MEASURING SYSTEMS

DESIGN AND EVALUATION OF A SMART INDOOR AIR QUALITY MONITORING SYSTEM

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Abstract. This paper presents the design and development of an intelligent air quality monitoring system that utilizes the widely adopted and versatile Arduino Uno microcontroller as its foundational platform. The system underwent comprehensive testing procedures to ensure its adherence to specified requirements. Moreover, a series of experiments were conducted in diverse areas of a residential environment to generate datasets for various air quality indicators. The research findings showcase the potential of the developed system in accurately monitoring and assessing indoor air quality in real time. Enhancing indoor air quality plays a crucial role in mitigating the transmission of common airborne viruses and pollutants, thus significantly benefiting respiratory health.

Key words: analysis, air quality, monitoring, temperature, humidity, health

1. Introduction

Indoor Air Quality (IAQ) holds a paramount role in shaping our well-being and health, given that a substantial portion of our lives is spent within enclosed spaces [1-3]. As the intricate interplay between indoor and outdoor environments continues to unfold, it becomes increasingly evident that prioritizing IAQ is pivotal not only for individual comfort but for the preservation of human health as well.

The consequences of subpar IAQ reverberate far beyond mere inconvenience, delving into the realms of physiological discomfort and potential long-term afflictions [4]. From the pervasive annoyance of headaches and respiratory irritations to the more insidious specter of chronic ailments like asthma and allergies, the manifestations of poor IAQ cast a wide net. Studies have sounded the alarm, linking extended exposure to diminished IAQ with an unsettling 16% uptick in the risk of developing cancer [1]. Such findings underscore the urgent need to delve deeper into the dynamics of indoor air composition.

Among the key culprits behind IAQ degradation stand Volatile Organic Compounds (VOC), a ubiquitous presence that often eludes our awareness [5]. These elusive gases, exhaled by various materials, exercise a potent influence over the delicate balance of indoor atmospheres. With a propensity to sow both immediate discomfort and long-term health challenges, VOCs emerge as formidable antagonists. From the vibrant hues of paint to the unassuming allure of everyday household products, the seemingly innocuous is often the source of VOC emissions. A vision of an indoor environment virtually free from VOC beckons, yet the pursuit of absolute eradication remains tantalizingly elusive.

Emerging as a beacon of hope within this complex scenario are strategies tailored to wrest control over VOC emissions [6-8]. The judicious choice of furnishings and coatings that bear a minimal VOC burden, alongside the vigilant stewardship of chemical stores, emerges as a practical arsenal in the battle against indoor pollution. Nevertheless, these measures, while potent, represent incremental steps toward a cleaner atmosphere, and the benchmarks for VOC levels remain steadfastly distant.

In the tapestry of air quality management, the existing narrative is rooted in vigilant surveillance and the design of purpose-built tools [6]. However, the narrative must evolve to encapsulate the intricate choreography between sources, sinks, and circulation. The journey toward comprehending and optimizing IAQ is still in its infancy, pregnant with the promise of novel discoveries and innovative solutions. The integration of cutting-edge sensor technologies, predictive modeling, and smart building designs holds the potential to revolutionize our approach to IAQ management. The path forward is replete with challenges, but it is also laden with unprecedented opportunities to safeguard our well-being, enhance our productivity, and ensure a healthier, more vibrant future.

2. Disadvantages

The research has several disadvantages that need to be considered. Firstly, it does not aim to provide universally applicable reference values for all apartments, limiting its direct practicality for broader contexts. Instead, its objective is to assess the effects of specific products on air quality within a controlled environment.

Moreover, the study was conducted within a controlled environment, which might not fully represent real-world scenarios. The absence of real-life variables, such as varying ventilation conditions and occupant behaviors, could impact the generalizability of the findings.

While the study highlights potential risks associated with specific products in the controlled setting, it may not encompass all potential risks and interactions that could arise from different product combinations or prolonged exposure.

Numerous air quality monitoring systems have been explored in existing literature [1, 9], showcasing the potential of Internet of Things (IoT) technology in utilizing low-cost sensors for IAQ assessment. The emergence of such systems was significantly influenced by the global pandemic in 2020, where the understanding of viral transmission heightened concerns about poorly ventilated indoor spaces. Recognizing the paramount importance of air quality in safeguarding human health [10], these systems became instrumental in ensuring safer living and working environments. Previous research primarily focused on evaluating the environmental quality of indoor spaces across various buildings.

