Advances in Thermal Processes
and Energy Transformation
Volume 4, 2021, DZUR01, pp. 20-24
ISSN 2585-9102

Model of the Balance of Fuel Wood Consumption and Emissions Production During Building Heating Depending on the Climatic Conditions of Slovakia

Ladislav Dzurenda[1] ● Adrián Banski[1]

[1]Technical University in Zvolen, Faculty of Wood Sciences and Technology, T. G. Masaryka 24, 960 01 Zvolen, Slovak Republic, dzurenda@tuzvo.sk

Category : Original Scientific Paper
Received : 21 June 2021 / Revised: 27 June 2021 / Accepted: 28 June 2021

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

Abstract : The paper presents 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. The temperature of atmospheric air in the range from -11°C to -18°C in winter and the number of days of the heating period in the range of 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 to balance the consumption of firewood and emission production for individual localities in Slovakia based on the climatic conditions of the locality, the size of the heated object, the thermal efficiency of the boiler and the type of firewood.

Citation: Dzurenda Ladislav, Banski Adrián: Model of Balance of Fuel Wood Consumption and Emissions Production During Building Heating Depending on the Climate Conditions of Slovakia, Advance in Thermal Processes and Energy Transformation, Volume 4, No. 2 (2021), pp. 20-24, ISSN 2585-9102.

1 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 climate is divided into three climatic areas: warm, moderately warm and cold.

The warm climate area extends to an altitude of 400 m 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.

2 Experimental

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:

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

The length of the heating season (d), according to the legislation valid on the territory of Slovakia [1, 2], is defined by the time: 1 September to 31 May of the following year. The real 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 and 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:

$$B_r = \frac{Q_r}{Q_n \cdot \eta} \cdot 10^5 \quad [\text{tons}\cdot\text{year}^{-1}] \qquad (2)$$

Firewood from forest stands as well as plantations of fast-growing woody plants [3 - 10] is from the energetic-chemical point of view formed by combustible elements: carbon C^d = 50.0 ± 1.5 %, hydrogen H^d = 6.1 ± 0.5 %, oxygen O^d = 43.3 ± 3.0 %, nitrogen N^d = 0.1 ± 0.05 % and inorganic content - ash A^d = 0.5 - 1.5 %. The negative property of firewood is its affinity for water and water steam. The moisture content of the firewood reduces both the calorific value of the fuel and the thermal efficiency of the boiler. Influence of moisture content on calorific value of firewood for the needs of practice the authors: [3, 5, 11, 12] describe by mathematical relation:

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

The rate of decrease in thermal efficiency (boiler) on the moisture content of firewood and the temperature of flue gases emitted from the heat source is quantified by Dzurenda and Banski in [13,14,15]. For energy-environmental combustion of firewood in accordance with the works [16 - 24] and 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} a ash with carbon black $EL_{C\text{-}TZL}$ = 150 mg.m^{-3} thermal efficiency, small heat source describes the relationship:

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

For small heat sources, hot water boilers for UK systems with heat input 5 - 50 kW and heat input 50 - 300 kW in Šoltés - 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.

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

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

To streamline the work for determining the annual fuel consumption of the boiler and the production of emissions, a program was developed in the EXCEL software - in the form of a calculation table. 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.

Table 1 Emission factors for solid renewable fuels burned in small heat sources with a heat input of 5 - 300 kW [25]

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

3 Results and discussion

The given mathematical model (program) is applied to determine the annual consumption of firewood of a small energy source - hot water boiler ATMOS DC 18 S for creating thermal comfort in a family house Kompakt 40 (Figure 1) located in the most favorable and unfavorable climatic conditions in Slovakia, Bratislava and Liptovský Mikuláš (Table 2).

Figure 1 Hot water boiler ATMOS and family house Kompakt 40

Table 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 [ºC]	+ 20	+ 20
Calculated temperature of atmospheric air in the exterior		t_e [ºC]	- 12	- 18
Average outdoor air temperature during the heating season		t_{es} [ºC]	+ 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 wood of wood Beech		w [%]	20	20
Temperature of emitted flue gases		t_{fg} [ºC]	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* family house, the consumption of firewood for creating thermal comfort in a given family 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 %.

4 Conclusions

The paper presents 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, moisture content in the fuel, heat output of the boiler and fuel gas temperature.

The application of the model allows the user for any location in Slovakia to objectively plan in preparation for the heating season the amount of firewood of the wood to create thermal comfort in the heated object and at the same time informs him 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·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·year^{-1};
Q_n - calorific value of firewood, kJ·kg^{-1};
η - thermal efficiency of a small heat source, %;
ε - correction factor for non-participation of heat losses, -;

5 The reference list

[1] Thermal Energy Act No. 657/2004 Coll.

[2] Decree of the Ministry of Economy of the Slovak Republic no. 152/2005 Coll. on the specified time and on the specified quality of heat supply for the final consumer.

[3] SIMANOV, V.: *Energetické využití dřeva*, Olomouc, Terapolis, 1995.

[4] DZURENDA, L., GEFFERTOVA, J., HECL, V. : Energy characteristics of wood-chips produced from Salix viminalis - clone ULV, *Drvna industrija*, Vol. 61, No. 1, pp. 27-31, 2010.

