7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

ibpc2018.org | #ibpc2018

Determination of the input data for computational simulation of active glazing with changeable optical properties

Dariusz Heim[1*], Dominika Knera[1] and Anna Wieprzkowicz[1]

[1]Department of Environmental Engineering, Lodz University of Technology, Poland

*Corresponding email: dariusz.heim@p.lodz.pl

ABSTRACT

Nowadays, many construction components applied in the energy efficient buildings are characterized by dynamically changeable physical properties. Some of them are actuated by the user or building management system, while the others are self-regulated. The second group of mentioned elements is often named intelligent or smart components. Change of their properties is triggered by physical processes e.g. thermal or chemical.

Energy performance of the building can be precisely determined based on the results of computational simulation obtained using one of the widely well-known computational tools e.g. Energy Plus or ESP-r. In the numerical analysis the effect of changeable properties can be also included towards better modelling of physical processes in the buildings. However, the exact material data and its characteristics are necessary for a proper definition of such component properties - thermal or optical characteristics. The main goal of this study is to refine the ESP-r material database, in order to include in the calculation the effect of changeable optical properties of glazing unit filled with material characterized by variable solar transmittance.

The basic general equation of transmittance, reflectance and absorptance as a function of incidence radiation were provided. The material optical database developed in this study consists of experimentally determined reflectance, absorption and transmittance of solar radiation for five angles of incident (as required for ESP-r optical databases). All these data were provided for double glazed unit where the inner cavity was filled with material characterized by changeable optical properties. All optical data were obtained based on the spectral characteristic of the material layer (in different thicknesses) in a wave length range of solar radiation (300-1200 nm). It was concluded, that overall transmittance is determined by the material filling the cavity, but the reflectivity mainly depends on the external surface of glazing and interrelations between glazing and subsequent layer.

KEYWORDS

Solar energy, heat transfer, transmittance, reflectance, phase change materials.

INTRODUCTION

The application of paraffin as a filling of transparent building components is well known since the end of the nineties. (Ismail and Henríquez 2002) proved that additional layer of PCM can improve the thermal efficiency of the whole window, while (Weinläder, Beck, and Fricke 2005) dedicated their research to comfort analysis. PCM was not only used as a layer of a glazing pane but also as a filing of the shading elements (Bianco et al. 2018) and in other technologies as well (Silva, Vicente, and Rodrigues 2016). Additionally, PCM was used in hybrid TPV systems where PV cells were thermally stabilized by PCM layer located at the back side of the panel (Machniewicz, Knera, and Heim 2015). Additionally, the application of PCM glazing components can also lead to achieve future energy standard according to the requirements of new energy performance directive (Firlag 2015). Determination of optical and

thermal properties of PCM-glazing component is very important for proper estimation of its efficiency using modelling techniques. Moreover, it is necessary to determine the optical data, especially of any complex glazing structure for the purpose of building energy performance simulation (Clarke 2001), (Hensen and Lamberts 2011). Many authors provided those data obtained experimentally using spectrophotometric techniques or direct measurements (Goia et al. 2012). Nevertheless, both techniques ignore the effect of local optical phenomena (Duffie and Beckman 2013) on interfaces between glass, air and PCM layer.
The main idea of using PCM in glazing was raised by the necessity of the improvement of their thermal inertia (Grynning, Goia, and Time 2015). Although PCM application in glazing is relatively brand new idea, some previous research study was devoted to analyse other liquids e.g. water as a glazing extender. (Chow, Li, and Lin 2011) revealed that water-flow window can work as a hot-water preheating device. (Sierra and Hernández 2017) showed the active behaviour of water flow glazing by a variable *g* factor. Additionally they concluded that the best glazing to manage the incoming solar energy is the one that allows to enter only visible spectra when the system is flowing and the absorption occurs only in the water chamber. The PCM glazing will play the similar role but the heat will not be extracted from the system to external storage tank but isothermally stored in the PCM layer.
The main purpose of this study was to develop the methodology for determining total solar transmittance, reflectance and absorptance in a glass pane with phase change material, in solid a liquid state. The basic equations were provided for double glazed window with PCM and optical data for standard angle of incidents was determined. Results were presented in the standard of ESP-r (Environmental System Performance) database format.

