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

# A Transparent Insulation Solar Façade Coupled with a Selective Absorber: An Experimentally Validated Building Energy Simulation Model

Miroslav Čekon [1,*] and Jakub Čurpek[2]

[1]Brno University of Technology, Faculty of Civil Engineering, Centre AdMaS
[2]Slovak University of Technology, Faculty of Civil Engineering, Dept. of Building Constr.

[*]*Corresponding email: cekon.m@fce.vutbr.cz*

## ABSTRACT

The development of various advanced materials and their subsequent integration into innovative building envelope concepts has the potential to achieve energy savings. Additionally, their usability in practical applications can be enhanced via the use of building energy simulation (BES) methods. Experimental procedures in conjunction with numerical computations could enable the prediction of the future performance of solar thermal façade concepts. The presented study is focused on the thermal response of a transparent insulation material (TIM) incorporated in a façade structure. An experimental prototype of a solar façade element with both a selective and a nonselective absorber was developed for use as part of an opaque building envelope. Experimental measurements were conducted using dynamic outdoor methods with the aim of verifying a BES model. Combined with the measured thermal and optical properties of key materials implemented, an integrated model was developed to simulate the effect on the thermal performance of the TIM-based façade prototype in the EnergyPlus computational engine. This was primarily focused on the capability of the thermo-optical properties of the proposed prototype to respond in an adequate way under transient boundary conditions. In the first part of this study, a specific characterization for the appropriate modelling and simulation of the given solar based prototype is presented. In the second part, the capability of one widely used BES tool is analysed in terms of its ability to model the energy and thermal performance of the presented façade model. The good consistency between the simulation results and the experimental data indicates that the simulation model was reliable when predicting the thermal performance of TIM based façade prototypes, though with some specific limitations. The methodology developed in this study is expected to provide a reference for simulating the thermal and energy performance of TIM-based building elements with two different solar absorbers.

## KEYWORDS

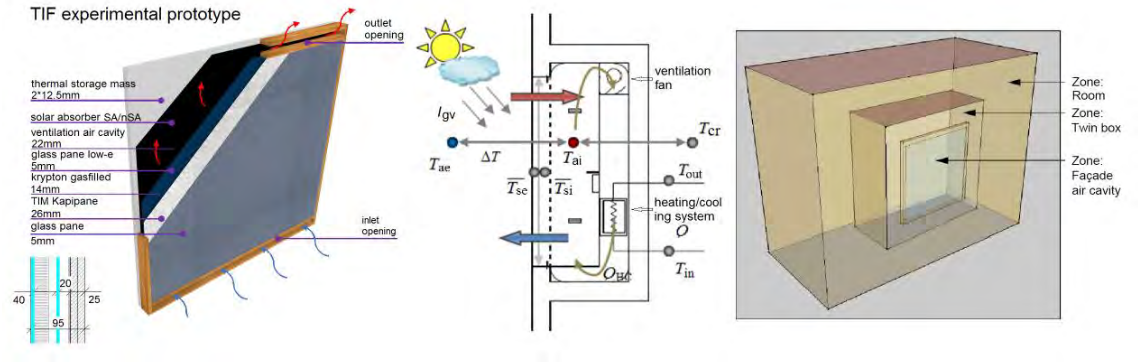
Solar façade, Transparent insulation, Selective absorber, Building simulation, Outdoor tests

