XI INTERNATIONAL CONFERENCE
INDUSTRIAL ENGINEERING AND ENVIRONMENTAL PROTECTION 2021
IIZS 2021, October 07-08, 2021, Zrenjanin, Serbia

POLLUTANT EMISSIONS FROM FOSSIL FUEL COMBUSTION USED FOR HEATING OF DETACHED RESIDENTIAL BUILDINGS

Amelija Đorđević[1], Ana Vukadinović[1], Jasmina Radosavljević[1], Bogdana Vujić[2]
[1]Faculty of Occupational Safety, University of Niš, Republic of Serbia
[2]Faculty of Technical Sciences – Mihajlo Pupin, University of Novi Sad, Republic of Serbia
amelija.djordjevic@znrfak.ni.ac.rs, jasmina.radosavljevic@znrfak.ni.ac.rs, ana.vukadinovic@znrfak.ni.ac.rs, bogdana.vujic@tfzr.rs

Abstract: The research presented in this paper is motivated by the fact that air quality monitoring in Serbia has indicated the presence of high concentrations of PM_{10}, $PM_{2.5}$, and other pollutants in outdoor ambient air, which are caused by the use of fossil fuels as energy-generating products. The research focuses on the cause-and-effect relationship between air pollution and the use of fossil fuels to heat detached residential buildings on the one hand and the cause-and-effect relationship between fuel consumption and structural and architectural elements on the other hand. Comparison of the analyzed models of detached residential buildings shows that structural and architectural characteristics can help reduce suspended particle emissions by more than 70%, as well as reduce emissions of other pollutants, including carbon monoxide, carbon dioxide, sulfur oxides, nitrogen oxides, heavy metals, and volatile hydrocarbons.

Key words: fossil fuels, pollutants, detached residential buildings, sunspace, emission factor, pollutant emission

INTRODUCTION

The measured ambient air pollutant concentrations, which are regularly monitored in urban areas in Serbia, vary, especially across the seasons, which may be linked to the activities of energy-producing facilities (district heating plants, industrial plants, and household heating systems) [1]. Energy facilities mostly use fossil fuels to transform the fuels' energy into heat and/or electricity [1]. The most commonly used fossil fuel worldwide as well as in Serbia is lignite. Products of lignite combustion emit NO_x (of the total emitted NO_x, NO constitutes about 90%), SO_x, CO, non-standard pollutants CO_2 and N_2O (emitted at temperatures over 800°C), CH4 (emitted from incomplete combustion), particulate matter of the diameter smaller than 10 µm (occurring in short-lived emissions), and 189 microelements belonging to the four hazardous pollutant classes according to Baig [1]. Owing to insufficiently developed gas distribution and district heating in Serbia, wood biomass is heavily used to heat detached residential buildings.

MATERIALS AND METHODS

In order to monitor pollutant emission from fossil fuel combustion used for heating of a residential building with a sunspace, we developed models to calculate the mass of pollutants emitted into the air.
Modeling of pollutant emissions from fossil fuels is based on the determination of emissions from the combustion of a unit quantity (mass or volume) of fossil fuel (emission factor). Emission of all pollutants in the air is assessed based on the emission factor and activity rate for each emission source.
The total pollutant emission from fossil fuel combustion is expressed as a product emission factors and the total energy required for heating depending on the fuel type [2].

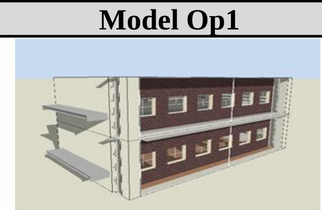
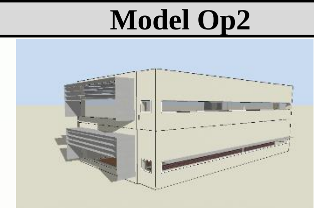
$$Ei = \sum g(EFi \cdot Qg)\,, \qquad (1)$$

where: Ei – total emission of ith pollutant [g], EFi – emission factor of the ith pollutant [g/GJ], and Qg – required primary energy for heating of a detached building with a sunspace [GJ].
The following fuels were considered in the modeling of pollutant emissions: natural gas, wood biomass, pellets, fuel oil, and coal (lignite, brown coal).

The analysis of pollutant emissions for the said fuels encompasses the fuels most frequently used for residential heating in Serbia. The following pollutants emitted from fuel combustion are considered: carbon dioxide (**CO_2**), carbon monoxide (**CO**), methane (**CH_4**), nitrogen oxides (**NO_x**), nitrous oxide (**N_2O**), sulfur oxides (**SO_x**), non-methane volatile organic compounds (**NMVOC**), cadmium (**Cd**), lead (**Pb**), total suspended particles (**TSP**), particles smaller than 10 µm (**PM_{10}**), and particles smaller than 2.5 µm (**$PM_{2.5}$**).