METHODOLOGY
The proposed methodology is based on the physical fundamentals of solar radiation's transmission through transparent media like glazing (Chwieduk 2014). Physical fundamentals of the phenomena occurring within glazing are mostly related to the optics. The phenomena of radiation's passage through two transparent covers should be analysed taking into account the multi inter reflections on all interfaces. These multi-reflections in double glazed window with air, argon or any other gases between glass panes are schematically presented in figure 1.

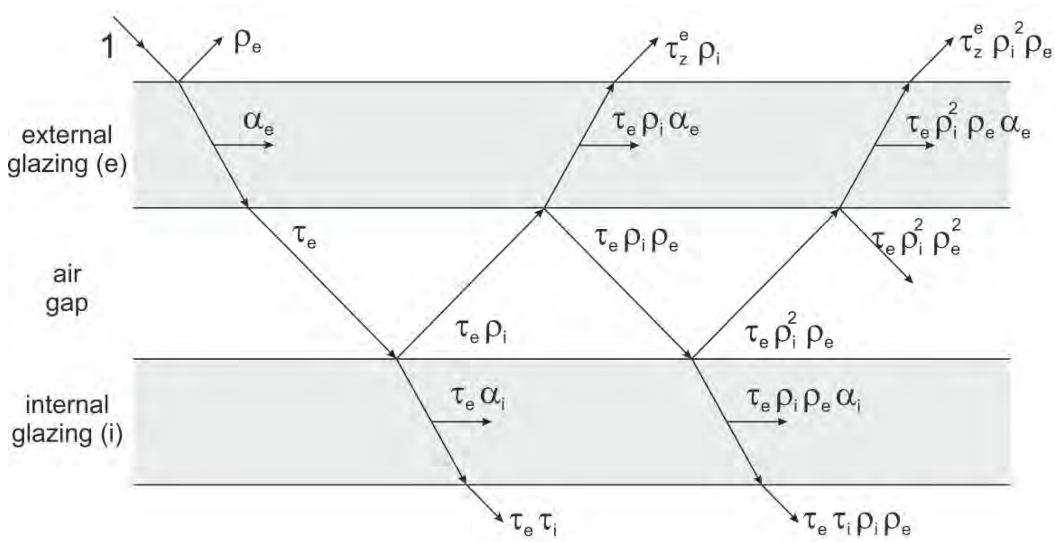

Figure 1. Transmittance, reflectance and absorptance components including inter reflections on glass surface and absorption in a glass pane.

Taking into account inter reflections on glass surface and absorption in a glass pane, the total reflectance (ρ), absorptance (α) and transmittance (τ) of the component can be calculated from the following formulas (eq. 1-3):

$$\rho = \rho_e + \frac{\tau_e^2\, \rho_i}{1 - \rho_e\, \rho_i} \tag{1}$$

$$\alpha = \alpha_e + \frac{\tau_e\, (\alpha_i + \alpha_e \rho_i)}{1 - \rho_e\, \rho_i} \tag{2}$$

$$\tau = \frac{\tau_e\, \tau_i}{1 - \rho_e\, \rho_i} \tag{3}$$

where indexes *i* and *e* refer to the internal and external glass covers respectively.

When glazing cavity is filled with PCM the repeated reflection on all interfaces become more complex due to additional effect of reflection on PCM layer. This process is schematically presented in figure 2, where *m* means material between two glasses.

