Development of Notification System to Prevent Working Productivity from Declining Caused by Increased Carbon Dioxide Concentration

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Abstract

In association with the change of work style to remote, the home environment should be considered in terms of carbon dioxide concentration (CDC) which has negative effects on the human body, such as less cognitive abilities. To challenge this problem, the authors developed an alert system that supports remote workers to be notified of an increase in CDC, by combining Raspberry Pi, CDC sensor, and Slack. As a result, the developed alert system was able to support the user in keeping the CDC in the room below the set threshold. In addition, the system shows that a significant increase in CDC can be observed in the room when it comes to insufficient ventilation.

Keywords: Carbon Dioxide Concentration (CDC), Raspberry Pi, Working Productivity

1. Introduction

In recent years, the spread of the Internet and the coronavirus have prompted many companies to adopt remote work. According to the Pew Research Center (2022), remote work rates have not declined much even after the peak of the pandemic [1]. In addition, many workers have a favorable attitude toward remote work after the pandemic (Da Silva et al., 2023) [2]. Therefore, remote work will likely continue to be promoted after the end of pandemic.

In consideration of the situation mentioned above, working productivity is noteworthy. Generally, the promotion of remote work in the wake of the coronavirus is interpreted as an increase in productivity of work. In fact, there is an argument that the shift to remote work leads to increased productivity, by thinking from the perspective of the amount of work, work-life balance, and job satisfaction (Kurdy, 2023) [3]. However, most of the papers referring to productivity in remote work simply compare productivity before the introduction of remote work with after doing that. In other words, there is little discussion from the perspective of changes in productivity caused by the home environment.

When pursuing productivity in remote work, a home environment that has become the working environment should be focused. Krivonossova (2022) points out that distractions in remote work are caused by the home environment, such as TVs, books, and beds [4]. However, different from the perspective above, this paper focuses on the composition of indoor air. According to Azuma (2018), increased indoor CDC due to human breathing and other factors can cause negative impacts on the human body, such as dizziness, headaches, and reduced cognitive and problem-solving abilities [5]. Therefore, remote workers need to maintain indoor air quality by ventilating and other ways. However, the increase in CDC cannot be perceived easily, and it is difficult to know the appropriate timing to ventilate. Therefore, there is a possibility that the increase in CDC is causing a decrease in working productivity even if remote workers do not perceive it.

The purpose of this paper is to prevent an increase in CDC and a decrease in working productivity by using the system developed to notify the appropriate timing of ventilation.

2. Previous Research to Set Threshold

The unit used to express CDC is the "ppm (parts per million)”. To determine the CDC threshold for the notification, it should be referred to the indoor CDC standards published by various public agencies.

The Wisconsin Department of Health Services (2023) states that 400 to 1,000 ppm is a reasonable standard for CDC indoors. Moreover, it points out that from 1,000 to 2,000 ppm will cause complaints of drowsiness and poor air quality, and from 2,000 ppm and above will cause health problems such as headaches, drowsiness, decrease in concentration to work, and mild nausea [6]. In addition, Japan's Ministry of Health, Labour and Welfare (2016) has set the environmental health management standard for CDC at 1,000 ppm in its Building Sanitation Law because CDC levels above 1,000 ppm cause fatigue, headaches, tinnitus, and breathlessness in the human body [7].

From the above, it is reasonable to set the threshold used in this paper at 1,000 ppm. Thus, the standard for notification used in the developed system in this paper can be set at 1,000 ppm.

3. Specifications of Developed System

3.1. System Overview

Fig. 1 shows a photograph of the overall CDC measurement and notification system created in this paper, and Fig. 2 shows a wiring diagram of the system. The system consists of a small computer called "Raspberry Pi model 4B" and two modules called "MH-Z19C" and "LCD 1602". The computer and display are connected by an i2c communication interface, "PCF8574".

