IMEKO TC11 & TC24 Joint Hybrid Conference
October 17-19, 2022, Dubrovnik, Croatia

ENVIRONMENTAL WIRELESS SENSOR MONITORING AND ESTIMATION OF GREEN INFRASTRUCTURE LOCATION IMPACT ON PARTICULATE MATTER REDUCTION FOR IMPROVED AIR QUALITY

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Abstract:

Low quality of the air is becoming a major concern in urban areas. High values of particulate matter (PM) concentrations and various pollutants may be very dangerous for the human health and the global environment. The challenge to overcome the problem with the air quality includes efforts to improve healthy air not only by reducing emissions, but also by modifying the urban morphology to reduce the exposure of the population to air pollution.

The aim of this paper is to analyze the influence of the green zones on air quality mitigation through measurements, and to identify the correlation with the meteorological factors.

Keywords: air pollution monitoring; PM concentrations measurements; meteorological factors

1. INTRODUCTION

Among the highest environmental risks for human health is air pollution. Major air pollutants in urban cities include particulate matter (PM), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), nitrogen oxides (NO_X), and volatile organic compound (VOCs) [1].

Except for human health, these pollutants can be serious danger to monuments and artwork, especially the memorials located in the city centres [2]. Research presented in [3], [4] show an increased rates of death, that have been associated with an increased air pollutants concentration (such as O_3, PM and SO_2). According to the report presented in [5], air pollution is a major cause of death in many European countries, responsible for more than 400000 premature deaths.

Various methods to deal with the air pollution are presented in many research works. One simple and innovative solution that is being applied for some time in many countries is by implementing green walls, green facades and green buildings for air pollution mitigation. Such measurement systems have been applied in many countries such as: Switzerland, Sweden UK, USA, Spain [6]. Some of the benefits of implementing vertical green walls and green roof surfaces on facades of the buildings are: improving the thermal characteristics of the objects, reducing the noise level as well as reducing the energy requirements of the facilities which lead to an air quality improvement [7].

In order to overcome the urban environmental problems some authors have analysed the effects of vegetation, particularly trees, on cooling urban air, shading buildings and absorbing gaseous air contaminants [8],[9]. Researchers in [8] measured the influence of the tree planting and re-roofing on ambient temperatures and air pollution. The experiments derive that the ambient temperature can be lower by up to 3° C and the air around the building can be cooler by implementing trees combined with cool roofs. In other works researchers have examined that the levels of air pollution can be reduced when wind blows, the particulates (PM2.5 and PM10) stick to the leaves and stems of the plants [10].

The research presented by [11] shows that the green area mitigates the PM of 2.5 or less micrometers (PM2.5) on average by 25% and PM of 10 or less micrometers (PM10) on average by 37% compared to the neighbouring non-green areas. The results show a strong correlation between PM2.5 and PM10, while the combination of low temperatures, high humidity and no, or low wind speed lead to high PM concentrations. The results presented in [12] show that the weather information parameters such as wind, temperature and humidity are correlated with air pollution, which allows to pose a machine learning air pollution model based on weather information and historical measurement data on the pollution.

Air quality measurement system consists of wireless sensor nodes (WSNs). Each sensor node includes a power unit, sensors for different gaseous pollutants measurement, a microprocessor and a transceiver. The air quality monitoring system is developed as a low - cost and energy - efficient replicable system, confirmed in the analysis presented in [13] and are associated with its implementation, replication and the consumption of the WSNs.

The paper researches related to the estimation of the impact of the relative position of the measurement sensors and the disposition of the green zones will be presented. The investigations will provide analysis on the particular influences of the meteorological factors, such as wind speed and direction, relative humidity, and temperature on air quality and their impact on particulate matter mitigation, based on measurement data, and argumented prognosis which parameter has the highest influence on the PM concentrations.

2. METHODS

The experimental measurement set up is located on a position near the Faculty of Electrical Engineering and Information Technologies in Skopje.