In order to analyze the microclimatic conditions of indoor space and the occupational or living thermal environment, models and standards for thermal comfort have been developed. This study utilizes the EnergyPlus™ model for energy analysis and heat load simulation of a building, composed of several program modules constituting a unity, which are able to calculate the energy required for building heating using different heating systems or different energy sources [3].
The structural and architectural elements of detached residential buildings are considered as models with G+1 levels, with the base aspect ratio of 2.25:1 and with a 1.2 m wide sunspace installed over the entire length of the south-facing façade. The building base dimensions are 14.4 m in length and 6.4 m in width. The base surface area is 184.32 m2, the sunspace base surface area is 34.56 m2, floor height is 3 m, the heated volume of the building is 552.96 m3, the surface area of the building's thermal envelope is 433.32 m2, and the building shape factor is 0.78.

Table 3. Characteristics of models Op1 and Op2

Parameter description	Parameter value: Model Op1	Parameter value: Model Op2
Building geometry with shadowing, Dec 21 at 1 pm		
Sunspace window-to-wall ratio (WWR)	$WWR_{sunspace}$=100%	$WWR_{sunspace}$=20%
South-facing façade WWR	WWR_{south}=21%	WWR_{south}=46%
East-facing façade WWR	WWR_{east}=21%	WWR_{east}=89%
West-facing façade WWR	WWR_{west}=10%	WWR_{west}=75%
North-facing façade WWR	WWR_{north}=10%	WWR_{north}=100%
Sunspace glazing type	Triple, low-emissivity, argon filled	Single, transparent glass, 6 mm
Glazing type of east-, west-, and north-facing façades	Triple, low-emissivity, argon filled	Double, reflective glass, air filled, 6mm/13mm
Façade wall type	Façade wall made of 0.4 m thick concrete and 0.14 m thick thermal insulation	Façade wall made of 0.2 m thick concrete and 0.067 m thick thermal insulation
Shading type of south-facing façade	Horizontal awning 0.5 m	Horizontal awning 0.5 m*
Shading type of east-, west-, and north-facing façades	Brise-soleils, horizontal and vertical awning 1.0 m	Brise-soleils, horizontal and vertical awning 1.0 m*

The structural and architectural elements of detached residential buildings are considered in the form of models Op1 and Op2 in a scenario involving the optimization of variable building parameters in order to meet the minimum heating energy requirements for a building with a sunspace.

RESULTS AND DISCUSSION

Dynamic simulations using EnergyPlus™ were carried out for models Op1 and Op2 of a detached passive building with a sunspace to determine the heating energy requirements. The total energy required for heating was 7,169.08 kWh for model Op1 and 32,772.88 kWh for model Op2. Based on the obtained data on the heating energy requirements for models Op1 and Op2, the total annual pollutant emissions by fuel type were determined, as shown in Tables 5

Table 5. Total annual mass of emitted pollutants in relation to heating energy requirements for model Op1 by fuel type [4]

Pollutant	Heating fuel type						
	Natural gas [kg]	Wood biomass [kg]	Pellets [kg]	Fuel oil in furnaces [kg]	Fuel oil in boilers [kg]	Coal in furnaces [kg]	Coal in boilers [kg]
CO_2	1.59E+03	2.89E+03	2.89E+03	2.40E+03	2.40E+03	3.39E+03	3.39E+03
CO	8.52E -01	1.03E+02	1.29E+01	3.10E+00	1.24E+00	6.71E+01	1.34E+02
CH_4	1.42E -01	7.74E+00	7.74E+00	9.29E -02	9.29E -02	1.01E+01	1.01E+01
NO_x	1.99E+00	3.10E+00	2.32E+00	1.55E+00	2.17E+00	5.03E+00	4.36E+00
N_2O	2.84E -03	1.03E -01	1.03E -01	1.86E -02	1.86E -02	5.03E -02	5.03E -02
SO_x	1.42E -02	7.74E -01	5.16E -01	4.34E+00	4.34E+00	1.51E+01	3.02E+01
NMVOC	2.84E -01	1.03E+01	5.16E -01	6.19E -01	4.65E -01	1.01E+01	1.01E+01
Cd	1.46E -05	5.16E -05	1.29E -05	9.29E -06	6.19E -05	3.36E -05	1.01E -04
Pb	2.79E -05	1.03E -03	5.16E -04	1.55E -04	6.19E -04	3.36E -03	2.01E -04
TSP	1.42E -02	1.29E+01	2.06E+00	4.65E -01	1.55E -01	8.39E+00	1.34E+01
PM_{10}	1.42E -02	1.23E+01	1.96E+00	3.10E -01	9.29E -02	8.05E+00	1.28E+01
$PM_{2.5}$	1.42E -02	1.23E+01	1.96E+00	3.10E -01	9.29E -02	7.38E+00	1.21E+01

CONCLUSION

The emissions, calculated using the emission factor for each pollutant and specified heating fuel, significantly differ in quantity. Such differences are due to the use of different fuel types and different amounts of fuel to achieve thermal comfort in the analyzed models. The smallest total annual mass of emitted pollutants was registered when natural gas was used as the heating fuel, whereas the largest total annual mass was associated with the use of coal and wood biomass. The comparison of two models regarding the total annual mass of emitted CO_2 when coal was used for heating showed that the mass for the optimal model Op1 was 12,102.01 kg, or 78.12%, smaller than for model Op2.

ACKNOWLEDGEMENT
This paper is a result of a research supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia according to contract no. 451-03-9 / 2021-14 / 200148.