Celal Bayar University Journal of Science

Analysis of the Impact of Human Activities on Indoor Air Quality with Internet of Things Based e-Nose

Mehmet Taştan[1]*, Hayrettin Gökozan[2], Alper Mutlu[3]

[1] Manisa Celal Bayar University, Department of Electronic and Automation, Turgutlu/Manisa, Türkiye
[2] Manisa Celal Bayar University, Department of Electric and Energy, Turgutlu/Manisa, Türkiye
[3] Dokuz Eylül University, Department of Electronic and Automation, Buca/İzmir, Türkiye
*mehmet.tastan@cbu.edu.tr
*0000-0003-3712-9433

Received: 3 November 2021
Accepted: 1 December 2022
DOI: 10.18466/cbayarfbe.1018796

Abstract

Air pollution has become a severe problem in most of the world and is among the governments' prior subjects. In the present time, urban dwellers spend most of their time in confined spaces such as home, office, school, shopping malls, and gyms. Contaminant gases (CO_2, CO, NO_2) and particulate matters arising from occupant activities such as exercise, sleeping, cooking, smoking, and cleaning are among the most critical factors which influence indoor air quality. Such gasses and particulate matter depend on human activities lower indoor air quality; hence, they cause many serious health problems, especially respiratory tract, cardiovascular and dermatological diseases.
In this study, the indoor air quality of housing is examined depending upon occupant activities. Air quality parameters of temperature, humidity, CO_2, CO, PM_{10}, NO_2, which are collected from the bathroom, kitchen, living room and bedroom of the housing, are measured using 32-bit ESP32 controller and a set of air quality sensors Obtained air quality data is saved to cloud server by the help of mobile user interface developed through Blynk IoT platform. As a result of the analysis, it is observed that occupant activities like sleeping, shower, laundry, and cooking adversely affect indoor air quality.

Keywords: Internet of things, e-nose, indoor air quality, human activities

1. Introduction

Air pollution either indoor or outdoor is a significant environmental health problem that influences developed or developing countries [1]. Indoor air quality is particularly crucial for those spending most of their time inside. However, most of the time, such individuals are not aware of internal pollutants that they are exposed to. Especially patients, elders, and children are exposed to a lot of physical, mental, and psychological diseases caused by low indoor air quality [2]. Serious health problems arising from indoor air contaminants may occur either immediately or in years [3]. Indoor air quality may not only stem from internal pollutants. Outdoor pollutants may significantly decrease air quality by entering the space in different ways [4]. Particularly occupant activities such as heavy traffic, industrial zones, and construction substantially exacerbate this problem [5]. Particulate matters (PM) are considered the most prominent pollutant material carried from the outside to the inside. PM refers to the particles that hang in the earth's atmosphere. PM is the tiny solid particles that are usually moved through solids, liquids, or air. Notably, children, elders, people having asthma or cardiovascular diseases are adversely affected by PM. PM may result in inflammation by profoundly penetrating the lungs. Specific heavy metal components contained in the PM may cause even lung cancer [6]. Carbon monoxide (CO) is one of the primary sources of air pollution and is called the silent killer. CO is colorless, odorless, tasteless, and relatively stable. It may substantially harm human health even at low levels of concentration. In indoors, CO can be generated through improper combustion of carbon-based fuels such as petroleum, firewood, and coal. In general, the outdoor level of CO is higher than indoor. Industry and automobiles are among the primary sources of CO output [7].

Carbon dioxide (CO_2) makes a significant impact on human health and is an essential index of indoor air quality. Indoor CO_2 levels over 1000 ppm correspond to an air problem [8].

Another prominent gas causing air pollution is nitrogen dioxide (NO_2). This gas is hazardous for human health. The foremost source of NO_2 in the areas where people populously dwell is motor vehicles. Remarkable studies should be conducted in order to decrease NO_2 emission arising from motor vehicles in urbanized areas [9]. NO_2 leads to air pollution on its own, but nitrogen oxide also generates ozone and ozone pollution, especially in summer [10].

Occupant activities cause the generation of various air contaminants indoors. Cooking activity in the residences leads to the output of pollutant substances such as PM, black carbon (BC), CO_2, polycyclic aromatic hydrocarbons (PAH), formaldehyde (HCHO), nitrogen oxide (NOx) [11]. Types and amounts of pollutant substances arising from the cooking activity may change depending upon fuels, cooking methods, and content materials [12]. Among the air contaminants generated in residences, PM mainly occurs during the cooking activity and causes severe breathing problems and even lung cancer. The distribution of these tiny particles may alter according to diversifying cooking ways and methods [13].

One of the vital data providers of a smart city is IoT platforms [14]. An IoT platform is a cluster of technological entities, including smart physical objects like sensors, actuators, cameras, smart tags, and connected software services and systems. In general terms, an IoT platform gathers and processes a large amount of real-time data through smart city objects to ameliorate city services [15].

Recent progress in semiconductor technology led to the development of the Internet of Things (IoT) by effectively reducing the cost thanks to the integrated circuits composed of sensors and embedded processors [16]. By means of the IoT, many different objects and devices surrounding us connect through the Radio Frequency Identification (RFID) [17] and sensor network technologies such as Z-Wave and ZigBee. IoT is connecting more devices day by day. The expected number of devices connected to IoT is forecasted 24 billion until 2020 [18].

