



Particulate Emission (PM₁₀ and PM_{2.5}) from Residential Wood Combustion in Bitola

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Abstract: An important source of atmospheric particulate matter PM₁₀ and PM_{2.5} in urban areas, especially in the winter period comes from burning firewood for individual house heating. In this regard, indicative measurements have been carried out on the mass concentration of the particles PM₁₀ and PM_{2.5} in the urban areas of Bitola. The measurements were carried out at three locations in the city, out of which the first is placed on the upper suburb area, the second in the downtown area (center) and the third at the lower suburb area of the city. Measurement locations were selected to be away from industrial pollutants, in the urban city area, in order to avoid industry's influence. Measurements were made in the months of October and November 2016 and February and March 2017. The results derived from the measurements shows that the concentration of PM₁₀ and PM_{2.5} emissions increased several times, compared to non-heating season period, as a result of firewood burning. Tabular and graphical displays of the same are part of this paper.

Keywords: residential firewood combustion, air pollution, particulate matters

1. Introduction

Lately, the problems caused by atmospheric particles in urban air are of growing attention. There are various sources of airborne particles, such as electricity generation, combustion processes in industrial facilities, suspended dust from roads and soil, biomass combustion and traffic. A significant source of emissions in winter is residential firewood combustion as a renewable and affordable fuel source for heating. Burning firewood contributes to the increase in total atmospheric particles and is notable source in regions with temperate and cold climates.

Unlike standard fossil fuels that generate greenhouse gases and impact on global climate change, burning wood is considered a sustainable energy source viewed from that perspective. Carbon dioxide emissions from burning wood for space heating energy is considered carbon neutral because it contributes to the process of the carbon cycle of the earth, i.e. it is considered that CO₂ emissions from burning wood will be equal to the emissions of CO₂ absorbed by wood in the process of photosynthesis. This is considered the main benefit for the environment during combustion of biomass and the main advantage of biomass compared to fossil fuels. Viewed from a local aspect, firewood can be a source of emissions of fine particles; volatile organic compounds and carbon monoxide that affect directly on the air into the urban environment. The emission of smoke as a product of residential wood combustion can cause short- and long-term health effects, including acute respiratory infections, tuberculosis, asthma, chronic lung disease, blindness, reduced weight and headaches. (Md. Aynul Bari, 2011)

The impact of residential wood combustion's emissions can be characterized as primary and secondary. The primary emissions are influenced by various parameters including the appliance which burns wood – the structure of the fireplace or stove, the regime of combustion including burning human's habits or controlled combustion with a sufficient amount of air which can lower emissions related to rampant insufficient amount of air, intake air humidity of the wood and the type of wood. Activities during the combustion of wood can vary in different regions and different seasons. Emissions can vary on hourly and daily basis depending on

the temperature and day of the week. Types of wood also depend on the region and can produce different rates of particle emissions. (Philip M. Fine, 2002)

Residential wood combustion for heat production is a major source of emissions of fine particles, polyaromatic hydrocarbons' particles (PAHs) and certain gaseous pollutants such as volatile organic compounds (VOCs). Particle emissions from combustion of firewood contain a large fraction of carbon materials consisting of elemental carbon and organic carbon as a result of incomplete combustion.

2. The process of residential wood combustion

Residential Wood Combustion is a chemical process where the fuel reacts with oxygen and releases heat. The combustion process can take place as a continuous or batch process, and air can be brought in forced or natural way. The process of burning wood consists of several stages: drying, pyrolysis, gasification and combustion (Van Loo and Koppejan, 2008).

In the first phase particles of wood is heated to a drying temperature leading to evaporation of water contained in the wood. Wood with a lot of water is difficult to ignite. Moisture evaporates at a temperature below 100 ° C. Drying the particles of fuel depends on the water content in the wood, the ratio of heat transfer and vapour pressure between the fuel and the environment.

