PARAFFIN AS PASSIVE SOLAR ENERGY ACCUMULATOR IN GLAZING

Andrejs Snegirjovs[1,2], Kristina Lebedeva[1], Martins Vanags[1], Peteris Shipkovs[1], Galina Kashkarova[1], Julia Kadish[2]

[1] Institute of Physical Energetics, Riga, (Latvia)

[2] PVStream, Riga, (Latvia)

Abstract

Theoretical model, experimental and real life tests done for estimate opportunity and gain from phase change material (PCM) application in glazing. Theoretical model and results of tests are described in the publication. Tested component was chosen according to widely used technologies and easily accessible materials. Double and triple glazed window with glazing thickness 6 mm was chosen. Pretested experiments show that pure paraffin could be used as PCM in glazing, however it has disadvantages. Annual real life test done in Temperate climate conditions.

This publication explores of passive control of solar energy gain. Increasing the thermal capacity of glazing gaps leads to the decrease of thermal resistance. But if the thermal energy absorption and desorption is transformed from temperature changes to phase changes we receive specific thermal barrier with fixed defined point phase change. This barrier has its positive and negative effects. Detailed research was conducted and is described.

Keywords: Solar energy accumulation; energy savings in buildings; optical properties, phase change material; window glazing.

1. Introduction

Heating (cooling), the use of air conditioners (heaters) or the use of windows are solutions for maintaining internal comfort, but these measures involve high initial and maintenance costs. On the other hand, the use of passive thermal methods, in general, necessitates large and costly building modifications. For these and other reasons, intense research activities were devoted towards increasing energy efficiency in buildings in order to reduce the traditional fossil fuels use for air heating or conditioning.

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Blind chase towards energy efficiency can cause harmful consequences, such as: interference in fresh air calculation due to decrease of building envelope infiltration and overall improvements in hermitization. The lack of fresh air calculation increases presence of mold and the presence of microorganisms that are harmful for humans, in the renovated buildings. The extreme focus on the energy efficiency causes us to overlook vital microclimate.

Since thermal resistance constructions mostly have low thermal capacities, buildings that are constructed from the energy efficient light materials have higher dependency on the stability of external and internal heat gains due to the low thermal capacity of such buildings. Low thermal capacity materials are incapable to act as heat absorbing buffers during the sudden changes of heat gains, and at the same time, conventional microclimate control systems do not have short enough reaction time to be able to compensate this effect. As a result, feasible temperature changes occur indoors.

Since the variations of solar intensity and outdoor temperature are unsteady, both the thermal conductivity and the specific heat of the insulation affect the heat flow. In this regard, insulations with low thermal conductivity and high thermal capacity are preferred materials (Alawadhi, Esam M., 2012). However, glazing components are commonly the weakest building envelope element considering thermos-physical properties (Knera, D. at al. 2018).

Glazing is usually examined with regards to sealing, constant thermal conductivity, and economical feasibility. Energy-efficient glazing, with using active coating, such as chameleon, allows to decrease ndoor solar radiance

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penetration during warm periods; but during the cold periods such coating is increasing heat deficit.

More effective solutions - active shading systems, such as kinetic shading or electrochromic glazing. Disadvantages of these solutions are: necessity of tuning and support; wearing out over time; energy consumption. In hot climates curtains, roof visor and similar methods are widely used as means of reducing incident direct solar energy radiation. Mills and McCluney (Mills, L.R., at al. 1993.), discuss the advantages of using shading materials especially internally installed ones as visor.

Ideal solution would be to transform shading energy into electricity and usage of the above-mentioned electricity in order to maintain indoor microclimate. At this point this solution will require to unite photovoltaic.

2. Theoretical model

The idea of improving the thermophysical properties of glazing components in buildings, for example, windows by PCM application is relatively new. There has been several researches in experimental and simulation analysis done up till now (Ismail, K. A. R., at al. 2002; Weinlader, H., at al. 2005 and Favoino, F., at al. 2015). In general, analyzing 120 scientific publications on these aspects it is concluded that was published is diverse and in many cases insufficient (Mavrigiannaki, A., at al. 2016). The diversity of experiments and reported values suggest that it is impossible to compare raw materials and already developed PCM elements directly .

At the earlier stages of the research various PCM materials were examined, and finally we've focused on Water-Salt mixtures and Paraffin. Water-Salt mixtures are difficult to use due to its chemical activity and stratification over time. Pure paraffin is also chemically active, but it is possible to use frame materials that are resistant to this.

Theoretical model that is described in the publication (Vanags, M., at al. 2019) informs about light reflection, transparency and absorption of PCM in liquid, solid and transitional states.

