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Influence of windows geometrical parameters on calculations of the heat conduction coefficient

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Abstract

The relationship between the geometrical and thermodynamic variables of windows, of several types, sizes and materials, is presented in this paper. The heat conduction coefficients were calculated, for all the presented windows' types. Results that are presented provide for the possibility to select the optimal construction solution of the window, as well as for the material of the frame and type of the filling, with respect to the best heat conduction coefficient. That, in turn, ensures the optimal energy efficiency of the window structure.

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*Keywords:*heat conduction coefficient; window; frame; filling; energy efficiency

1. Introduction

Reducing the energy consumption and carbon-dioxide emission is one of the most important tasks in the areas of design and civil engineering. The key point for reducing the carbon-dioxide emission is increasing of the thermal characteristics of the buildings' envelope. That can be achieved in several ways, for instance by adding insulations to existing or new buildings. Considering the fact that about 30 to 50% of the heat conduction is lost through the windows, improvement of the thermal characteristics of windows can significantly contribute to savings of energy.

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Nomenclature

A_{cg}	area of the glass center, [mm^2]
A_{eg}	area of the glass edges, [mm^2]
A_f	area of the frame (opaque), [mm^2]
A_g	area of the glass (transparent), [mm^2]
A_t	total area of the window, [mm^2]
A_{pf}	area of the opening for the window reduced for the mounting clearance, [mm^2]
E_t	total incoming radiation, [W/m^2]
F_f	solar heat loss coefficient of the frame,[-]
F_g	solar heat loss coefficient of the glass, [-]
T_{in}	interior air temperature, [K]
T_{out}	outside air temperature, [K]
U_{cg}	heat conductivity coefficient of the glass center, [W/m^2K]
U_{eg}	heat conductivity coefficient of the glass edges, [W/m^2K]
U_f	heat conductivity coefficients, [W/m^2K]
U_w	heat conductivity coefficientsof the window, [W/m^2K]
b	the window frame width [mm]
d	the window frame thickness [mm]

The great attention is thus paid to reducing the heat conductivity or the U-value of windows, Jelle et al. [1].

The windows represent a component which affects the most the energy needs of the building. They consist of the opaque and transparent elements, which all together should provide for the high thermal characteristics, in order to reduce the heat losses. Thus, the design of each of the window's components (frame, glass, blinds and mosquito blinds) becomes important in realizing the energy savings. For example, aluminum has a very low heat resistance, but the thermal characteristics of the frame can be improved by applying the heat breaks and introduction of air fillings. They are characterized by the complex mechanisms of the heat exchange that were investigated by various procedures. Gustavsen et al. [2] have analyzed the profiles of the air fillings in the rectangular geometry.

There are several papers where the researchers were dealing with influence of windows on thermal and energy characteristics of buildings. Tsikaloudaki et al. [3] have analyzed how the windows influence energy characteristics of a building in conditions of the warm Mediterranean climate. In work by Thalfeldt et al. [4] an optimal model of a window for the case of an object in Estonia, in cold climate conditions and several months of need for heating, is presented. Cardinale et al. [5] have performed numerical and experimental analysis of six different types of the window frames and four different models of blinds in order to establish the optimalsolution.In paper by Asdrubali et al. [6], the influence of the openings geometry in frames on thermal performances of aluminum window frames was analyzed. Van Den Bergh et al. [7] have conducted a survey of commercial spacers and seals for windows and analyzed their influence on windows thermal characteristics.

Considering that improvement of the windows thermal characteristics is potentially a big source of energy savings, it is necessary to perform a calculation, which would include as large as possible data base on materials, which are used for manufacturing the windows frames and glasses, data on inert gases, which are used for filling the chambers in the windows profiles, data on standard windows dimensions, etc. From such a data base one would be able to choosethose materials that would satisfy required construction and energy requirements for the particular application.