Pyrolysis is essentially thermal decomposition of organic matter under inert atmospheric conditions or in a limited amount of air, leading to the release of volatile compounds and coal formation. Pyrolysis of wood begins at about 200°C and takes up to 450-500°C depending on the type of wood.

Pyrolysis is composed of several complex parallel and subsequent chemical reactions. In pyrolysis, the constituent elements of the fuel oxidized and dehydrated and large structures of cellulose, hemicelluloses and lignin are broken. Hemicelluloses decomposition occurs at a temperature of 200-350 ° C until the cellulose decomposes at a temperature of 250-450°C. Lignin decomposes at a temperature of 200-500°C. In the process of pyrolysis to form liquid and gaseous products, such as volatile organic compounds, water, carbon dioxide, carbon monoxide and hydrogen (Van Loo and Koppejan, 2008).

Gases in combustion are firing when the production of thermal energy is bigger than the heat that is expelled to the environment. Typically the products of pyrolysis burn as a diffuse flame around the particles of fuel and generate heat also for other reactions of pyrolysis. Pyrolysis gases oxidize molecules of air and the products of pyrolysis. Due to the increasing rate of heat, fuel temperature increases and accelerates the combustion gases while producing gas' pyrolysis tow.

During pyrolysis relationship carbon / hydrogen rises and begins burning the remaining charred wood charcoal. Burning the coal consist of reactions between gaseous products and partial reactions between gases and solid surface of the coal. The rate of mixing oxygen with the surface of the coal is very low and this limits the speed of combustion of the coal because burning charcoal is the slowest stage.

The process of Residential Wood Combustion can be implemented as a continuous combustion or in batches. Continuous and stable combustion process controlled by continuously adding fuel and combustion phases occur in the layers of the fuel. While burning in the series have a permanent separation of the stages of combustion in terms of position and time. The combustion process can be divided into three phases: ignition, combustion stage and phase of burning. Ignition phase is defined as the duration from the moment of ignition of the fuel until the required achieving minimum oxygen concentration. This phase includes drying, heating and initial stage pyrolysis combustion in batches. The phase of combustion is the time from achieving the minimum oxygen concentration until reaching the oxygen concentration of 14%. Stage combustion includes beginning and development of the flame. And the phase of burning is from that moment until the end of combustion. In each series all the stages of combustion occur repeatedly.

The most important parameters for complete Residential Wood Combustion are high temperature, air required for combustion and good mixing of the air by gases from combusting fuel. The combustion's temperature has the greatest impact for the complete fuel's combustion. At very high temperatures oxidation's reactions are faster and time for combustion is shorter. Supplying a sufficient amount of air is also an important parameter for completing combustion. The rate of gasification of wood is mostly controlled by air intake. Bringing air into the stoves of Residential Wood Combustion can be done by forced air or by naturally induced drafts. Too small draft leads to a lack of air and flame extinguishing. The

complete combustion requires good mixing of air and fuel gases sufficient time for oxidation flue gases. Good mixing reduces the required amount of air and provides high temperatures of combustion.

Many factors affect the combustion conditions and emissions. Burning firewood depends on its chemical properties (heating, reactivity), physical (heat capacity, thermal conductivity) and structural properties (particle size, density, and porosity). While emissions depend on operating practices as conditions of the season fuel, distribution of fuel in the combustion chamber, models of combustion and combustion rates.

2. The residential wood combustion's emissions

Emissions from Residential Wood Combustion can be divided into two groups: emissions from complete combustion (oxidized contaminants) and emissions from incomplete combustion (unburned pollutants). When burning wood, the combustion products are carbon dioxide, carbon monoxide, nitrogen, oxygen, water, hydrogen, unburned hydrocarbons, sulphur dioxide, nitrogen oxides, hydrogen chloride and particulate solid and a liquid phase.

In complete Residential Wood Combustion, products of combustion are only carbon dioxide, water and a small amount of particles (mostly organic). The most important parameters for the complete combustion at high temperature are sufficient amount of combustion inlet air and proper mixing of combustion air and fuel. The complete combustion is possible only in ideal conditions. In practice this never happens and the incomplete combustion is always present and results in emissions of incomplete combustion.