2.1. Test equipment

In order to see the influence of the green areas, movement of traffic and people, different position of the sensor nodes were chosen. Near the location of the sensor nodes there is a small green area (as a part of the building patio), one small building and a parking place. As depicted in Figure 1, the sensor node 1 is close to the pedestrian pavement, sensor node 2 is located near the green area and node 3 is positioned close to the Faculty parking place.

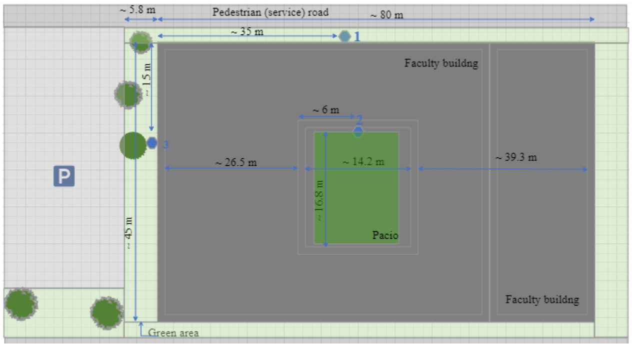

Figure 1: Position of the sensor nodes at the Faculty building

Position of the sensor nodes was chosen to be on different locations in order to see the influence of the environment and meteorological factors on the air pollution reduction.

2.2. Measurement system description

The originally developed measurement system based on wireless sensor network technology is composed of particulate matter and gas sensors for monitoring the parameters of the air quality. The measurement monitoring system consists of three sensor nodes each of them containing four sensors and a Wi-Fi module integrated on a single-board controller. Sensors integrated in each node can measure the following parameters: particulate matter 2.5 or less micrometers (PM2.5), particulate matter 10 or less micrometers (PM10), CO and NO_2.

Figure 2: Sensor node box including sensors, microprocessor, Wi-Fi module

SDS011 [14] is an integrated PM2.5 and PM10 sensing unit for measurement the concentration of particulate matter. The principle of operation is by using the technique of laser scattering. This sensor unit can get the particle concentration between 0.3 and 10μm. The basic characteristics of this unit are: accurate, reliable and quick response. Less than 10 seconds is the response time when the scene changes. The resolution of the sensor unit is $0.3\mu g/m^3$.

A combined CO and NO_2 used for these measurement set-up is MiCS-4514 [15]. These are two sensors in one SMD package with miniature dimensions. High sensitivity, wide detection range and low heater current are some of the main characteristics of this sensor unit. Detection of the polluted gases can be achieved by measuring the sensing resistance of both sensors: reduced sensor resistance in the presence of CO decreases, while oxygen sensor resistance in the presence of NO2 increases.

The integrated controller is responsible for processing the data, before they are transmitted to the network. ESP32-WROOM-32D [16] is a powerful module that covers wide range of applications, from low – power sensor networks, to the most demanding tasks like voice encoding, music streaming. At the core of the module is the ESP32-D0WD chip. ESP32 combines a set of Hall sensors, capacitive touch sensors, SD card interface, high speed SPI, UART, Ethernet, I2S and I2C. The sleep current mode of the ESP32 chip is less than 5 µA. This value of the sleep current mode makes the module suitable for battery powered and wearable electronics applications. ESP32 supports a data rate of up to 150 Mbps, and 20.5 dBm output power at the antenna to ensure the widest physical range.

The task of the Wi-Fi module is to send the data to the closest router at the Faculty building. The data is then uploaded on an open platform (Internet of Things open platform, 2020) and can be monitored on-line or downloaded for additional analyses.

Further information and technical specifications of the used hardware can be found in [11].

The sensor node box including sensors, microprocessor and the Wi-Fi module is shown in Figure 2.

3. AIR QUALITY GUIDELINE VALUES FOR PARTICULATE MATTER CONCENTRATION

The range of the negative effects of the polluted air is wide, but are predominantly to the respiratory and cardiovascular systems. The risk categories of the population may vary with health problems or age.