This research has proved to be of great value, encompassing monitoring scenarios in offices with varying occupancies, tracking air quality in conference halls and offices with different room characteristics, and assessing the environment of spaces with diverse functions within hospital settings [11-12]. However, there remains a notable scarcity of studies dedicated to monitoring air quality in contrasting rooms within residential households. In response, this article introduces a novel tool specifically designed for monitoring the surrounding environment in residential spaces, aiming to explore the relationship between room properties and air quality fluctuations. By delving into this aspect, the research aims to advance our understanding of IAQ dynamics and further enhance the implementation of air quality monitoring systems in residential settings.

3. Goal of the work

The primary objective of this work is to conduct a comprehensive review and subsequently develop an intelligent air quality monitoring system, with Arduino Uno as the foundation, undergoing rigorous testing to ensure its compliance with established requirements and standards, involving a series of experiments within a residential setting and focusing on creating a diverse and extensive dataset of various air quality indicators, measured in contrasting rooms of the house with consideration of the room size, occupancy, ventilation, and activities conducted within each space.

4. Implementation of the system

The implementation of the system is built upon the reliable and versatile Arduino Uno platform, known for its sufficient computational power and wide-ranging support for numerous protocols through its ports. This choice of hardware ensures ease of use and compatibility, making it a popular and widely adopted option in various applications.

To measure an extensive range of air quality indicators, the system incorporates two advanced sensors: the BME680 and CCS811. These sensors are carefully selected for their capability to accurately measure essential parameters, including temperature, humidity, atmospheric pressure, carbon dioxide (CO_2) levels, VOC, and overall IAQ assessment.

The BME680 sensor, with its multi-functionality, enables precise measurements of temperature, humidity, atmospheric pressure, and VOC concentration. By leveraging these capabilities, the system provides comprehensive insights into the overall air quality within the monitored environment.

In addition to the BME680, the CCS811 sensor plays a critical role in detecting and measuring the levels of CO_2 and VOC present in the air. This sensor's ability to precisely gauge these specific elements contributes significantly to the accuracy and reliability of the system's air quality assessments.

As depicted in Figure 1, the external appearance of the developed system is thoughtfully designed to be user-friendly and intuitive. Its compact and sleek design ensures seamless integration into various indoor spaces, allowing users to monitor air quality effortlessly. The visual presentation of the system provides an immediate understanding of its purpose, encouraging users to engage proactively in assessing and maintaining IAQ.

The combination of Arduino Uno, the BME680, and CCS811 sensors, along with the system's thoughtfully crafted external appearance, exemplifies the successful integration of hardware and aesthetics. This intelligent air quality monitoring system strives to provide a user-friendly and reliable solution for IAQ assessment, catering to the growing demand for smart home technologies that contribute to environmental health and well-being.

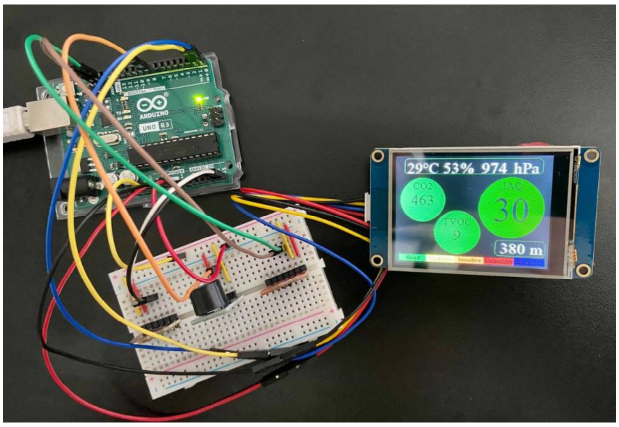

Fig. 1. External appearance of the developed system

In conjunction with the visual representation of the system's external configuration in Figure 1, the functional electrical circuit diagram of the intelligent air quality monitoring system is presented in Figure 2. This comprehensive diagram reveals the relationships between the system's elements and the specific functions it performs, providing valuable insights into its operational mechanisms and internal processes.