Carbon monoxide CO is the product of incomplete combustion. Oxidation of CO to CO₂ comes late in the reaction if there is a sufficient amount of oxygen. Just under ideal conditions, with sufficient oxygen, high temperatures and enough time around the carbon monoxide will oxidise into carbon dioxide.

Hydrocarbons are intermediate products in converting carbon fuel CO₂, and hydrogen fuel H₂O. They appear before the CO in the reaction, which means they have lower emission levels. Unburned hydrocarbons are due to the closing of the flame from the walls of the combustion chamber.

As a result of wood incomplete combustion, there is formation of particles in large quantities which is a serious problem for the environment. Emissions of particles from incomplete combustion can occur as smoke, soot and condensed heavy hydrocarbons (tar droplets). Carbon black is agglomeration of carbon particles, as a result of lack of oxygen in the flame zone. There are mainly three sources of primary particles by origin and mechanisms of formation that are emitted directly into the ambient air from combustion devices of wood as follows: particles of soot, particles and organic particles from the ash.

Burning wood with poor quality (high moisture content), overheating of the firebox or insufficient amount of air conditions that can lead to incomplete combustion of fuel which is characterized by low temperature. Emissions from such bad conditions of combustion dominate the organic carbon particles sized between 50 and 600 nm determined by electron microscopy (Anette Kocbach Bølling, 2009). These particles come from the degradation of components of wood (cellulose, hemicelluloses and lignin) at low temperature (300-500) °C without being further incinerated because of bad conditions of combustion. Particles arising from carbon in wood can be classified as organic and elemental carbon.

First fine particles are formed in the burning wood - particles of soot which are formed in the hydrocarbon flame. During incomplete combustion due to insufficient air at higher temperatures (800-1000)°C PM emissions are increasingly dominated soots. They are a complex mixture consisting of elemental carbon and organic material. Soot particles are formed mainly in the hydrocarbon flame. Most soot particles are formed by complex mechanisms inside the fire zone rich in fuel. Soot formation begins during hydrocarbon pyrolysis fragments that are separated from the fuel particles. These fragments disintegrate into small pieces and react with each other and with the gas surrounding them form aromatic rings. These aromatic rings then begin to form polycyclic aromatic hydrocarbons (PAH). Further PAH growth leads to the formation of soot (M. Obaidullah, 2012).

Pellets' combustion and wood boilers and stoves with modern technology provide favourable conditions for combustion at high temperatures (> 900°C), good supply of oxygen and sufficient mixing between gas and air in the combustion chamber. This results in almost complete combustion and exhaust emission is dominated by particles of inorganic ashes.

Solid fuels, such as wood, contain a significant amount of ash in the form of inorganic elements. During combustion, these inorganic species in the combustion products produce ash. Most of the ash formed in the combustion of wood remains the bottom of the oven. In addition a small fraction of ash called flying ash along with the exhaust is expelled into the environment. Emissions of particles of flying ash can be characterized as aerosols (size $<1\mu\text{m}$) and coarse particles from fly ash. The size of the particles of the coarse fly ash ranges from several micrometers to about 200 micrometers (M. Obaidullah, 2012).

Evaporation of the alkali metals of the fuel leads to the formation of fine particles of fly ash that appear in complete combustion of fuel. These fine particles are formed by nucleation, condensation, surface reactions, agglomeration and coagulation. The fine particles of fly ash with size of less than $1\mu\text{m}$ are formed from compounds such as KCl , NaCl , K_2SO_4 . (Mario Ortega, 2008)