The objective of this work was to create a way for calculation of the heat conduction coefficient, based on the given characteristics of the window frame, which would provide for the best insight in the construction solution of a window, frame material and type of the gas, which should be used to obtain the most energy efficient windows.The intention was to show the mutual dependence of geometrical parameters and thermodynamic variables for several types of windows, made of different materials; namely to model the construction of the window, based on the required material selection, type of window and given heat conduction coefficient. The calculations are done by the programming package Autodesk Inventor Professional 2010, which draws necessary data from the Microsoft Office Excel package.

2. Problem formulation

For calculation of the heat conduction coefficient one needs standard models of widows of various dimensions, which are presented in Tab. 1. Wood, aluminum and plastics (PVC) were considered as materials for the windows frame. The single and double glazed windows were considered, with chambers between the glasses filled with either air or argon.

Table 1. Types of windows

Glass	Glazing	Number of windowpanes	
Glass	Single pane	Single wing	Double wing
	Double pane		
Low E glass	Single pane		
	Double pane		

The windows frames and glasses dimensions were adopted based on technical documentation given in catalogue of the windows and doors manufacturer, Roloplast [8].The various types of windows with active surfaces that are used in calculations for the heat conduction coefficient U_w are presented in Tab. 2.

Table 2.Geometrical characteristics of windows used in the heat conduction coefficient calculation

Window [mm]	Frame [mm]				Glass [mm]			Filling [mm]			Active area [mm^2]		
	a	h	d	b	a	h	d	a	h	d	A_f	A_g	A_t
600x600	600	600	54	66	596	596	4	596	596	22	464	3552.16	3552.16
1200x900	1200	900	54	66	1196	896	4	1196	896	22	824	10716.2	10716.2
1200x1200	1200	1200	54	66	1196	1196	4	1196	1196	22	944	14304.2	14304.2

The heat is through the windows transferred in three ways: by conduction and convection due to temperature difference between the outside and inside air, by irradiation from the long wave radiation (above 2500 nm) between the window and the surroundings and between the glass layers, as well as by the shortwave radiation (below 2500 nm) coming from the Sun, either directly or reflected from the ground and neighboring objects.

Assuming that the temperatures of the irradiating surfaces (sky, grounds and neighboring objects) are equal to the temperature of the outside air, the basic equation for the heat exchanged through the window is, Gustavsen et al. [9]:

$$q = U_w \cdot A_t \cdot (T_{out} - T_{in}) + E_t \cdot (A_g \cdot F_g - A_f \cdot F_f) \ , \qquad (1)$$

where U_w is the heat conduction coefficient, T_{out} is the outside air temperature, T_{in} is the inside air temperature, A_t is the total window area, A_g is the area of the glass (transparent), A_f is the area of the frame (opaque), F_g is coefficient of the glass heat gain, F_f is the coefficient of the frame heat gain and E_t is the total incoming radiation.

Variables U_w, F_g and F_f are considered as constant, though they are actually functions of the environmental variables; of those the most important are temperature and the wind velocity. The temperature variation due to weather conditions is small on the absolute temperature scale and it controls the magnitude of the heat transferred by radiation. Coefficients of the solar heat gains depend on the incoming angle of the Sunlight.

If the Sunlight, infiltration of air and moisture condensation were not present, the first term in equation (1) would represent the magnitude of the heat transfer through the window system. The majority of those systems consist of the transparent, multi-fold glass units and the opaque wings and frame, together constituting the window frame.

The heat conduction coefficients for windows depend on window frame's material, Asdrubali et al. [6] (wood, aluminum, PVC), construction of the frame (breaks by thermal bridges or not), type of glazing, Van Den Bergh [7] (single, double or triple glazing, low-emission glass, space between the glasses, the type of filling ...).

The window heat conduction coefficient can be calculated if one knows the heat conduction coefficients of the individual window elementsas, [9]:

$$U_w = \frac{A_{cg} \cdot U_{cg} + A_{eg} \cdot U_{eg} + A_f \cdot U_f}{A_{pf}} \ , \quad (2)$$

whereU_{cg}, U_{eg} and U_f are coefficients of the heat conduction of the glass center, glass edge and frame, respectively, A_{cg}, A_{eg} and A_f are the areas of the glass center, glass edge and frame, respectively, while A_{pf} is the area of the window opening reduced for the mounting clearance.

