Energy and Buildings 145 (2017) 188–199

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Window frame thermal transmittance improvements without frame geometry variations: An experimentally validated CFD analysis

Agnieszka A. Lechowska[a,*], Jacek A. Schnotale[a], Giorgio Baldinelli[b]

[a] Department of Environmental Engineering – Cracow University of Technology, ul. Warszawska 24, 31-155 Cracow, Poland
[b] Department of Engineering—University of Perugia, Via Duranti, 67 – 06125 Perugia, Italy

ARTICLE INFO

Article history:
Received 27 December 2016
Received in revised form 14 March 2017
Accepted 1 April 2017
Available online 11 April 2017

Keywords:
Window frames
CFD modeling
Calorimetric chamber
Building energy use simulations

ABSTRACT

In this paper, two ways to improve the PVC window frame thermal transmittance without frame geometrical dimension and material variations are presented. The first variation considered relies on inserting polyurethane foam into the air gaps. The second variation counts on low-emissivity coating on PVC surfaces in the frame air gaps. To investigate these modifications two-dimensional CFD simulations of PVC window frames were used which then were validated by measurements performed in a calorimetric chamber. A hot box methodology was implemented for the measurements. The experimental work was focused on verification of simulation results of modeled frame thermal transmittances. A calorimetric chamber was used, consisting of a metering box, simulating indoor conditions (warm side), and a climate box, simulating outdoor conditions (cold side). It was concluded that the air gap filling with polyurethane foam in window frames can reduce window frame thermal transmittance by about 27% while covering PVC surfaces with low-emissivity coating can reduce window frame thermal transmittance by about 28%. These variations do not change the frame geometry or its total thickness.

To answer the question what would be the expected impact of proposed frame variations on annual energy demand of different types of buildings additional simulations of two buildings with a DesignBuilder with EnergyPlus engine software were performed for a set of different climatic conditions.

1. Introduction

During recent decades, there have been significant developments in the construction of window systems including: glazing, spacer bars, frames and shading systems. Spacer barsthermal resistance was analyzed in works [1–9]. Innovative glazing units and their thermal performance was the subject of analysis of much research, for example in [10] and [11]. The interest of the authors of this paper is focused on window frames. Frame construction materials can be roughly divided into three groups: wood, metals (aluminum) and plastic (PVC). Significant effort is still necessary to reduce thermal transmittance of window frames. The introduction of thermal breaks, gaskets or the air gaps insertion, as well as small changes in frame geometry may contribute to reducing window frames thermal transmittance [7,12–20].

The origin of the research comes from specific enquiries derived by industries. Two European laboratories (Cracow University of Technology, Poland and the University of Perugia, Italy) were independently asked by major European manufactures to scientifically assess the opportunity to improve window frames thermal transmittance to be achieved without frame geometry alteration. The laboratory in Cracow was asked to check the influence of insulation material insertion into the frame air gaps. It was clear that the thermal transmittance would be diminished, but it was not equally evident the quantitative amount of the performance improvement. On its turn, the laboratory in Perugia was asked to check the influence of low emissivity coatings on frame surfaces in contact with air gaps. Again it was clear that low emissivity coating reduced the radiation heat exchange and thus reduced frame thermal transmittance, but it was not trivial to predict the reduced value and what method could bring better results. That is how the two universities found a common ground of research and set the goal of joined efforts.

This work presents two ways of increasing the PVC window frames thermal performance; the analysis is focused on PVC frames, as they represent the major part of the market, being relatively cheap, durable and high performing from the thermo-acoustic point of view.

The first solution is easy and cost effective and consists of placing polyurethane foam into air gaps in PVC frames. The second one

* Corresponding author.
E-mail address: alechowska@quino.wis.pk.edu.pl (A.A. Lechowska).

http://dx.doi.org/10.1016/j.enbuild.2017.04.002
0378-7788/

Nomenclature

A	Area, m^2
b_f	Width of the frame section, m
b_p	Visible width of the insulation panel, m
c_p	Specific heat capacity, J/(kgK)
d	Depth of the surround panel reveal, m
d_{fi}	Insulation panel filling thickness, m
d_{sp}	Specimen thickness, m
F	Fraction
H	Height, m
L	Length, m
$L_f^{\ 2D}$	Thermal conductance of the entire model, W/(mK)
$\dot{q}$	Heat flux density, W/m^2
R	Thermal resistance, m^{2}K/W
U	Thermal transmittance, U-value, W/(m^{2}K)
α	Radiant factor
Δx	Measurement uncertainty
Φ	Heat flow rate, W
λ	Material conductivity, W/(mK)
Λ	Material thermal conductance, W/(m^{2}K)
v	Air velocity, m/s
μ	Dynamic viscosity, kg/(ms)
θ	temperature, °C
ρ	Material density, kg/m^3
Ψ	Linear thermal transmittance, W/(mK)