An annual average concentration of 10 µg/m^3 was chosen as the long-term guideline value for PM2.5, while the annual average concentration of 20 µg/m^3 was chosen as the long-term guideline value for PM10. The short-term guide value for PM2.5 was chosen to be 25 µg/m^3, while the same value for PM10 was chosen to be 50 µg/m^3.

Besides the guideline value, three interim targets (IT) are defined for PM2.5 as presented in Table 1. These have been shown to be achievable with successive and sustained abatement measures. Many countries including Republic of North Macedonia may find these interim targets particularly helpful in gauging progress over time in the difficult process of steadily reducing population exposures to PM.

Table 1: WHO air quality guidelines and interim targets for particulate matter: annual mean concentrations [17]

	PM10	**PM2.5**	**Basics for the selected level**
Interim target -1 (IT-1)	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target -2 (IT-1)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2–11%] relative to the IT-1 level.
Interim target -3 (IT-1)	30	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [2-11%] relative to the -IT-2 level.
Air quality guideline	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM2.5

4. MEASUREMENT RESULTS

The air quality measurement system has started with the acquisition of the measurement data in May 2018 at the Faculty of Electrical Engineering and IT in Skopje.

This paper presents measurement periods taken during the summer months concentrating on the period June 2020-October 2020, which was the period when the World Health Organization (WHO) declared COVID pandemic. The measurement set for the period December 2018-February 2019 when the air pollution is usually higher compared to summer months was already presented in [11]. The highest PM concentrations, which reach the values of 306 µg/m^3 for PM2.5 and 391 µg/m^3 for PM10 and occurred around midnight on 19th of January 2019, have been measured. These values are far above the allowed annual average PM concentrations for PM2.5 and PM10.

In this paper the measurement period is selected to be during the summer months and even more during the COVID-19 pandemic. This was the period when the Faculty building and the faculty staff were mainly working from home, the exams and the lessons were held online. At that period the traffic in the campus was drastically reduced compared to the years before.

The graphs on Figure 3 and Figure 4 present hourly average data for PM2.5 and PM10 concentrations respectively, including the first analysed period of about 9 days, starting from 28th of June 2020 until 6th of July 2020, and serve to show typical summer days, with periods of low PM concentrations. Even more this is the period when the first anti-Covid restriction rules (quarantine) started according to the World Health Organization. The values for PM2.5 and PM10 concentrations are in the range of the allowed annual average PM concentrations.

The analysed periods show higher average values of PM concentrations during the day, then during the night-time.