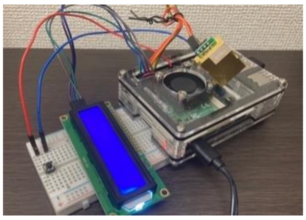

Fig. 1. Overall Picture of CDC Measurement and Notification System

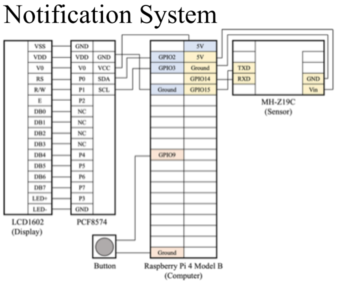

Fig. 2. Wiring Diagram of the System

The functions implemented in this system can be divided into measurement and notification. These two functions are intended to solve the problem stated in Chapter 1.

3.2. Measurement Function

The CO2 sensor module, MH-Z19C, was used to measure CDC. In terms of the program code to measure CDC, the function from the library available on GitHub created by Ueda (2018) is utilized to simplify source code [8]. There are two measurement functions using this. The first is to record measurement results as csv file for analysis. The second is to immediately check the results at any given time through a small display.

3.3. Notification Function

In the system, Slack, the communication tool in business, was used for the CDC notifications. The purpose of this is to send a notification to the user to urge them to ventilate when the CDC value exceeds the threshold level of 1,000 ppm.

In addition, three conditions were set for notification. First, the Raspberry Pi must be connected to the Internet. Second, the notification is sent when the measured CDC value exceeds 1,000 ppm. Third, the judgment on whether to send a notification is made every five minutes.

4. Methods of Evaluation and Data Measurement

4.1. Environment during Measurement of Carbon Dioxide Concentration Data

The data measurements in this paper were conducted by the authors in their room. A simplified figure of the room where the data measurements were taken is shown in Fig. 3. To measure CDC as close as possible to the air that a person breathes, the sensor was placed close to the person. At this time, the position of the sensor was adjusted to avoid direct contact with the exhaled breath to obtain accurate data. Also, the "natural ventilation system" in this paper refers to the 24-hour ventilation system in the bathroom outside the "door", and the room is ventilated by taking in fresh air through the gaps around the "door" in the experimental environment.

When measuring data, test measurements were conducted under the same environment for at least 60 minutes prior to the start of the measurement to confirm that the CDC remained stable at less than 1,000 ppm. In addition, the working human was not away from the seat during the measurement and was assumed to be engaged in constant breathing activity.

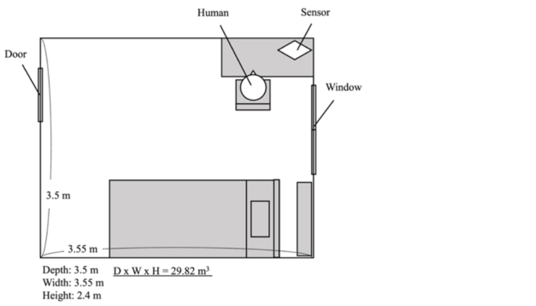

Fig. 3. Environment of Room during Measurement

4.2. System Evaluation

In the evaluation of the system, the effect of the notification system on the increase in CDC is evaluated. Assuming a situation of inadequate ventilation, the "natural ventilation system" is stopped. Then, the "Window" in Fig. 3 is opened at the time of the notification to urge the user to ventilate the room. As a result, the system will be evaluated whether it has been able to contribute to reducing the CDC in the room below 1,000 ppm.

5. Results

Under the environment and conditions described in Chapter 4, an experiment was conducted by opening the "Window" and ventilating the room when the measured CDC value in the room exceeded 1,000 ppm, and a Slack notification was received. Table 1 shows the date and time of the measurement and the total measurement time, and Table 2 shows the elapsed time until when the notification was sent and the conducted ventilation time. Also, the CDC transition obtained from this measurement is shown in Fig. 4. In Fig. 4, the period during which the ventilation was conducted is colored.

