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Comparative analysis of the study of microclimate parameters in wooden houses in North-Eastern Bulgaria

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Comparative analysis of the study of microclimate parameters in wooden houses in North-Eastern Bulgaria

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Abstract. The subject of this study are some parameters of the microclimate in wooden houses in North-Eastern Bulgaria. This is necessary to identify the most influential parameters that affect human health and effectively improve energy efficiency in modern wooden residential buildings. Internal temperature, relative humidity and air speed and fine particulate matter were measured. External temperature and relative air humidity were also measured. The research results confirm that wood is a natural thermo-protective and moisture-regulating material. The analysis proposed can be applied to all energy efficiency projects in areas with similar climatic conditions.

1. Introduction

Prefabricated wooden buildings are an effective means of building private homes and are currently very popular in Europe and North America [1]. They have contributed to the transition of mankind from concrete structures to a life in a comfortable and natural environment [2]. Energy efficiency, healthy living environment, short time for construction and low prices are very important factors [3]. Wood is a natural heat-shrinkable [4] and moisture-regulating material [5]. Thus, an optimal balance of the natural air humidity is maintained in the house [6]. If the internal humidity level increases, the walls begin to absorb. If the air is too dry, the wood gives out the moisture absorbed. In this way the humidity in wooden houses is maintained steadily and permanently [7].

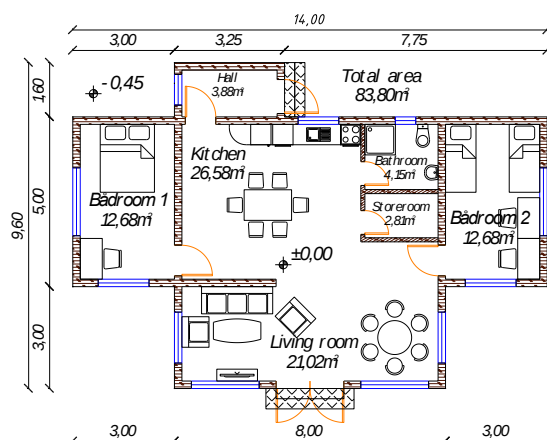


Figure 1. Floor layout of the Object 1.

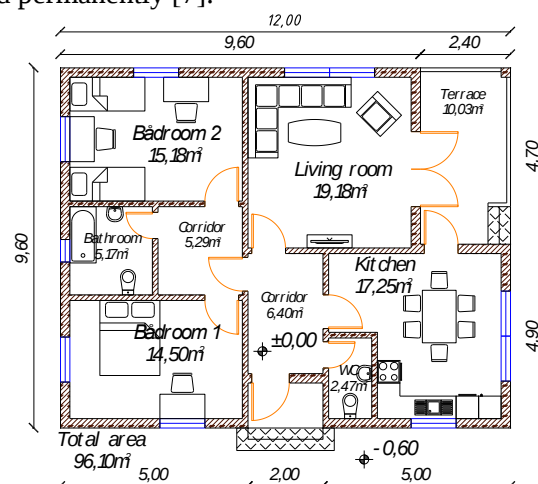


Figure 2. Floor layout of the Object 2.



Following various studies [8-9], it has been found that the complex air parameters in the rooms affect the lifestyle of the occupants and their comfort [10]. The research covers some of the microclimate parameters and some air quality indices in wooden buildings. The tests are carried out in two single-story houses with wooden elements incorporated in the façade walls located in the Black-Sea climatic region of North-Eastern Bulgaria as shown in Figure 1 and Figure 2 respectively. Object 1 is occupied by a family of two adults. The heating of Object 1 is a water jacket pellet stove developing a heat output of 13 kW and radiators connected to the collectors of the switchboards - a two-pipe system. Object 2 accommodates a three-member family. The heating in Object 2 is a water jacket stove producing a heat output of 13kW and a radiator arrangement identical to that in Object 1.

2. Research methodology

The measurements are made in two consecutive seasons - winter and spring, in randomly selected consecutive days for each season, thus meeting the minimum requirements for microclimate in buildings [11]. According to [12], the adopted fine particulate matter threshold limit values are as follows: PM10 average daily rate of 50 $\mu\text{g}/\text{m}^3$; PM10 average annual rate of 40 $\mu\text{g}/\text{m}^3$; PM2,5 average annual rate of 25 $\mu\text{g}/\text{m}^3$.