This study proposes a low-cost, portable, IoT-based e-nose to measure indoor air quality parameters of contaminant gases like CO_2, CO, PM_{10}, NO_2, temperature, and humidity by using a set of sensors. An embedded 32-bit ESP32 controller is used for the proposed e-nose. As for the measurement of air quality parameters, GP2Y1010AU, MH-Z14, MICS-4514, and DHT22 sensors are employed. The users can monitor air quality parameters in real-time numerical and graphical formats utilizing an android-based interface developed through the Blynk IoT platform for the proposed e-nose. In the case of measured gas concentrations exceeding pre-determined limit values, it sends mobile notifications through e-mail, twitter, and so on mobile platforms. Thanks to the data which can be monitored in graphs through the mobile interface, users can inspect the influences of individual activities like sleeping, cleaning, cooking on indoor contaminant gas concentrations.

2. Related works

Ozone, one of air quality parameters, is a crucial environmental problem in megacities where intensive human activities take place to the extent that can harm human health. In a study [19], examining the data collected from various living environments in China, it is concluded that, in addition to seasonal factors, human activities also cause ozone pollution. Smoking indoors may result in remarkably serious health problems, notably on children and elders. In a study on this subject [20], the data is gathered from 12 separate bedrooms at different residences to determine the differentiation between smokers and non-smokers in terms of the rates of contaminant gases CO, VOC, CH_2O, $PM_{2.5}$, and PM they are exposed to. The study, of which participants smoke either in the balcony or outside, remarks that pollutants arising from the cigarette smoke accumulated on the clothes of smokers contaminate the living environment at a considerable rate. Various wood-burning methods are investigated in the places heated by biomass regarding their effect on indoor pollutant concentrations [21]. Based on CO, CO_2 and PM10 measurements, which are taken from the rooms heated by an open fireplace and wood stove; it is reflected that cancer risk in the room heated by the open fireplace is seven times more than the one with the woodstove, likewise, that the level of PM10 is 25 times more in the former. In the research which is conducted to compare seasonal and spatial alterations in indoor air quality as well as differentiation at various climatic zones in the tropics and the subtropics [22], internal and external ambient temperature, relative humidity (RH), formaldehyde (HCHO), CO_2, bacteria, and fungi are monitored at eight different residences between 2012 and 2015 during the four seasons. According to the results, significant differences in terms of indoor air quality have been observed dependently upon the structure of the buildings, heating methods, climate, indoor smoking, cleaning, cooking, dampness, and humidity. A study [23] deals with a small investigation in a student cafeteria designed for leisure time to develop an extensive air quality monitoring program. As a result, even if average levels of comfort parameters and regulated air contaminants generally fall within the international intervals, CO_2 and PM values display remarkable fluctuations depending on activities and occupancy rate. Likewise, more than 80 % of PM concentration is generated in the inner space. In the study [24] investigating contaminant gases such as CO_2, CO, HCOH, NO_2, O_3 and the particles that hang in the air like PM_1, $PM_{2.5}$, PM_{10} as well as meteorological/comfort parameters in 101 confined microenvironment (classes, bedrooms, and cafeterias) from 25 kindergartens and primary schools; samples are collected from each confined space for at least 24 hours and nine consecutive days. According to the results, thermal discomfort and low humidity are observed respectively in 60.1 % and 44.1 % of the classes. Likewise, it is observed that students are exposed to PM2.5 at 69.1 % and CO_2 of 41.3 %. Children have narrower trachea and bronchi in comparison to adults. Therefore, irritation led by air pollution in an amount which only causes a mild reaction in an adult may considerably block a small child's trachea and bronchi. On this grounds, evaluation of indoor pollutant exposure of children is important, especially in microenvironments such as kindergartens where they spend most of their time. Based on the results provided by the indoor air quality research [25] conducted in daycare centers in 25 separate provinces in Seoul, mold levels are remarkably higher in the facilities having water damage than those without such damage. Moreover, it is concluded that new buildings with larger spaces have a lower level of bacteria and mold. Ventilation of the environment is suggested in the morning before the arrival of children because of high levels of VOC, which increases during the night. A study [26] conducted at two primary schools and a kindergarten in Kozani/Greece from Monday to Friday deals with 15 physicochemical air quality parameters to examine indoor air contaminants that children are exposed to and possible health risks in the school. It is stated that natural ventilation falls short in all these schools, that ambient air, occupant activity, and material emissions are determinant on indoor air quality, and that estimated average life-long cancer risks are low. In the study [27] examining the influence of cooking activity in the kitchen over indoor air quality, the alteration of PM contingent upon five different cooking methods [steaming, boiling, stir-frying, pan-frying and deep-frying cooking]. Whereas the lowest PM is observed during the steaming process, the highest level is noted during the deep-frying cooking activity. It is indicated that the PM level decreases at a rate of 60-85 % when air cleaner is used. In Colorado, indoor air quality measurements [28] are conducted during the cooking activity at 11 buildings having distinct construction characteristics. Accordingly, it is reflected that 20 minute's cooking activities cause average PM2.5 concentration between 100 and 500 $\mu g.m^{-3}$, that CO2 concentration exceeds 1000 ppm at six of tested ten residences, that the level of formaldehyde exceeds 9 $\mu g.m^{-3}$ the chronicle limit determined by California Office of Environmental Health Hazard Assessment (OEHHA) at 3 of the buildings, and that the usage of hood reduces PM concentration at the rate of 75 %. People spend approximately one-third of their lives in their bedrooms. Therefore, maintaining proper conditions, including air quality, is crucial in such spaces. Individuals may have trouble while falling asleep in non-ventilated bedrooms, or they may not appropriately have rest during the sleep and may awake wearily. As a result of indoor air quality measurements [29] conducted in the bedroom of a single-family residence, it is monitored that CO_2 concentration increases during the night and exceeds the permitted standard of 1000ppm.