The crucial air quality sensors, BME680 and CCS811, are intelligently integrated into the system's architecture. Utilizing the I2C serial bus for seamless communication with the Arduino Uno microcontroller, these sensors diligently read and measure various air quality indicators, including temperature, humidity, atmospheric pressure, CO_2 levels, and VOC. The acquired data is then effectively transmitted to the central controller for further analysis and processing.

Within the heart of the system, the Arduino Uno microcontroller receives the data from the sensors. Employing its computational power, the microcontroller processes the incoming data with precision, enabling sophisticated calculations and assessments of IAQ parameters.

The NX3224T028 display serves as a user-friendly interface, establishing a seamless connection with the Arduino Uno through the UART port, utilizing both the receive stream (RXD) and transmit stream (TXD) modules. This display promptly showcases real-time air quality data to the users, fostering informed decision-making and proactive engagement in IAQ management.

Additionally, an audible alert mechanism is ingeniously integrated into the system. The speaker operates through a single information input, facilitating the transmission of signals that generate sound when critical air quality indicators surpass pre-defined thresholds. This functionality serves as a vital warning system, ensuring prompt responses to potential air quality issues and creating a safer indoor environment.

In conclusion, the comprehensive functional electrical circuit diagram unveils the intricate interplay of the system's components, enabling a thorough understanding of its operations and processes within the internal environment. The intelligent integration of hardware elements, such as the air quality sensors, microcontroller, display, and speaker, exemplifies the system's capability to deliver real-time air quality assessments and enhance overall IAQ management.

The intelligent air quality monitoring system boasts a remarkable feature in the form of a color-coded display, specifically designed to present essential air quality indicators. This display offers users a quick and intuitive glimpse into the current IAQ, CO_2 levels, and VOC concentration within the monitored environment.

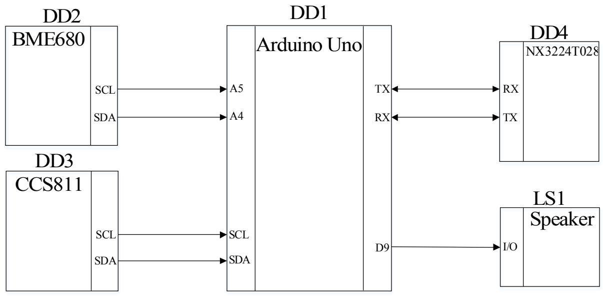

Fig. 2. Functional electrical circuit diagram of the system

The color-coded visual representation serves as a user-friendly interface, where distinct colors are associated with different air quality levels. This design enables users to promptly assess and comprehend the overall air quality status without the need for complex data analysis.

The air quality ranges for IAQ, CO_2, and VOC indicators are thoughtfully compiled and presented in Table I. This table acts as a reference guide, providing users with the corresponding numerical values for different color-coded levels. By consulting this table, users can gain a deeper understanding of the specific air quality thresholds associated with each color on the display.

The incorporation of a color-coded display elevates the system's usability and accessibility, making it suitable for various users, regardless of their technical expertise. It enables individuals to effortlessly engage with the system, fostering a proactive approach towards monitoring and managing IAQ effectively.

Overall, the color-coded display, coupled with the comprehensive air quality ranges in Table 1, embodies the system's commitment to delivering user-friendly and insightful air quality assessments.

Table 1. Color-Coded Air Quality Indicators and Ranges

Quality Index (color)	CO_2	IAQ	VOC
Good (Green)	≤ 700	≤ 50	≤ 200
Moderate (Yellow)	701 - 1000	51 - 175	201 - 400
Sensitive (Orange)	1001 - 1500	176 - 200	401 - 600
Unhealthy (Red)	1501 - 2500	201 - 300	601 - 1000
Hazardous (Purple)	> 2500	> 300	> 1000

Table 2. Measurement Errors of Air Quality Indicators in the Intelligent Monitoring System

Air indicator	Maximal Possible Error	Measurement ranges
Atmospheric pressure	± 1 hPa	300 — 1100 hPa
CO_2	± 3%	400 — 8192 a. u.
Humidity	± 3%	0 — 100 %
Temperature	± 1.0 °C	-40 — 85 °C
Volatile Organic Compounds	± 3%	0 — 11870 ppb

Table 2 presents the measurement errors for all air indicators in our intelligent air quality monitoring system. These errors align with the values declared by the sensor manufacturers, ensuring accuracy and reliability in our measurements.