Values of the heat conduction coefficient, U_{cg} depend on the structural characteristics of the glazing, like the number of glass panes, dimensions of the space filled with gas, orientation with respect to vertical, radiation at each of the surfaces and on the type of the gas which is used for filling the space between the glass panes. The thermal properties of the construction elements are presented in Tab. 3, Lyons et al. [10].

The heat conduction of the glass edge is two-dimensional and Gustavsen et al. [11] have developed a correlation for calculating the heat conduction coefficient through the glass edges as a function of the spacer type and heat conduction coefficient of the glass center.

The window frame consists of wings, column, (under-the-)window boards, connector and spacers of the glass panes, [5]. The coefficient of the heat conduction through the frame is influenced by the type of the window, combinations of materials used for manufacturing the frames, windows' dimensions, glass widthand type of spacers, [9]. According to the type, one can differentiate the following: windows with wings, sliding or fixed windows, doors leading to a garden, roof windows, etc. The usually applied materials for the frame elements are wood, aluminum and PVC, [9]. Manufacturers sometimes combine those materials to extend the window's working life and to improve the aesthetics.

3. Resultsand discussion

The calculated values of the window's heat conduction coefficient U_w,in terms of different parameters, discussed above, are given in Tab. 3.

Values of the heat flux for windows made of various materials and with different dimensions and fillings are shown in Figs. 1 and 2, while values of the heat conduction coefficient through the windows made of various materials and with different dimensions and fillings are shown in Figs. 3 and 4.

Table 3: Calculated values of the window's heat conduction coefficient *U*

Window's heat conduction coefficient U_w[W/m^{2}K]					
Type of the window	Window	Frame material			Filling
	Glass	Wood (oak)	PVC	Aluminum	Air
Fixed single glazed	1.168	5.852	1.663	1.664	1.168
					Argon
	0.799	5.483	1.294	1.295	0.799
Fixed double glazed	Window	Frame material			Filling
	Glass	Wood (oak)	PVC	Glass	Wood
	0.537	4.406	0.796	0.796	0.537
					Argon
	0.367	4.236	0.625	0.626	0.367

From the histograms in Figs. 1 and 2 one can notice that the largest heat flux is for the wooden, two-winged, single pane windows and the smallest for the fixed aluminum double-pane windows. Thus, the conclusion is that the largest amount of heat is conducted through the wood as the frame material, i.e. the heat losses are the highest. It can also be seen that PVC and aluminum, as the frame materials, provide for the best heat insulation, i.e. the heat losses are the least for those materials. The fixed windows with double glazing especially stand out, since the heat flux values are particularly small, the insulation is the best and the heat losses are the least. They would contribute to significant energy savings and thus to increase of the total energy efficiency coefficient for the whole building.

From histograms in Figs. 3 and 4 can be seen that the value of the heat conduction coefficient depends on the window's material, as well as on the type of the filling gas. It can be concluded that for the fixed, double glazed windows, made of PVC, with argon filing, one obtains the smallest value of the heat conduction coefficient (U_w = 0.625 W/m^{2}K), so they provide for the best insulation and the least heat losses.

4. Conclusions

The windows have a decisive role in construction of residential and commercial buildings and they should be so designed to realize the highest energy savings. Due to that, it is necessary to create a calculation, which would include as large as possible data base on materials used for manufacturing the windows frames and windows glasses, on gasses used to fill the chambers between the glass panes, on standard windows dimensions, based on which the materials should be selected that would satisfy both structural and energy requirements.