3. Measurements and analysis

To measure the concentrations of suspended particles and determine the impact of burning firewood three locations are designated. One location is set in Brusnichka Quarter – Location 1 of peripheral urban part of town. This location is characterized by no traffic and no industrial combustion processes in the vicinity of the measuring point. In terms of particulate emissions for this location it is typical firewood burning in winter. The second measurement location is set in a park near the Elementary school “Stiv Naumov” – Location 2 and it is located in the urban part of the city in the downtown area characterized by relatively low frequency of traffic and no industrial combustion processes in the vicinity of the measuring point. Typical for this location in winter are the particulate emissions from the residential wood combustion and the third location is set in the lower peripheral part of the city in the suburb Streliste - Location 3. This location is different from the other two because of residential wood combustion influenced by traffic emissions in the immediate vicinity of the boulevard’s entrance to the city with a significantly high frequency of vehicles. Near this location is the industrial part of the city. For comparison of the measurement values from the set measuring locations are included the measurements from the stationary measuring station of the Ministry of Environment of the Republic of Macedonia, located in the central city area - location Bitola2. Characteristic for this measured location is the high frequency of vehicles and the impact of combustion of firewood from the Bair settlement located north of the measured location. Near this location there are no industrial facilities. Figure 1 shows the measurement locations.

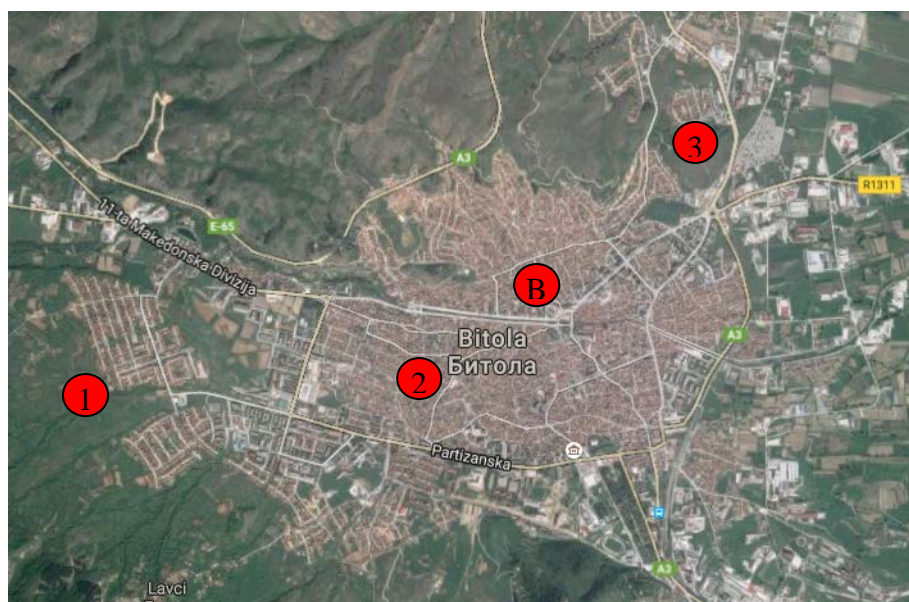


Figure 1. Overview of measurement locations to determine the concentration of PM_{10} and $\text{PM}_{2.5}$ in Bitola

Measurements are made with hand-held detector Turnkey-Dustmate. The instrument is set to environmental mode, measures TSP, PM_{10} , $\text{PM}_{2.5}$ and PM_1 and displays the measured values in $\mu\text{g} / \text{m}^3$. The operating temperature of the instrument is from -5°C to $+40^\circ\text{C}$. The measuring range of the instrument is from 0 to $>$

6000 $\mu\text{g} / \text{m}^3$ with a resolution of 0.01 micrograms. The measurements were made in an open space at pre-determined locations at a height of 1 meter from the surface of the ground.

Three consecutive measurements at each location were made, where the measuring device takes into account the average value of the measured values. They were made in the evening period at 7 pm from October 2016 - March 2017 in the span of 20 minutes. The first measurements were made in the period from 1st to 12th October. During this period no burning firewood happen because of the high ambient temperatures and since the heating season begins on 15th of October. The average measured temperature during the measuring period in October at 7 pm is 16.4°C. The second part of the measurements is made in the period from 7th to 25th November; this period is characterized as the beginning of the heating season. The measured average temperature during this period at 7 pm is 6.9°C. Third part of the measurements were made in the period from 6th to 13th February – time when the heating season is still going on and the concentrations of the particles reach high value before its end. The average temperature at 7 pm over that period was 5.2 C. And the last part of the measurements is made in the period from 6th to 13th March, where the heating season is nearing the end. The measurements are made in order to determine the impact and contribution of burning firewood on the ambient air.