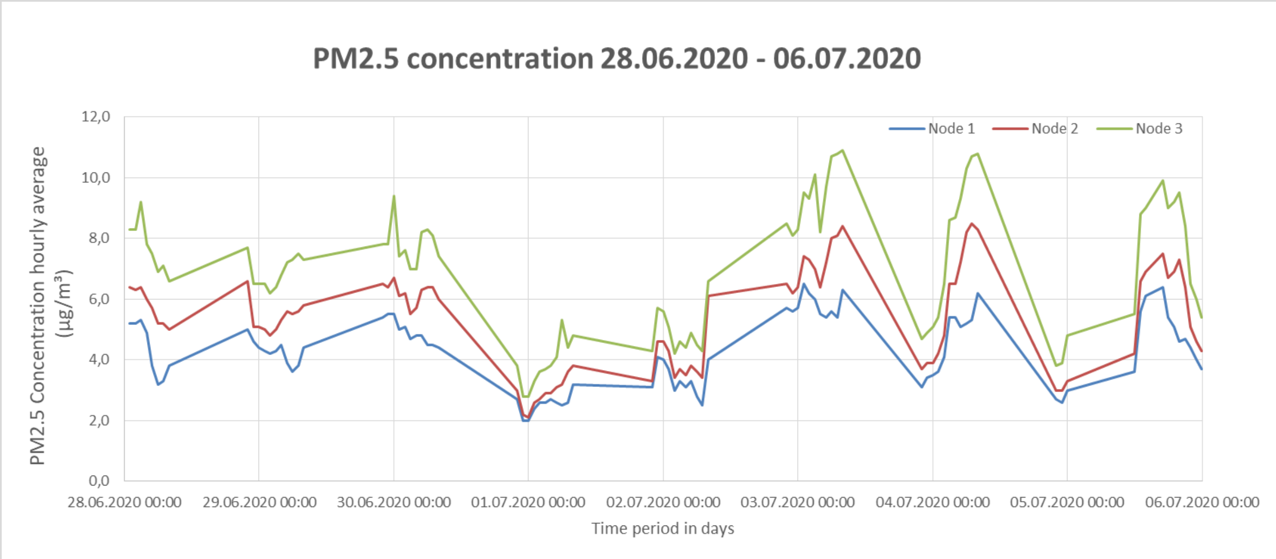

Figure 3: Concentration of PM2.5 for 9 days, average hourly data

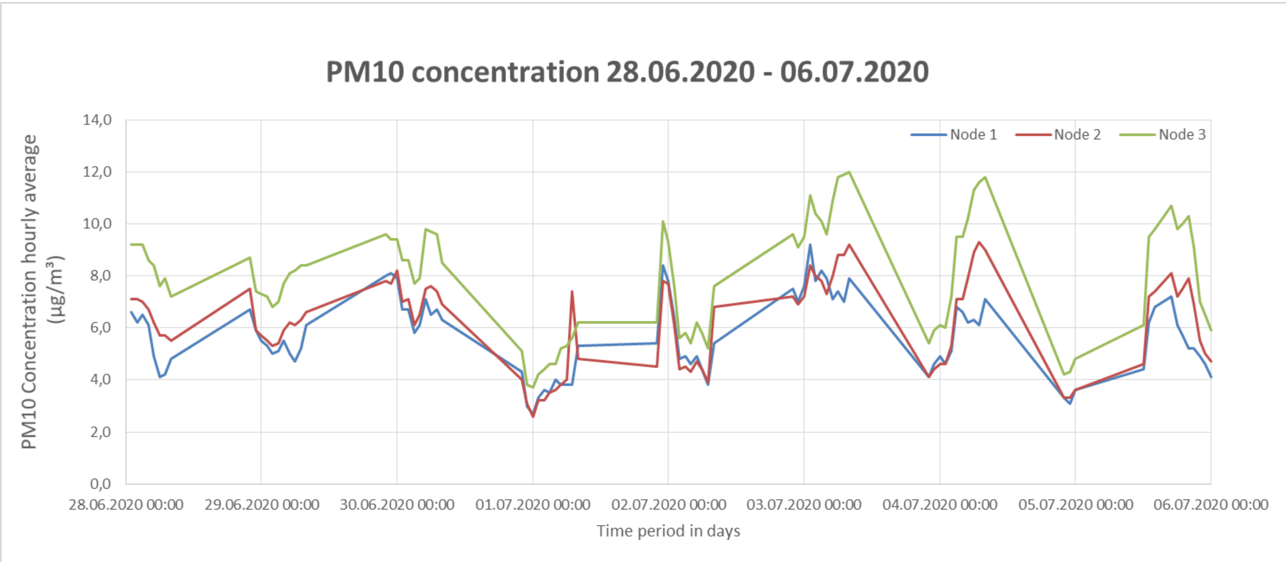

Figure 4: Concentration of PM10 for 9 days, average hourly data

The graphs on Figure 5 and Figure 6 present hourly average data for PM2.5 and PM10 concentrations respectively, for the second analysed measurement period of about one week, starting from 5th of October 2020 until 13th of October 2020 also the period during COVID-19 pandemic, but at this time no quarantine rules were applied. The values for PM2.5 and PM10 concentrations show slightly bigger values compared to the first measurement period.

Also, it can be noticed that the concentration of PM2.5 is higher at the location of Node 2 (than at Node 1) but lower for PM10 (it is important to note that this sensor is locate in the building patio). The highest value for PM2.5 and PM10 concentration is noticed at node 3, which is located near the parking place.