3. Materials and Methods

Indoor air quality is a significant health threat for children and individuals in need of care, who spend most of their time in indoor environments. Harmful gases within the confined spaces are a part of our lives; but, most of us do not have precise data about the air quality we respire. Indoor air quality may change because of the influence of outdoor pollutants and individual activities of the occupants residing in the ambiance. In this study, an IoT-based e-nose is proposed to measure the real-time alteration of indoor air quality contingent upon individual activity parameters.

Ambient temperature, relative humidity, and contaminant gases such as CO_2, CO, PM_{10}, NO_2 can be real-timely monitored thanks to the proposed e-nose. The system, which is based on an IoT architectural design developed by a 32-bit ESP32 controller, offers an entirely wireless solution. In Fig.1, the architecture of the proposed e-nose system is displayed.

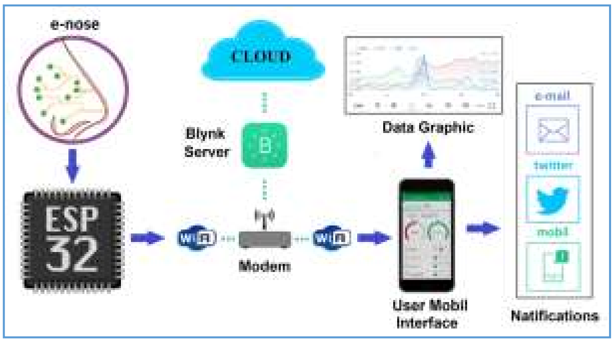
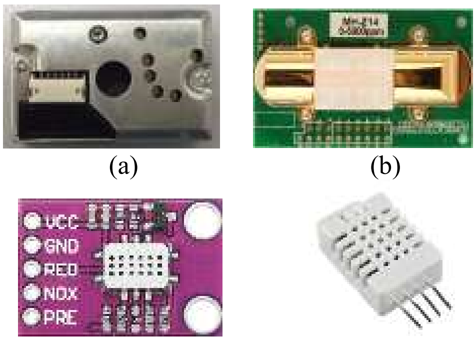


Fig.1. Structure of the proposed IoT-based measurement system.

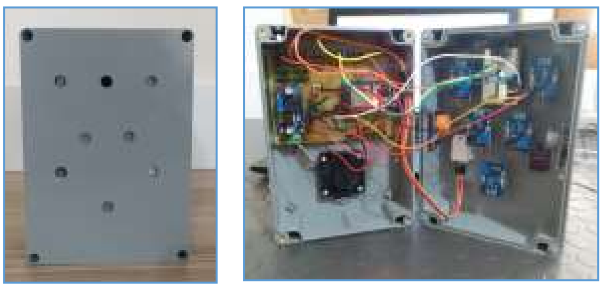
The embedded ESP32 microcontroller for the e-nose air quality measurement and monitoring system in Fig. 1 contains the Harvard Tensilica Xtensa LX6 32-bit Dual-Core processor, which can operate up to 240 MHz frequency [30]. For the measurement of contaminant gas concentration, an array of sensors containing GP2Y1010AU, MH-Z14, MICS-4514, and DHT22 sensors are utilized. Android based mobile application, which enables user interaction with the measurement system, is generated by means of the Blynk IoT platform. Blynk is a hardware-agnostic IoT platform with customizable mobile apps, private cloud, device management, analytics, and machine learning [31]. Thanks to the cloud server service of Blynk, data is hidden and easily accessible when required.



(a) (b) (c) (d)

Fig. 2. The sensor array used in the proposed e-nose system; a) GP2Y1010AU, b) MH-Z14, c) MICS-4514, d) DHT22.

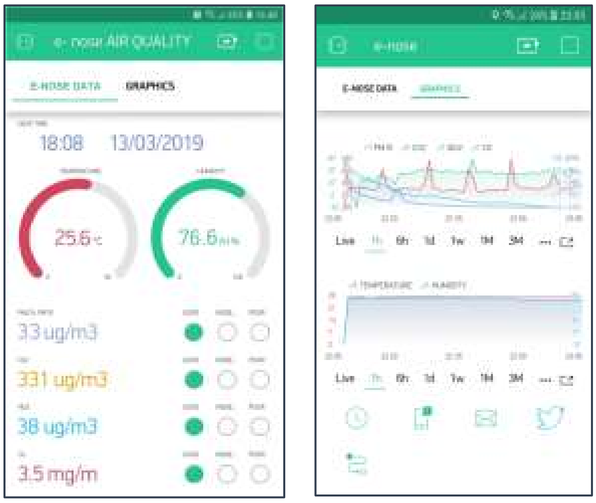
Fig. 2 displays the sensors used to measure the contaminant gas concentration in the e-nose system. GP2Y1010AU is a dust sensor equipped with the optical sensing system and the analog output. An infrared light-emitting diode (IRED) and a phototransistor are installed diagonally. The phototransistor detects the IR light reflected from the dust arriving the air chamber of the sensor and generates a voltage accordingly. MH-Z14A CO_2 sensor module utilizes the non-dispersive infrared (NDIR) principle. It also performs measurements between 0-5000 ppm and at 5ppm resolution along with ±50 ppm accuracy. MICS-4514 is employed in the measurement of gas concentrations such as NO_2, CO, and hydrocarbons. It has two sensor chips, including independent heaters and sensitive layers. One of these chips recognizes oxidizing gases (OX), and the other one identifies reducing gases (RED). DHT22 temperature and humidity sensor consists of two parts; capacitive humidity sensor and thermistor temperature sensor. It is equipped with an 8-bit microcontroller. Its relative error values are noted as ± 0.5 °C in temperature and ± 2 % rH in humidity measurement [32].