The following building microclimate parameters are measured: air temperature ($^{\circ}\text{C}$); relative humidity (%); air velocity (m/s) as well as air quality indices - concentrations of PM10 ($\mu\text{g}/\text{m}^3$) and PM2,5 ($\mu\text{g}/\text{m}^3$). Temperature, humidity and airflow, PM10 and PM2,5 concentrations are measured in 12-hour series. Air velocity and PM10 and PM2,5 concentrations are measured per second. Air temperature and humidity are measured at 10 s. The external temperature and the relative air humidity are also measured simultaneously with the measurements in the residential buildings. All internal measurements are taken in a living room about 1 m above the floor. All external measurements are taken outdoors at a height of about 2 m from the elevation of the adjacent terrain, in a place that has maximal protection against direct sunlight [13].

3. Results and Discussion

The results obtained and illustrated in figures 3 to 10 are used for a comparative analysis of the two wooden houses.

3.1. Object №1 is located in a rural area

3.1.1. Winter Season Measurements

The air speed in a room in Object №1 for the period from 20:17:46 h on 05.03.2017 to 07:55:03 h on 06.03.2017 (winter season) has an average value of 0.092 m/s. The average PM2.5 concentration is 6.22 $\mu\text{g}/\text{m}^3$, and the average PM10 concentration is 11.23 $\mu\text{g}/\text{m}^3$. The air velocity for this period is characterized by constant values – Figure 3. The registered PM2.5 concentrations are between 4 and 12 $\mu\text{g}/\text{m}^3$, showing a decreasing trend and the registered PM10 levels are between 22 and 6 $\mu\text{g}/\text{m}^3$. The humidity in the room is constant and is of about 40 %, while the outside air humidity fluctuates from 45 % to 72 %. The room temperature is constant between 20 – 21 $^{\circ}\text{C}$. The outside temperature varies between 7 $^{\circ}\text{C}$ and 13 $^{\circ}\text{C}$ – Figure 4.

The air speed in a room in Object №1 for the period from 08:57:46 h on 06.03.2017 to 19:57:07 h on 06.03.2017 (winter season) has an average value of 0.116 m/s. The average PM2,5 concentration is 8.50 $\mu\text{g}/\text{m}^3$ and the average PM10 concentration is 15.18 $\mu\text{g}/\text{m}^3$. Air velocity is characterized by constant values to 17:00 h, which is followed by variable air velocity values up to 19:57 h. The registered PM2.5 amounts are between 3 $\mu\text{g}/\text{m}^3$ and 14 $\mu\text{g}/\text{m}^3$ and the registered PM10 levels are between 5 $\mu\text{g}/\text{m}^3$ and 26 $\mu\text{g}/\text{m}^3$. Air humidity in the room is about 40 – 48 %, while the outside air humidity is 45 – 82 %. The temperature in the room is 20 – 21 $^{\circ}\text{C}$. The outside temperature is between 7 $^{\circ}\text{C}$ and 19 $^{\circ}\text{C}$.

The air speed in a room in Object №1 for the period from 9:57:07 h on 06.03.2017 to 08:00:07 h on 07.03.2017 (winter season) has an average value of 0.137 m/s. The average PM2.5 concentration is

5.75 $\mu\text{g}/\text{m}^3$ and the average PM10 concentration is 10.02 $\mu\text{g}/\text{m}^3$. Air velocity to 05:00 h is highly variable, which is followed by a period of constant values. The registered PM2.5 concentration is between 3 $\mu\text{g}/\text{m}^3$ and 8 $\mu\text{g}/\text{m}^3$ and the registered PM10 levels are between 7 $\mu\text{g}/\text{m}^3$ and 15 $\mu\text{g}/\text{m}^3$. Air humidity in the room is 40 – 50 % and the outdoor air humidity is 60 – 92 %. The room temperature is between 21 – 23°C. The outside temperature is between 3°C and 15°C.