## INTRODUCTION

The integration of transparent insulation material (TIM) as an interstitial structure between glazing panes reduces heat transfer and allows the penetration of solar radiation. It basically provides a combination of different solar and heat transfer processes. In addition, when these systems are also integrated into an opaque building envelope, e.g. as a specific type of transparent insulation façade (TIF) with solar absorber functionality, it can allow a completely different approach to a rather complicated issue. Current building energy simulation programs are not accurate enough to model these complex transparent insulation systems, often because of the simplified thermal and optical models used to solve heat transfer as well as light transmittance. Basically, one dimensional methods are used for both thermal transfer and solar transmittance through these systems (Sun et al. 2018). In practice, with the integration of a more complex structure within the air cavity of a double glazing unit, there will be a significant effect on the free convection, longwave radiative heat transfer and solar energy transmitted through the system that has not been typically considered. This was recently analyzed by Sun et al. (2017), who comprehensively studied all these aspects in a glazing system with a TIM for building energy saving and daylight comfort. They aimed to develop a comprehensive method of analysing these specific glazing systems (Sun et al. 2017). Specifically, in most of the previously conducted studies, longwave radiation heat transfer, which accounts for two thirds of the total heat transfer across the air cavity (Gan 2001), is neglected within TIM-based structure during numerical modelling. In addition, when integrated in an opaque building envelope with a multilayer construction that employs several low-e barriers, this can result in a completely different situation and give rise to a more complex task that needs to be investigated. Although improved simulation methods have been implemented by Avedissian and Naylor (2008), who used a surface-to-surface model in order to include radiation, they only employed the model to calculate the $U$-value of the whole system instead of evaluating the effects of the internal structure on longwave radiative heat transfer. In order to create a proper computational model of a façade construction that contains TIM, it is necessary to determine the thermo-optical physical properties of the material. Through this approach, the required values were obtained from laboratory testing based on spectrophotometer measurements and outdoor in-situ measurements for solar transmittance quantification (Čekon and Slávik 2017). Additionally, the thermal and optical properties were obtained via experimental measurements. All of these are input into the building energy simulation (BES) program DesignBuilder that works under the EnergyPlus computational engine. The main goal of the simulation is to analyse the influence of two TIF prototypes with different solar absorbers on heat transfer through their components using outdoor climatic conditions and subsequently compare the results with real measured data. It is necessary to use this process to properly define the simulation model according to the results of experimental measurements.

## EXPPERIMENTAL TRANSPARENT INSULATION FAÇADE MODELS

Two transparent insulation façade (TIF) samples were designed for the analysis of optical properties behind a transparent insulation system coupled with an additional air cavity layer. Two 1.19 m × 1.19 m test prototypes (Figure 1) were built using a system based on the Kapilux (2017) TIM fitted with honeycomb transparent (also may be considered as light translucent) PMMA-based insulation. Each was equipped with a different type of integrated solar absorber (a selective low-e *SA* and a nonselective *nSA* solar absorber). Thus, the absorber used was the main difference between both prototypes. Both had almost the same solar absorbance level (around 0.94 and 0.96, respectively), whilst their emissivity was diametrically opposite: 0.06 and 0.94, respectively. As a result the difference of the thermal performance between the TIFs is up to 18% due to different solar absorbers. Both prototypes were subsequently tested outdoors throughout the heating season. The TIM system comprises double low-e glazing incorporating honeycomb PMMA transparent insulation with a krypton-filled cavity. The declared thermal and optical properties are as follows: thermal transmittance $U_g$ is 0.7 W/(m$^2$·K), total solar energy transmittance or solar heat gain coefficient is 61%, and light transmission is 70%. As demonstrated in Figure 1, this prototype may allow the implementation of a ventilation function, though in this study related to the heating period this has not been applied. The second illustration presents a functional scheme of two identical boxes surrounded by a compensation room, in which both samples (reference (*nSA*) and experimental (*SA*)) were installed facing south-east at the Central Lab at the Faculty of Civil Engineering at the Slovak University of Technology (48°10'36" north and 17° 10'32" east). The twin-box measurement apparatus is used to identify and compare the non-steady state heat transfer through the tested building elements (for more details see Čekon 2013). The monitoring of outdoor ambient temperature $T_{ae}$ , indoor box air temperature $T_{ai}$ and the total solar vertical radiation intensity $I_{gv}$ represents an important part of the tests in relation to this stage of the presented analysis. The compensating room is a zone where both metering boxes are installed; it is controlled in order to eliminate heat flows through the internal box envelopes at a constant interior temperature $T_{cr}$.



a) b) c)

Figure 1. Test transparent insulation façade (TIF). a) TIF experimental model, b) Test experimental twin-box apparatus scheme, c) BES simulation model

