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Real-Time Monitoring the Indoor Air Quality Parameters of Intensive Care Unit During the Pandemic Period

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Abstract: People spend most of their time in enclosed spaces (e.g., hospital, houses, office buildings, public transportation, and schools). The coronavirus in late 2019 has rapidly spread throughout the world. After the pandemic, people started to spend more time in indoor environments, especially in hospitals. In this study, air quality monitoring was carried out in the Intensive Care Unit of a hospital in Bolu - Turkey. This is the first comprehensive study done in Turkey. In this study, $PM_{2.5}$, PM_{10}, temperature, and relative humidity parameters affecting indoor air quality were monitored instantly for one month with a Wireless Sensors Network-based system. By the results of the study, the maximum concentration of these parameters except relative humidity was higher than the limited by accepted values parameters by the United States Environmental Protection Agency (EPA), The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and the World Health Organization (WHO).
Keywords: Intensive Care Unit, PM, Indoor Air Quality, Monitoring, Wireless Sensor Network.

1. Introduction

Indoor air pollution has become a serious issue affecting public health, and indoor air quality monitoring system helps in the detection and improvement of indoor air quality. Air pollution is a major environmental hazard to human health and a leading cause of mortality and morbidity worldwide (Chen and Hoek, 2020). Indoor air quality monitoring in the healthcare environment has become a critical part of hospital management, especially in intensive care units. It is thought that air quality in intensive care units does not get the standard levels with routine preventions and requires additional measures. The indoor air quality monitoring system helps to determine and improve air quality.

Many studies have shown that particulate matters are higher indoors than outdoors (Karakas et al. 2013) PM is highly associated with the incidence of respiratory and cardiovascular diseases and mortality (Kim et al. 2015).

Average indoor PM concentrations reported in hospitals in developed countries, including European countries and Taiwan, are generally low(Heibati et al. 2021a). PM with aerodynamic diameter below 2.5 μm ($PM_{2.5}$) and 10 μm (PM_{10}) are < 20 μg/m^3 and < 25 μg/m^3, respectively (Baurès et al. 2018; Fernández et al. 2009; Loupa et al. 2016). However, those measured in China ($PM_{2.5}$, 98, and 124 μg/m^3) (Wang et al. 2006) and South Korea (PM_{10}, 57 μg/m^3) (Hwang et al. 2018) is substantially higher with levels up to 250 μg/m^3 (Heibati et al. 2021b).

After the SARS-CoV-2 pandemic was started to spread rapidly in the world, healthcare organizations and healthcare professionals were focused on the treatment processes and the infection risk rather than limiting the spread of the disease. However, the fact that the indoor air quality in the hospitals, which has been a great risk, is an important factor in determining the rate of spread of the disease has been ignored. The increased risk of occupational exposure of healthcare workers to SARS-CoV-2 is of particular concern (Stern et al. 2021).

After the SARS-CoV-2 virus emerged in China, it is started to be seen in almost all countries in a short time. The first official deaths caused by COVID-19 in Turkey have been reported by the Ministry of Health on March 18, 2020 (Interior Republic of Turkey Ministry of, 2020).

In the pandemic period, one of the important transmission of the disease was having a great impact on international human transport. As of March 21, 2020, the number of countries with a flight ban reached 46 in total (Against and Turan, 2020). Turkey is a transit point for international human transport when viewed from this angle ıt has a critical geopolitical position. Apart from the travel restrictions, with the advice of the Scientific Committee, about blocking entering of the virus into Turkey or delaying the disease to enter Turkey, serious steps were taken. One of these steps is to close the border gates with neighbor states.

In Turkey during the pandemic process, the treatment of critical patients in the intensive care unit was carried out. In this study, real-time monitoring of the ICU indoor air parameters and evaluation of the results will provide opinions about limiting the spread of the disease. As a result of the study, the physical conditions of the intensive care units used in the treatment of this disease will be discussed and concrete data will be revealed.

This is the first comprehensive study done during the COVID-19 in Turkey. In this study, indoor air quality levels were monitored in real-time using Wireless Sensor Networks from the intensive care unit. Indoor levels of PM_{10}, $PM_{2.5}$, temperature, and relative humidity were measured by using wireless sensor networks.

Reduction of hospital infections and other diseases due to environmental factors through real-time monitoring and communication system in a hospital environment will provide an extensive impact on society by reducing expenditures on health. It was formed an important database for more extensive projects to be carried out in the future.

