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Modelling the Heat Loss of a Building

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Abstract: The aim of this paper is to calculate the heat loss and annual energy demand for heating of an administrative building for three variants of thermal-technical design and their evaluation. The heat losses were determined according to the legislation in force and in accordance with the normative requirements. The calculations made can be used in the next phase for the design of the heat source and heating system for heating and for the design of forced ventilation with heat recovery. Based on the optimum choice of technical equipment, it is also possible to evaluate the investment and operating costs for the installation of the different heating and ventilation concepts. Given the current significant increase in energy prices, the present topic is very topical.

Keywords: Heat loss, indoor temperature, heat recovery.

1. Introduction

Rising energy prices around the world have in recent years become an incentive to look for energy saving opportunities in various energy consumption sectors. One of the dominant objectives targeted by EU programmes is the reduction of energy consumption in building operations (heating and hot water, air conditioning), which today in many European countries represents on average about one third of the total national consumption [1]. Already when designing buildings, it is possible to create the prerequisites for energy-saving building operation, both by appropriate design of the construction part of the project and by designing energy-saving HVAC systems [2]. The aim is therefore to reduce heat loss to a minimum. In the building design, there is a tendency to substantially increase the thermal insulation capacity of the building envelope [3]. From the point of view of energy consumption for heating, compact buildings are the most advantageous [4]. The energy saving programmes pay particular attention to leakage joints in the building envelope [5]. By careful construction and window sealing, it is theoretically possible to reduce heating energy by 20 to 30 % [6]. Increasing window tightness is relatively easy to do in renovations of existing buildings and is therefore of paramount importance [7]. In terms of heat loss, but also as a result of modern construction methods and higher comfort requirements, forced ventilation with heat recovery is becoming increasingly popular [8, 9]. The development of heating systems is moving towards greater efficiency in energy conversion [10]. In this direction and in the current energy market situation, the heating of buildings with heat pumps is very promising [11, 12].

2. Calculation of heat loss of buildings

Calculation of heat losses of buildings is described in detail in the document ČSN EN 12831-1 Energy performance of buildings – Calculation of heat output. Buildings must comply with EN 73 0540 Thermal protection of buildings. The heat loss calculation for the base cases is based on the following assumptions: **A/** The temperature distribution in the rooms, building (air temperature and operative temperature) is uniform, **B/** Heat

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losses are calculated for steady state conditions assuming constant properties, e.g. temperatures, characteristics of building structures, C/ The height of the room does not exceed 5 m, D/ Determination of the outdoor calculation temperature in winter according to the location of the building (Ostrava = –15°C), E/ Determine the condition of the space (heated or unheated) and determine the indoor design temperature of each heated space, F/ Determine the dimensional and thermal characteristics of all building structures for all heated or unheated spaces [13, 14].

From a physical point of view, the total heat loss of a building is the sum of the heat loss through the building structure and the heat loss through ventilation according to relation (1).

$$P_T = P_P + P_V \quad \text{(W)} \qquad (1)$$

Where: P_T - total heat loss through heat transfer and ventilation (W), P_P - heat loss through heat transfer (W), P_V - heat loss through ventilation (W).

The heat loss through the penetration is determined according to relation (2) as the sum of the heat fluxes through the individual structures enclosing the room (building).

$$P_P = \sum U_j \cdot S_j \cdot (t_i - t_e) \quad \text{(W)} \qquad (2)$$

Where: U_j - coefficient of heat transfer through the building structure (W·m^{-2}·K^{-1}), S_j - area of the structure (m^2), t_i, t_e - indoor design temperature, outdoor area design temperature (°C).

By increasing the thermal resistance of the building envelope, the heat loss through penetration decreases and the heat loss through ventilation becomes more important [15]. For this reason, elements for heat recovery from exhaust air are now being installed in ventilation systems [16]. In practice, a number of incorrect or simplified names are used for heat recovery such as heat recovery units, heat savers, etc. Heat recovery systems can basically be divided into: A/ Heat recovery, where heat is transferred between the incoming outdoor air and the exhaust air directly through the heat exchanger wall. B/ Regenerative, where the heat from the exhaust air is transferred to the storage mass and the heat is then released into the incoming outdoor air. C/ With an auxiliary fluid, where the heat from the exhaust air is transferred to the auxiliary fluid and from the auxiliary fluid to the supply air.