The results presented in Figure 3, Figure 4, Figure 5 and Figure 6 suggest that there is a difference between the concentration of PM concentration (PM2.5 and PM10) on these three different locations (during the whole period, daytime and night-time). These results indicate that during night-time the level of PM concentration is lower compared to the PM concentration during daytime, which was not case during the winter months. The highest values for PM concentration for winter months were reached during night-time.

With the regression model implemented on the measured data from the period June 2020-October

2020, the considered meteorological factors (temperature, humidity, pressure and wind speed) have more influence on the location of the Node 2 than on the other two locations. Even more, the influence of the meteorological factors is more affected on the PM2.5 concentration than on the concentration of PM10, and more during daytime than during night-time as it is presented in Table 2. The analysis shows a weak negative correlation between the wind and PM concentration, and a slightly stronger correlation between the real temperature and PM concentrations.

Statistical tools like Mann-Whitney and ANOVA [18] were deployed for estimation of the the influence of the sensor node location and the other conditions that have significant influence on PM concentration. Some of the derived results were presented in [19].

Table 2: Meteorological factors influence on the PM concentration for the observed period in %

	PM10		PM2.5	
	day	night	day	night
Node 1	5.4	3.8	8.9	7.5
Node 2	9.0	8.1	13.9	11.5
Node 3	6.9	6.5	10.3	9