The dispersion of particles in the urban part of the city, which comes from other sources such as energy production, are not considered in this research, because according to the Pilot program for improving the air quality in Bitola, prepared by the municipality of Bitola, it can be concluded that the highest concentrations of exhaust gases are not emitted in the city. The dispersion of nitrogen oxides and the dispersion of sulfur dioxide are calculated by the dispersion model UDM-FMI. As a result of the dispersion modeling calculations, the highest concentrations occur at 2-8 km south or east of the plant, while the city is 14 km west of the plant. According to the research with the dispersion model, the concentrations of nitrogen oxides and sulfur dioxide measured in the city are below the limit values for average, annual, daily and hourly concentrations. Such low concentrations are the result of the wind rose, that is, the constant flow of air masses in the north-south direction above the plant shown according to the study on desulfurization of REK Bitola, developed by AD Power plants of Macedonia. It is also not considered in this research because there are no significant industrial facilities in the city of Bitola, transport, and dust from roads and soil are not considered in this study. Also the influence of meteorological conditions such as wind, rain that affect particulate emissions are not taken into account. During the survey, it was taken in account the temperature and the relative humidity.

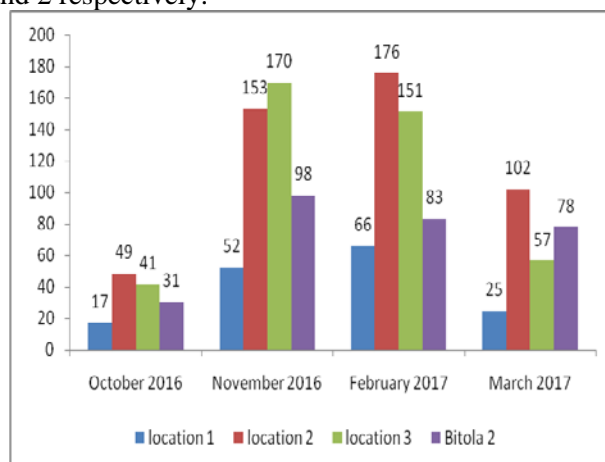
Table 1 shows the measurements performed in these periods. The table shows the measurement values of mass concentration given in $\mu\text{g}/\text{m}^3$ for particles up to 2.5 μm ($\text{PM}_{2.5}$) particles with a size of 10 μm (PM_{10}) in the three measurement locations.

Table 1: Overview of measurement values for the concentration of PM_{10} and $\text{PM}_{2.5}$ given in $\mu\text{g}/\text{m}^3$ at three measurement locations and from the existing measuring location and from the constant measuring location Bitola2