Heat recovery systems include mainly plate and tube heat exchangers. Regenerative systems are rotary, switching exchangers. The auxiliary fluid is handled by liquid circulating exchangers, natural refrigerant circulating tubes (heat pipes) and refrigerant compressor systems (heat pumps).

Heat recovery devices should now be an integral part of all ventilation and air conditioning systems. The development of heat recovery equipment is ongoing, improving both its technical characteristics and its application and operation. The heat loss in forced ventilation with heat recovery is calculated according to relation (3) [17].

$$P_V = \frac{V_i \cdot n_{min} \cdot \rho \cdot c \cdot (t_i - t_e) \cdot (1 - \eta)}{3600} \quad \text{(W)} \qquad (3)$$

Where: V_i - internal volume of the heated space (m^3), n_{min} - minimum ventilation intensity (h^{-1}), ρ - air density (kg·m^{-3}), c - specific heat capacity of air (J·kg^{-1}·K^{-1}), t_i, t_e - indoor design temperature, outdoor area design temperature (°C), η - heat recovery heat exchanger efficiency (1).

3. Calculation part

The calculation considers a fictitious building of administrative character. The external dimensions of the building are 16 x 10 m, the clear height of the rooms is 3.6 m. The total thickness of the perimeter wall is 500 mm. The building is adjacent to the ground and has a flat roof. The dimensions of the structures were read from the building model, see Figure 1. The building is located in Ostrava, according to ČSN the design outdoor air temperature is t_e = –15°C. The indoor air temperature for the office space according to ČSN is chosen as t_i = 20°C. For the modelling of heat loss and annual heating energy demand, indoor air temperatures of 20°C (according to ČSN) and 19°C (option) are assumed throughout the building.

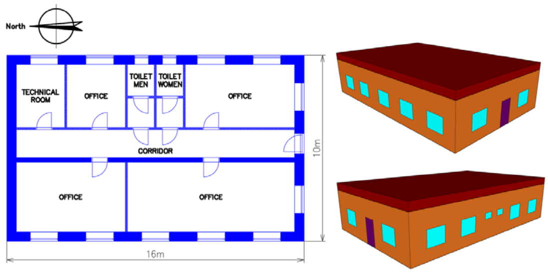

Figure :1 Model of the building

Table 1: Input values

Construction	*Variant A* Energy-saving standard Natural ventilation	*Variant B* Low-energy standard *Natural ventilation*	*Variant C* Energy-saving standard *Heat recovery $\eta = 80$ %*
	Coefficient of heat transfer *U* (W·m^{-2}·K^{-1})		
Perimeter wall	0.25	0.18	0.25
Roof	0.16	0.12	0.16
Floor on soil	0.17	0.12	0.17
Windows, doors	1.10	0.80	1.10

The modelling of heat losses for the given building geometry was further solved for 3 variants of thermal parameters, see Table 1. In variants A and B, the calculations considered natural ventilation (infiltration and windows). In variant C, forced ventilation with heat recovery system was considered.

Figure 2 presents the graphical outputs of the results of modelling the heat loss of the designed building depending on the outdoor air temperature. The calculations were performed for the same boundary conditions and for variants A, B and C. Temperature t_{em} characterizes the mean daily outdoor temperature for the beginning and end of the heating period, t_{es} is the average temperature during the heating period, t_e is the outdoor design temperature for the site. The length of the heating period is d = 229 days. For both natural and forced ventilation with heat recovery, the room air exchange rate $n = 0.5$ h^{-1} was considered. The results of the heat loss modelling show that with a 1°C reduction in the indoor temperature and outdoor air temperatures of –15°C, +4°C and +13°C, there is a 2.9, 6.3 and 14.3 % reduction in heat loss for all options at the above boundary conditions. It is also clear from the results that the lowest heat loss is