2. Materials and Method

2.1. Study Area

This study was carried out in the Intensive Care Unit (ICU) of a hospital in Bolu, Turkey. The intensive care unit consisted of a nursing station, a washing stand, an isolated room, and 13 beds. The area of the ICU is approximately 250 m^2. High-Efficiency Particulate Air filters (HEPA) were installed above the 13 beds. The layout of the floor plan of the ICU is presented in Figure 1.

2.2. Sampling

Wireless Sensor Networks were installed on a flat and horizontal surface at about 1.5 meters above the floor. Continuously the changes indoor air quality levels in intensive care units were being monitored by using Wireless Sensor Networks (WSN). Data were collected by WSN from four different points for one month in the ICU;

a) Near the entrance door
b) Near the nursing station
c) Near the isolated room
d) Isolated room

Every sampling day, the number of persons, activities in the ICU, and the cleaning program were recorded and can be summarized as below:

a) In the morning; doctors, interns, and nurses examined the patients.
b) At 10:00 am, washing/transferring of patients, changing bedclothes, and cleaning the beds and floor were performed.
c) In the evening patients were asleep or resting and two or three nurses stayed in ICU.

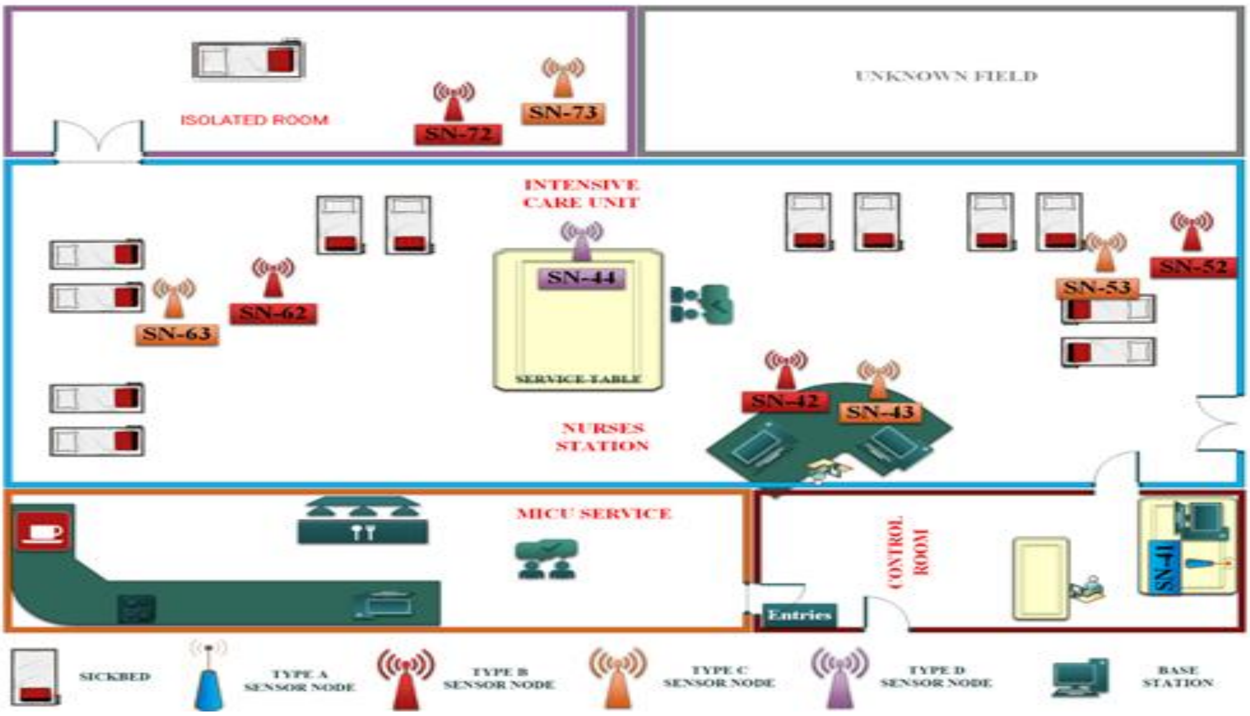

Fig. 1 Schematic layout of Intensive Care Unit (Not drawn to scale).

