IMPROVEMENT OF WINTER HEAT BALANCE OF WORKSHOPS

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Abstract. The aim of this paper is to describe the principles and methods of heat balance calculation in winter, which can be useful for assessment and improvement of heat transmission in the building. There are set up formulas and calculated the required heating capacity in two workshops to keep the standard internal temperature (from 16 °C to 20 °C) for students' practice during a winter day with external temperature about -12 °C. In the frame of this research, the structure of two workshops was directly measured and surveyed, and along with it, there were also the construction documents consulted. The formulas for heat balance calculation were set up from theories of energy balance and real construction of the building. The reduction of roof windows' area or improvement of the shape of the windows would influence the heat losses of the building. There can be also the heat exchange and efficiency of the heating equipment improved. The obtained results are the basis for proposal of a suitable building design, choosing and using of heating systems to achieve reasonable and economical conditions. The difference between workshops shows the influence of the structure of the workshop on the heat balance. As a general conclusion, it must be said that the roof windows' areas have a big influence on the heat transmission and they are the main factor responsible for heat losses and heat gains in the buildings. The formula could be useful for the designer of the building, which saves time, cost, energy and resources to keep indoor thermal comfort for the workers' performance.

Keywords: calculation, heat transfer, temperature, workshop.

Introduction

By understanding the building's thermal loads and its intended using, we can more effectively use energy from the sun to save energy from the passive heat system [1]. We can even generate energy on-site using resources that would otherwise be thermal loads that would demand energy. High performance buildings seek to reduce these loads as much as possible [2; 3].

The thermal load includes external thermal loads and internal thermal loads. External thermal loads come from heat transfer through the building envelope from the sun, weather, and the outside environment [4; 5]. The building envelope includes roofs, floors, walls, windows, and any other surfaces that separate the inside and outside of the building. The building envelopes interact with external thermal load to product external gains or losses for the building.

The internal thermal loads come from heat generated by people, lighting, and equipment. In winter, the internal gains by people and lighting are not enough to keep warm inside the building [6]. Therefore, designers have to calculate, how much heat energy to use for warming up and then they will choose suitable heat equipment to achieve reasonable and economical conditions.

In summer, the external heat that enters through the building is very high. The common ways are solar radiation and indirect solar gains that warm up exterior building surfaces [7].

In winter, mainly heat flows to the building by radiant energy that is from sunlight entering through windows to heat interiors or store energy in thermal mass (direct solar gains). The heat that flows out of the building is causedby two main reasons: heat conduction leaving the building envelope to outside air or ground; losing inside air to the outside by ventilation or through leaks and infiltration [8].

Internal and external thermal loads translate to heating and cooling loads. This is how much heat energy we need to heat and cool the building and control moisture within the building. The heating thermostat set point is often different than the cooling thermostat set point both to save energy and because of human preference. The distribution of heating and cooling loads is climate dependent [9].

Material choices, envelope design, and envelope sealing dramatically affect the amount of solar conducted and convection energy that enters and leaves the building envelope [10]. The degree of impact of each of these on building loads and the occupants' comfort also depend on the temperature and humidity differences between indoors and outdoors, which are all constantly changing by season and time of day [11].