5. Analysis of variations in air quality across different living rooms in one building

The primary focus of this research entailed a comprehensive analysis of air quality variations within a single building, specifically investigating three distinct living spaces: a bedroom, a kitchen, and a bathroom. To accomplish this, a meticulously designed experiment was conducted, during which sensor data was collected continuously for 10 days. Daily recordings were scheduled at precisely 1:00 PM to minimize potential inaccuracies and fluctuations caused by temporal variations. Moreover, a preliminary half-hour warm-up period was employed before each measurement session, ensuring optimal sensor performance and precision throughout the data collection process. This robust approach aimed to provide a thorough and insightful understanding of the diverse IAQ dynamics experienced across these distinct rooms.

The results of the data collection process encompassed four crucial air quality indicators: IAQ, humidity levels, CO_2 concentrations, and VOC. These essential parameters were recorded and analyzed separately for each of the three designated rooms. Figure 3 illustrates the outcomes for IAQ, Figure 4 presents the findings for humidity levels, Figure 5 showcases the data for CO_2 concentrations, and Figure 6 provides insights into the VOC measurements.

By scrutinizing the data represented in these figures, the research aimed to unveil the intriguing patterns and disparities that emerge across the diverse living spaces. This exploration of air quality variations not only provides valuable insights into the potential factors influencing IAQ but also offers opportunities for further research and potential interventions to optimize and enhance the overall living environment. The comprehensive findings, derived from this meticulous investigation, serve as a foundation for informed decision-making and evidence-based measures to promote healthier and more sustainable indoor living conditions.

Figure 3 highlights the varying CO_2 concentrations in the kitchen, bathroom, and bedroom. The kitchen records the highest CO_2 levels, possibly owing to factors like poor ventilation, the use of gas stoves, and the presence of household chemicals. While the bathroom exhibits lower CO_2 levels compared to the kitchen, they are still higher than those observed in the bedroom, owing to better ventilation in the bathroom. However, the use of cleaning agents and air fresheners in the bathroom contributes to reduced air quality in comparison to the bedroom.

Figure 4 illustrates the differences in humidity levels observed across the kitchen, bathroom, and bedroom. The bathroom and kitchen tend to have higher humidity levels due to the inherent nature of these spaces, involving constant water usage and relatively inadequate ventilation. Activities like drying clothes in the bathroom and cooking in the kitchen further contribute to increased humidity levels in these rooms.