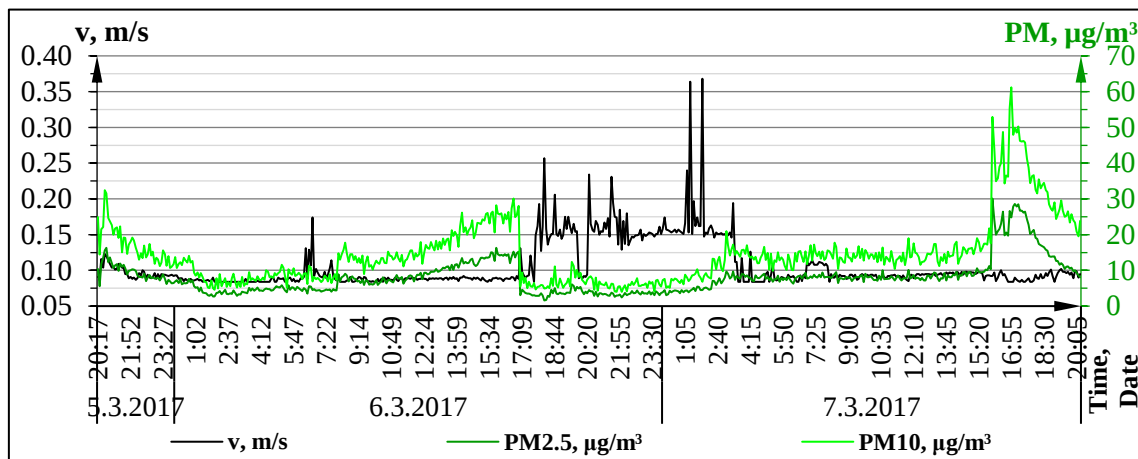


Figure 3. WINTER - Time distribution for 48h of air velocity and fine particulate matter – Object 1.

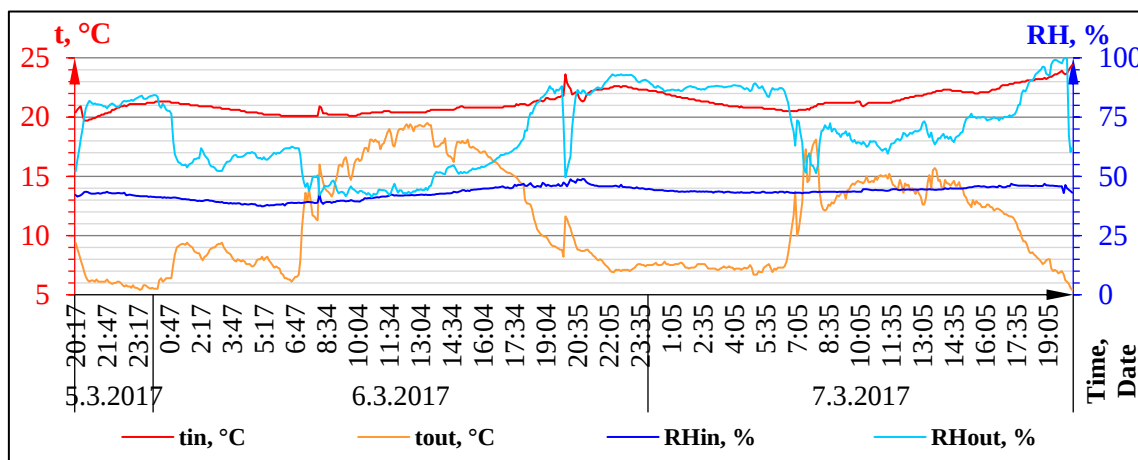


Figure 4. WINTER – Time distribution for 48h of temperature and relative humidity – Object 1.

The air speed in a room in Object №1 for the period from 08:00:07 h to 19:57:07 h on 07.03.2017 (winter season) has an average value of 0,098 m/s. The average PM2,5 concentration is 11,96 $\mu\text{g}/\text{m}^3$ and the average PM10 concentration is 21,91 $\mu\text{g}/\text{m}^3$. The air velocity is approximately constant. The registered PM2,5 concentration is between 3 $\mu\text{g}/\text{m}^3$ and 25 $\mu\text{g}/\text{m}^3$ and for the registered PM10 levels are between 14 $\mu\text{g}/\text{m}^3$ and 45 $\mu\text{g}/\text{m}^3$. The air humidity in the room is 40 – 42 %, and outdoor air humidity fluctuates from 62 % to 98 %. The room temperature is 21 – 23°C. The outside temperature varies between 7°C and 15°C.