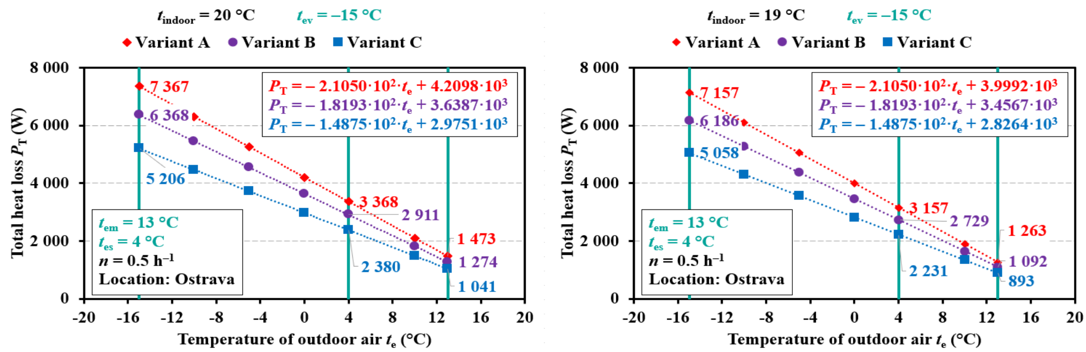

Figure 2: Dependence of heat loss on outdoor air temperature

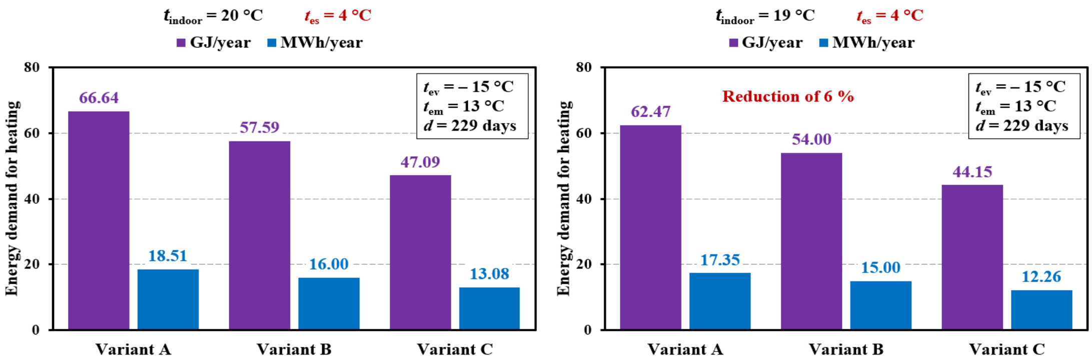

Figure 3: Total annual energy demand for heating of the designed building

achieved in both cases for Variant C.

The evaluation of the total annual energy demand for heating for the variants A, B and C of the designed building follows the previous heat loss calculations and respects the defined boundary conditions. The calculation also considers a heat distribution efficiency of $\eta_d = 0.9$, a control method efficiency of $\eta_c = 0.9$ and a heat source efficiency of $\eta_s = 0.9$. The results are presented in graphical form below in Figure 3. The annual heating energy demand is expressed in GJ and MWh. From the results it can be seen that a reduction of 1°C in the building temperature at these boundary conditions results in a reduction of 6.3 % in the annual heating energy demand for all options. The lowest annual heating energy demand is based on the previous heat loss calculations as assumed for Variant C.

4. Conclusions

Calculations of heat loss and annual energy demand for heating were performed for 3 variants of the thermal-technical design of the administrative building with a reduction of the interior temperature by 1°C, i.e. from 20°C to 19°C depending on the course of the outdoor temperature in the heating period. In addition, the calculations for variants A and B considered natural ventilation, and for variant C forced ventilation with a heat recovery system. Variants A and C had the same values for the thermal resistance of the structures. The boundary conditions for all variants were also identical. The results of the heat loss modelling show that if the interior temperature is reduced by 1°C and the outside air temperatures are –15°C, +4°C and +13°C, the heat loss for all variants is reduced by 2.9, 6.3 and 14.3 % respectively. If the interior temperature is reduced by 2°C, i.e. from 20°C to 18°C, the heat loss is reduced by 5.7, 12.5 and 28.6 %, i.e. twice as much. However, these significant savings would lead to a significant deterioration in the thermal comfort of the occupants of this type of building. The lowest heat losses were achieved in Option C, where the heat loss was reduced by 18.2 % compared to Option B and by up to 29.3 % compared to Option A, with the same values of thermal resistance of the structures. The heat loss calculations were followed by calculations of the total annual heating energy demand. A 1°C reduction in building temperature will result in a 6.3 % reduction in annual heating energy demand for all options. The lowest annual heating energy demand is assumed to be for option C. The results show that in the current low-energy building construction, whether the building has forced ventilation with a heat recovery unit has a decisive influence on the total heat loss. From the point of view of design practice, natural ventilation is no longer suitable for today's construction from a hygiene, energy and economic point of view. The present paper is very topical at the present time of dramatically increasing energy prices and can contribute to the reflection on the choice of a suitable building concept in terms of thermal-technical parameters.

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