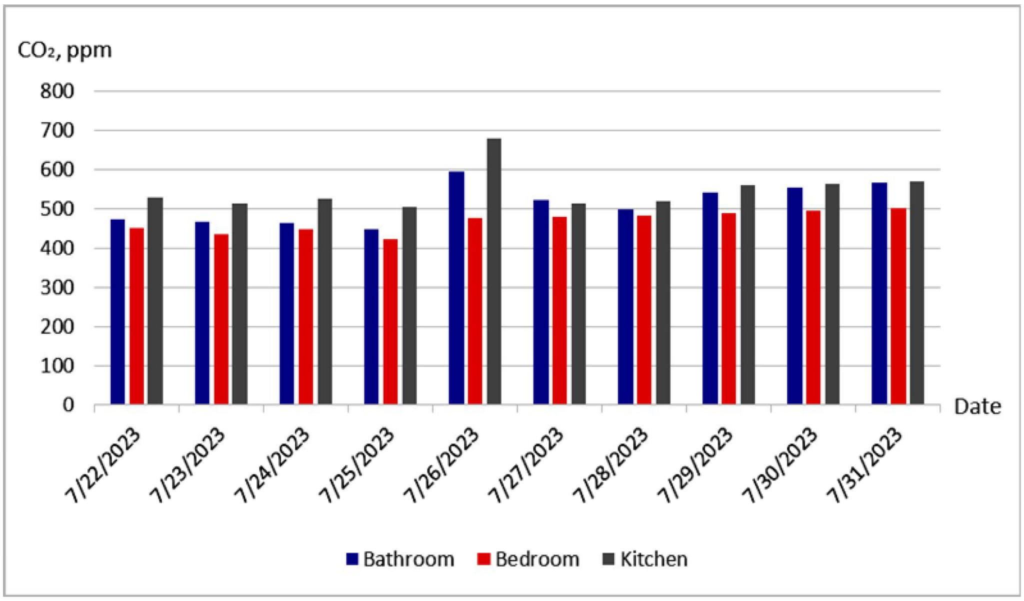

Fig. 3. Dataset for Carbon dioxide

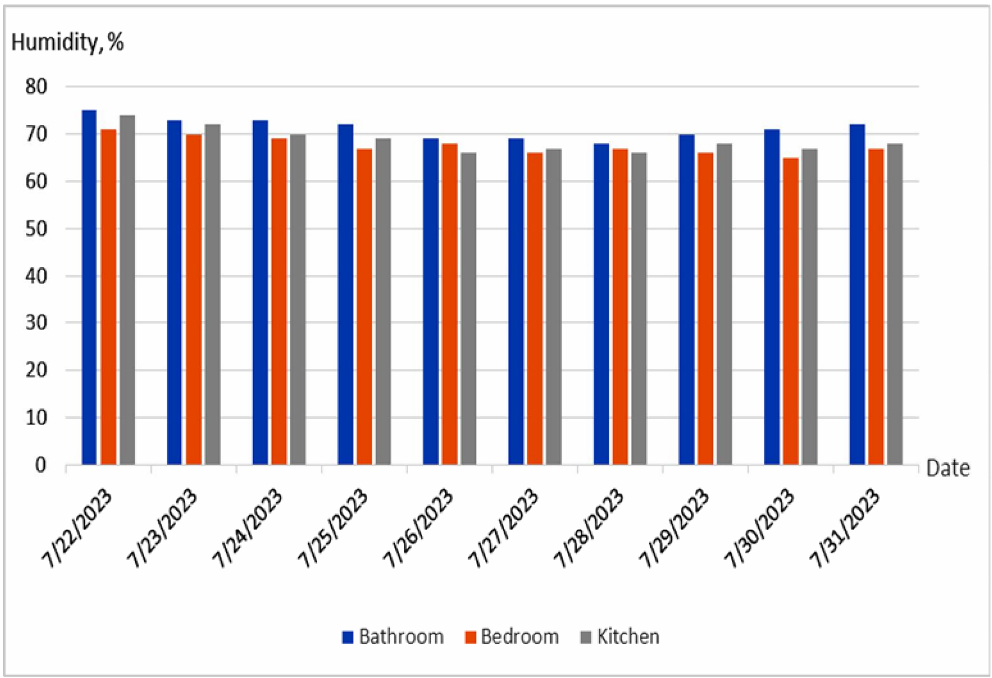

Fig. 4. Dataset for Humidity

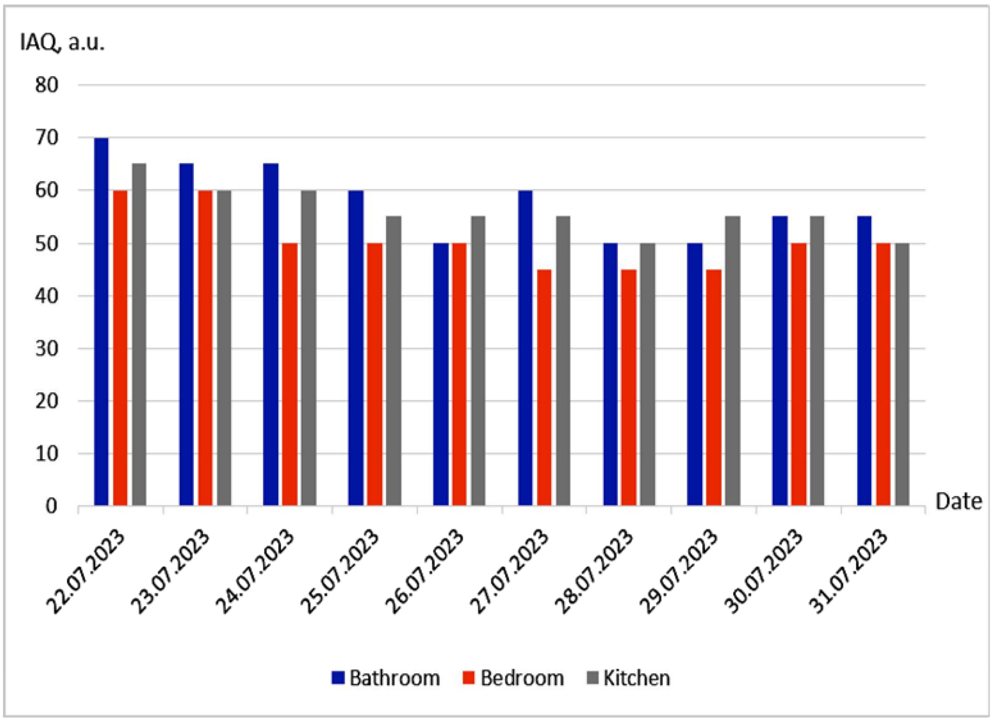

Fig. 5. Dataset for Indoor Air Quality

Figure 3 showcases the variations in IAQ among the three distinct living spaces: the kitchen, bathroom, and bedroom. The IAQ readings indicate that the kitchen and bathroom exhibit poorer air quality compared to the bedroom. This discrepancy can be attributed to the usage of household chemicals, cleaning agents, and air fresheners in these areas, along with higher relative humidity levels.

Figure 6 presents the abundance of VOC across the three living spaces. The bathroom demonstrates higher VOC levels, primarily emitted from air fresheners, cleaning agents, cosmetics, and personal care products used in the area. Moreover, VOC can also originate