Thermal Energy Efficiency Analysis for Residential Buildings

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The concern of energy conservation, the reduction of green house gases and sustainability was continuously growing in last years. The concept of green building has been introduced, and refers the practice of increasing the efficiency with which buildings and their sites use and harvest energy, water, and materials, and reducing building impacts on human health and on environment, through better design, construction, operation, maintenance, and removal. Starting from the national and international trends in development of environmental performance of new and existing home buildings, an interactive system for assisting the calculation of home energy efficiency has been created and validated, and its performances are presented.

Mathematical Model

According to [9], the total heat flux losses through a building (Φ) is given by the formula: $\Phi = \Phi_1 + \Phi_2 + \Phi_3$ (1)

where Φ_1 = the heat flux losses through transmission, Φ_2 = the heat flux losses through ventilation, and Φ_3 = the heat flux needed for preparing the domestic hot water. The heat flux lost through transmission is distributed between the walls, the floor, the ceiling and the windows. According to these, the formula of the Φ_1 is: $\Phi_1 = \Phi_{1.1} + \Phi_{1.2} + \Phi_{1.3} + \Phi_{1.4} + \Phi_{1.5}$ (2)

where $\Phi_{k.j}$ = heat flux losses through: walls ($\Phi_{1.1}$), ceiling ($\Phi_{1.2}$), windows ($\Phi_{1.3}$), main floor ($\Phi_{1.4}$), and basement ($\Phi_{1.5}$). The heat flux losses through ventilation depend directly by the global insulation of the building in conformity with formula: $\Phi_2 = \varepsilon\cdot\Phi_1$(3)

where ε = a coefficient correlated with the global insulation of the building. This coefficient is assumed: 0.7 - buildings without insulation, 0.8 - with minimal insulation, 0.9 - good insulation, and 1 - very good insulation (buildings with low energy consumption, passive buildings regarding the energy consumption). The heat flux needed for preparing the domestic hot water depend on the following parameters: number of persons (n), the working time per day of water heating system (τ - seconds), the volume of hot water needed per person per day, water density, the specific heat of water, the imposed temperature of hot water (t_{Wi}), and the assumed temperature of the external cold water (t_{We}). The heat flux needed for preparing the domestic hot water is given by the formula: $\Phi_3 = n\cdot\rho\cdot V\cdot c_p\cdot(t_{Wi} - t_{We})/\tau$ (4)

The expression of heat fluxes lost through walls ($\Phi_{1.1}$), ceiling ($\Phi_{1.2}$), windows ($\Phi_{1.3}$), main floor ($\Phi_{1.4}$), and basement ($\Phi_{1.5}$) must be reported to the total surface of the house ($S_{1.i}$ taking into consideration only those elements that are connected with the outside), according to the global heat transfer coefficient ($k_{1.i}$), temperature from the outside of the building (t_{out}), inside of the building (t_{int}), soil (t_{sol}) and basement (t_{sub}). The generic formula of the heat fluxes lost through transmission become [$t_1 = t_{int}$ (i = 1..5), $t_0 = t_{out}$ (i = 1..3), $t_0 = t_{sol}$ (i = 4), $t_0 = t_{sub}$ (i = 5)]: $\Phi_{1.i} = S_{1.i}\cdot k_i\cdot(t_1-t_0)$ (5)

The heat transfer coefficient is a function of the convective heat transfer from inside ($\alpha_{1.i.1}$) and from the outside ($\alpha_{1.i.2}$), heating conductivity ($\lambda_{1.i.1}$ - for the main structure, and $\lambda_{1.i.2}$ - for the insulation structure). The formula is: $k_{1.i}\text{-}1 = \alpha_{1.i.1}\text{-}1 + \alpha_{1.i.2}\text{-}1 + \delta_{1.i.1}/\lambda_{1.i.1} + \delta_{1.i.2}/\lambda_{1.i.2}$ (6)

The assumed value of the inside convective heating transfer was considered equal with 8 W/m^2K (corresponding to normal natural convection conditions); for the outside convective heat transfer coefficient was assumed a value of 25 W/m^2K (corresponding to the most unfavourable conditions). In the case of the main floor, the heat transfer coefficient has a specific value for the outside and other value for the inside. It was considered that the outside convective heat transfer coefficient for the main floor ($\alpha_{1.i.2}$-1) is infinite for a building without basement.