Simulation model is based on conducted optical and thermal flow measurements of PCM and glazing. Thermal flow was tested by using HFP01SC heat flux sensors. To measure total transmittance of paraffin Spectrophotometer Specord 210 was used. Integral sphere was used to measure total transmittance, wavelength range from 200 nm to 1100nm. Theoretical model was created for simplifying measurement procedure for PCM light transmittance at different angles of the light source. The transmission of light through a window with filled PCM depends on the location of the Sun at the sky or the angle of incidence of light α from the window plane. Assuming that the solid state of the PCM is homogeneous, the light path through the PCM changes only from the angle of incidence α (Fig. 1).

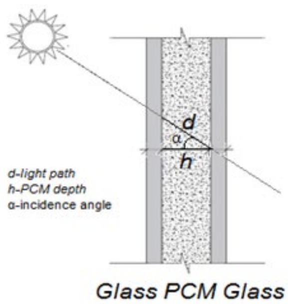


Fig. 1: Light path through the PCM to the angle of incidence.

Consequently, the light path d through PCM depending on the angle of incidence of light on a window plane can be expressed by the following formula:

$$d = \frac{h}{cos\alpha}, \qquad \text{(eq.1)}$$

where h is the gap thickness in which the phase change material is filled. This assumption allows us to study the optical properties of samples of different thickness of PCM and to express the thickness as the angle of incidence of the light source on the window plane (Vanags, M., at al. 2019).

Theoretical model was created for understanding the influence of glass on the properties of light transmittance. In operation, the external glass receives solar radiation, where part of it is absorbed, part is reflected and the rest, about 80 %, is transmitted to the PCM initially in the solid phase (Uribe, D., 2018). Light transmittance through the glass, depending on the location of the light source, will not be significantly affected by the thickness of glass, but the reflection of light on the glass surface. Thus, it is experimentally necessary to determine light transmittance through a glass sample at different angles of incidence of light.

Knowing light transmittance through PCM samples of different thicknesses and knowing light transmittance through a glass sample at various angles and summing up the absorption of light in both materials and converting total absorbance into permeability, it is possible to obtain light transmission through a common system of glass-PCM glass (Vanags, M., at al. 2019).

Theoretical model was developed and tested experimentally that is described in the publication (Vanags, M., at al. 2019). It was concluded that:

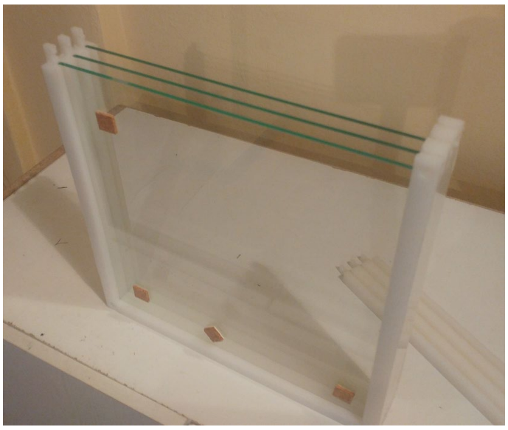
- light beam shines on the PCM layer at different angles horizontally and vertically because of different sun position;
- a luminance through the PCM layer varies horizontally and vertically from different angles, as the sun positions differ.

According to a conventional window form, light beam goes through a thicker layer of PCM in case of perpendicular beam direction. Pure paraffin is homogeneous in the liquid phase, and the solid phase of paraffin has small crystals with directorial structure. Crystal form has insignificant impact on results in cases with big size samples. Hence, light reflection and absorption depend on PCM thickness and angles of incidence of the rays.

EnergyPlus, a state-of-art energy simulation tool, allows simulating the heat transfer through opaque elements that incorporate PCMs. However, EnergyPlus does not allow this for transparent elements with PCMs. Partners from Pontificia Universidad Catolica de Chile in the framework of the ERA-NET-LAC project „Solar hybrid translucent component for thermal energy storage in buildings" (SOLTREN) developed a mathematical thermal model of double glazing windows with PCM in the cavity to be coupled with EnergyPlus in the future. Developed mathematical heat transfer model, the sensible and latent heat of the PCM is mathematically modelled in MATLAB. The PCM RT25 HC of Rubitherm shows the better performance because it keeps the internal surface temperature of the window near the comfort range for more time and the Predicted Mean Vote (PMV) below 1.0 (Ismail, K.A.R., 2001).