from cooking and the use of air heaters, resulting in higher levels in the kitchen compared to the bedroom, where such sources are absent. For a comprehensive analysis of air quality disparities among different rooms, conducting this experiment in various seasons would be valuable to observe the impact of weather phenomena on the measured parameters.

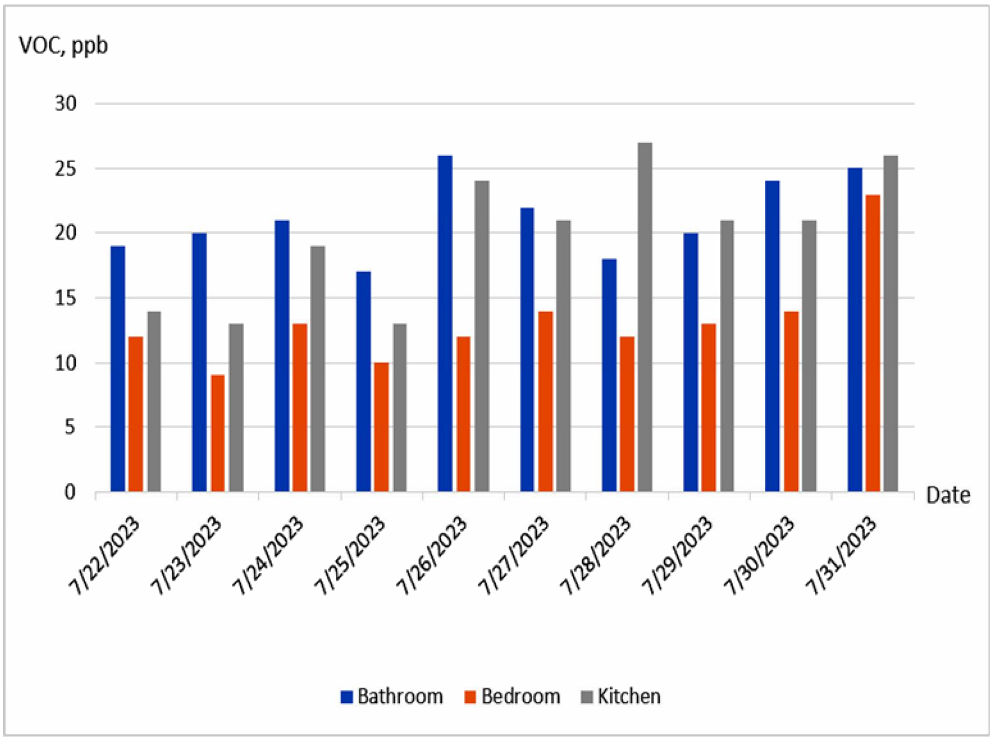

Fig. 6. Dataset for Volatile Organic Compounds

6. Analysis of the impact of fragrance products on IAQ

In contemporary scientific research, the investigation of IAQ has become paramount due to the potential risks posed by VOC emitted from various household cleaning agents and chemical reactions. These VOC, released into the air during the use of everyday items in our homes, can significantly compromise the overall IAQ, potentially leading to health issues and discomfort for occupants.