Construction Parameters

The system validation was performed through analysis of the energy efficiency of a new building. Starting from the supposition that a field of 2300m2 is available in Alba Iulia County, Romania, a residential building has been designed and the characteristics of the energy efficiency were analyzed. The considered environmental conditions were as follows: *The wind speed*: up to 40 km/h; *The relative humidity*: could vary from 60% to 90%; *The distribution of raining water*: could not be considering homogenous, some variations existing according with the season and the calendaristic month. The average in the last year was considered (equal with 714 mm). The characteristics for the experimental designed residential building are below (Dimensions of the Home and Rooms Surfaces).

Room	Kitchen	Living room	Bathroom1	Bathroom2
Surface (m^2)	27.5	36	9	7
Bedroom1	Bedroom2	Bedroom3	Vestibule	Lobby
21.25	10.5	10.5	10	8.25

Results

The application designed for assisting the users in analysis of the heat flux requirement for a residential building has developed and is available online. Programs have been designed and implemented. The form.php program allows the user to introduce the characteristics of the environment and of the building according to personal desires and/or own building. Based on the mathematical model presented in Material and Method section, a total number of twenty-five functions were implemented and stored in func.php file. The func.php computes the heat losses through windows, the heat losses through walls, and the global heat losses by transmission. The parameters displayed by the program are graphically represented.

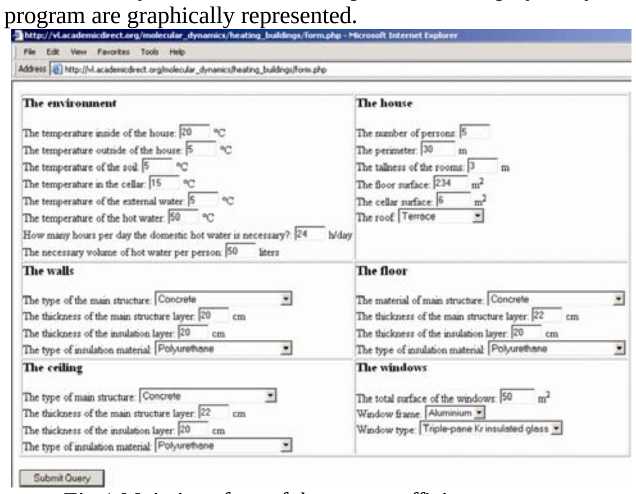
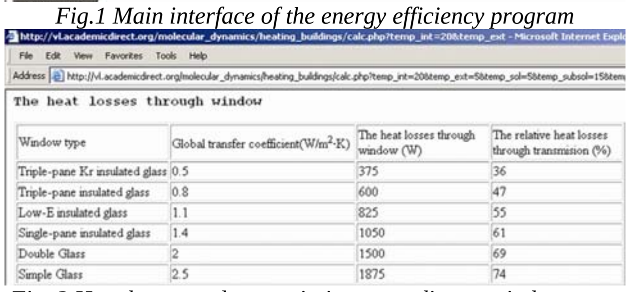


Fig.1 Main interface of the energy efficiency program


The heat losses through window

Window type	Global transfer coefficient(W/m2·K)	The heat losses through window (W)	The relative heat losses through transmission (%)
Triple-pane Kr insulated glass	0.5	375	36
Triple-pane insulated glass	0.8	600	47
Low-E insulated glass	1.1	825	55
Single-pane insulated glass	1.4	1050	61
Double Glass	2	1500	69
Simple Glass	2.5	1875	74

Fig. 2 Heat losses and transmission according to windows type

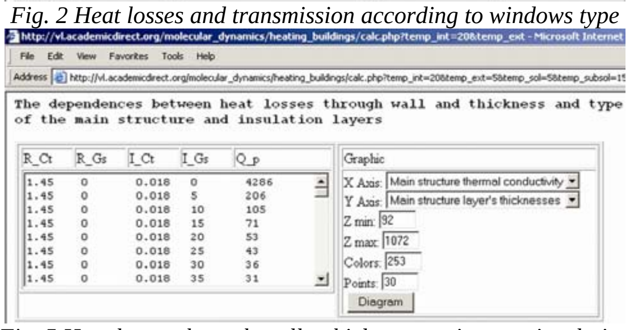


Fig. 5 Heat losses through walls: thickness, resistance, insulation

Discussions

The evaluation of the developed application can be done through analyzing its advantages (noted with + sign) and disadvantages (noted with - sign) as followed:

+ Assisting calculation of coefficients and heat losses: according to the input data, the application compute and display in a real time a number of twenty-four coefficients
+ Accessibility: free access and availability at any hour
+ Multi-user: can be used simultaneously by more than one user

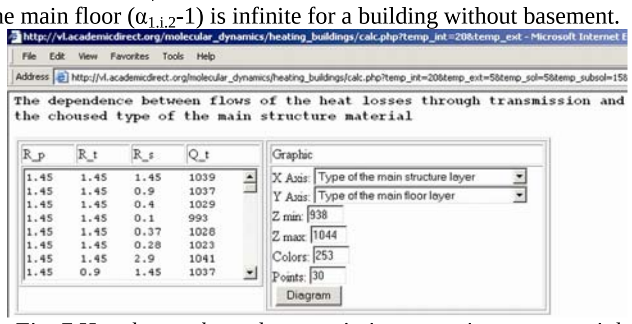


Fig. 7 Heat losses through transmission vs. resistance material

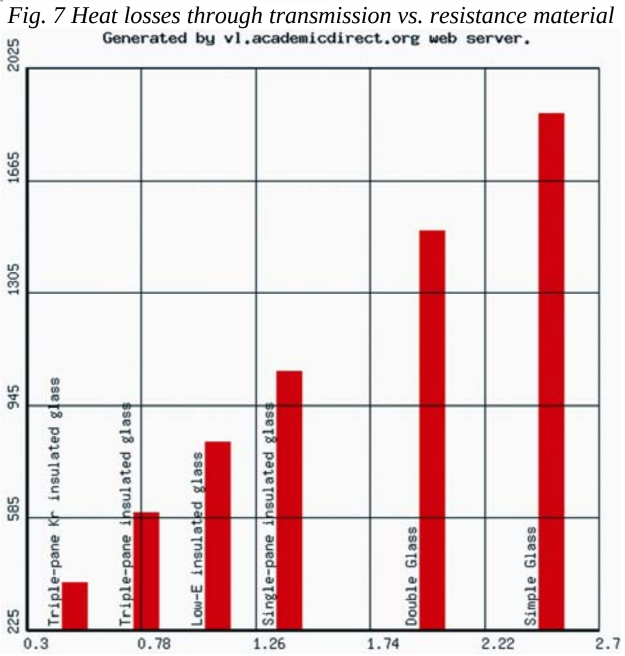


Fig. 3 Heat losses through windows according to their type

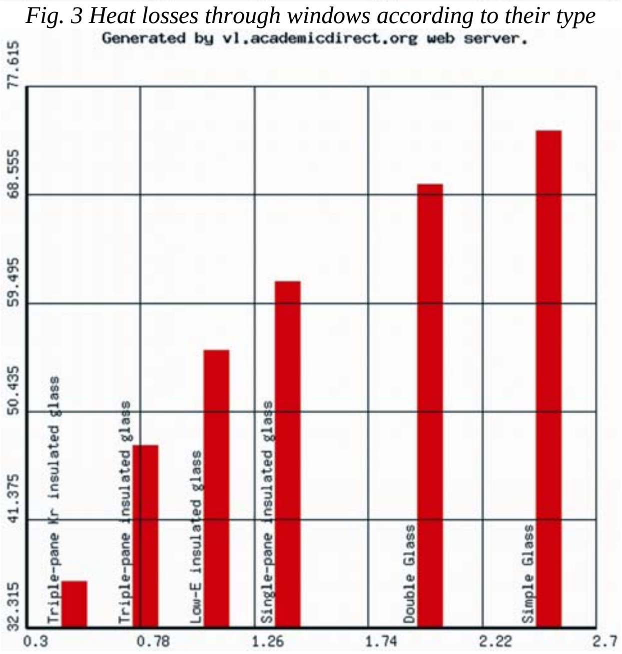


Fig. 4 Heat losses through transmission vs. windows type

+ Interaction with the users: the users can choose his/her own residential building parameters
+ Interactivity: the user is free to choose the graphical representation of the interest parameters
+ Multi-tasking: the application can be use simultaneously with other applications
+ Updating: the updating of the application is an effortless process, and can be done in real time and as many time as it is consider being opportune