3. Tests and results

It has been decided not to conduct tests in the public buildings, due to the risk of leakage, since heavy evaporation of paraffin can be harmful for the human health, therefore special experimental boxes have been constructed. Final stage of the research consists of the following field test: Two identical boxes were created, with the only difference between them being in glazing. One has conventional glazing, while the other one has PCM glazing.



a) Triple glass structure

b) Placing of the sensors

c)Setting up and running the test

Fig. 2: Construction of the experimental installation

Envelope of experimental boxes is made from waterproof 21mm plywood. The boxes impermeability is secured by with rubber seals. Glazing consists of 3 transparent 4mm glasses and 12mm gaps between the glasses.

Air temperature was monitored inside both boxes as well as monitoring of ambient air temperature. PT1000 temperature sensors were used for all air temperature measurements. Penetration of solar radiation to both boxes was measured with Kipp&Zonen Pyranometer CMP3. The result of the field test identified differences with simulation model in the transitional states and its post effects. The publication describes the results of this field tests and discussion of them.

Construction of the experimental installation highlighted technical barriers for the implementation of this technology in the mass market. Laboratory tests have shown that paraffin has significant expansion of about 14% for the temperature range from -25°C to +60°C. Consequently, it is essential to provide air gaps (fig. 2) or expansion containers in the upper parts of the glazing, to compensate for the thermal expansion.

The expansion leap occurs at the paraffin melting temperature. In cases when the melting is not steady this effect creates concentrated pressure to the specific parts of the enclosing surface, which in the long run can lead to the destruction of the whole construction.

It is much more convenient to fill in glazing with the paraffin while paraffin is in its liquid phase, but this process will lead to complications while working with the high melting temperature paraffins.

Pure paraffin is chemically active, the experiments has proven that paraffin is capable to dissolve almost all materials that are usually used for sealing in double glazing. Longer term results are obtained when using sanitary teflon thread, or polyurethane sealant such as "Gravit 630 NOVOL".

Evaporations of the pure paraffin are harmful for human health, so there have additional safety requirements have to be in place during the manufacturing, exploitation and dismantling.

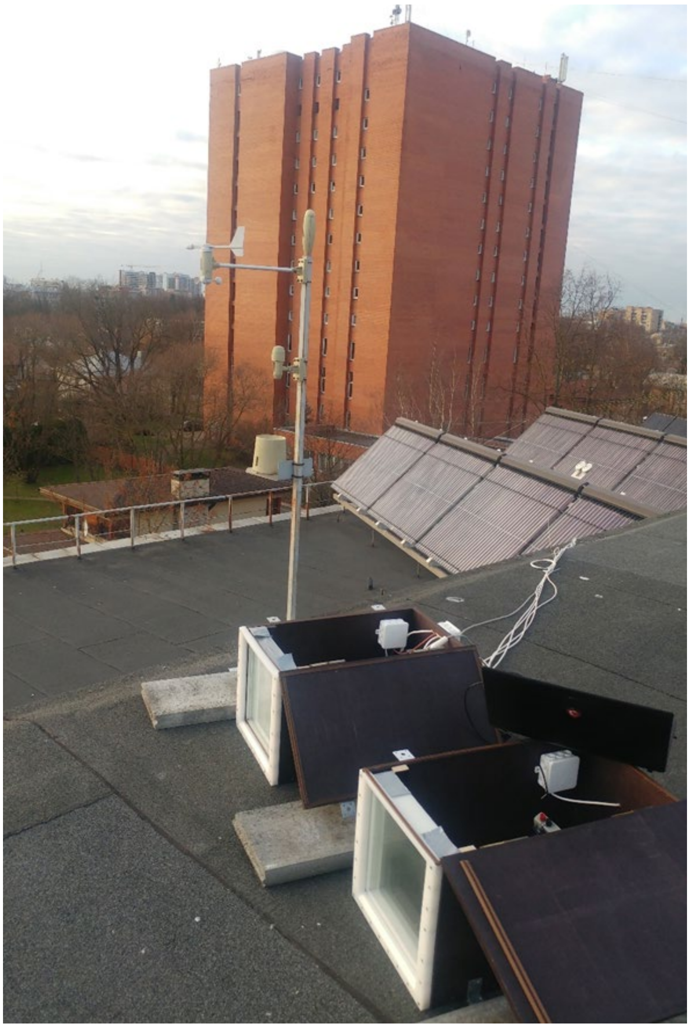


Fig. 3: Two boxes with conventional glazing and with PCM glazing under real test condition on the Solar energy testing polygon. (during experiments top of experimental boxes was closed)

The benefits of the usage of PCM for energy efficiency of building cooling have been proven. But there is no reliable data on the impact of usage of PCM during the heating season yet. The main goal of the research is to explore the energy-efficiency of the passive solar technology- PCM, in glazing during the winter season. The most evident example is the indoor temperature in unheated rooms.