To comprehensively assess the impact of these VOC-emitting household products on IAQ, a meticulous experiment was conducted, featuring a range of commonly used items found in homes. These included aromatic diffusers, perfumes, and aerosols, which are often present in households for various purposes like air freshening, personal grooming, and cleaning routines.

The experiment employed sophisticated analytical techniques to measure and analyze the concentrations of IAQ-relevant parameters, such as CO_2 and VOC. CO_2 levels serve as an essential indicator of indoor air ventilation and occupant respiration patterns, while VOC concentrations directly reflect the emission of potentially harmful compounds into the air. The generalized diagram of the effect of aromatic diffuser and perfume on CO_2, IAQ, and VOC is shown in Figure 7.

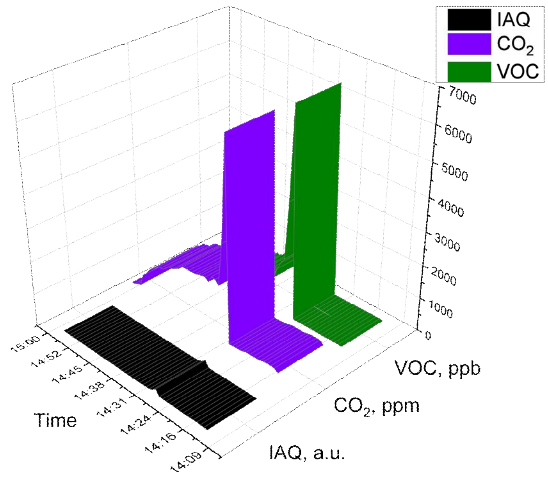

Figure 7. Diagram of the effect of aromatic diffuser and perfume on CO2, IAQ, and VOC

Figure 8, showcased the detailed results of CO_2 levels, offering insights into how the tested household products influenced indoor air ventilation n. Understanding these CO_2 levels is crucial for gauging the effectiveness of air circulation and the potential presence of elevated CO_2, which could signify insufficient ventilation.

Figure 8, b presented the IAQ data, indicating the overall air quality impacted by the tested household products. IAQ is a comprehensive measure that considers various factors, including VOC, particulate matter, and other pollutants that influence the air's health within an indoor environment. Analyzing Figure 8, b allows for a holistic assessment of the IAQ implications of using these common household items.