- The use of application requires minimum computers skills
- Financial estimations were not included into application
- There are not included into application any evaluation of the construction (such as strength structure calculations, etc)
- The application can be use just by the user that had a computer connected to the Internet.

Conclusion

The presented software application can be considered useful in the computer assisted analysis of buildings, it calculates the components of the heat flux demands and it allows important observations about the parameters that influence the heat losses.

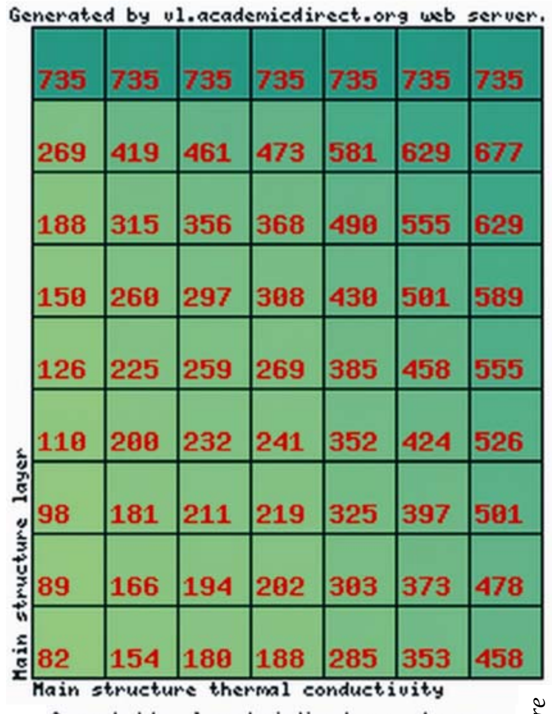


Fig6 Heat losses through walls vs. structure layer & thermal conductivity

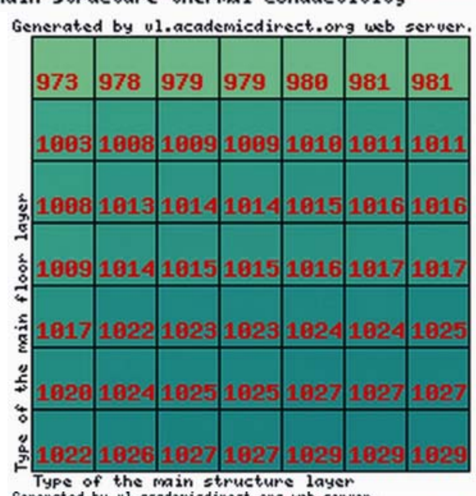


Fig8 Heat losses through transmission vs main floor layer and structure

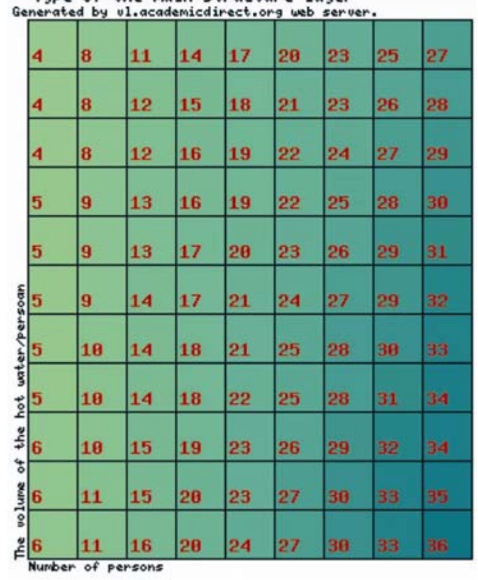


Fig9 Heat losses necessary to warm up the water vs persons' number and hot water volume

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