## BUILDING ENERGY SIMULATION MODEL

The simulation model was modelled based on experimental measurements in the building energy simulation (BES) tool DesignBuilder that works under the EnergyPlus dynamic simulation engine. The testing period covered the winter heating season. Real weather data was measured by every two minutes and then implemented in the simulation using the open-source program Elements for creating and editing custom weather files for building energy modelling. An overall experimental setup is assumed for the measured façade elements. It is divided into three zones covering the whole geometry of the simulation model. Each zone is specified and preadjusted with different interior thermal energy management regimes in correlation with real measured values. The façade's TIM component was modelled as a window because it allows solar radiation to penetrate the structure. Accordingly, it was necessary to create another two zones for the appropriate completion of the simulation model. The second zone represents a metering box space with 120 mm thermal insulation all around the envelope, except for the front south-east oriented wall with the measured sample. Depending on outside conditions, the real thermal regime of the zone varied with heat flux values ($Q$) ranging roughly from +50 W (nighttime) to -140 W (daytime) based on response of heating/cooling supply system. This phenomenon was included in the simulation by properly adjusting the schedule of process gains that set the design level of energy consumption due to process activity per unit of floor area. The third zone represents the air cavity between the TIM insulating glazing unit (IGU) and the absorber layer on the wall structure. The TIM IGU was modelled as a triple-glazed window, where the middle glass pane represents the honeycomb TIM with thermo-optical properties. The really small krypton-filled gas cavity (0.01 mm thick) between the outermost glass pane and the middle pane should be created by modelling the obstruction of the interstitial structure so that it is different from the gas cavity. The second larger gas cavity is modelled as a krypton gas cavity according to the dimensions of the façade structure. The innermost glass pane is modelled as low emissivity glass. The dimensions of the modelled glazed structure were completed by a wooden frame.

The above-mentioned methodology for modelling a façade prototype in computer software was implemented in the BES part of this research study. The airtightness of zone structures plays an important role in the modelling of zone air temperature. It is described by the infiltration rate ac/h, which is assumed to be constant throughout the simulation. The most suitable infiltration value in the Twin-boxes zone was set at 1.0 ac/h; the lowest values caused the air temperature to increase in the façade cavity. Additionally, it is more complex to adjust the appropriate thermal conductivity value of the TIM mainly due to its dynamic value – the function of the mean temperature of the TIM and the temperature difference between the two isothermal surfaces (glass panes). The parameters from laboratory measurements taken during a previous study (Čekon and Slávik, 2017) were used for the purpose of configuring thermal and optical properties, as those are considered highly sensitive variables in this study, and characteristics specifically related to transparently insulated components. Table 1 depicts the thermo-optical properties of each layer in both simulated TIF elements.

Table 1. Key thermo-optical properties of TIF elements

| Material | Width [mm] | Thermal conductivity [W/(m.K)] | Solar transmittance / absorbtance [-] | Outside emissivity [-] |
|---|---|---|---|---|
| Outermost glass pane | 5 | 1.0 | 0.73 | 0.84 |
| TIM Kapipane | 26 | 0.069* | 0.74* | 0.9 |
| Krypton | 14 | 0.009 | - | - |
| Innermost glass pane (coated) | 5 | 1.0 | 0.73 | 0.1 |
| Non-ventilated air cavity | 22 | - | - | - |
| *SA* solar absorber (TiNOx Al) | 0.3 | 65 | 0.96* | 0.06* |
| *nSA* black painted absorber | | | 0.94* | 0.96* |
| Gypsum board | 25 | 0.2 | - | 0.9 |

* measured according to Čekon and Slávik (2017)