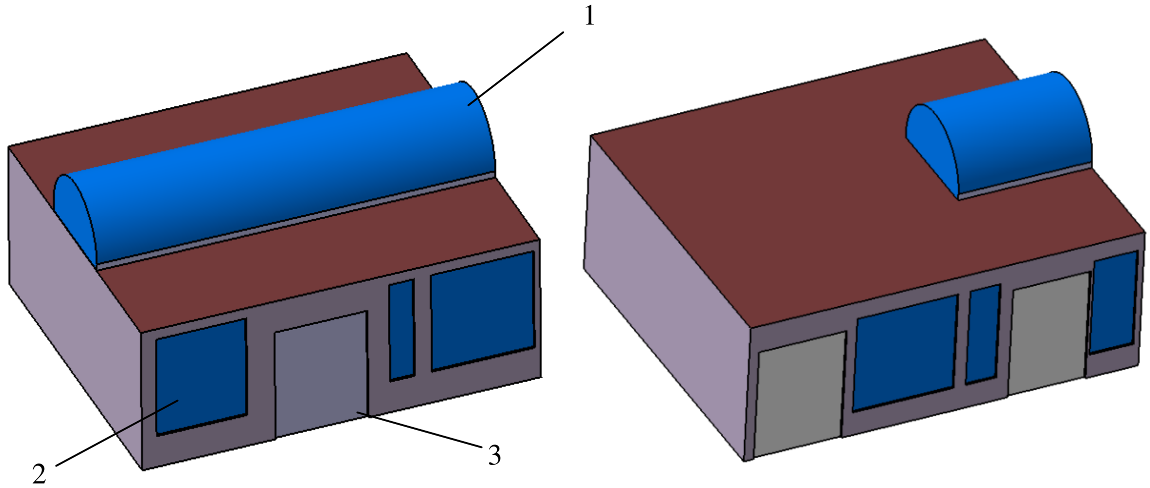
Understanding where heat energy is gained and lost in your design is an important first step towards successful passive design strategies [12; 13]. When it is hot and sunny, it can be very important to reduce loads from solar radiation by using properly designed shades and windows with low solar heat gain. On the other hand, in a cold climate or in winter, it is often desirable to capture this free solar energy in some way [14].

The aim of this research paper is to set up a calculation formula of the heat transfer and using the obtained formula to calculate the required heating capacity in two workshops to keep the standard internal temperature (20 ºC). We also used on-line heat transfer loss calculation to compare with the results by calculation that was set up in the program Mathcad. The influence of the building construction and the heating equipment of the buildings will be evaluated.

Materials and methods

This research work and measurements were carried out in two similar large workshops with 6.5 m height for research work and students' practices. The building construction in the two workshops is a little bit different regarding the area of the wall window and roof window. The data of the building construction were measured and also were found in the document of the project.

Two workshops in this research are located side by side and beside the next workshops. Therefore, each workshop has three inside walls and only one outside that includes wall windows and the garage door. The model object is a typical industry one-storey hall with the roof window from light-permeable plastic coverings to improve the light inside the hall. Simplified general sketches of the two workshops are given in Fig. 1.



Workshop 1 (WS1) Workshop 2 (WS2)

Fig. 1. **3D simplifiedsketches of experimental workshops:**
1 – roof window; 2 – wall window; 3 – garage door

The supporting structure is a reinforced concrete skeleton with a perimeter cladding made of slag-concrete blocks. The ceilings are constructed from reinforced concrete. The floor is concrete without thermal insulation. The windows in the building are made from plastic VEKA Softline AD with thermal insulating double glazing. Skylights are made of hollow polycarbonate. The garage sectional doors are filled with a heat-insulating panel.

The roof of the hall part of the building was additionally insulated with polystyrene foam of 100 mm thickness. At the same time, the facade of the hall was insulated by means of thermal insulation from expanded polystyrene of 100 mm thickness.

Fig. 1 shows that the roof window of WS1 is bigger than the roof window of WS2. This difference has a large influence in summer because of radiation impact, and it made increased temperature inside the halls. But in winter, during sunny days, the radiation could help make decreased energy of the heat system inside the workshop. Heat gains from solar radiation are based on the calculation of equation (1).

$$Q_r = [\, S_{os} \cdot I_o \cdot c_o + (S_o - S_{os}) \cdot I_{o\,dif} \,] \cdot s, \tag{1}$$

where Q_r – heat transmission by radiation, W;
S_{os} – sunlit window area, m^2;
S_o – window area, m^2;
I_o – overall intensity of the solar radiation passing through a standard single glazing, $W \cdot m^{-2}$;
c_o– correction factor for the purity of the atmosphere of rural area;
I_{odif} – intensity of diffuse solar radiation passing through simple glazing, $W \cdot m^{-2}$;
s– s hading coefficient.

In winter, when the outside temperature decreases explicitly, energy for keeping the inside temperature in the recommended value depends on the construction of the building (material, architect etc.). The main building materials of thetwo workshops and the material heat transfer coefficient are given in Table 1.