3.1.2. Spring Season Measurements

The speed of the air in space of an object №1 for the period from 08:29:11 h on 08.05.2017 to 08:29:21 h on 09.05.2017 (spring season) has an average value of 0,126 m/s. The average quantity of

PM2.5 is $13.64 \mu\text{g}/\text{m}^3$ and average quantity of PM10 is $26.30 \mu\text{g}/\text{m}^3$. The air speed is slightly variable after which there is a strong increase due to the increased occupant's activity upon awakening from sleep – Figure 5. The recorded PM2.5 and PM10 levels increase by about 5 times after the tenth hour. The probable cause is the activity of the occupants. The room air humidity remains constant at about 60 %, while outside air humidity ranges from 88.4 % to 62 %. The internal temperature throughout the period is about 21 – 23°C. The outside temperature ranges from 11.2°C to 19.7°C – Figure 6.

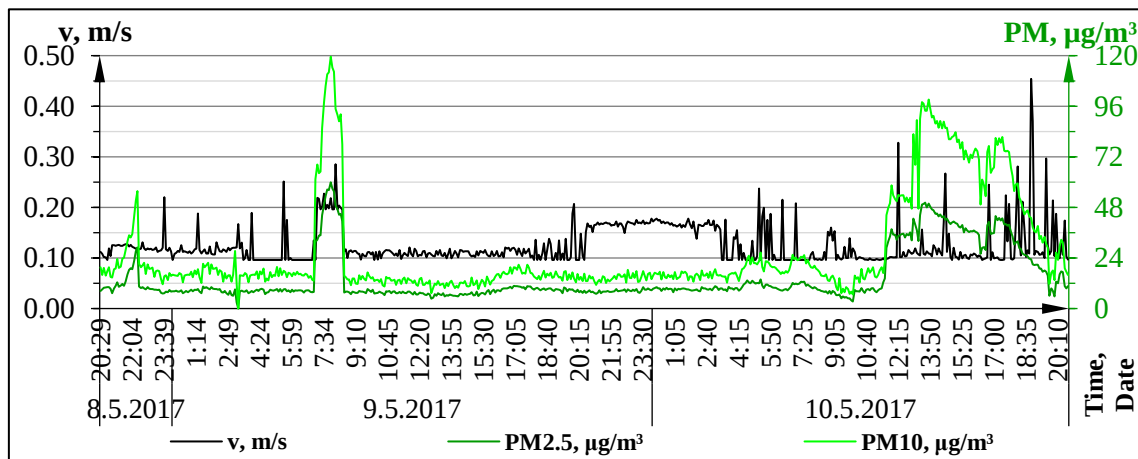


Figure 5. SPRING - Time distribution for 48h of air velocity and fine particulate matter – Object 1.