## EXPERIMENTAL AND SIMULATION RESULTS

The experimental results were achieved under outdoor conditions where the maximum sun height above the horizon (about 31°) was at midday. It corresponds to a 31° incline from the normal angle of incidence representing the maximum solar incidence ($I_{gv}$) at the tested location. At the same time, the lowest outdoor ambient temperatures were reached that would allow the results to be used in BES modelling. The testing period was thus specified for the thermodynamic performance analysis of the time-transient winter heating aspect and solar heat gain. The outdoor ambient temperature ($T_{ae}$) varied from a nocturnal -15.0°C up to a diurnal +2.5°C. The incident solar radiation rate ($I_{gv}$) reached a maximum of 900 W/m$^2$ in the area where samples were measured during totally clear sky conditions. The data presented in the graph below (Figure 2) shows the results of both the real measured (exp) and simulated (sim) values. The difference in the internal air temperature ($T_{ai}$) response and thermal performance of the *SA* compared to the reference *nSA* sample is demonstrated. Although the solar absorbance values of both samples are very similar, the longwave spectrum and thermal emissivity, have a major influence on both obtained results. Low emissivity properties lead to a nearly 2K higher temperature under nocturnal conditions, thus the heat loss due to longwave radiation is recognizably reduced there by the low-e solar absorber. The simulated model *SA* reaches temperatures up to 1.5K higher compared to the real measured data. During the daytime, all simulated values are significantly higher. Here, the calibration of optical parameters seems to be needed in order to match the real measured values. With cloudy conditions and a low level of solar radiation exposure, i.e. the first two days of the study, the peak difference between the measured and simulated internal temperatures is up to 5 K, while between *SA* and *nSA* it corresponds to the measurements. The next two days are characterized by the maximum level of solar radiation exposure obtained. At the beginning, good agreement was achieved with *SA;* however, *nSA* does not correspond well and additionally both models have their maximum peak at the same level. The second simulated clear sky day does not agree with the measured progressions. Instead, it responds in the following manner: the lower the outdoor temperature was, the higher the indoor air temperatures simulated.

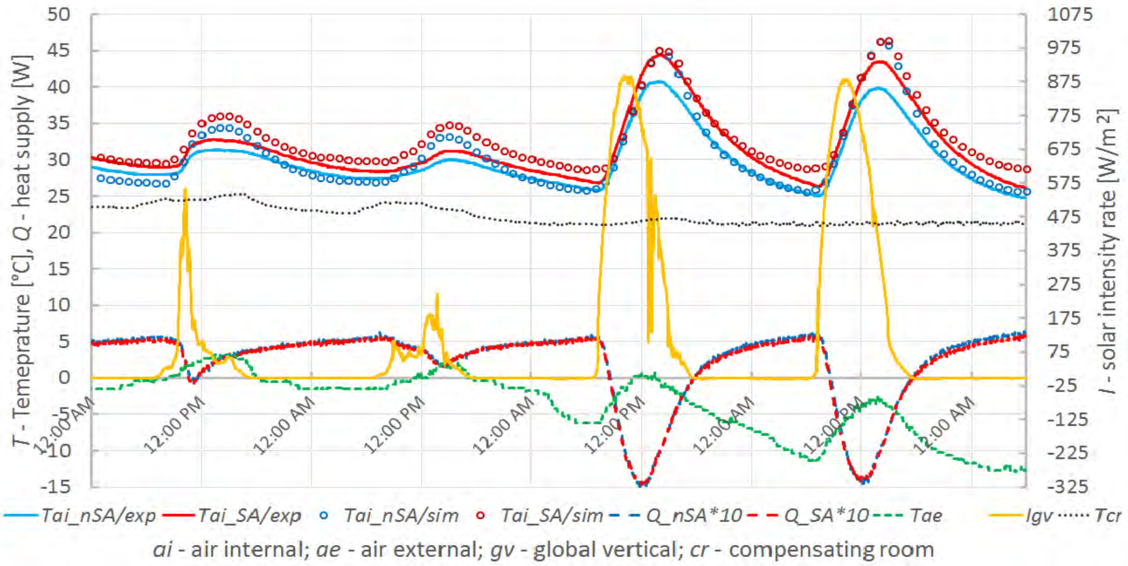


Figure 2. Experimental and simulation results for the presented period

## DISCUSSIONS

The integration of solar based absorbers (selective/non-selective) behind a complex fenestration system enhanced with TIM is a challenge for building simulation modelling throughout the climatic year, mainly due to the difficulty of making reasonable performance predictions. The experimental part of the research demonstrates that the presence of low-emissivity surfaces within a façade air cavity based on Trombe wall principles has a significant effect on the internal space temperatures recorded during the presented experimental measurements. A comparison between experimental and simulation results indicated agreement occurred only during nighttime periods with the *nSA* model. At time periods with high solar radiation the temperature gap between the *nSA* and *SA* models is nearly zero. This leads to the fundamental obstructions of the BES calculation concerning the radiation exchange between surfaces with low-emissivity (view factors). The simulation also showed that the operating temperature of the façade cavity zone has nearly equal values to the air and radiant temperature, which indicates that low emissivity surfaces have a higher effect. In the case where a zone is defined as a cavity, it is also important to adjust the zone's inside convection algorithm in order to properly describe surface heat transfer phenomena. The utilised BES tool provides a "Cavity algorithm" that correctly calculates the convection coefficients for a narrow sealed vertical cavity based on the ISO 15099 standard as well as the "Full interior and exterior solar distribution algorithm" for the transmission of solar radiation through glazing. As the thermo-optical properties of the TIM layer inside the fenestration system were assumed to be static values, they might be used for the proper performance prediction of this façade system. Nevertheless, the above-mentioned complexity of the simulation of the dynamic value of thermal conductivity of a TIM glazing unit with regard to the temperature difference of each surface might be improved in a better manner through programming in the Energy Management System under EnergyPlus.