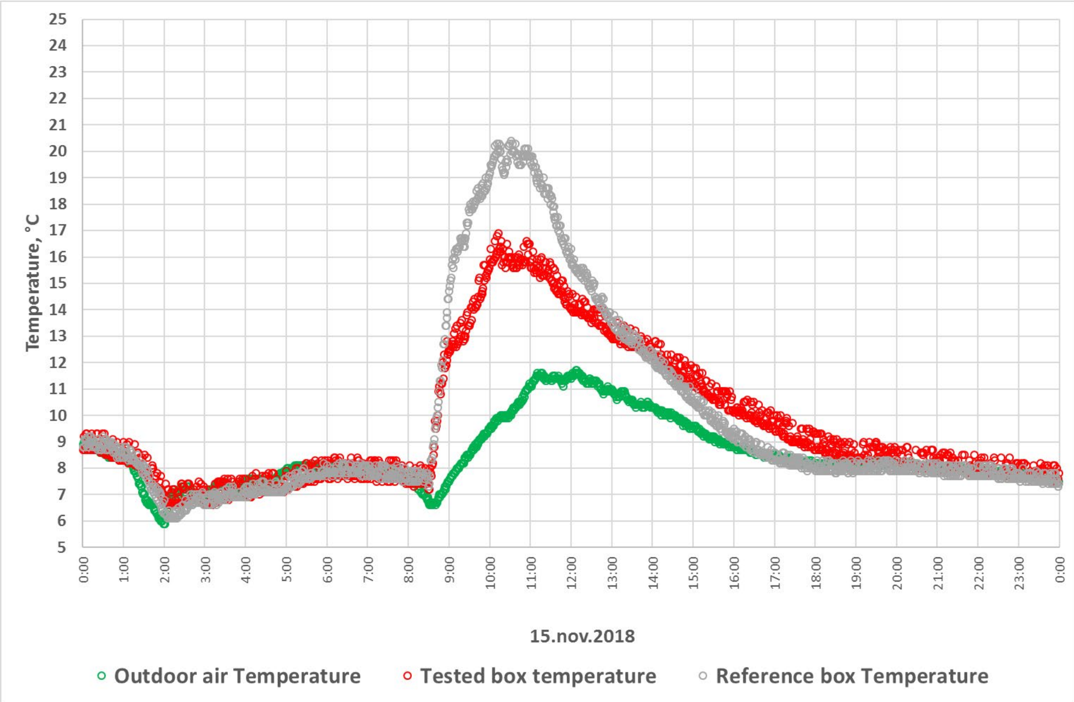


Fig. 4: Temperatures of Outdoor, inside of test and reference boxes the on a sunny winter day.

The boxes are mostly heated by the solar light. Solar trajectory in the winter period is quite close to the horizon. The lighting of the sidewalls and the lid of the box has minimal impact on the temperature inside the boxes- this has been proven by changes the places of the boxes. The temperature distribution seen on the fig. 4 illustrates most of the testing results during the winter period. It is seen from the graph that the initial heating of the experimental box occurs slower. This is caused by the fact that paraffin in its solid phase is dull white. Further on the melting of the paraffin occurs- temperature changes are smoother, and leaps are evened out in the tested box. During the second part of the day, the cooling down of the experimental box is slowed down.