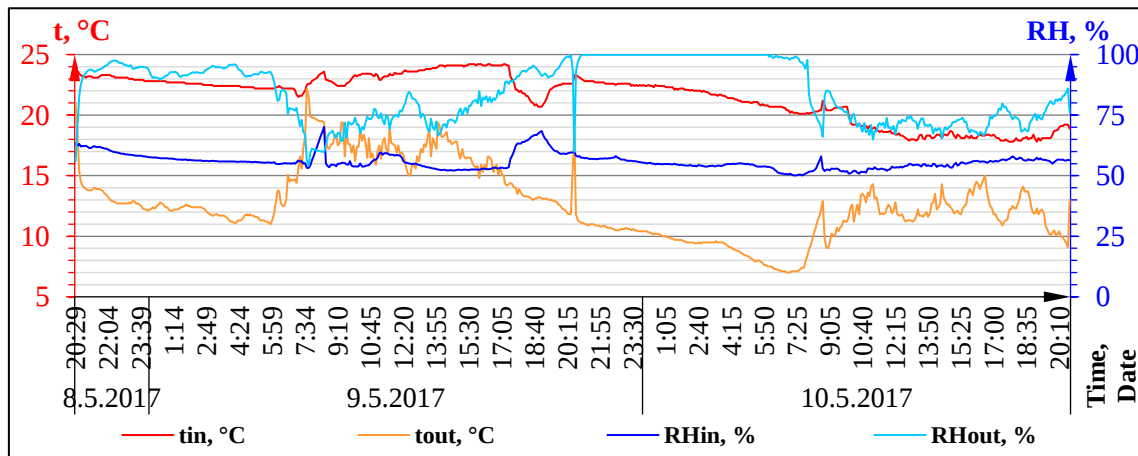


Figure 6. SPRING – Time distribution for 48h of temperature and relative humidity – Object 1.

The air speed in a room in Object №1 for the period from 08:35:09 h to 20:35:16 h on 09.05.2017 (spring season) averages 0.11 m/s. The average amount of PM2.5 is $7.95 \mu\text{g}/\text{m}^3$, the average amount of PM10 is $13.94 \mu\text{g}/\text{m}^3$. The air speed is constant. The registered PM2.5 concentration ranges between $6 \mu\text{g}/\text{m}^3$ and $10 \mu\text{g}/\text{m}^3$, and for PM10 it is between $10 \mu\text{g}/\text{m}^3$ and $18 \mu\text{g}/\text{m}^3$. Air humidity in the room is between 55 % and 65 %, and outside air humidity increases from 67.8 % to 92.2 %. The internal temperature increases from 20°C to 24°C. The outside temperature drops to 12.6°C.

The speed of the air in space of an object №1 for the period from 20:37:11 h on 09.05.2017 to 08:29:21 h on 10.05.2017 (spring season) has an average value of 0.121 m/s. The average quantity of PM2.5 is $13.28 \mu\text{g}/\text{m}^3$ and average quantity of PM10 is $25.58 \mu\text{g}/\text{m}^3$. The air speed is slightly variable after which there is a strong increase due to the increased occupant's activity upon awakening from

sleep. The recorded PM2.5 and PM10 levels increase by about 5 times after the tenth hour. The probable cause is the activity of the occupants. The room air humidity remains constant at about 62 %, while outside air humidity ranges from 72.6 % to 61.5 %. The internal temperature throughout the period is about 21 – 23°C. The outside temperature ranges from 10.8°C to 18.9°C.

The air speed in a room in Object №1 for the period from 08:40:10 h on 10.05.2017 to 20:45:38 h on 10.05.2017 (spring season) averages 0.143 m/s. The average amount of PM2.5 is 26.90 $\mu\text{g}/\text{m}^3$, the average amount of PM10 is 49.99 $\mu\text{g}/\text{m}^3$. The air speed is variable. The registered PM2.5 amounts to between 6 $\mu\text{g}/\text{m}^3$ and 44 $\mu\text{g}/\text{m}^3$ and for PM10 the concentration is between 10 $\mu\text{g}/\text{m}^3$ and 85 $\mu\text{g}/\text{m}^3$. Air humidity in the room ranges from 51 % to 55 %, and the external air humidity drops from 80.8 % to 70.2 % and stays at these levels. The room temperature decreases from 17.5°C to 15°C during the 5th hour and stays at these levels. The outside temperature fluctuates between 10°C and 14°C.

3.2. Object 2 is located in a suburban area

3.2.1. Winter Season Measurements

The air speed in a room in Object №2 for the period from 20:13:07 h on 02.03.2017 until 08:00:07 h on 03.03.2017 (winter season) has an average value of 0.214 m/s – Figure 7. The average amount of PM2.5 is 28.84 $\mu\text{g}/\text{m}^3$ and the average amount of PM10 is 51.77 $\mu\text{g}/\text{m}^3$. The average values of the room air parameters are: humidity – 64.7 %, temperature – 18.3°C. The average values of outdoor air parameters are: humidity – 77.9 %, temperature – 6.2°C – Figure 8. The internal air speed is variable due to effect of the heating system.