2.3. Creating Sensor Nodes and Establishing a Wireless Sensor Network

In the proposed study, 3 different nodes are designed. These are the Gateway node, Sensor node, and repeater node. The task of the sensor nodes is to measure the parameter in the physical environment and transmit it to the gateway node. Gateway node acts as a bridge for transmitting data from nodes which has measurement capability to the station. Repeater nodes, on the other hand, are responsible for strengthening the signal when the communication between sensor nodes and gateway nodes is disrupted due to distance or physical obstacles. Arduino Uno with ATmega328P microcontroller was used as a microcontroller board in all nodes. The circuit elements that make up the nodes are soldered using Proto Shield. Gateway node and Repeater Nodes consist of Arduino Uno and nRF24L01 communication Devices. The antenna has been added to increase the signal distances of the nRF24L01 communication modules. In sensor nodes, Arduino UNO consists of sensors that detect the parameters to be measured, as well as the NRF24L01 module. The sensors forming the sensor nodes are described in detail below. The technical components used in the nodes created within the scope of the study are explained in Figure 2.

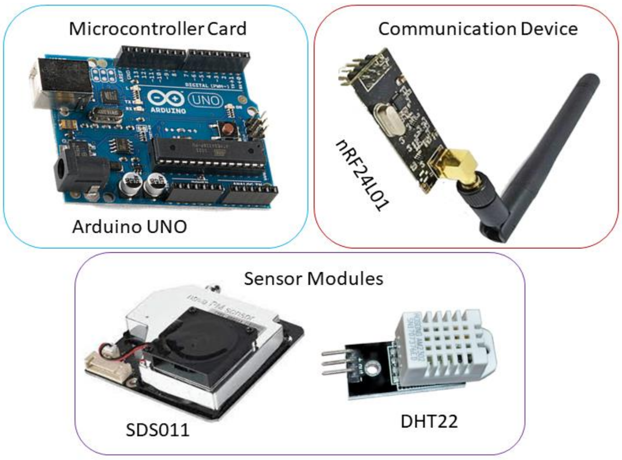

Fig. 2 Hardware components that makeup sensor nodes

Within the scope of the study, 4 different parameters were collected in the intensive care unit chosen as the measurement environment. These parameters are PM2.5, PM10, temperature, and humidity data. Two different sensors were used to collect these 4 parameters. For the measurement of temperature and humidity values, the DHT22 sensor module, which is frequently used by researchers, was used. The DHT22 sensor module is a low-cost, digital output active sensor. It is also an ideal sensor for recommended operation with low power consumption and a high degree of accuracy. Nova SDS011 sensor module was used to measure PM2.5 and PM10 values. This sensor module detects particles of 0.3-10 µm in the air with laser scanning technique. Particles in the scanning area are detected by laser scattering. The reflected light is converted into an electrical signal. The analyzed particle amount is transmitted to the microcontroller card by serial communication. Detailed information about the installation of the sensor nodes is found in the article previously published by the project team (AKTAŞ et al. 2020).

2.4. Deployment of Sensor Nodes and Collection of Data

Sensor nodes developed to measure indoor air parameters were distributed homogeneously in the measurement environment. A total of 6 nodes, including 4 sensor nodes, 1 gateway node, and 1 repeater node, were designed to perform healthy measurements in the Intensive Care Unit, which was determined as the measurement environment. After the sensor nodes were deployed to the measurement environment, the sensors were calibrated for 1 day, some technical problems were solved and more accurate measurements were tried to be obtained. After it was seen that all sensor nodes started to send healthy data, the process of saving to the database was started. Each sensor node is programmed to measure only one data per minute.

In the study, Microsoft Structured Query Language (MSSQL) Server platform was used as a database for storing sensor measurements. MSSQL-Server is a relational database management system (RDBMS) that supports a wide variety of transaction processing, business intelligence, and analytics applications widely used by researchers. Structured Query Language (SQL), on the other hand, is a query language that performs operations such as recording, editing, adding, deleting, and pulling records to the database. The hourly averages of the data coming to the Base Station through the Gateway have been recorded in the MSSQL-Server database to avoid unnecessary repetitions.

2.5. Monitoring

After the sensor nodes were placed in the 4 locations in the ICU, and the data was sent properly, the data collection process was started on 02.09.2020 at 11:03. Each sensor in the installed system is programmed to measure an average per minute and send it to the gateway. During the data collection process, the hourly average of the collected data was added to MSSQL, a relational database, to avoid unnecessary sensor repetitions. MSSQL is a client/server-based SQL database management system used to save data in many studies. MSSQL is used as a database in this study because it is a system that is consistent, easy to use, and familiar to the project team. In addition, MSSQL has been preferred as a relational database in this project as it provides a clear user interface for sensor data monitoring and management.