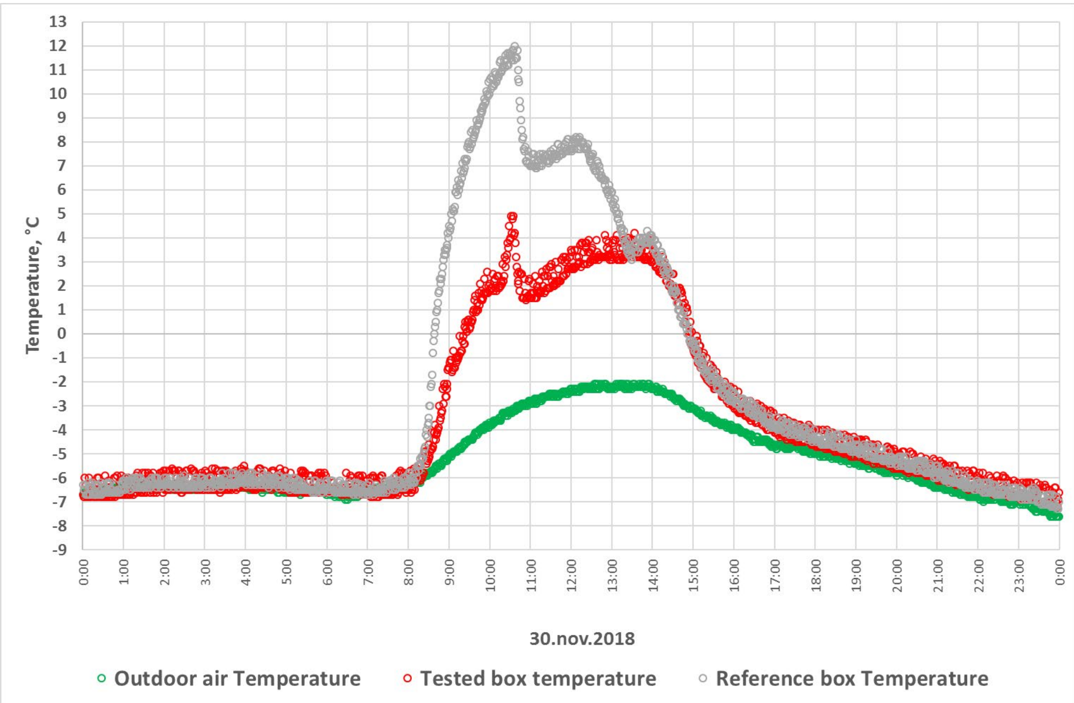


Fig. 5: Temperatures of Outdoor, inside of test and reference boxes the on a partly cloudy winter day.

Curious results were received during the experimental day, when PCM melted down, and began to crystallize almost right away, see fig. 5. In the period from 12:30 AM paraffin starts to melt again, and after 1 PM it begins to crystallize again, this causes the temperature inside the box to be more stable. Drops of the temperature around 10:30-11:00 are caused by the slight cloudiness outside.

4. Acknowledgments

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5. Conclusion

Using a passive solar energy accumulator in glazing with integrated paraffin material has positive effect on building energy performance and internal microclimate stabilisation in the conditioning season. When the paraffin aggregate state changes, for instance, when it melts, its phase transition temperature is preserved but when a complete phase transition has occurred, the temperature of the material starts increasing in proportion to the amount of the supplied thermal energy. On the basis of the applied great potential of the latent heat it becomes a possible solution for the development of the new technologies connected with the indoor microclimate stabilization. The effect of solar energy latent heat storage will result in effective heat transfer coefficient. But, during the heating season the effect on energy efficiency is negative, due to the fact that paraffin in its solid phase practically doesn't transmit sunlight, and thermal conductivity of paraffin is greater than that of the air gap.

Test in the real time illustrates the heating of the spaces when paraffin is used in glazing, in comparison with the standard glazing.

6. References

Esam M. Alawadhi, 2012. Using phase change materials in window shutter to reduce the solar heat gain. Energy and Buildings, Volume 47, April 2012, Pages 421-429.

Favoino, F., Overend, M., Jin, Q., 2015. The optimal thermo-optical properties and energy saving potential of adaptive glazing technologies. Applied Energy, Volume 156, Pages 1-15.

Ismail, K.A.R., Henriquez, J. R., 2002. Parametric study on composite and PCM glass systems, Energy Conversion and Management, vol. 43(7), 973-993.

Ismail, K.A.R., Henriquez, J.R., 2001. Thermally effective windows with moving phase change materials curtains. Applied Thermal Engineering, 21, pp. 1909– 1923.

Knera, D., Heim, D., 2018. Daylight availability in a room equipped with PCM window. 7th International Building Physics Conference, IBPC2018, 809-814.

Mavrigiannaki, A., Ampatzi, E., 2016. Latent heat storage in building elements: A systematic review on properties and contextual performance factors. Renewable and Sustainable Energy Reviews, Volume 60, Pages 852-866.

Mills, L.R., McCluney, W.R., 1993. The benefits of using windows shades, ASHRAE Journal 35, 20–27.

Uribe, D., Benavente, N., Bustamante, W., Vera, S., 2018. Numerical thermal model of double-glazed window filled with phase change materials". 7th International Building Physics Conference, pp. 1233-1238.

Vanags, M., Lebedeva, K., Snegirjovs, A., Kashkarova, G., Shipkovs, P., 2019. Optical properties of new type of glazing unit modified by phase change material (theoretical approach). Latvian Journal of Physics and Technical Sciences, v.56 (1), pp. 21-28.

Weinlader, H., Beck A., Fricke, J., 2005. PCM façade panel for daylighting and room heating, Solar Energy, vol. 78 (2), 177-186.