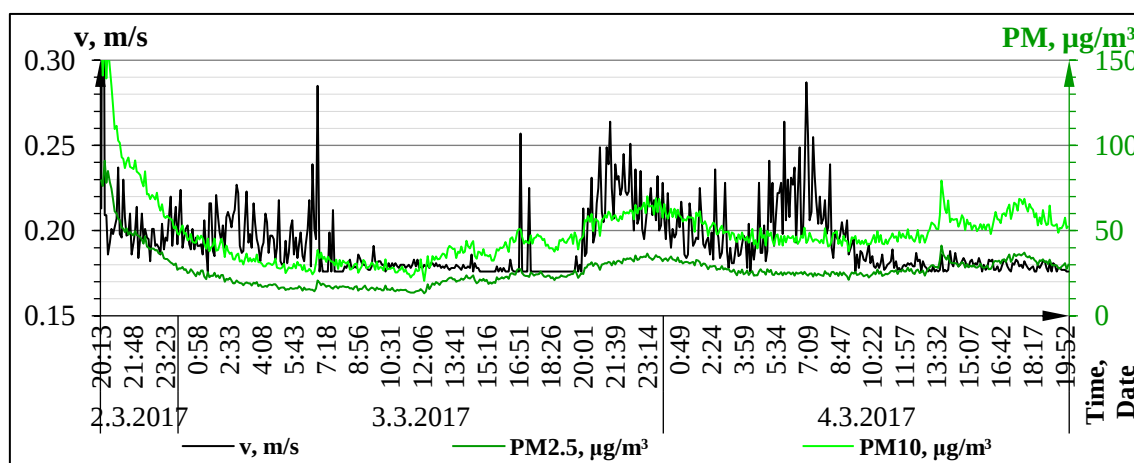


Figure 7. WINTER - Time distribution for 48h of air velocity and fine particulate matter – Object 2.

The air speed in a room in Object №2 for the period from 08:19:07 h until 20:00:07 h on 03.03.2017, (winter season) averages 0.179 m/s. The average concentration of PM2.5 is 28.69 $\mu\text{g}/\text{m}^3$, that of PM10 is 52.45 $\mu\text{g}/\text{m}^3$. The average values of the room air parameters are: humidity – 61.2 %, temperature – 20.3°C. The average values of outdoor air parameters are: humidity – 73.4 %, temperature – 5.7°C. The air velocity for this period is characterized by relatively constant values.

The air speed in a room in Object №2 for the period from 20:22:07 h on 03.03.2017 to 08:22:07 h on 04.03.2017 (winter season) has an average value of 0.206 m/s. The average amount of PM2.5 is 28.90 $\mu\text{g}/\text{m}^3$ and the average amount of PM10 is 52.61 $\mu\text{g}/\text{m}^3$. The average values of the room air parameters are: humidity – 51.5%, temperature – 18.4°C. The average values of outdoor air parameters are: humidity – 54.4 %, temperature – 13.3°C. The air velocity for this period is characterized by variable values within a short interval.

The air speed in a room in Object №2 for the period from 08:22:07 h to 20:17:07 h on 04.03.2017 (winter season) has an average value of 0.181 m/s. The average amount of PM_{2,5} is 28.8 $\mu\text{g}/\text{m}^3$ and the average amount PM₁₀ is 52.2 $\mu\text{g}/\text{m}^3$. The average values of the room air parameters are: humidity – 51.5 %, temperature – 22.8°C. The average values of outdoor air parameters are: humidity – 54.6 %, temperature – 13.3°C. The air velocity for this period is characterized by constant values.