The date range of the data collection process performed in the intensive care unit is also the same time the Covidien-19 outbreak in Turkey corresponds to the second peak it reached in October. The data collection process in ICU was ended on 01.10.2020. A total of 30 days of uninterrupted data was collected at the 4 different selected measurement sites. Between these dates, each sensor made approximately 43,000 measurements, and a total of approximately 1,400,000 measurements were made. Within the scope of this project, in the ICU designated as the second measurement area, doctor controls were carried out between 09:00 and 11:00 am every day. Besides, every day between

12:00 and 14:00 is determined as visitor hours. These situations have been beneficial in terms of evaluating the results of the project to what extent the human density and human activities affect the environmental conditions during these hours.

The monitoring data were collected from 1 October to 2 November 2021. Data were recorded hourly by using WSN in the ICU.

3. Results

3.1. The concentration of Indoor the Environmental Parameters

Table 1. showed the mean, maximum, minimum concentrations, and standard deviations of temperature, relative humidity, $PM_{2.5}$, and PM_{10} in the ICU and ısolated room.

The maximum concentration of PM_{10} 99.94 µg/m3 was measured by WSN near the entrance door in the ICU. The maximum concentration of $PM_{2.5}$ 81.71 µg/m3 and Relative humidity (RH) of 45.80 % was measured by WSN near the nursing station (Table 1).

Table 1. Maximum, Minimum, Standard Deviation, and Mean Concentrations of Data Were Collected by Wireless Sensor Networks (WSN) in the ICU

	*N	Max.	Min.	Mean± SD
Sensors Near The Nursing Station				
Temperature °C	720	28,47	20,42	24,69±1,12
Relative Humidity %	720	45,80	18,68	30,83±5,43
$PM_{2.5}$ (µg/m^3)	720	81,71	0,01	4,86±5,89
PM_{10} (µg/m^3)	720	99,94	0,05	6,92±7,79
Sensors Near The Entrance	***N**	**Max.**	**Min.**	**Mean± SD**
Temperature °C	720	28,28	21,6	25,39±1,10
Relative Humidity %	720	44,68	19,15	30,83±4,77
$PM_{2.5}$ (µg/m^3)	720	64,29	0,01	5,37±6,62
PM_{10} (µg/m^3)	720	91,04	0,04	7,80±8,56
Sensors Near The Isolated Room	***N**	**Max.**	**Min.**	**Mean± SD**
Temperature °C	720	29,05	20,43	25,32±1,36
Relative Humidity %	720	44,87	17,49	30,82±5,46
$PM_{2.5}$ (µg/m^3)	720	76,26	0,01	4,75±6,38
PM_{10} (µg/m^3)	720	95,47	0,03	7,78±8,85
Sensors in The Isolated Room	***N**	**Max.**	**Min.**	**Mean± SD**
Temperature °C	718	27,35	20,89	24,44±1,13
Relative Humidity %	720	39,12	13,91	28,31±4,60
$PM_{2.5}$ (µg/m^3)	720	51,85	0,01	4,44±4,40
PM_{10} (µg/m^3)	720	73,79	0,01	6,08±7,58

***N**: Number of samples

3.2. Statistical Analysis

Statistical calculations were performed using the Stat graphics Centurion Statistical Software. The environmental parameters were initially investigated by descriptive statistics (mean and standard deviation). The ANOVA test was done between environmental parameters. The differences between the groups were determined at a 95% confidence interval for each parameter ($p<0.05$) (Table 2).

Table 2. One-Way ANOVA comparison test of environmental factors

	Temperature °C	Relative Humidity %	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
Temperature °C		0.00	0.92	0.99
Relative Humidity %	0.00		0.00	0.00
$PM_{2.5}$(µg/m^3)	0.92	0.00		0.00
PM_{10} (µg/m^3)	0.99	0.00	0.00	

Since the P-value of the F-test is less than 0.05 there is a statistically significant difference between the mean of temperature and RH%, $PM_{2.5}$ with PM_{10} and RH%, PM_{10} with $PM_{2.5}$ and RH% to another at the 95.0% confidence level.

The *p*-value was greater than 0.05 which demonstrates that there was not a statistically significant difference between the mean of temperature, $PM_{2.5}$, and PM_{10}.