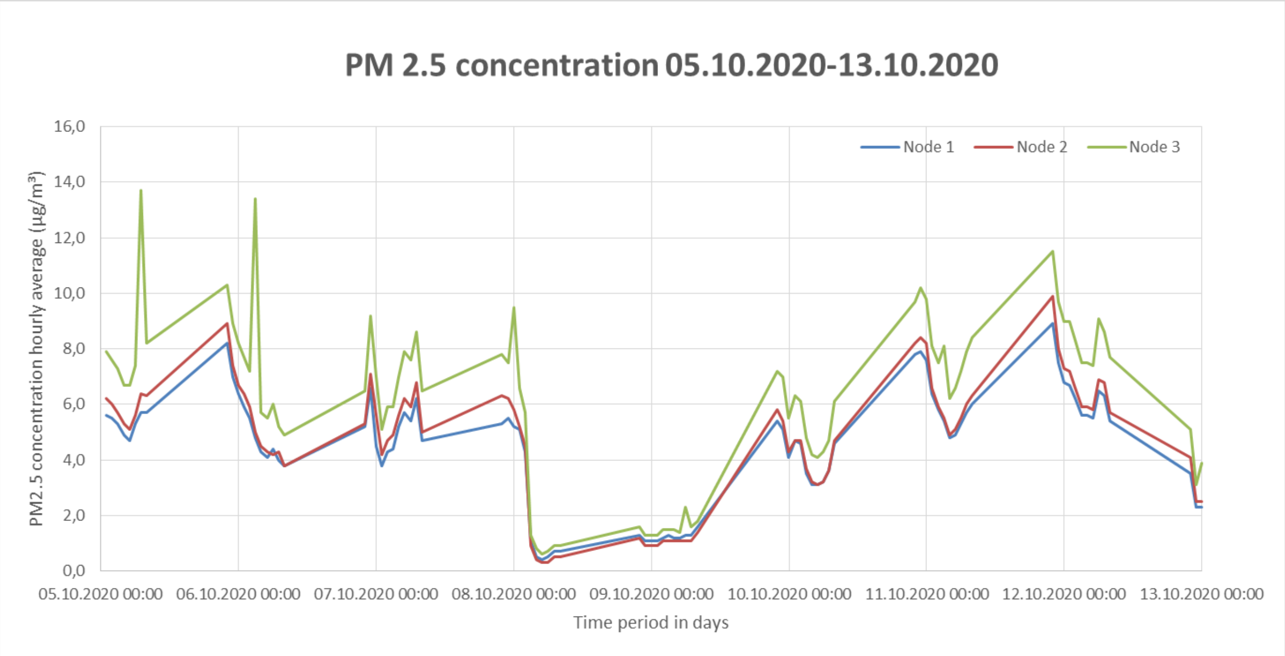

Figure 5: Concentration of PM2.5 for one-week, average hourly data

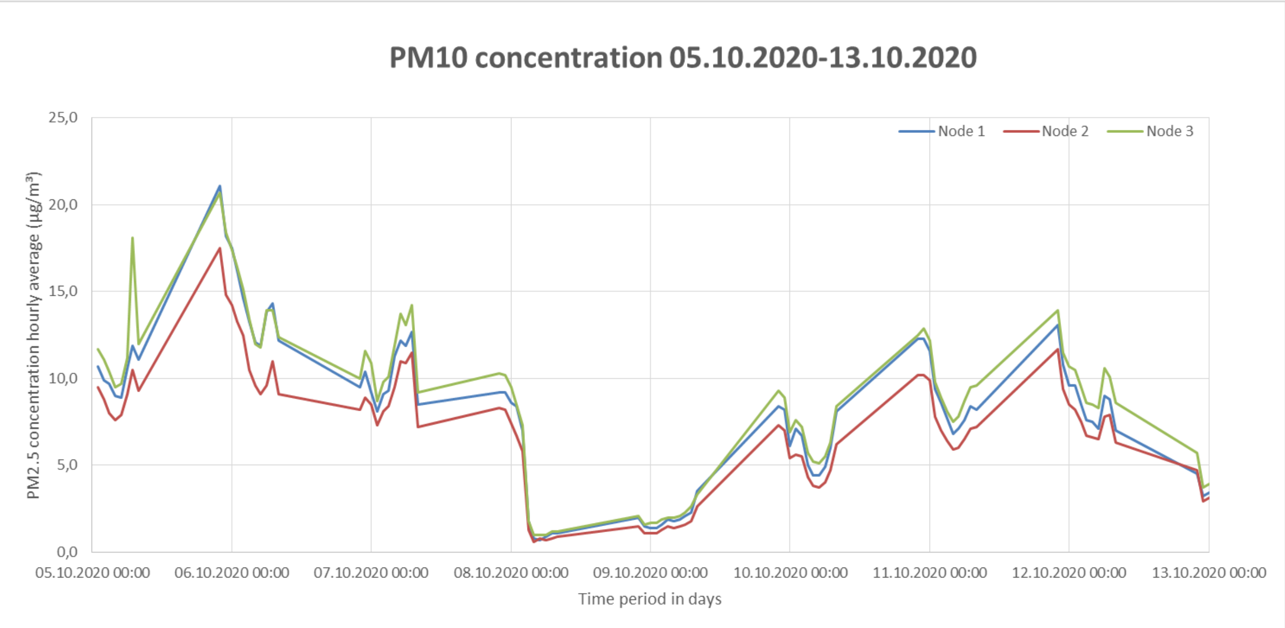

Figure 6: Concentration of PM10 for one-week, average hourly data

5. CONCLUSION

In this paper an air quality measurement system for particulate matter monitoring was presented. The measurement results collected for a period of few years indicate that particular matter concentrations tend to be lower in the area near to the green zones.

The WSNs system for online monitoring of the measurement data and data acquisition, collected data that can be further analysed in order to evaluate the influence of green areas on PM concentration are analysed. The results in this paper show that position of the sensor nodes plays an important role when the PM concentration is concerned.

In the experimental results highest concentration of PM2.5 and PM10 at the location of the Node 3 are measured, as expected, because the location of this node is close to the parking place.

The measured values of PM10 concentration are the lowest at Node 2 (which is located in the building patio). The average PM2.5 concentration for the analysed period is slightly lower at Node 1 (compared to Node 2), but still Node 3 shows the highest values.

During the Covid-19 pandemic extreme pollution during the night hours were not detected. Even more, the PM concentration was significantly lower during night time.

In this research few factors have significant influence in the reduction of PM concentration during the analysed period. The green areas at the Faculty patio, the reduced traffic vehicles and the reduced mobility of the faculty staff, have high impact in the reduction of PM concentration.