## CONCLUSIONS

Based on experimental data concerning a transparent insulation façade (TIF) concept with a TIM glazing unit and two different solar absorber types (selective and non-selective), a performance prediction model was created in BES tool. The process of simulation modelling according to experimental measurements is quite a tricky affair but could provide the first insight into the thermal/optical process of a specific solar based building façade. It was demonstrated by this study that thermo-optical properties of the TIM layer inside the fenestration system as static values might be used for the performance prediction of this façade system. Though, the validation of the simulation model determined the causes of deviations between real and simulated outputs of the amount of overall heat transfer through the investigated TIF components. As result of that, current BES programs appear to have problems specifically with surface radiant heat exchange mainly during high levels of impinging solar radiation. BES coupling with computational fluid dynamics modelling could be further step of clarifying of this complex issue.

## ACKNOWLEDGEMENT

This research is under the project GJ 16-02430Y "Contemporary concepts of climatically active solar façades integrating advanced material solutions" of Czech Science Found. and by the Slovak Research and Development Agency under the contract No. APVV-16-0126.

## REFERENCES

Avedissian T. and Naylor D. 2008. Free convective heat transfer in an enclosure with an internal louvered blind International, *J. Heat Mass Transf.* 51, 283–293.

Brandl D., Mach T., Kaltenecker P., Sterrer R., Neururer C., Treberspurg M., Hochenauer C. 2015. CFD assessment of a solar honeycomb (SHC) façade element with integrated PV cells. *Sol. Energy* 118, 155–174.

Brandl D., Mach T. and Hochenauer C. 2016. Analysis of the transient thermal behaviour of a solar honeycomb element with and without integrated PV cells. *Sol. Energy* 123, 1–16.

Čekon M. 2013. Thermodynamic properties of reflective coatings. *Advanced Materials Research*, 649, 179-182.

Čekon M., Slávik R. 2017. A Non-Ventilated Solar Façade Concept Based on Selective and Transparent Insulation Material Integration: An Experimental Study. *Energies*, 10, 815.

DesignBuilder. 2016. *DesignBuilder EnergyPlus Simulation Documentation for DesignBuilder v5*. DesignBuilder Software Ltd.

EnergyPlus. 2017. *EnergyPlus$^{TM}$ Version 8.8.0 Documentation*, Engineering Reference, U.S. Department of Energy.

Gan G. 2001. Thermal transmittance of multiple glazing: computational fluid dynamics prediction, *Appl. Therm. Eng*. 21, 1583–1592.

Kapilux. 2017. *Capillary system,* Okalux, http://www.okaluxna.com/kapilux/#kapilux-twd

Sun Y., Wu Y., Wilson R., Lu S. 2016. Experimental measurement and numerical simulation of the thermal performance of a double glazing system with an interstitial Venetian blind, *Build. Environment* 103, 111–122.

Sun Y. 2017. Glazing system with transparent insulation material for building energy saving and daylight comfort. *PhD thesis*, Fac. of Engineering, University of Nottingham, p. 201.

Sun Y., Liang R., Wu Y., Wilson R., Rutheford P. 2017. Development of a comprehensive method to analyse glazing systems with Parallel Slat Transparent Insulation material (PS-TIM), *Appl.Energy* 205, 951–963.

Sun Y. Liang R., Wu Y., Wilson R., Rutheford P. 2018. Glazing systems with Parallel Slats Transparent Insulation Material (PS-TIM): Evaluation of building energy and daylight performance, *Energy Build*., 159, 213–227.