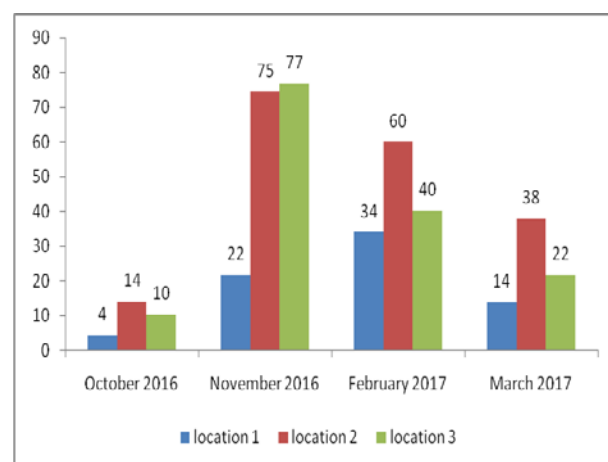
	Temperature	Relative humidity	LOCATION 1 PM_{10}	LOCATION 2 PM_{10}	LOCATION 3 PM_{10}	LOCATION B PM_{10}	LOCATION 1 $\text{PM}_{2.5}$	LOCATION 2 $\text{PM}_{2.5}$	LOCATION 3 $\text{PM}_{2.5}$
October 1, 2016	22.9	34	10.9	34.1	45.9	26.77	1.32	6.63	7.48
October 2, 2016	22.4	34	31.1	56.3	54	51.28	6.83	8.28	10.62
October 3, 2016	24.1	46	24.6	51.3	60.8	20.61	4.54	8.31	6.23
October 4, 2016	19.7	47	9.5	26,4	27.1	28.85	1.64	5.44	4.57
October 5, 2016	13.4	42	16.3	15.8	12.2	13.08	9.56	3.58	2.56
October 6, 2016	14.6	42	19.4	25	17.7	12.62	5.63	6.46	1.78
October 7, 2016	13.7	49	20.5	63.8	19.6	14.99	7.1	17.19	4.13
October 8, 2016	11.1	57	12.3	44.6	12	27.73	0.88	17.03	2.96
October 9, 2016	12.5	52	10	40.4	82.4	82.80	2.26	8.18	26.41
October 10, 2016	11.0	60	15.5	119.6	75.3	27.01	6.95	69.19	43.32
October 12, 2016	14.7	61	20.5	56	48.6	30.95	1.97	5.51	4.22

November 7, 2016	18.4	47	98	101	119.4	44.83	18.76	19.95	2.,72
November 8, 2016	14.3	56	81.5	129.4	86.1	86.7	12.69	39.25	23.98
November 9, 2016	10.5	40	31.5	130.6	72	108.16	21.08	90.3	14.79
November 10, 2016	11.3	41	13.8	111.3	238.7	76.66	1.53	21.77	28.54
November 11, 2016	9.4	51	27.3	170.1	109.5	81.72	6.46	65.12	54.77
November 13, 2016	5.6	46	25.5	121.2	85.7	35.56	6.93	38.32	19.52
November 14, 2016	5.1	44	40.3	62.2	73.4	55.97	18.38	27.21	18.08
November 15, 2016	3.3	48	32.5	65.3	40.7	81.91	18.1	32.9	17.68
November 16, 2016	2.7	52	39.1	150.9	105.5	/	19.05	81.9	56.69
November 17, 2016	3.8	45	15.6	93.5	189.4	/	5.42	47.88	78.63
November 18, 2016	5.4	45	35.3	117	171.3	130.04	14.48	68.12	78.29
November 19, 2016	6.6	48	22.8	111.5	359.8	160.06	9.64	46.47	244.77
November 21, 2016	5.1	48	31.8	131.1	146	94.05	12.42	58.53	78.5
November 22, 2016	4.5	48	68.2	146.8	352.5	133.55	15.55	65.39	135.12
November 23, 2016	3.8	47	41.5	159.3	187.4	118.9	15.13	71.52	86.06
November 24, 2016	4.3	46	237.2	428.4	326	157.14	144.34	263.72	212.4
November 25, 2016	3.3	47	49.1	371.7	224.6	105.08	27.03	229.01	133.91
February 6, 2017	6.5	42	21.6	69.1	32.8	38.87	6.94	31.01	12.08
February 7, 2017	6.5	42	34	124.6	98.7	91.91	17.05	81.64	59.21
February 8, 2017	5.5	44	11.6	204.8	79	/	5.14	101.4	29.21
February 9, 2017	5.2	44	96.6	114.3	151.9	/	82.05	81.94	92.42
February 10, 2017	4.6	43	84.8	338.3	285.7	95.30	42.05	43.12	21.66
February 11, 2017	4.5	37	98.2	139.4	172.9	78.22	56.01	31.78	27.13
February 12, 2017	3.5	43	110.6	153	189.3	77.29	18.64	33.64	35.99
February 13, 2017	5.5	42	69.1	264.8	199.7	117.29	44.24	76.05	44.87
March 6, 2017	11.5	39	28.6	140.8	56.1	74.75	14.79	44.22	10.78
March 7, 2017	10	40	21.5	107	58.2	39.27	7.33	16.27	12.94
March 8, 2017	7.5	38	13.4	89.6	31.5	157.3	8.59	70.36	16.67
March 9, 2017	10.8	41	36.7	213.2	140.7	122.5	18.44	60.03	59.13
March 10, 2017	8.8	39	12.5	20.5	23.1	29.32	8.76	12.46	11.61
March 11, 2017	5	38	35.6	65.7	68.5	54.00	23.08	25.6	25.43
March 12, 2017	5.8	41	27.8	43.5	37.8	82.25	18.32	31.95	27.58
March 13, 2017	6.4	40	21.4	135	36.7	62.93	12.11	41.59	9.01