(a) (b)

Fig. 3. IoT based e-nose measurement system a) Outer view, b) Interior view.

Fig.3 displays the images belonging to the IoT based e-nose system, which is used for indoor air quality measurement and includes sensors to measure various gas concentrations. In Fig.3, the interior and outer views of the measurement system are respectively provided. The fan, which is installed at the rear cover of the plastic box of the measurement system, constantly vacuums air from the environment. There are holes on the front side of the box to enable air contact with the sensors' measurement surface. Data to be recorded in the cloud server can be sent to the user as an e-mail at request.



(a) (b)

Fig. 4. User Interface; a) Numeric Panel b) Graphic Panel.

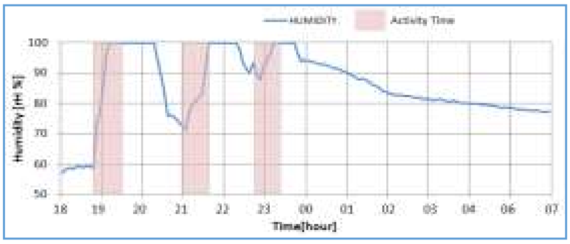
Front panel views of the developed android based mobile user interface are shown in Fig.4. In the "e-nose data" window displayed in Fig.4-a, data of the measurement system can be seen in numbers; additionally, it visualizes the levels of PM_{10}, CO_2, NO_2 and CO values as "good", "moderate" and "poor" according to their intervals. In the "Graphics" window shown in Fig.4-b, graphics can be seen as the data is sent to the cloud server by the e-nose measurement system. The dataset that is updated by the cloud server in a minute can be monitored in graphics live, hourly, daily, weekly, monthly, and annually at request. Furthermore, the data recorded by the cloud server can be sent to the e-mail address of the user in the "csv" format.

4. Results and Discussion

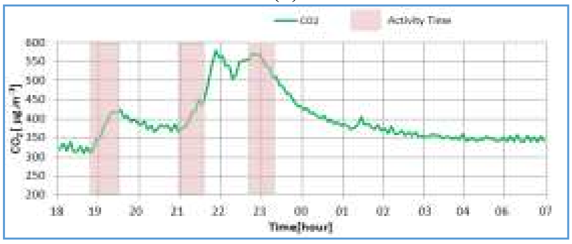
By means of the schemed IoT based e-nose measurement system, six different indoor air quality datasets, including PM_{10}, CO_2, NO_2, CO, temperature, and humidity, are collected from the various living spaces of a residence like the living room, kitchen, bathroom, and bedroom. The data extracted with a frequency of 5 seconds is transformed into a-minute and

Celal Bayar University Journal of Science
Volume 18, Issue 4, 2022, p 393-401
Doi: 10.18466/cbayarfbe.1018796

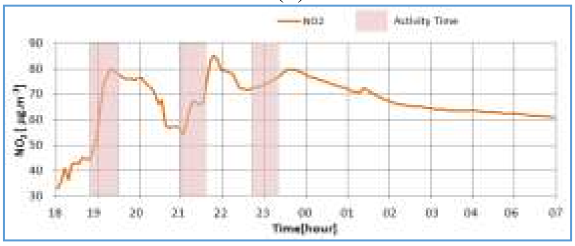
hourly average values. Data gathered by the IoT-based e-nose system is recorded in the cloud server in one minute's intervals. Graphics are drawn by normalizing the collected data. The residence does not contain an air cleaning system, and ventilation is performed through natural ways by means of opening the doors and windows of the rooms. During the measurements, doors of the test rooms are kept closed, and transmission of gas and PM concentrations to other rooms is blocked. Thereby, the effect of natural ventilation over alterations in gas and PM concentrations is determined.



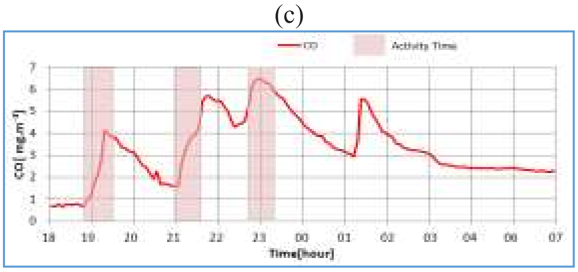
(a)



(b)



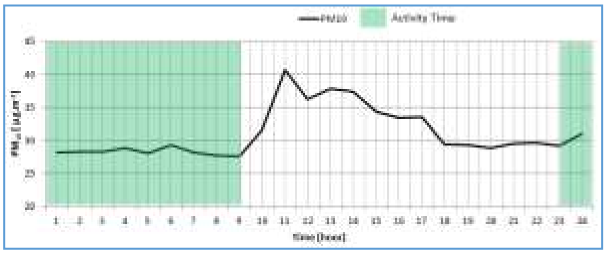
(c)



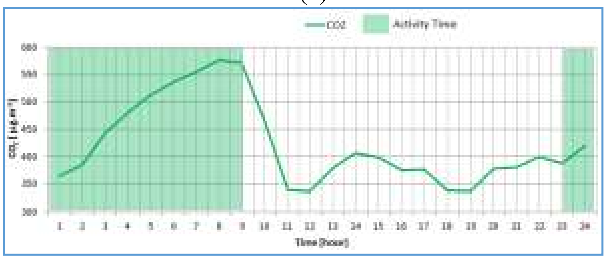
(d)