[5] JANDAČKA, J., MALCHO, M., MIKULÍK, M.: *Biomasa ako zdroj energie*, Žilina, GEORG, 2007.

[6] DZURENDA, L., ZOLIAK, M.: Chemické zloženie horľaviny energetickej štiepky z dendromasy plantážnicky pestovanej dreviny Populus klon Max 5, *Acta Facultatis Xylologiae Zvolen*, Vol. 53, No. 1, pp. 87-92, 2011.

[7] PŇAKOVIČ, Ľ., DZURENDA, L. : Combustion characteristics of fallen fall leaves from ornamental trees in city and forest parks, *BioResources*, Vol. 10, No. 3, pp. 5563-5572, 2015.

[8] NOSEK, R., HOLUBČÍK, M.: Energy properties of air dry firewood, *Acta Facultatis Xylologiae Zvolen*, Vol.58, No. 1, pp. 105−112, 2016.

[9] PASTOR M., et al.: Energetic Characteristics of the Dendromass of Branches in the Sweet Chestnut (Castanea Sativa Mill.). *Acta Facultatis xylologiae Zvolen*, Vol. 59, No. 2, pp. 127-135, 2017.

[10] DZURENDA, L., BARTKO, M., RIDZIK, Ľ.: Energetické vlastnosti zelenej štiepky vyrobenej z konároviny plantážnicky pestovanej dreviny Populus x euroamericana klon Koltay, *Acta Facultatis Xylologiae Zvolen*, Vol. 54, No. 2, pp. 115-122, 2012.

[11] KOLLMANN, F. : *Technologie des Holzes und der Holzwerkstoffe*, I. Band, Berlin-Göttingen-Heidelberg-Munchen, Springer-Verlag, 1951.

[12] SETNIČKA, F.: *Tepelná technika pre drevárskych inžinierov*, Bratislava, ALFA, 1981.

[13] DZURENDA, L., BANSKI, A.: Dependence of the boiler flue gas losses on humidity of woody biomass, *Archives of Thermodynamics*, Vol. 36, No. 4, pp. 77-86, 2015.

[14] DZURENDA, L., BANSKI, A.: Influence of moisture content of combusted wood on the thermal efficiency of a boiler, *Archives of Thermodynamics, Vol.* 38, No. 1, pp. 63-74, 2017.

[15] DZURENDA, L., ŠUPÍN, M., PALUŠ, H., BANSKI, A. : *Tvorba mikroklímy v interiéroch a vykurovanie budov palivovým drevom*, Zvolen, Vydavateľstvo Technická univerzita vo Zvolene, 2020.

[16] ČARNOGURSKÁ, M., PŘIHODA, M., BRESTOVIČ, T.: Modelling of nitrogen oxides formation applying dimensional analysis, *Chemical and Process Engineering - Inzynieria Chemiczna i Procesowa, Vol. 32, No. 3, pp.* 175-184, 2011.

[17] HOLUBČIK, M., NOSEK, R., JANDAČKA, J.: Optimization of the Production Process of Wood Pellets by Adding Additives, *International journal of energy optimization and engineering*, Vol. 1, No.2, pp. 20-40, 2012.

[18] CHABADOVÁ, J., PAPUČÍK, Š., NOSEK, R.: Particle emissions from biomass combustion. *AIP Conference Proceedings, Vol.67, p.1*608, 2014.

[19] DZURENDA, L., LADOMERSKÝ, J., HRONCOVÁ, E.: Conversion Factor of Fuel-Bound Nitrogen to Oxides in the Process of Spruce Wood Combustion in Boiler Grate Furnaces, *Polish Journal of Environmental Studies*, Vol. 24, No. 2, pp. 505-509, 2015.

[20] RIMÁR, M., et al.: Determination of excess air ratio during combustion of wood chips respect to moisture content, *Acta Facultatis Xylologiae Zvolen, Vol. 58, No.2, pp.* 133-140, 2016.

[21] DZURENDA, L., HRONCOVÁ, E., LADOMERSKÝ, J.: Extensive Operating Experiments on the Conversion of Fuel-Bound Nitrogen into Nitrogen Oxides in the Combustion of Wood Fuel, *Forests, Vol. 8, No. 1, pp.* 1–9, 2017.

[22] DZURENDA, L., BANSKI, A.: Firewood consumption model to create thermally comfortable indoor environment regarding the climate in Slovakia, *AIP Conference Proceedings, Vol.* 2118, 030012 , 2019.

[23] JANDAČKA, J., HOLUBČIK, M.: Emissions Production from Small Heat Sources Depending on Various Aspects, *Mobile Networks & Applications, Vol. 25, No. 3, pp.* 904-912, 2020.

[24] DZURENDA, L., BANSKI, A.: The Effect of Firewood Moisture Content on the Atmospheric Thermal Load by Flue Gases Emitted by a Boiler, *Sustainability, Vol. 11, p*. 284, 2019.

[25] ŠOLTÉS, J., RANDA, M.: *Spracovanie návrhu emisných faktorov pre spaľovacie zariadenia pre MŽP SR*, Banská Bystrica, Národná energetická spoločnosť, 2018.

Acknowledgments

This paper was prepared within the grant project: KEGA–SR No: 003TU Z-4/2018, as the result of work of author and the considerable assistance of the KEGA–SR agency.