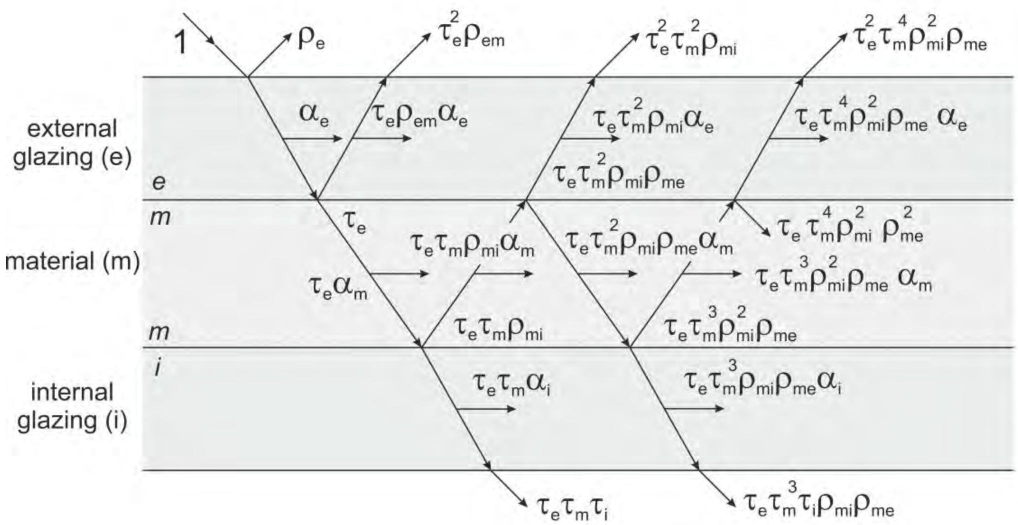

Figure 2. Transmittance, reflectance and absorptance components including inter reflections on glass surface and absorption in a glass pane filled with PCM (material).

The general formula for total solar reflectance (ρ), absorptance (α) and transmittance (τ) becomes as follows:

$$\rho = \rho_e + \tau_e^2 \rho_e + \frac{\tau_e^2\, \tau_m^2\, \rho_{mi}}{1 - \tau_m^2 \rho_{me}\, \rho_{mi}} \tag{4}$$

$$\alpha = \alpha_e \left(1 + \tau_e \rho_{em} + \frac{\tau_e\, \tau_m^2 \rho_i}{1 - \tau_m^2 \rho_{me} \rho_{mi}}\right) + \alpha_m \left(\tau_z \frac{1 + \tau_m \rho_{mi}}{1 - \tau_m \rho_{me} \rho_{mi}}\right) + \alpha_i \left(\frac{\tau_e \tau_m}{1 - \tau_m^2}\right) \tag{5}$$

$$\tau = \frac{\tau_e\, \tau_m\, \tau_i}{1 - \tau_m \rho_{me}\, \rho_{mi}} \tag{6}$$

The indexes concerns the surface where optical processes appears, where *i* and *e* refer to the internal and external glass covers respective and *m* corresponds to PCM layer.

The equations presented above require very precise sets of data which are usually unavailable or impossible to be obtained during tests. Therefore, the following assumptions and simplifications were done:
1) The absorptivity of the single PCM layer in both phases is the same for all angles of incident. It means that reflectivity of the whole component is determined primarily by reflectivity of external glass surface.
2) The reflectivity of single PCM layer in liquid state changes versus angle of incident cognately as the glass – only direct reflectance is considered.
3) The transmissivity of single PCM layer in both phases is a function of the incident angle according to the optical length of the beam during transmission through the material.

OPTICAL PROPERTIES OF PCM DOUBLE GLAZED WINDOW

The results of presented analysis were obtained for glass pane that consists of two glasses 4 mm each with 16 mm air cavity or PCM layer between them. The cross section through the unit is presented in figure 3a - standard double glass pane and 3b - glass pane with PCM.
The main difference between both cases is the heightened potential to absorb solar radiation in a material layer located between glasses. Especially, when PCM is in solid state the absorption appears on the surface exposed to solar radiation. The total transmittance of single PCM (16 mm thick) layer in solid state is less than 10%, while in liquid state it is above 80%. It means that for the case considered here the solid PCM is similar to opaque material. The colour of solid paraffin or fatty acids is white or light grey. It means that reflectivity can be assumed as 0.5 - 0.7 and decreases when material melts. The liquid PCM is fully translucent and has neutral colour.