Fig.5. Air Quality Data of Shower Activity a) Humidity, b) CO_2, c) NO_2, d) CO

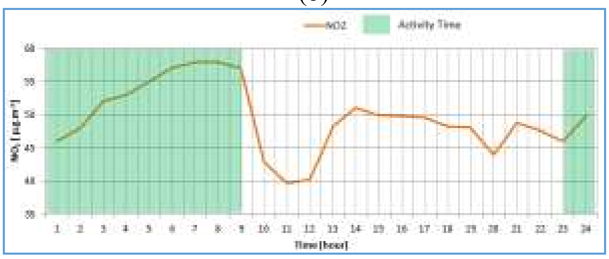
In Fig.5, the graphic shows the data of air quality change in time for the shower activity at three different times at 18.45, 21.00, and 22.45. The bathroom area is m^2 and naturally ventilated through a 40x40cm window, which is always open. The air quality measurement system is installed at a point with 1m altitude, where it is not directly exposed to humidity. During the shower activity, only soap and shampoo are used for personal cleaning. As shown in Fig.5-a, upon the shower activity starting at 18.45, humidity, CO_2, NO_2, and CO values rise quickly. These values increase during the activity; and, at the end, humidity rises from 60% to 99.9%, CO_2 concentration from 320 μm.m^{-3} to 430 μg.m^{-3}, NO_2 value from 45 μg.m^{-3} to 80 μg.m^{-3} and CO gas concentration from 0.8 mg.m^{-3} to 4.1 mg.m^{-3}. After the first shower activity that takes half an hour, upon the natural ventilation, humidity decreases from 99.9% to 72%, CO_2 concentration from 430 μg.m^{-3} to 370 μg.m^{-3}, NO_2 value from 80 μg.m^{-3} to 58μg.m^{-3} and CO gas concentration from 4.1 mg.m^{-3} to 1.6 mg.m^{-3}. After the 2nd shower activity that starts at 21.00, the level of gas concentration and humidity increase once again. At the end of the 2nd shower activity, humidity reaches the level of 99.9% from 71% whereas CO_2 concentration rises from 370 μm.m^{-3} to 570 μg.m^{-3}, NO_2 value from 58 μg.m^{-3} to 85 μg.m^{-3} and CO gas concentration from 1.6 mg.m^{-3} to 5.5 mg.m^{-3}.



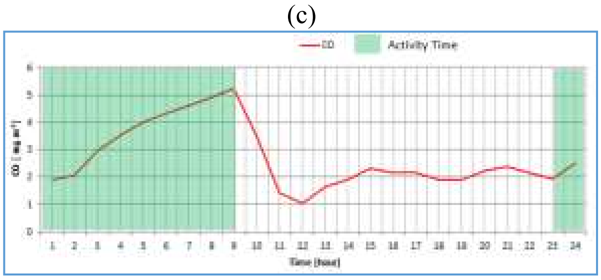
(a)



(b)



(c)



(d)

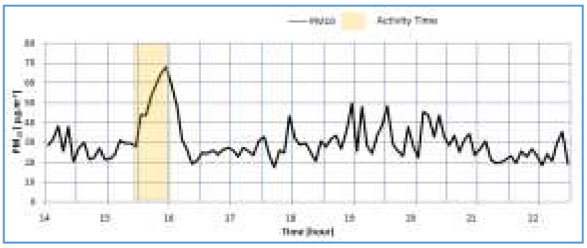
Fig.6. Air Quality Data Collected from the Bedroom a) PM_{10}, b) CO_2, c) NO_2, d) CO

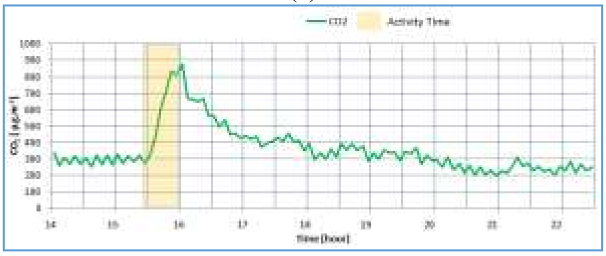
Celal Bayar University Journal of Science
Volume 18, Issue 4, 2022, p 393-401
Doi: 10.18466/cbayarfbe.1018796

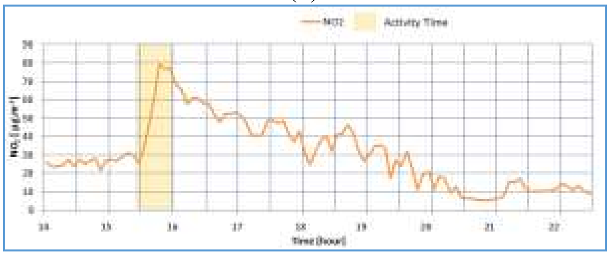
After the 2nd shower activity, which also lasts half an hour, natural ventilation was performed; and, it is seen that humidity declines from 99.9% to 90%, CO_2 concentration from 570 µg.m^{-3} to 500 µg.m^{-3}, NO_2 value from 85 µg.m^{-3} to 72 µg.m^{-3} and CO gas concentration from 5.5 mg.m^{-3} to 4.3 mg.m^{-3}. At the end of the 3rd shower activity, the humidity surges from 90% to 99.9%, CO_2 concentration from 500 µm.m^{-3} to 560 µg.m^{-3}, NO_2 value from 72 µg.m^{-3} to 80 µg.m^{-3} and CO gas concentration from 4,3 mg.m^{-3} to 6,5 mg.m^{-3}. After the natural ventilation until 07.00 following the half-hour 3rd shower, the values decline to the levels of 77% for humidity, of 350 µg.m^{-3} for CO_2 concentration, of 61 µg.m^{-3} for NO_2 value and of 2,2 mg.m^{-3} for CO gas concentration.