Table 1

Characteristics of energy-relevant data of research construction

Construction of the building envelope	Area symbol, m^2	Area, m^2		Temperature reduction factor	Heat transfer coefficient, $W \cdot m^{-2} \cdot K^{-1}$
		WS1	WS2		
Outside wall	S_1	42.1	38.8	1.00	0.15
Inside wall	S_2	302.3	298.8	1.00	0.23
Roof	S_3	169.8	242.1	1.00	0.27
Roof window	S_4	80.6	28.5	1.00	2.50
Wall window	S_5	54.1	34.3	1.00	1.50
Ground floor	S_6	260.2	269.8	0.07	4.00
Garage door	S_7	18.2	36.4	1.00	1.70

The outside wall has garage doors and wall windows like in Fig. 1. The outside wall is the facade of the workshop. The other three walls are called inside walls that are between premises and the premises have different temperatures.

We choose internal temperature in the recommended value (20 ºC) and external temperature in winter is -12 ºC. We consider that the beside rooms are not heated and these rooms have the same temperature as outside (-12 ^{0}C). We calculated general heat flow through the walls by using the below formula (2) and the heat transfer coefficient in Table 1.

$$Q_T = k \cdot S \cdot (t_i - t_e), \tag{2}$$

where Q_T – heat transfer, W;
k – heat transfer coefficient, $W \cdot m^{-2} \cdot K^{-1}$;
S – wall area without windows, m^{-2};
t_i – internal temperature, ºC;
t_e – external temperature, ºC.

We set up the equations (1), (2) in the program Mathcad and then we put the data of solar radiation from the weather station and data of construction to the equations. We also used online calculation to find out the heat transfer. We showed the obtained results in Table 2.

By using formula (1), (2) and the heat transfer coefficient of the material in Table 1, we could also describe the total of heat losses and heat gains by relationships with general areas of these buildings.

$$Q_T = 6.3 \cdot S_1 + 75.5 \cdot S_2 + 45.9 \cdot S_3 + 202.5 \cdot S_4 + 81 \cdot S_5 + 72.8 \cdot S_6 + 30.6 \cdot S_7 \tag{3}$$

$$Q_r = 101.9 \cdot S_4 + 47.8 \cdot S_5 \tag{4}$$

where S_1, S_2, S_3, S_4, S_5, S_6, S_7 – areas of the building in Table 1, m^2.

In the case of design or change if areas of the building construction in these workshops or similar halls, we could use relationships (3) and (4) to find out the heat transfer. When we need to reduce or improve any areas of the workshops or even building materials, we could quickly calculate the required heating capacity and compare the obtained results to each other to find the best way to save energy for the heating system.

Results and discussion

According to the Czech standards [15], when the calculatedexternal temperature in winter is -12 °C, the calculatedtemperature in the neighbouring unheated rooms is 0 °C and the calculatedtemperature of floor without thermal insulation is -3 °C. Especially, according to the Czech standards [16], the temperature reduction factor of the floor is only 0.07, it makesremarkable decreased heat transfer from inside to the ground. The thermal-technical calculations were performed for all areas of the two workshops in the program Mathcad. The obtained results are shown in Fig. 2.