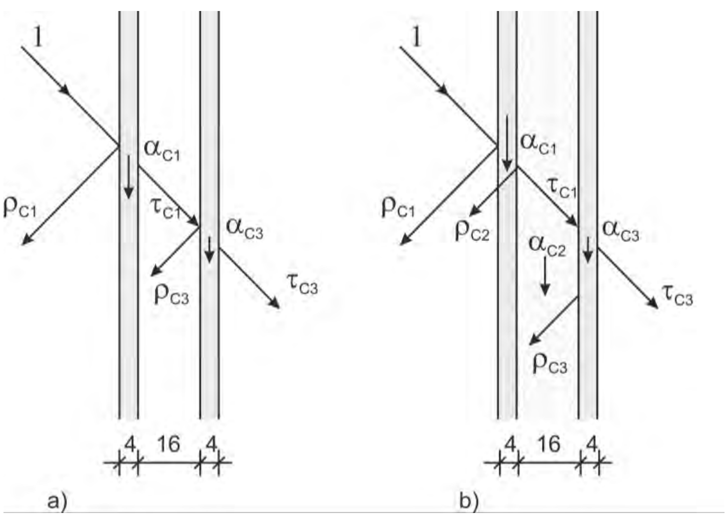

Figure 3. Cross section through glass pane a) standard, b) with PCM.

For the purpose of computational simulation the datasets including angular optical properties are necessary to analyse any physical processes in a glazing unit. The main goal of the work presented in the paper was to develop the characteristic data based on the physics of radiation transmission through glazing. Taking into account the formulas 1-6, the optical characteristics of double glazed unit without, with liquid and with solid PCM were determined. The results are presented in figure 4 a-c as a function of incident angle. It can be noted that when material is solid, PCM glazing characteristic is similar to standard glazing but transmittance is slightly lower as an effect of higher reflectance. In solid state the reflectance is much higher and strongly depends on reflectance of PCM.

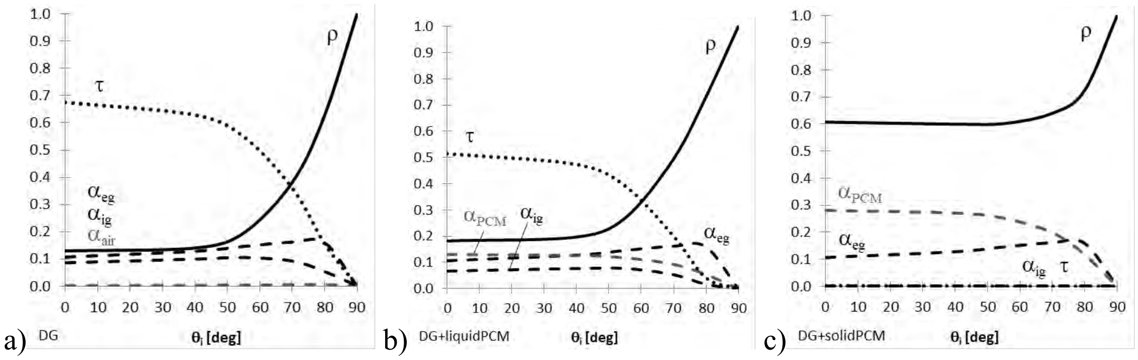

Figure 4. Transmittance, reflectance and absorptance versus angle of incident for a) clear glass double pane window unit, b) glass unit with liquid PCM, c) glass unit with solid PCM.

DISCUSSIONS

In a case of liquid PCM the obtained results show that total transmittance is more than 20% lower than for standard glazing unit and its function versus angle of incident has similar character. The absorptance of liquid PCM is similar to external glazing for the angles up to 50 deg. For higher angles the absorptance of external glazing increases due to the additional reflections between glass and PCM layer.

In solid state the glazing unit is almost blind and most of solar energy is absorbed on the PCM external surface due to the highest absorptivity, almost 0.3. This absorptivity decreases as a function of angle of incident while absorptivity of external glazing increases. This is caused by the longer optical path of the radiation beam, and as it was stated for the liquid state, the interreflections between glass and PCM occur.

In both cases the absorptance on the internal glass surface is very low and has no effect on thermal performance of the whole system. It means that PCM layer should protect building interior against overheating caused by solar radiation. The excessive solar heat gains will be stored as an latent heat in PCM layer and any heat transfer to external environment will be possible only by conduction (inside the component) and convection between glass surface and internal air. Heat exchange by radiation, when melting temperature will be close to indoor air temperature, seems to be negligible.

CONCLUSIONS

The paper presents the methodology of optical properties determination for complex glazing structure. The formulas were developed based on the physical fundamentals of solar radiation's transmission through transparent media. The problem was graphically illustrated and related formulas were also derived.