Further considerations include comparison of the measurement data at the same period (summer months) during COVID pandemic and the years before.

ACKNOWLEDGMENT

The authors would like to acknowledge the support of the Ss Cyril and Methodius in Skopje, Faculty of Electrical Engineering and Information Technologies in Skopje for the support of the research presented in this paper through the project FEIT4O_2.

6. REFERENCES

[1] H. Mayer, "Air pollution in cities," Atmosferic Environment, vol. 33, pp. 4029-4037, 1999.

[2] J. Samet, S. Zeger, F. Dominici, F. Curriero, I. Coursac, D. Dockery, J. Schwartz and A. Zanobetti, "The national morbidity, mortality, and air pollution study. Part II: Morbidity and mortality from air pollution in the United States" Res. Rep. Health Eff. Inst., vol. 94, pp. 5-79, 2000.

[3] D. Dockery, J. Schwartz and J. Spengler, "Air pollution and daily mortality: Associations with particulates and acid aerosols," Environ. Res., vol. 59, pp. 362-373, 1992.

[4] J. Schwartz and D. Dockery, "Increased mortality in Philadelphia associated with daily air pollution concentrations," Am. Rev. Respir. Dis., vol. 145, pp. 600-604, 1992.

[5] EEA, E.E.A., “Air quality in Europe — 2019 report”, European Environment Agency, 2019.

[6] A. Alberto, N. Ramos, and R. Almeida, “Parametric study of double skin facades performance in mild climate countries,” Journal of Building Engineering, vol. 11, pp.87–98, 2017.

[7] M.B. Radic, “Green Facades and Living Walls-A Review Establishing the Classification of Construction Types and Mapping the Benefits,” Sustainability, vol. 11(4579) (2019).

[8] Akbari H, Pomerantz M, Taha H (2001) Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Sol Energy 70(3):295–310

[9] Bass B (2001) Addressing urban environmental problems with green roofs. Encyclopaedia of global environmental change, vol. 3. Wiley, Chichester, UK

[10] Hosker RP Jr, Lindberg SE (1982) Review: atmospheric deposition and plant assimilation of gases and particles. Atmospheric Environment 16(5):889–910

[11] M. Srbinovska, V. Andova, A. Krkoleva Mateska, and M. Celeska Krstevska, “Effect of The effect of small green walls on reduction of particulate matter concentration in open areas,” Journal of Cleaner Production, 279(200):123306, 2021

[12] V. Andonovic, H. Gjoreski, M. Srbinovska, V. Andova, A. Krkoleva Mateska, M. Celeska Krsteska, and Z. Todorov, “Machine learning model for air pollution prediction in Skopje, Republic of North Macedonia,” SEE.SDEWES 2020, Sarajevo, Bosnia and Herzegovina, June 28-July 2, 2020.

[13] M. Srbinovska, A. Krkoleva Mateska, V. Andova, M. Celeska Krsteska and T. Kartalov, “Low - Cost Energy - Efficient Air Quality Monitoring System Using Sensor Network,” Int. J. Reasoning-based Intelligent Systems, vol. 13(4), pp.204–211, 2021.

[14] Laser PM2.5 Sensor specification, SDS011, Version V1.3 datasheet, Nova Fitness Co.,Ltd, 2015

[15] A1A-MiCS-4514 Version 2 datasheet, 2008

[16] ESP32-WROOM-32D & ESP32-WROOM-32U Datasheet V1.4, 2018

[17] World Health Organization (WHO), https://www.who.int/, 2020

[18] S.L. Jackson, “Research Methods and Statistics: A Critical Thinking Approach”, Cengage Learning, 2012

[19] M. Srbinovska, A. Krkoleva Mateska, M. Celeska Krstevska, V. Andova, “Location impact on particulate matter (PM) concentration reduction during COVID-19 pandemic”, 57th International Scientific Conference on Information, Communication and Energy Systems and Technologies, Ohrid, North Macedonia, 16-18 June, 2022 (in print)