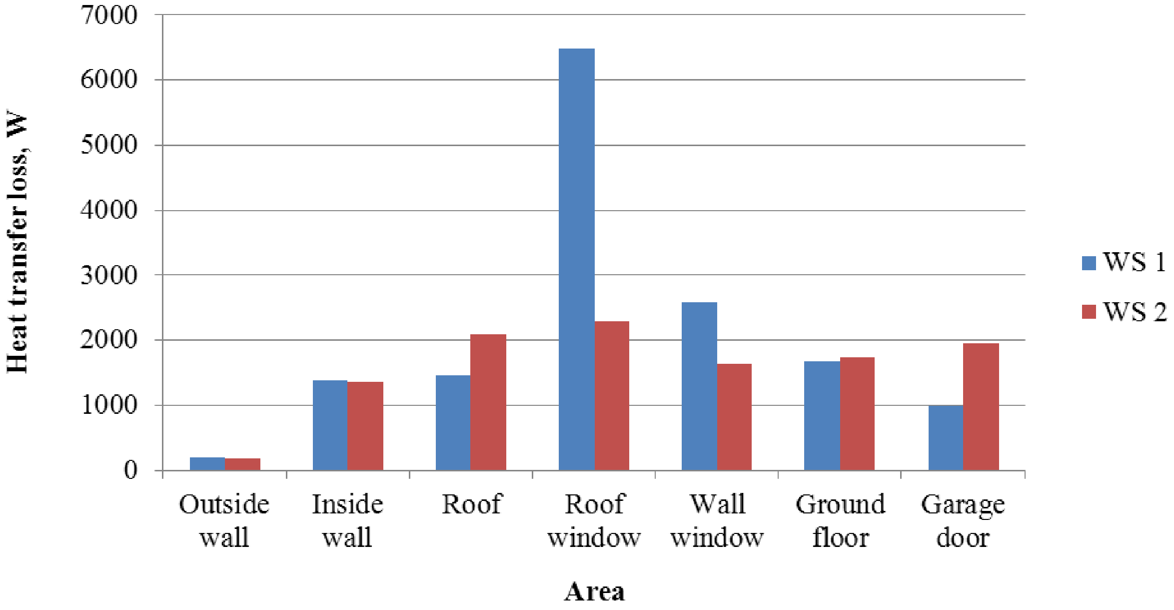


Fig. 2. **Heat transfer loss of two experimental workshops**

The roof window from polycarbonate is mainly to use daylight that has high heat transfer coefficient. This roof has also big surface in the WS1; therefore it made the heat transfer loss in a biggest amount (6480 W). In the WS2, the roof window is reduced (about 64.6 %), the heat transfer loss decreases (2280 W). The ground floor is the biggest and it has also the highest heat transfer coefficient, but the temperature reduction factor is very low (0.07), therefore the heat transfer loss of the floor without isolation is not high (about 1700 W). Theheat transfer loss is at the lowest level in the area of the outside wall that has small area plus the smallest heat transfer coefficient (0.15 $W \cdot m^{-2} \cdot K^{-1}$).

We also used on-line calculation that is available in the Czech website [17]. In this calculation we fill all information of the research constructions. The obtained results from on-line calculation and from program Mathcad are shown in Table 2.

Table 2

Heat transfer loss through the parts of the two workshops

Workshop	Heat transfer loss from Mathcad, W	Heat transfer loss from on-line calculation, W	Mean heat gain from solar radiation, W	
			Roof window	Wall window
WS 1	14790	13556	8257	1306
WS 2	11260	11872	2905	812

In this research, we calculated heat transfer in these buildings without forced ventilation; all windows and doors were closed. The obtained results from both methods of calculation show that heat transfer loss in WS2 is lower than in WS1 (about 23.8 % in case of using formulas). The main reason is the influence of the roof window. Therefore, we have to use more energy for the heating system in the WS1. In some cases, we must use ventilation for the workshop; it will increase the heat transfer loss. The heat installation device in the two workshops is from brand ROBUR from the Czech Republic. Every workshop has three units, which have nominal heat output 21 kW. It is enough to keep the inside temperature in the recommended value.

The average heat gain was calculated from solar radiation in the period from 8 am until 4 pm and thermal radiation gains mainly by the roof window. During sunny days in winter, solar radiation could help improve thermal comfort in the building, when the heating system is not active or the radiation helps decrease the energy consumption of the heating system, when it is used. In this case, by heat gain from solar radiation, energy consumption for the heating equipment in WS1 is 5,497 W and in the WS2 is 7,543 W. Therefore, the roof window is useful in this case.

Conclusions

1. Roof windows' area is the main factor that influences the heat transfer of the WS1. The heat loss by the roof window takes about 43.8 % of the total heat loss.
2. When the roof windows' area is smaller about 64.6 %, the heat loss reduces about 23.8 %. It means that during cloudy days of winter, the WS1 uses more energy consumption for heating than WS2.
3. Roof windows' area is useful in case of illumination by direct light from the sun. In the days with sunlight, the energy consumption for the heating equipment reduces 8993 W in the WS1 and 3717 W in the WS2. In this case, the WS2 uses more energy consumption for heating than WS1 (about 32.2 %).
4. The formula could be basic for the designer of the building, which saves time, cost, energy and resources to keep indoor thermal comfort for the workers' performance.

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