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MODEL OF THE INFLUENCE OF THE CLIMATIC CONDITIONS OF THE SLOVAK TERRITORY ON THE CONSUMPTION OF FIREWOOD AND THE PRODUCTION OF EMISSIONS DURING THE HEATING OF BUILDINGS

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ABSTRACT

A model of the influence of the climatic conditions of Slovakia on the consumption of firewood and the production of emissions in creating thermal comfort in a heated building is presented in the paper. The temperature of atmospheric air ranges from -11°C to -18°C in winter and the number of days of the heating period in the range between 202-253 in individual localities of Slovakia is reflected in the size of heat losses of the heated building, fuel consumption, and emissions production. The presented model allows for balancing the consumption of firewood and emission production for individual localities in Slovakia, following the locality's climatic conditions, the heated object's size, the boiler's thermal efficiency, and the type of firewood.

Keywords: Buildings, Climatic conditions, Heating, Wood, Emissions.

INTRODUCTION

The surface of the territory of the Slovak Republic is characterized by great diversity and representation of several geographical types. From the lowlands in the south of Slovakia, the country passes through a range of hills and highlands to the mountains – the High Tatras located in the north of Slovakia. However, most of the country is slightly undulating with an average altitude of 392 m. The territory of Slovakia, from the aspect of the climate, is divided into three climatic areas: warm, moderately warm and cold.

The warm climate area extends to an altitude of 400 m and occupies lowlands and low-lying basins with an average air temperature of 8 - 10°C. The length of the annual sunshine is more than 1500 hours.

The mildly warm climate area is located at an altitude of 400 to 800 m and occupies higher basins, highlands and lower mountains with an altitude of 700 - 800 m. The average annual air temperature in this area does not exceed 8°C.

The cold climatic region of Slovakia consists of the highest positions of the mountains with an altitude of over 800 m. The average air temperature in these localities is below 8°C.

The mentioned climatic conditions and the alternation of seasons were and are the reason for heating the buildings in which one stays in order to create thermal comfort.

The aim of this work is to present a model for calculating the annual consumption of firewood and emissions in creating thermal comfort in the interior of the building or building located on the territory of Slovakia depending on the location, the size of the heat loss of the interior, or the heated object, the thermal efficiency of the heat source for individual assortments of firewood.

MATERIALS AND METHODS

The heat loss of a heated object Q is quantified according to STN EN 12 831. The calculation of the heat loss of a heated object for the heating seasonal period is described by the equation:

$$Q_r = \frac{3600 \cdot 24}{10^9} \cdot Q \cdot \varepsilon \cdot \frac{t_i - t_{es}}{t_i - t_e} \cdot d \qquad [\mathrm{GJ \cdot year^{-1}}] \tag{1}$$

The length of the heating season (d), according to the legislation valid on the territory of Slovakia, is defined by the time: 1 September to 31 May of the following year. The natural length of the heating season of a given locality lasts from 202 to 253 days, depending on climatic conditions. It starts when the average ambient air temperature drops below 13°C for two consecutive days. The weather forecast does not indicate that it should not warm up and ends when the average atmospheric air temperature rises above 13°C for two consecutive days.

The fuel consumption to compensate for the heat loss of a heated building during the heating season is balanced by the equation:

$$B_r = \frac{Q_r}{Q_n \cdot \eta} \cdot 10^5 \quad [\mathrm{tons \cdot year^{-1}}] \tag{2}$$

Fuel wood from forest stands as well as plantations of fast-growing trees according to works: Senelwa-Ralph (1999), Domanski *et al.* (2008), Dzurenda *et al.* (2010), Dzurenda and Zoliak (2011), Pastor *et al.* (2017) is from the energetic-chemical point of view formed by combustible elements: carbon $C^d = 50.0 \pm 1.5$ %, hydrogen $H^d = 6.1 \pm 0.5$ %, oxygen $O^d = 43.3 \pm 3.0$ %, nitrogen $N^d = 0.1 \pm 0.05$ % and inorganic content – ash $A^d = 0.5 - 1.5$ %. The combustion heat of dry firewood, depending on the type of wood, is from $Q_s = 18.5$ to $Q_s = 20.5$ kJ.kg-1 and the calorific value of dry wood is in the range of values between $Q_n = 17.5 – 18.3$ MJ.kg-1 Dzurenda *et al.* (2012), Hytönen and Nurmi (2014), Nosek and Holubčík (2016).

The negative property of firewood is its affinity for water and water vapor. Due to humidity, the heating value of firewood decreases Nord-Larsen *et al.* (2011), Nosek and Holubčík (2016) Horák *et al.* (2018). The influence of humidity on the calorific value of firewood for the needs of practice is reported in the professional literature by the equation

$$Q_n^r = 18\,840 - 21\,353 \cdot \frac{w}{100} \quad [\mathrm{kJ \cdot kg^{-1}}] \tag{3}$$

The rate of decrease in the thermal efficiency (of the boiler) on the moisture content of the firewood and the temperature of the flue gas discharged from the heat source is quantified in the works of Dzurenda and Banski (2015) and Dzurenda and Banski (2017). For energy-environmental combustion of firewood in accordance with the works: Holubčík *et al.* (2012), Chabadova *et al.* (2014), Dzurenda *et al.* (2015), Soltes and Randa (2018), for the temperature range of flue gases emitted from a small heat source to the atmosphere t_{fg} = 150 - 400°C and not exceeding the emission values: carbon monoxide EL_{CO} = 3000 mg.m^{-3} ash with carbon black $EL_{C\text{-}TZL}$ = 150 mg.m^{-3},for thermal efficiency of small heat source following equation was derived:

$$\eta = [(-0.003. w^2 + 0{,}069. w + 86.746) - (0.001. w + 0.071). (t_{fg} - 150)] \quad [\%] \qquad (4)$$

For small heat sources, hot water boilers for central heating systems with heat input 5 - 50 kW and heat input 50 - 300 kW in work: Šoltés and Randa: "*Elaboration of design of emission factors for combustion plants for the Ministry of the Environment of the Slovak Republic*" they state emission factors for solid renewable fuels (lump wood, energy chips and wood pellets). The values of emission factors are given in Table 1.