Table 1. Date and Total Time of Measurement for Fig. 1

Start date and time	End date and time	Total Time
2023/9/27 19:00	2023/9/28 0:00	300 minutes

Table 2. Elapsed Time from Start of Measurement to Notification and Ventilation Time

Elapsed Time (minutes)	Ventilation Time (minutes)
65	15
95	15
120	30
190	35

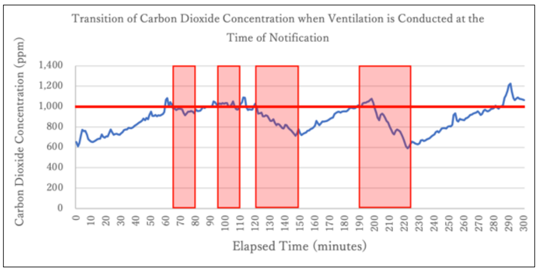

Fig. 4. Transition of Carbon Dioxide Concentration when Ventilation is Conducted at the Time of Notification

As shown in Table 2 and Fig. 4, it can be said that ventilation at the time of the notification contributes to keeping the CDC in the room below 1,000 ppm. However, when the "Window" was closed, the CDC rapidly rose and exceeded 1,000 ppm. In the end, 135 minutes of ventilation time was required out of 300 minutes. However, it would be fair to say that positive results were obtained for the question, "Can the notification system help to keep the CDC in the room below 1,000 ppm?"

6. Discussion

It is fair to say that the system developed in this paper can help to prevent the increase of CDC in a room, as shown in the results of Chapter 5. In addition, it also showed that a room with inadequate ventilation has a high possibility of increasing CDC causing not only reduced productivity but also health problems. In other words, the system developed in this paper can prevent the decline in working productivity by knowing the adequate timing to ventilate. Also, the social value of this system in realizing the goal of improving productivity in remote operations can be well recognized.

However, this paper does not actually compare working productivity. Therefore, it is necessary to consider the possibility that Slack notifications may interfere with concentration on work. From this viewpoint, this system will not necessarily lead to increased working productivity based on the only verification in this paper.

In addition, the system developed in this paper only notifies the user of appropriate ventilation timing. Thus, the control of CDC in the room depends on the opening and closing of windows by the user. This is sufficient for remote work but needs further expansion to be utilized in other locations. As Fig. 4 shows, in rooms with inadequate ventilation, ventilation by opening and closing windows only becomes a temporary measure. Considering that the CDC rose immediately after the window was closed, a ventilation system that automatically adjusts the CDC independent of user behavior would be needed to maintain the appropriate working environment.

Also, according to OPEN ACCESS GOVERNMENT (2021), since the COVID-19 pandemic, workers' awareness of flexible work styles and better working environments has increased [9]. Therefore, the system developed in this paper can be used to improve the working environment at a more advanced stage than the promotion of remote work. The importance of this system will be recognized, and its demand will rise in the current situation that COVID-19 has promoted not only remote work but also awareness of the work environment.

7. Conclusion

The purpose of this paper is to prevent an increase in CDC and a decrease in working productivity by using the system developed to notify the appropriate timing of ventilation.

The CDC notification system developed in this paper could be utilized to improve the working environment for remote workers. As shown in Fig. 4, the system was able to help keep the CDC in the room below 1,000 ppm by encouraging ventilation at the appropriate time. However, it does not indicate whether it was possible to prevent working productivity decline. Therefore, further verification of working productivity will be necessary in the future.

The data measurements in this paper were conducted in the limited environment of the authors' room, and the number of experimental subjects is insufficient. Therefore, it will be necessary in the future to acquire a large amount of data and to consider detailed environmental conditions such as the location of ventilation fans, actual flow of air, the number of people, room size, and temperature. This would provide detailed findings and suggestions for ventilation.

Acknowledgement

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Authors Introduction

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