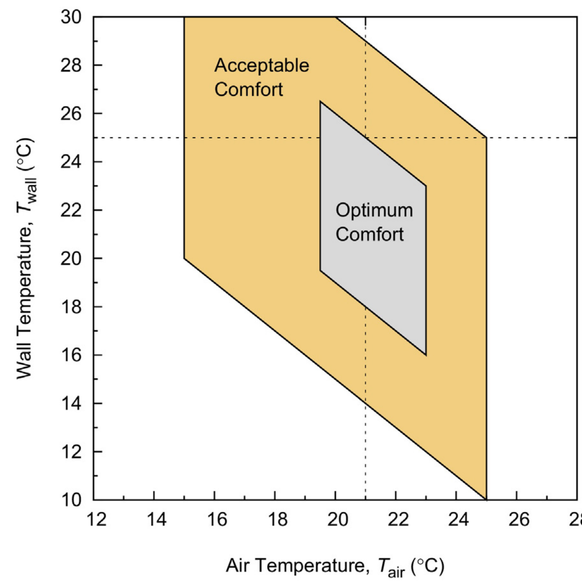

Fig. 2. Thermal comfort conditions [6]. During periods of stagnation the incoming heat flux increases the wall temperature even if the room temperature can be maintained. If the wall temperature exceeds the maximum acceptable surface temperature thermal comfort is lost.

which has shown that the position of the PCM is an important free parameter [17–19] and that an accurate determination of the optimum location of the PCM is necessary for good performance. We therefore attempted to use both degrees of freedom, the position of the PCM in the wall and the PCM melting temperature, to find an optimum solution, which guarantees thermal comfort in the room behind the collector in the worst case scenario of several consecutive days of stagnation.

2. Simulation model

In our simulation we used the simplest possible geometry with a minimum number of components (see Fig. 3) to represent a facade integrated solar thermal collector. A selective absorber of 0.5 mm

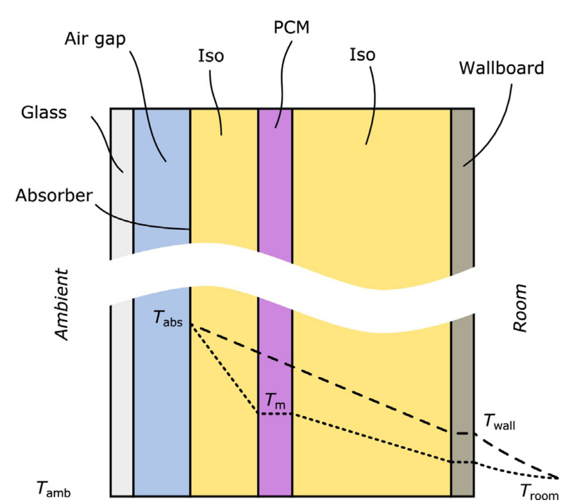

Fig. 3. Geometry of the simulation model. There are two main heat transfer paths away from the hot absorber: the forward path leads through the air gap and the glass to ambient; the backward path through the PCM sandwiched between the two insulation layers and through the wallboard to the room. Without a PCM the temperature gradient in the insulation is constant (dashed). Embedding a PCM layer controls the temperature at its position (dotted). This reduces the heat flux to the room and consequently the surface temperature of the wall.