From these measurements, the average concentrations of PM₁₀ are calculated and PM_{2.5} monthly for each location separately over the period. The average concentrations of PM₁₀ and PM_{2.5} are displayed on Graph 1 and 2 respectively.



Graph 1. Average amount of concentration of PM₁₀ in µg/m³ measured at 7 pm in those four locations



Graph 2. Average amount of concentration of PM_{2.5} in µg/m³ measured at 7 pm in those three locations

From graph 1 it can be only concluded that the average concentrations of PM_{10} in October on measuring location 1 is $17 \mu\text{g} / \text{m}^3$ which is rather low compared to other measurement locations which were $49 \mu\text{g}/\text{m}^3$ and $41 \mu\text{g}/\text{m}^3$ respectively. As noted previously these low concentrations are due to the fact that there are no indirect emission sources around the measuring location 1, and this location will have the biggest impact of burning firewood in winter. The average concentrations of $17 \mu\text{g}/\text{m}^3$ refers to the period when the heating season hasn't started and there is no burning firewood, while the other locations 2 and 3 have higher concentrations in the same period which indicates the presence of other sources emissions.

With the temperatures drop and the beginning of the heating season in November, it can be noticed an increase of the average PM_{10} concentrations at all measuring locations. The locations 1 and 2 have average concentrations increased about 3 times while the measuring location 3 is with 4 times increased value compared to concentrations measured in October.

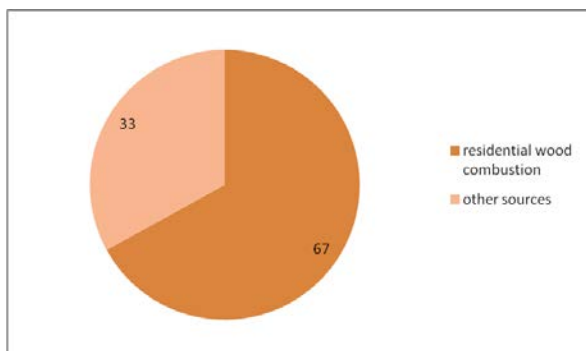
From the measured values in February it can be concluded that the high concentration of PM_{10} in the air is still present and is increasing at all three measurement locations. So that the average concentrations of PM_{10} in February increased about 21% compared to the measured values in November in the measuring location 1 and was increased about 3.9 times compared to the measured values for October on the same site. In terms of PM_{10} concentrations dimensional location 2 in February, they rose by 13% compared to November and increased 3.5 times compared to concentrations measured in October. Measured values are given for March in the period before the end of the heating season. From the average values of the measured concentrations it can be noticed decline in PM_{10} concentrations of measurement locations 1 and 3 in which the concentrations decreased by about 2.6 times compared to February, while the measuring location 2 concentrations reduced compared to February when they were still high.

From the measurement values obtained from the measuring station Bitola 2 we can conclude that the average concentrations of PM_{10} in November increased more than three times compared to October. While in the months of February and March, the average value of PM_{10} concentrations is about 2.5 times higher than in October. Values from this measured location show lower values compared to the locations 2 and 3 and higher values compared to the location 1 for the entire measuring period.