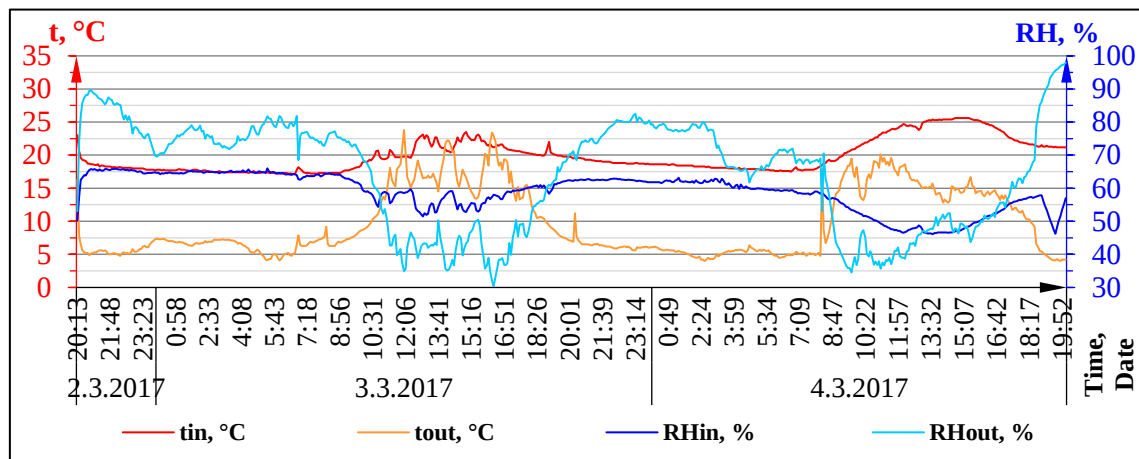


Figure 8. WINTER – Time distribution for 48h of temperature and relative humidity – Object 2.

3.2.2. Spring Season Measurements

The air speed in a room in Object №2 for the period from 08:08:07 h to 20:10:02 h on 28.04.2017, (spring season) averages 0.171 m/s – Figure 9. The average amount of PM_{2,5} is 25.15 $\mu\text{g}/\text{m}^3$ and that of PM₁₀ is 43.25 $\mu\text{g}/\text{m}^3$. The average values of the room air parameters are: humidity – 52.5 %, temperature – 23.7°C. The average values of outdoor air parameters are: humidity – 47.3 %, temperature – 17.3°C – Figure 10. Air velocity is characterized by variable values.

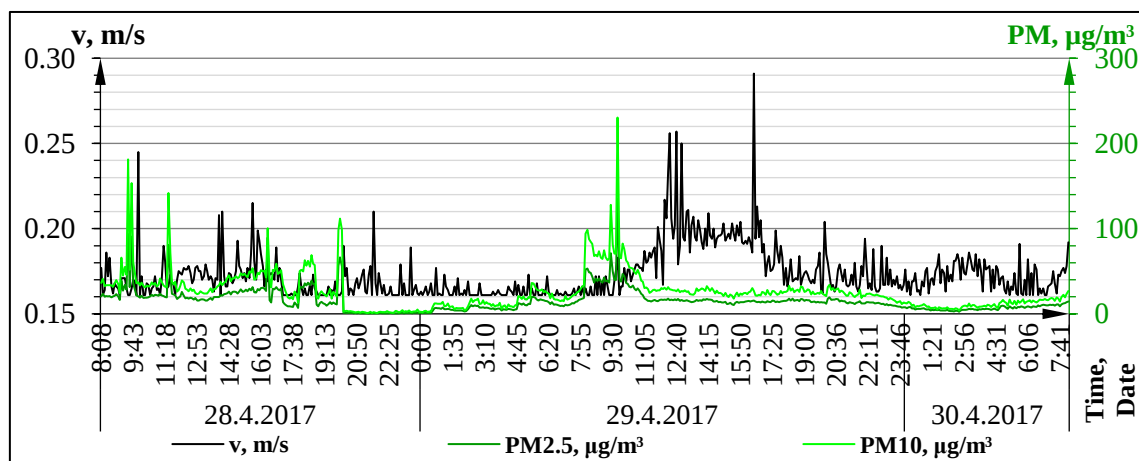


Figure 9. SPRING - Time distribution for 48h of air velocity and fine particulate matter – Object 2.

The air speed in a room in Object №2 for the period from 20:10:07 h on 28.04.2017 until 08:10:02 h on 29.04.2017, the spring season averaged 0.166 m/s. The average amount of PM_{2,5} is 6.12 $\mu\text{g}/\text{m}^3$, PM₁₀ is 10.8 $\mu\text{g}/\text{m}^3$. The average values of the room air parameters are: humidity – 57.5 %, temperature – 23.7°C.

temperature – 21.6°C. The average values of outdoor air parameters are: humidity – 73.3 %, temperature – 8.7°C. Air velocity is characterized by relatively constant values.