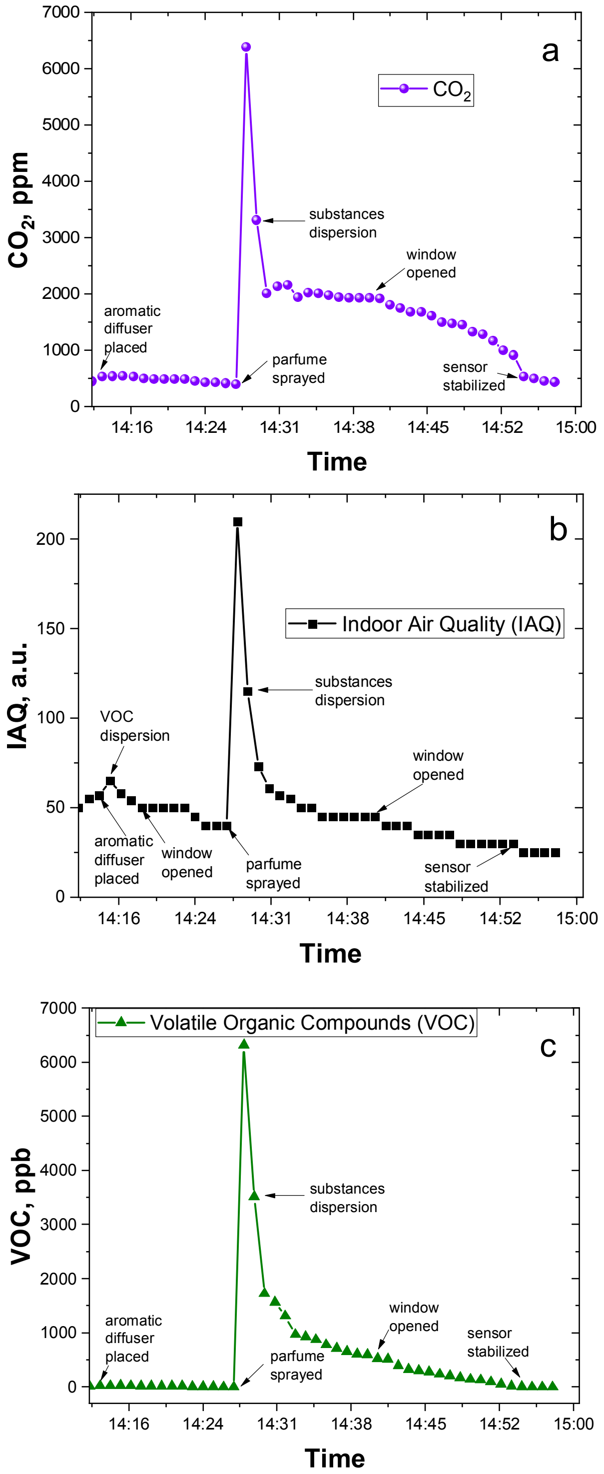

Figure 8. Impact of Aromatic Diffuser and Perfume on CO_2 (a), IAQ (b), and VOC (c)

In Figure 8, c, the comprehensive VOC data was revealed, offering a breakdown of individual VOC and their respective concentrations released during the experiment. This detailed analysis enables precise identification of the most prevalent and potentially concerning VOC emitted by each household product, contributing to a more comprehensive understanding of indoor air pollution sources and potential health risks.

In a controlled scientific experiment aimed at investigating the impact of household products on IAQ, the system was operated for one hour before initiating measurements to ensure sensor stability.

The first pollutant introduced was an aromatic diffuser, positioned approximately five meters away from the sensor. The aromatic diffuser placement occurred at 14:13, and the readings reached their peak at 14:15. Thereafter, starting from 14:16, VOC gradually dispersed into the environment. By 14:19, the IAQ showed significant improvements after the window was opened. However, the window was closed again at 14:25.

Next, at 14:27, a perfume with a 17% concentration was sprayed, leading to a substantial deterioration in air quality. Critical readings were recorded, indicating a high concentration of VOC in the indoor environment. The VOC started to dissipate at 14:29. By 14:31, the readings began to stabilize, and considerable improvement in air quality was observed after the window was opened. The sensors fully stabilized at 14:54.

In summary, the experiment demonstrated that aromatic diffusers, while causing some degradation in IAQ, did not reach hazardous levels of pollution. However, aerosols, as evident from the perfume's impact, can severely affect air quality, making them unsuitable for use in bedrooms or confined spaces where occupants may be exposed to their potential health effects.

The careful analysis of these household products' effects on IAQ provides valuable insights into choosing safer alternatives to maintain a healthier indoor environment and protect the well-being of occupants. This research contributes to the broader understanding of how everyday products can influence IAQ and serves as a foundation for formulating effective strategies to enhance overall indoor living conditions.

7. Conclusions

This work transcends the boundaries of traditional IAQ monitoring systems, ushering in an era of intelligent, data-driven air quality management. By shedding light on the concerning impact of household products and by providing an extensive dataset for research and analysis, this study serves as a cornerstone for further advancements in the realm of IAQ research. Ultimately, the insights gleaned from this research can pave the way for informed decisions, healthier indoor environments, and improved public health outcomes. The researched monitoring system aims to be intuitive, user-friendly, and capable of providing real-time data on IAQ. It aspires to empower residents with valuable insights into the air they breathe within their homes, allowing them to make informed decisions about their living environment.

8. Gratitude

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9. Conflict of Interest

The authors state that there are no financial or other potential conflicts regarding this work.

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