4. Discussion

4.1. Maximum Acceptable Levels for Measured Parameters

Accepted values parameters by the United States Environmental Protection Agency (EPA), The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and the World Health Organization (WHO), Guidelines on Energy Efficiency of Air Conditioning Installations (EMSD) and Indoor Air Quality guideline value for Japan and South Korea were shown in table 3 and table 4.

Table 3. The Acceptable Values of Parameters to be provided by WHO, EPA and ASHRAE Organization in Indoor Environment

Organization	PM_{10} µg/m^3	$PM_{2.5}$ µg/m^3
WHO EPA (Pickett and Bell, 2011)	50 (24 hours)	25 (24 hours)
ASHRAE (Tucker, 2002)	50 (24 hours)	25 (24 hours)

Table 4. The Acceptable Values of Parameters to be provided by EMSD Organization, Japan and South Korea in Indoor Environment

Organization	Temperature °C	Relative Humidity %
EMSD (*Guidelines on energy efficiency of cultural heritage - ScienceDirect*, 1998) (Guidelines on the energy efficiency of cultural heritage - ScienceDirect, 1998)	20 to <25.5 (8 hours) (Excellent class)	
EMSD (*Guidelines on energy efficiency of cultural heritage - ScienceDirect*, 1998) (Guidelines on the energy efficiency of cultural heritage - ScienceDirect, 1998)	<25.5 (8 hours) (Good class)	
Indoor Air Quality guideline value for Japan and South Korea (Jeong, 2012)		40 to <70 (8 hours) (Excellent class)

Limit values accepted by EPA and WHO for PM_{10} and $PM_{2.5}$ were set as the daily average (24 hours) respectively 50 µg / m^3 and 25 µg / m^3. Accepted values by ASHRAE for PM $_{10}$ were shown in table 3.

The maximum concentration of PM_{10} and $PM_{2.5}$ in the ICU and the isolated room were measured higher than the accepted value by EPA, WHO, and ASHRAE's limited (Figure 3).

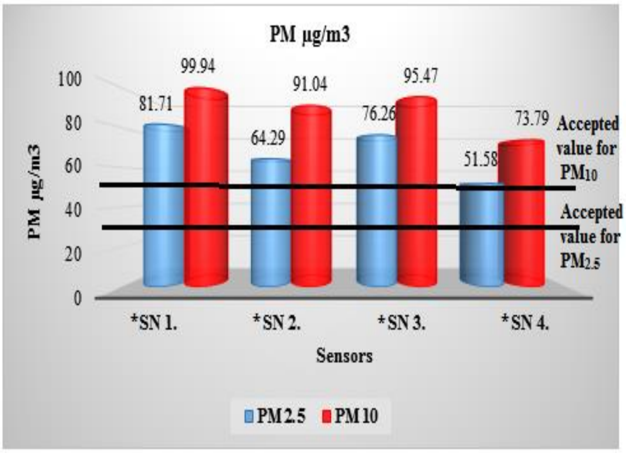

Fig. 3 The maximum concentration of PM_{10}, $PM_{2.5}$, and acceptable limited
***SN1:** Sensors Near The Nursing Station, ***SN2:** Sensors Near The Entrance Door, ***SN3:** Sensors Near The Isolated Room**, *SN4:** Sensors in The Isolated Room

It is important to note that temperature and RH will always relate to affect the survival of airborne viruses in aerosols. Temperature is one of the most major factors affecting virus survival, as it can affect the state of the virus genome. Virus survival decreases progressively at 20.5°C –24°C. The maximum temperature was recorded by sensors in the ICU and the isolated room was higher than the accepted limits (Wingate, n.d.) (Figure 4).

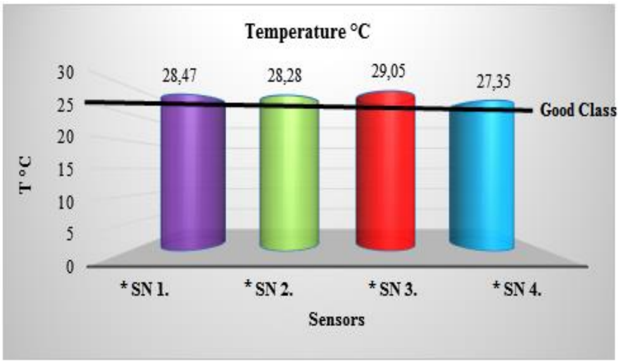

Fig. 4 The maximum concentration of temperature and acceptable limited
***SN1:** Sensors Near The Nursing Station, ***SN2:** Sensors Near The Entrance Door, ***SN3:** Sensors Near The Isolated Room**, *SN4:** Sensors in The Isolated Room

Relative humidity ranges about 55%–60% for more critical areas, such as operating theatres and recovery and the intensive care unit. Maximum percentages of relative humidity were measured in the ICU and the isolated room were lower than the acceptable value from the Indoor Air Quality guideline value for Japan and South Korea (Figure 5).