Fig.6 displays the graph of changes in air quality data gathered from the bedroom for 24 hours. The area of the bedroom is 20m^2 and naturally ventilated through a 1.2x0.8m window. The measurement system is installed at the center of the bedroom with 1m altitude. The sleeping period is between 01.00-09.00, and there was no ventilation in the meantime. An increase in CO_2, NO_2, and CO gas concentrations is observed after the beginning of the sleeping period. Within this period, there is not a considerable change in PM_{10} value. However, CO_2 concentration, which was around the levels of 360 µg.m^{-3} at the beginning of the sleeping, surges to 570 µg.m^{-3} at 09.00. Similarly, NO_2 concentration rises from 46 µg.m^{-3} to 58 µg.m^{-3}, and CO concentration from 2mg.m^{-3} to 5.2 mg.m^{-3}. After naturally ventilating the environment through open windows at 09.00 that remain closed during the night, CO_2, NO_2, and CO gas concentrations respectively decline to 340 µg.m^{-3}, 40 µg.m^{-3}, and 1mg.m^{-3}. On the other hand, an increase in PM_{10} value is observed upon entrance of outdoor PM contaminants into the room during the ventilation. The PM concentration reaches up to 41 µg.m^{-3} after the ventilation, whereas it was 27 µg.m^{-3} previously. After two-hour ventilation that lasted until 11.00 am, the door and windows are reclosed. Henceforth, concentrations of CO_2, NO_2, and CO gasses in the room reincrease, though lower than the rises during the sleeping. PM_{10} amount displays a declining trend after the termination of external contaminant occupancy.

The graphic in Fig.7 shows the changes in air quality data of the cooking activity. The kitchen has an area 15m^2 and is naturally ventilated through a 2.2x1.5m sliding door. During the cooking activity, the door was kept open for ventilation, and any other ventilation or filtering like aspirator is not used. The natural gas oven is used for cooking, and meals are cooked by boiling and frying. The cooking activity, which starts at 15.30, ends at 16.00.


(a)


(b)


(c)

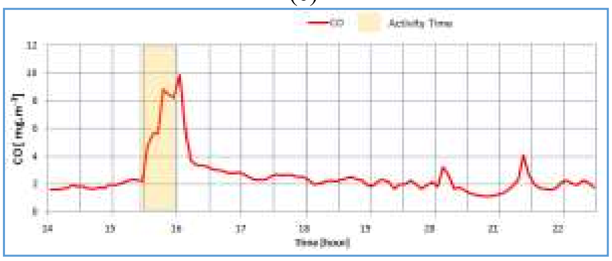
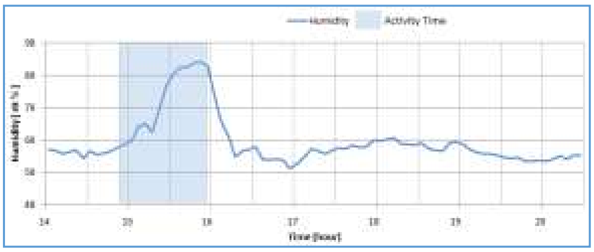

(d)

Fig.7. Air Quality Data of Cooking Activity a) PM_{10}, b) CO_2, c) NO_2, d) CO

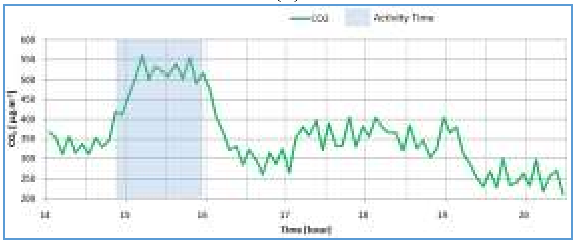
It is observed that CO_2, NO_2, and CO gas concentrations and PM_{10} increase during the 30-minute cooking activity. PM_{10} rises from 30µg.m^{-3} to 68 µg.m^{-3}, CO_2 gas concentration from 300 µg.m^{-3} to 880 µg.m^{-3}, NO_2 from 30 µg.m^{-3} to 80 µg.m^{-3} and CO concentrations from 2,1 mg.m^{-3} to 10 mg.m^{-3}. After the natural ventilation that is performed after the cooking activity, all these values rapidly decrease.

The graphic in Fig.8 presents the trends of normalized values belonging to air quality data during the laundering activity. Laundry room, where the washing machine is situated, has an area of 10m^2 and is naturally ventilated through a 40x40cm window, which is always open. The measurement system is installed at the center of the room with 1m altitude.

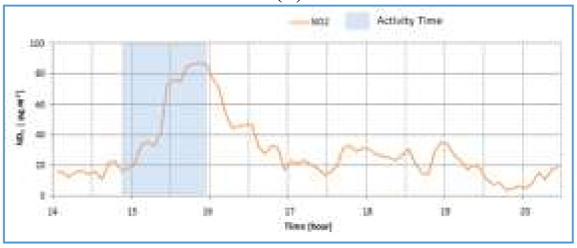
Celal Bayar University Journal of Science
Volume 18, Issue 4, 2022, p 393-401
Doi: 10.18466/cbayarfbe.1018796



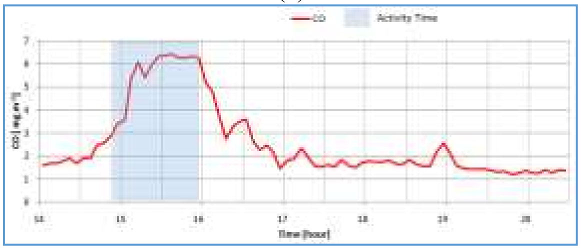
(a)



(b)



(c)



(d)

Fig.8. Air Quality Data of Laundering Activity a) Humidity, b) CO_2, c) NO_2, d) CO