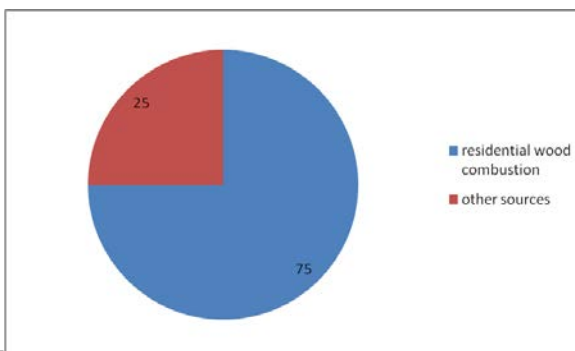
From graph 2 it can be concluded that the average concentrations of $PM_{2.5}$ in November at the beginning of the heating season rose dramatically compared to October and about 5.5 times in the locations 1 and 2 and 7.7 times in the location 3. From the measured values in February it can be seen that it increased compared to October - 4 times and locations 2 and 3 increased by 8.5 times than the location 1. This suggests that the rise of emissions of the surrounding air extraction slot PM_2 is higher than the increase in PM_{10} emissions due to burning firewood. The measured values for $PM_{2.5}$ in March indicate that burning wood is still present at all locations even though the values are significantly lower than in February.

According to the measured values over the period of measurement, the impact of PM_{10} emissions from the residential wood combustion on the total emissions of PM_{10} in the air is between 67-74% of the location 1, 67-72% of the location 2, 67-76% of the location 3, and 60-68% on the measuring location Bitola2. The graph 3 shows the impact of PM_{10} emissions from burning firewood on the total emissions of PM_{10} in ambient air extraction slot of the three locations which at least 67%.

From the data on $PM_{2.5}$ concentrations it can be concluded that the impact of $PM_{2.5}$ emissions from burning firewood on the total emissions of $PM_{2.5}$ is 82-88% of the location 1, 77-81% of the site 2 and 75-87 % location 3. The graph 4 shows the impact of $PM_{2.5}$ emissions from burning firewood on the total emissions of $PM_{2.5}$ in ambient air extraction slot of the three locations which is at least 75%.



Graph 3. The impact of concentrations of PM_{10} from the residential wood combustion on total emissions of PM_{10} in ambient air in Bitola in the period from October 2016 - March 2017 in %



Graph 4. The impact of concentrations of $PM_{2,5}$ from the residential wood combustion on total emissions of PM_{10} in ambient air in Bitola in the period from October 2016 - March 2017 in %

5. Conclusion

The burning of firewood proved to be the dominant source of emissions of PM_{10} and $PM_{2,5}$ in total emissions in the urban part of the city of Bitola during the winter. The average values of the performed measurements indicate consistently high concentrations during the measurement period at all measurement locations. Unlike location 2, at the locations 1 and 3 are measured lower values, which indicates that the downtown area is with higher emissions of particles compared to the peripheral parts of the city during the entire period of measurement. From individual measurements it can be noted that the highest concentration of PM_{10} and $PM_{2,5}$ has been measured at the location 2, while low values are measured at the location 1. Based on the performed analysis from the performed measurements we can conclude the following:

- The average value of concentrations measured at location1 in October before the start of the heating season compared to February indicates on increased concentration of PM_{10} by 4 times, at locations 2 and 3 increased by 3.5 times, while at the measuring station Bitola2 they increased by 2.5 times
- From the measured values of concentrations of $PM_{2,5}$ in February it is shown that it increased compared to October by 4 times the locations 2 and 3 and increased by 8.5 times at location 1.
- The impact of residential wood combustion on the total emissions of PM_{10} is at least 67% in all three measurement locations.
- The impact of residential wood combustion on the total emissions of $PM_{2,5}$ is at least 75% in all three measurement locations.
- The growth of emissions to the surrounding air extraction of PM_2 is higher than the increase in PM_{10} emissions due to residential wood combustion.

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