Subscripts

b	Baffle
c	Convective
ca	Calibration panel
e	External side, cold side
ed	Edge zone between the calibration panel/specimen and surround panel
i	Internal side, warm side
in	Input in hot box
f	Frame
fi	Insulation panel filling
g	Glazing
m	Measured
M	Model
n	Environmental
p	Surround panel reveal
r	Radiative, mean radiant
s	Surface
sp	Specimen
sp-b	Direction from specimen to baffle
sp-p	Direction from specimen to surround panel reveal
sur	Surround panel
t	Total

is implemented by the insertion of a low emissivity coating inside PVC frame cavities. CFD simulations of the heat transfer through three PVC frames were performed according to standard ISO 10077-2 [21]. The Ansys Fluent CFD program using a finite volume method has been applied. A two-dimensional simulation was performed for a standard PVC frame hosting a triple pane glazing, and then again for two configurations of the frame with the same geometry but with selected air spaces filled respectively with two and four insertions of polyurethane foam. Data gathered from the simulations have been compared to calorimetric chamber measurement results obtained by the hot box method. Due to the satisfactory agreement between measurements and numerical simulations, further simulations of windows with similar PVC frames have been assumed

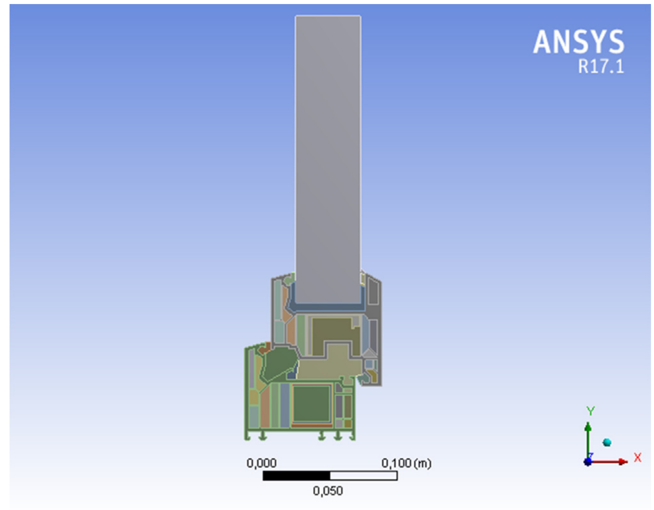

Fig. 1. Model 1 – standard polyurethane frame.

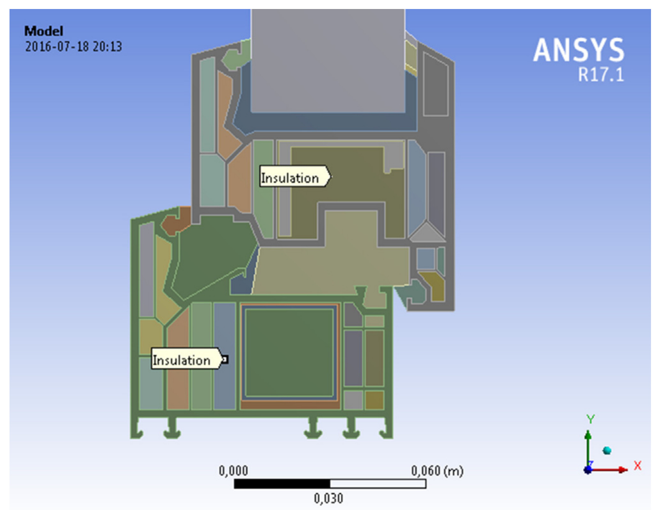

Fig. 2. Model 2 – two polyurethane insertions, lower model part.

as positively validated. In one set of the simulations, the frame cavities, typically filled with air, were packed with insulation; in the second set of calculations, the internal surfaces of the PVC frame were covered with a low-emissivity coating. The impact of these frame improvements on the energy performance at the building scale was executed through the simulations implemented by DesignBuilder, with the EnergyPlus engine software package.

2. Preliminary CFD modeling of the window frames

2.1. Geometries and materials

Three configurations of the PVC frame supporting a triple glazing were analyzed: Model 1 is a standard PVC frame (Fig. 1), Model 2 is the same frame with two air spaces filled with polyurethane foam (Fig. 2) and Model 3 has four spaces filled with polyurethane (Fig. 3).

For the sole frame thermal transmittance evaluation, the triple glazing with a 49 mm wide spacer [22] was substituted by a 190 mm long insulation panel, as indicated in the standard [20]. The frame has a maximum thickness of 100 mm and a length of 125 mm. All surface emissivities were assumed to be equal to 0.90 [21].

Thermal conductivities of PVC, steel, silicone, polyurethane and insulation panel were considered respectively equal to