Laundering activity, which starts at 14.45, ended at 15.50. Rapid upsurges in CO_2, NO_2, and CO gas concentrations and humidity are observed after the beginning of laundering. Humidity increases from 58% to 83% whereas CO_2 gas concentration rises from 350 $\mu g.m^{-3}$ to 560 $\mu g.m^{-3}$, NO_2 gas concentration from 20 $\mu g.m^{-3}$ to 87 $\mu g.m^{-3}$ and CO concentration from 3 $mg.m^{-3}$ to 6,5 $mg.m^{-3}$. After the cease of laundering at 15.50, declines in gas concentrations and humidity are observed contingent upon the natural ventilation. Indeed, daily routine activities like sleeping, shower, laundry, and cooking make direct impacts on the indoor air quality of the areas where we reside. As it can be seen through the graphics generated by the data, such daily activities cause the deterioration of air quality that is determinant on our health and that we perpetually respire. Whereas it is probable to take relatively pricy measures like the usage of air cleaning systems to enhance indoor air quality, even implementation of easy precautions like simply opening doors and windows is of vital importance in the improvement of air quality. The only way of doing that efficiently and affordably is to measure indoor air quality regularly. Accessibility of the measured data by the residents is also an essential factor. In this respect, the e-nose air quality measurement system developed by us collects data for the residents with its properties of easy set-up, cheapness, and mobility and shares the data with the users through the Blynk IoT platform.

5. Conclusion

This study investigates alterations in indoor air quality contingent upon occupant activities of a household such as sleeping, laundering, shower, and cooking. The developed e-nose air quality measurement and monitoring system measures ambient temperature and humidity, along with the gas concentrations such as CO, NO_2, CO_2, and PM_{10}, which cause indoor air pollution and informs the users about measurement values. By virtue of this awareness, users can minimize their exposure to the polluted air and immediately take proper measures to reduce the contaminant concentration. The analysis results have shown that there is a strong correlation between individual activities -like sleeping, cooking, shower, and laundering- and indoor air quality. Based on the data provided by the research, the following outcomes can be concluded;

- The most significant change during the shower is observed in terms of humidity and NO_2 concentration. There are smaller changes in CO_2 and CO values. After the natural ventilation procedures following the shower activity, gas concentration and humidity values significantly decline.
- During the sleeping period between 01.00-09.00, significant increases are observed in CO_2, NO_2, and CO gas concentrations. In the meantime, there are slight changes in PM_{10} values. As a result of natural ventilation after 09.00, remarkable decreases are observed in the values of CO_2, NO_2, and CO gas concentrations, while PM_{10} values increase because of outdoor contaminants.
- There occur significant upsurges in the levels of PM_{10}, CO_2, NO_2, and CO during the cooking activity; and, following the natural ventilation, these concentrations diminish. Cooking appears as the activity that damages health most seriously.
- The highest surge during the laundering activity is observed in the levels of NO_2 and CO gas concentrations.

Low indoor air quality is undoubtedly a significant parameter that directly influences human health. Even the most uncomplicated measures to reduce the harmful gas concentration in the ambiance, like opening the windows, might enhance the indoor air quality to a significant extent. Quantitative data obtained through the research shows that the low-cost air quality measurement system could contribute to a healthier living environment.

Author's Contributions

Mehmet Taştan: Drafted and wrote the manuscript, performed the experiment and result analysis.
Hayrettin Gökozan: Assisted in analytical analysis on the structure, supervised the experiment's progress, result interpretation and helped in manuscript preparation.
Alper Mutlu: Searched the literature and helped in manuscript preparation.

Ethics

There are no ethical issues after the publication of this manuscript.

References

[1] Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: a review. *Frontiers in Public Health*, 14.

[2] Humphreys, A., Walker, E. G., Bratman, G. N., & Errett, N. A. (2022). What can we do when the smoke rolls in? An exploratory qualitative analysis of the impacts of rural wildfire smoke on mental health and wellbeing, and opportunities for adaptation. *BMC Public Health*, 22(1), 1-12.

[3] Steinemann, A., Wargocki, P., & Rismanchi, B. (2017). Ten questions concerning green buildings and indoor air quality. *Building and Environment*, 112, 351-358.

[4] Taştan, M. (2022). A low-cost air quality monitoring system based on Internet of Things for smart homes. *Journal of Ambient Intelligence and Smart Environments*, (Preprint), 1-24.

[5] Silva, L. T., Pinho, J. L., & Nurusman, H. (2014). Traffic air pollution monitoring based on an air–water pollutants deposition device. International *Journal of Environmental Science and Technology*, 11(8), 2307-2318.

[6] Ye, T., Guo, Y., Chen, G., Yue, X., Xu, R., Coêlho, M. D. S. Z. S., ... & Li, S. (2021). Risk and burden of hospital admissions associated with wildfire-related PM2· 5 in Brazil, 2000–15: a nationwide time-series study. *The Lancet Planetary Health*, 5(9), e599-e607.

[7] Fazlzadeh, M., Rostami, R., & Hazrati, S. (2016). Concentrations of carbon monoxide in outdoor and Indoor air of residential buildings in Ardabil. Asrar, *Journal of Sabzevar School of Medical Sciences*, 23(2), 161–168.

[8] Marques, G., Ferreira, C. R., & Pitarma, R. (2019). Indoor Air Quality Assessment Using a CO 2 Monitoring System Based on Internet of Things. *Journal of Medical Systems*, 43(3), 67.