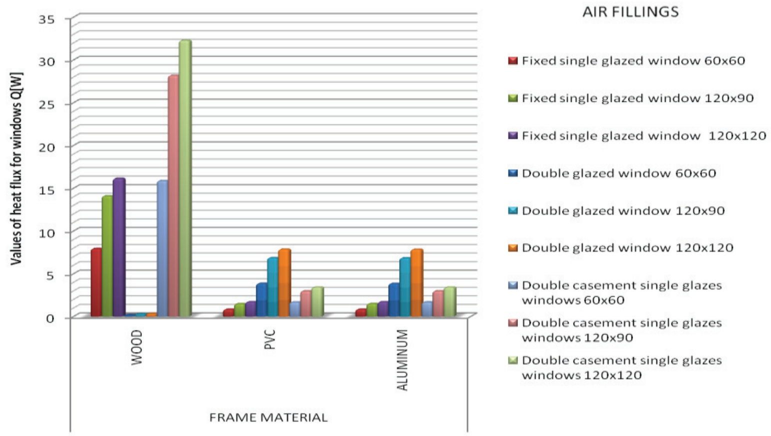

Fig. 1. Heat flux through the window in terms of various materials, for different dimensions and with air filling

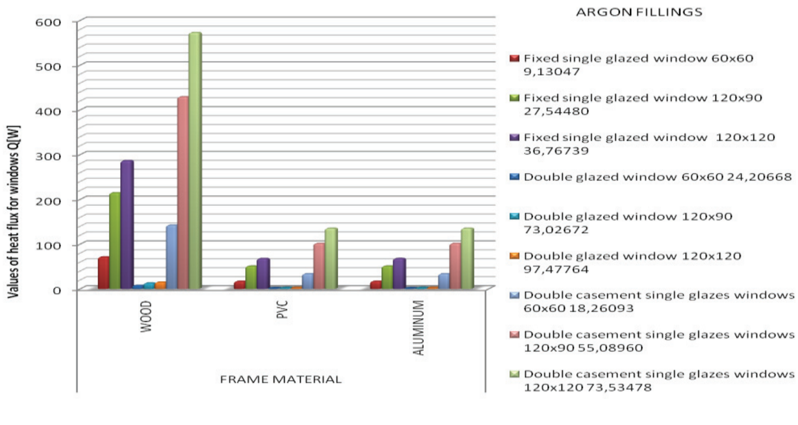

Fig. 2. Heat flux through the window in terms of various materials, for different dimensions and with argon filling

Based on the given geometrical characteristics of the frame and the windows glasses, the calculations was performed of the heat conduction coefficient. Results have shown that the lowest value of the heat conduction coefficient is obtained when the plastic is used for the windows frame whose chambers are filled with argon, which possesses the significantly higher resistance to heat conduction than air. The heat conduction coefficient has much smaller values for the double glazed windows with respect to the single glazed ones.

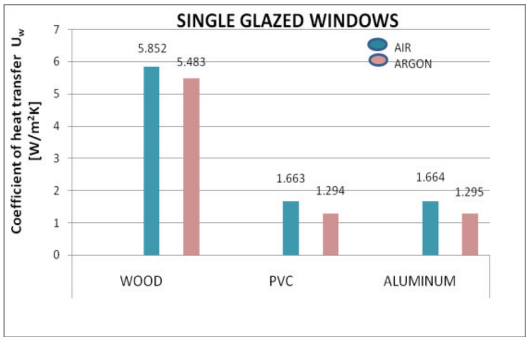

Fig. 3. The windows heat conduction coefficient in terms of various materials with two different fillings for the single glazed windows

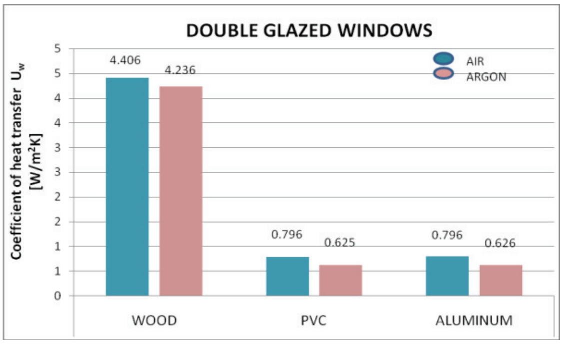

Fig. 4. The windows heat conduction coefficient in terms of various materials with two different fillings for the double glazed windows

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