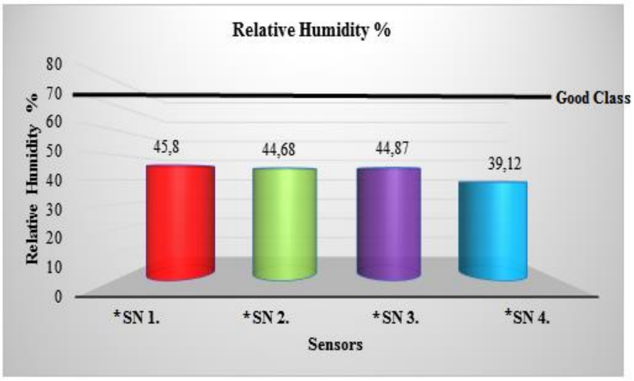

Fig. 5 The maximum concentration of RH and acceptable limited
***SN1:** Sensors Near The Nursing Station, ***SN2:** Sensors Near The Entrance Door, ***SN3:** Sensors Near The Isolated Room**, *SN4:** Sensors in The Isolated Room

5. Conclusion

In public places such as hospitals and schools, the level of indoor air quality is important for local administrators as social health is important.

However, poor indoor air quality in buildings can cause short and long-term health problems. Indoor air quality has been the outcome of diseases such as including deficits in lung function, chronic respiratory disease, lung cancer, heart disease, nervous system, liver, or kidneys(Lakestani et al. 2013).

Especially during the COVID-19 pandemic, it is thought that in critical areas like the intensive care units that will reduce the rate of spread of the diseases by the continuous monitoring of indoor air pollutants. Improving and increasing the indoor air quality in the hospitals for healthcare staff, patients, and visitors has been a part of the policies of hospital local governments.

The aim of this study, to provide real-time monitoring of indoor air quality levels by using wireless sensor networks in critical areas such as the intensive care units in hospitals and helping to take necessary measures. The results of this study include:

- Doctor controls of all the ICU services are done at approximately 10 o'clock. When the measured parameters were analyzed, it was seen that the increase usually at the doctor's control hours. To minimize the spread of the viruses, especially in cases such as the COVID-19 pandemic, the number of people in the indoor environment, such as the ICU, should be reduced as much as possible. Therefore, doctors' hours of control of the ICU patients should be spread throughout the day.
- According to the results, when the number of patients was more than 6 people, it is seen that the measured values, especially PM's values, sometimes exceed the maximum limits recommended by internationally accepted institutions.

The results have shown that the quality and quantity of HEPA filters were insufficient. Hospital management has been advised to review this situation.

After the COVID-19 pandemic, in the places where social public health is important and potential disease risk is high using new technologies that produce ozone, hydroxyl radicals, and emit UV light in addition to HEPA filets, can reduce environmental pollutants in the air to a minimum. Thus, in high-risk areas, it can use the negative pressure factor to minimize the connection of the potential virus with the outdoor.

To improve the maximum levels of indoor air quality in critical regions such as the ICU the following issues will be taken into consideration in future studies.

- By placing more sensor nodes in the ICU in which place the density of the parameters of indoor air quality is higher. In the ICU, a density map of indoor air quality in terms of parameters will be determined. It is thought by using this map will placement of HEPA filters and increase the efficiency of the filters. The increasing efficiency of the filters in the ICU affects the improvement of indoor air quality.
- When the indoor air parameters will be higher than the accepted level by worldwide, the relevant personnel will be automatically alerted with the instant messaging application and necessary measures will be taken urgently.

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Authors' contributions:

SL: Project Design and management, Methodology and Data processing, Writing, Review & Editing. **ML:** Design of wireless sensor networks**,** Software and Data processing, Writing, Review & Editing. **İY:** Investigation & Literature Review **AD:** Investigation & Literature Review

Conflict of interest disclosure:

The authors declare no conflict of interests

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