[9] Hamra, G. B., Laden, F., Cohen, A. J., Raaschou-Nielsen, O., Brauer, M., & Loomis, D. (2015). Lung cancer and exposure to nitrogen dioxide and traffic: a systematic review and meta-analysis. *Environmental Health Perspectives*, 123(11), 1107-1112.

[10] Boningari, T., & Smirniotis, P. G. (2016). Impact of nitrogen oxides on the environment and human health: Mn-based materials for the NOx abatement. *Current Opinion in Chemical Engineering*, 13, 133-141.

[11] Kang, K., Kim, H., Kim, D. D., Lee, Y. G., & Kim, T. (2019). Characteristics of cooking-generated PM10 and PM2. 5 in residential buildings with different cooking and ventilation types. *Science of The Total Environment*, 668, 56-66.

[12] Mangaraj, P., Sahu, S. K., Beig, G., & Yadav, R. (2022). A comprehensive high-resolution gridded emission inventory of anthropogenic sources of air pollutants in Indian megacity Kolkata. *SN Applied Sciences*, 4(4), 1-17.

[13] Wangchuk, T., He, C., Knibbs, L. D., Mazaheri, M., & Morawska, L. (2017). A pilot study of traditional indoor biomass cooking and heating in rural Bhutan: gas and particle concentrations and emission rates. *Indor Air*, 27(1), 160-168.

[14] Fahmideh, M., and Didar Z. (2020). An exploration of IoT platform development. Information Systems, 87, 101409.

[15] Jin, J., Gubbi, J., Marusic, S., & Palaniswami, M. (2014). An information framework for creating a smart city through internet of things. *IEEE Internet of Things Journal*, 1(2), 112-121.

[16] Mocrii, D., Chen, Y., & Musilek, P. (2018). IoT-based smart homes: A review of system architecture, software, communications, privacy and security. *Internet of Things*, 1, 81-98.

[17] Wang, K. H., Chen, C. M., Fang, W., & Wu, T. Y. (2018). On the security of a new ultra-lightweight authentication protocol in IoT environment for RFID tags. *The Journal of Supercomputing*, 74(1), 65-70.

[18] Touqeer, H., Zaman, S., Amin, R., Hussain, M., Al-Turjman, F., & Bilal, M. (2021). Smart home security: challenges, issues and solutions at different IoT layers. *The Journal of Supercomputing,* 77(12), 14053-14089.

[19] Zhao, X., Zhou, W., & Han, L. (2019). Human activities and urban air pollution in Chinese mega city: An insight of ozone weekend effect in Beijing. *Physics and Chemistry of the Earth*, Parts A/B/C, 110, 109-116.

[20] Canha, N., Lage, J., Coutinho, J. T., Alves, C., & Almeida, S. M. (2019). Comparison of indoor air quality during sleep in smokers and non-smokers' bedrooms: A preliminary study. *Environmental Pollution*, 249, 248-256.

[21] Vicente, E. D., Vicente, A. M., Evtyugina, M., Oduber, F. I., Amato, F., Querol, X., & Alves, C. (2020). Impact of wood combustion on indoor air quality. *Science of The Total Environment,* 705, 135769.

[22] Jung, C. C., Hsu, N. Y., & Su, H. J. (2019). Temporal and spatial variations in IAQ and its association with building characteristics and human activities in tropical and subtropical areas. *Building and Environment*, 163, 106249.

[23] Alves, C. A., Vicente, E. D., Evtyugina, M., Vicente, A. M., Nunes, T., Lucarelli, F., ... & Oduber, F. (2020). Indoor and outdoor air quality: A university cafeteria as a case study. *Atmospheric Pollution Research*, 11(3), 531-544.

[24] Branco, P. T. B. S., Alvim-Ferraz, M. C. M., Martins, F. G., & Sousa, S. I. V. (2019). Quantifying indoor air quality determinants in urban and rural nursery and primary schools. *Environmental Research*, 176, 108534.

[25] Hwang, S. H., Seo, S., Yoo, Y., Kim, K. Y., Choung, J. T., & Park, W. M. (2017). Indoor air quality of daycare centers in Seoul, Korea. *Building and Environment*, 124, 186-193.

[26] Kalimeri, K. K., Saraga, D. E., Lazaridis, V. D., Legkas, N. A., Missia, D. A., Tolis, E. I., & Bartzis, J. G. (2016). Indoor air quality investigation of the school environment and estimated health risks: two-season measurements in primary schools in Kozani, Greece. *Atmospheric Pollution Research*, 7(6), 1128-1142.

[27] Sharma, R., & Balasubramanian, R. (2020). Evaluation of the effectiveness of a portable air cleaner in mitigating indoor human exposure to cooking-derived airborne particles. *Environmental Research*, 183, 109192.

[28] Militello-Hourigan, R. E., & Miller, S. L. (2018). The impacts of cooking and an assessment of indoor air quality in Colorado passive and tightly constructed homes. *Building and Environment*, 144, 573-582.

[29] Gładyszewska-Fiedoruk, K. (2019). Indoor Air Quality in the Bedroom of a Single-Family House—A Case Study. In *Multidisciplinary Digital Publishing Institute Proceedings* (Vol. 16, No. 1, p. 38).

[30] Taştan, M. (2018). An IoT based air quality measurement and warning system for ambient assisted living. *European Journal of Science and Technology*, (16), 960-968.

[31] Taştan, M. (2019). Nesnelerin İnterneti Tabanlı Akıllı Sulama ve Uzaktan İzleme Sistemi. *Avrupa Bilim ve Teknoloji Dergisi*, (15), 229-236.

[32] Taştan, M., & Gökozan, H. (2019). Real-time monitoring of indoor air quality with internet of things-based E-nose. *Applied Sciences*, 9(16), 3435.