The final results of transmittance, reflectance and absorptance versus angle of incident were presented in a form of ESP-r optical database and compared with case of standard, double glazed clear glass window. In both phases, solid and liquid, PCM-glazing is characterized by the lower transmittance than standard glass unit. In solid phase the component is almost blind, but the absorptance of PCM layer is relatively high. This feature will determine the ability to absorb solar energy and convert it to heat.

ACKNOWLEDGEMENT

This work was funded in a framework of ERANet-LAC 2nd Joint Call on Research and Innovation by NCBiR as part of the project entitled: Solar hybrid translucent component for thermal energy storage in buildings (acronym: SOLTREN).

REFERENCES

Bianco, Lorenza, Anna Komerska, Ylenia Cascone, Valentina Serra, Michele Zinzi, Emiliano Carnielo, and Dariusz Ksionek. 2018. "Thermal and Optical Characterisation of Dynamic Shading Systems with PCMs through Laboratory Experimental Measurements." *Energy and Buildings* 163 (March). Elsevier: 92–110. doi:10.1016/j.enbuild.2017.12.015.

Chow, Tin Tai, Chunying Li, and Zhang Lin. 2011. "The Function of Solar Absorbing Window as Water-Heating Device." *Building and Environment* 46 (4). Pergamon: 955–60. doi:10.1016/j.buildenv.2010.10.027.

Chwieduk, Dorota. 2014. *Solar Energy in Buildings - Chapter 4*. *Solar Energy in Buildings*. doi:10.1016/B978-0-12-410514-0.00004-9.

Clarke, JA. 2001. "Energy Simulation in Building Design." *Energy Simulation in Building Design*, no. Second edition: 384. doi:10.1016/B978-075065082-3/50016-4.

Duffie, John A., and William A. Beckman. 2013. *Solar Engineering of Thermal Processes*. *Solar Engineering of Thermal Processes*. Wiley Online Books. doi:doi:10.1002/9781118671603.fmatter.

Firlag, Szymon. 2015. "How to Meet the Minimum Energy Performance Requirements of Technical Conditions in Year 2021?" In *Procedia Engineering*, 111:202–8. Elsevier. doi:10.1016/j.proeng.2015.07.077.

Goia, Francesco, Michele Zinzi, Emiliano Carnielo, and Valentina Serra. 2012. "Characterization of the Optical Properties of a PCM Glazing System." In *Energy Procedia*, 30:428–37. Elsevier. doi:10.1016/j.egypro.2012.11.051.

Grynning, Steinar, Francesco Goia, and Berit Time. 2015. "Dynamic Thermal Performance of a PCM Window System: Characterization Using Large Scale Measurements." In *Energy Procedia*, 78:85–90. Elsevier. doi:10.1016/j.egypro.2015.11.119.

Hensen, Jan L M, and Roberto Lamberts. 2011. *Building Performance Simulation for Design and Operation*. Routledge. doi:doi:10.4324/9780203891612.

Ismail, K. A R, and J. R. Henríquez. 2002. "Parametric Study on Composite and PCM Glass Systems." *Energy Conversion and Management* 43 (7). Pergamon: 973–93. doi:10.1016/S0196-8904(01)00083-8.

Machniewicz, Anna, Dominika Knera, and Dariusz Heim. 2015. "Effect of Transition Temperature on Efficiency of PV/PCM Panels." In *Energy Procedia*, 78:1684–89. doi:10.1016/j.egypro.2015.11.257.

Sierra, Pablo, and Juan A. Hernández. 2017. "Solar Heat Gain Coefficient of Water Flow Glazings." *Energy and Buildings* 139 (March). Elsevier: 133–45. doi:10.1016/j.enbuild.2017.01.032.

Silva, Tiago, Romeu Vicente, and Fernanda Rodrigues. 2016. "Literature Review on the Use of Phase Change Materials in Glazing and Shading Solutions." *Renewable and Sustainable Energy Reviews*. Pergamon. doi:10.1016/j.rser.2015.07.201.

Weinläder, Helmut, Andreas Beck, and Jochen Fricke. 2005. "PCM-Facade-Panel for Daylighting and Room Heating." In *Solar Energy*, 78:177–86. Pergamon. doi:10.1016/j.solener.2004.04.013.