The air speed in a room in Object №2 for the period from 08:10:02 h to 20:10:02 h on 29.04.2017 the spring season averages 0,186 m/s. The average amount of PM2.5 is 21.04 $\mu\text{g}/\text{m}^3$ and the average amount of PM10 is 36.42 $\mu\text{g}/\text{m}^3$. The average values of the room air parameters are: humidity – 57.2 %, temperature – 24.5°C. The average values of outdoor air parameters are: humidity – 54.12 %, temperature – 18.3°C. The air velocity for this period is variable.

The air speed in a room in Object №2 for the period from 20:10:02 h on 29.04.2017 to 08:11:20 h on 30.04.2017 (spring season) has an average value of 0.168 m/s. The average quantity of PM2,5 is 8.8 $\mu\text{g}/\text{m}^3$ and the average amount of PM10 is 15.09 $\mu\text{g}/\text{m}^3$. The average values of the room air parameters are: humidity – 58.2 %, temperature – 23.6°C. The average values of outdoor air parameters are: humidity – 67.4 %, temperature – 13.6°C. The air velocity for this period is variable.

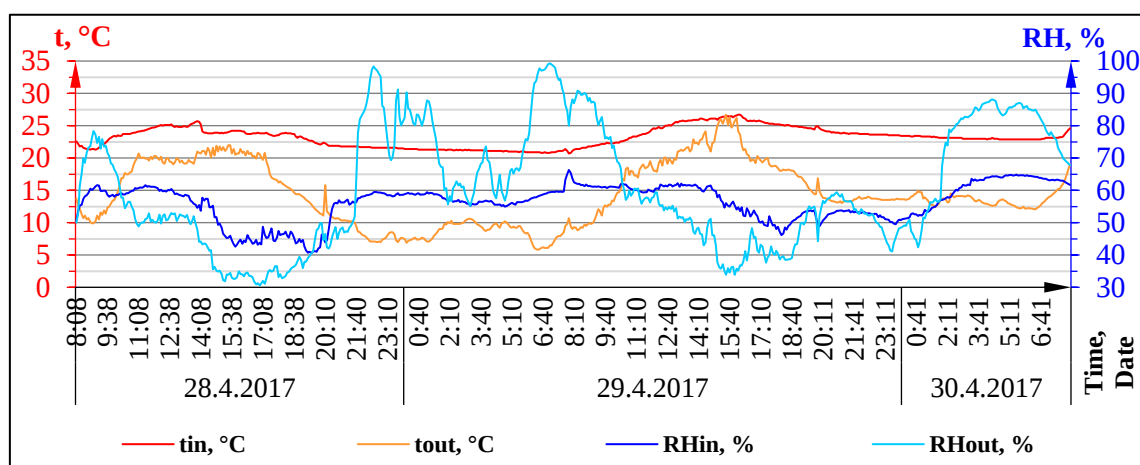


Figure 10. SPRING – Time distribution for 48h of temperature and relative humidity – Object 2.

4. Conclusions

The comparative analysis of the studies conducted shows that in both wooden houses the average quantity for PM2.5 is 21 $\mu\text{g}/\text{m}^3$ and for PM10 is 38 $\mu\text{g}/\text{m}^3$ is several times lower than the limit values according to the legislation of Bulgaria. Room air velocity is lower than the maximum acceptable for the minimum microclimate requirements of up to 0,187 m/s. The optimal air humidity is between 40 % and 60 %, and the maximum humidity is between 30 % and 75 %. There is a tendency for stable relative air humidity to be maintained in the investigated premises, irrespective of relative humidity fluctuations in the outside air, whereupon the wooden components are an "internal regulator" of relative humidity. The analysis of temperature dependences shows that the external temperature does not have a significant effect on the internal temperature, which proves the good insulation properties of wooden houses and their ability to maintain normal microclimate parameters. The analysis of results can be applied to all energy efficiency projects in regions with similar climatic conditions.

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