Tab. 1 Emission factors for solid renewable fuels burned in small heat sources with a heat input of 5 - 300 kW Soltes and Randa (2018).

Fuel	Boiler	Heat input kW	Emission factor [kg.t^{-1}_{fuel}]		
			PM	CO	NO_x
Firewood	Combustion	5 - 50	2.31	36.19	1.22
		50 - 300	2.05	30.90	1.27
	Gasification	5 - 50	0.96	17.93	0.61
		50 - 300	0.90	14.09	0.58

The production of emissions for the heating season is balanced by the equation:

$$M_{(emission\text{-}i)} = B_r \cdot EF_{(emission\text{-}i)} \quad [\text{kg.year}^{-1}] \qquad (5)$$

A program in the EXCEL software was developed as a calculation table to streamline the work for determining the boiler's annual fuel consumption and emissions production. After entering the data: heat loss from the building, locality of Slovakia, type of fuel, moisture content in the fuel, heat output of the boiler and flue gas temperature, the program provides information such as annual heat loss of the building in the given locality of Slovakia, annual consumption of firewood in tons and annual emission production (PM, CO, NOx) in kilograms.

RESULTS AND DISCUSSION

The given mathematical model (program) is applied to determine the annual consumption of firewood from a small energy source – a hot water boiler ATMOS DC 18 S for creating thermal comfort in a detached house Kompakt 40 located in the most favorable and unfavorable climatic conditions in Slovakia, Bratislava and Liptovský Mikuláš, Table 2.

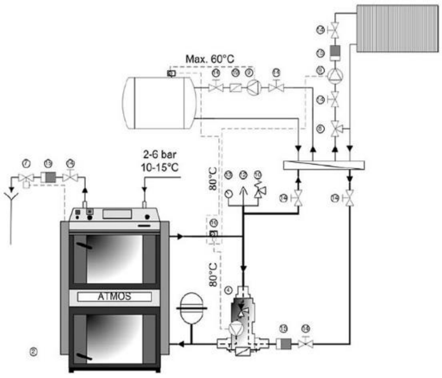

Fig. 1 Heating the house KOMPAKT 40 with an ATMOS DC 18 boiler burning firewood.

Tab. 2 Annual fuel wood consumption and emissions for localities: Bratislava and Liptovský Mikuláš.

Input parameters		Symbol	Location	
			Bratislava	Liptovský Mikuláš
Heat loss of the building according to STN EN 12 831		Q [W]	8 000	9 500
Calculated indoor air temperature		t_i [°C]	+ 20	+ 20
Calculated temperature of atmospheric air in the exterior		t_e [°C]	- 12	- 18
Average outdoor air temperature during the heating season		t_{es} [°C]	+ 4	+ 2.4
Number of days of the heating season		d [-]	202	253
Correction factor for the absence of heat losses		ε [-]	0.9	0.9
Moisture of burnt beech wood		w [%]	20	20
Temperature of emitted flue gases		t_{fg} [°C]	200	200
Annual thermal heated building		Q_r[GJ.year^{-1}]	62.83	86.56
Annual consumption of firewood		B_r [t.year^{-1}]	5.24	7.21
Emissions	particulate matter	PM[kg.year^{-1}]	5.03	6.92
	carbon monoxide	CO [kg.year^{-1}]	93.87	129.32
	nitrogen oxides	NO_x[kg.year^{-1}]	3.19	4.40

A comparison of the annual heat loss of a Kompakt 40 house, the consumption of firewood for creating thermal comfort in a given detached house and the production of emissions shows that the worse climatic conditions of Liptovský Mikuláš are reflected in an increase in the consumption of air-dried beech firewood by 2.15 t.year^{-1} is 37.8 % more and increase the production of emissions PM by 43.6%, CO = 37.7 % and NOx = 37.7 %.

CONCLUSION

A model for calculating the annual consumption of firewood and emissions production for the creation of thermal comfort in the interior or heated object located in Slovakia depending on the locality of Slovakia, the size of heat loss of the heated object, type of fuel, the moisture content in the fuel, heat output of the boiler and fuel gas temperature is presented in the paper.

The model allows the user to plan the heating season objectively and the amount of firewood for thermal comfort in the heated object in any location in Slovakia. At the same time, it informs about the degree of atmospheric emissions.

Used symbols:

d – number of days of the heating season in the given locality, -;
t_i – indoor air temperature, °C;
t_e – outdoor air temperature, °C;
t_{es} – average outdoor air temperature during the heating season, °C;
t_{fg} – temperature of flue gases emitted from the heat source, °C;
w – firewood moisture %;
B_r – fuel consumption to compensate for heat losses of the heated object during the heating season, $t \cdot year^{-1}$;
$EF_{emission\text{-}i}$ – emission factor, $kg.t^{-1}{}_{fuel}$;
Q – heat loss of the heated object, W;
Q_r – heat loss of the heated object during the heating period, $GJ \cdot year^{-1}$;
Q_n – calorific value of firewood, $kJ \cdot kg^{-1}$;
η – thermal efficiency of a small heat source, %;
ε – correction factor for non-participation of heat losses, -;

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