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Information Delivery System to Maintain Intellectual Productivity in Teleworking

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Abstract - The COVID-19 pandemic highlighted the importance of effective telework environments, particularly in maintaining intellectual productivity. Prior research suggests that productivity is closely linked to environmental satisfaction in the workplace. However, many remote workers lack systems that facilitate optimal conditions at home. To address this, we developed an IoT-based tool that monitors indoor temperature, humidity, and CO_2 levels and provides tailored feedback to support user-driven environmental adjustments. Over a two-month experimental period, the system demonstrated reliable performance and led to observable behavioral changes, such as the proactive use of humidifiers. These findings suggest that personalized environmental information delivery can effectively support productivity improvement in telework settings.

Keywords: telework, IoT, indoor environment, CO_2, productivity

1 INTRODUCTION

Following the initial COVID-19 emergency declaration, many workers in Japan transitioned from office settings to telework. According to a survey by the Japan Business Federation [1], approximately 60% of companies adopted telework systems (Fig. 1 [2], [3]).

While environmental factors such as temperature, humidity, and carbon dioxide levels were initially overlooked, subsequent studies revealed a strong correlation between environmental satisfaction and intellectual productivity [4]. In the United States, improving such environmental conditions is estimated to contribute between $40 and $200 billion in annual economic benefits (Table 1) [5]. Recognizing this, many companies have implemented Building Energy Management Systems (BEMS) and smart office technologies to improve in-office environments.

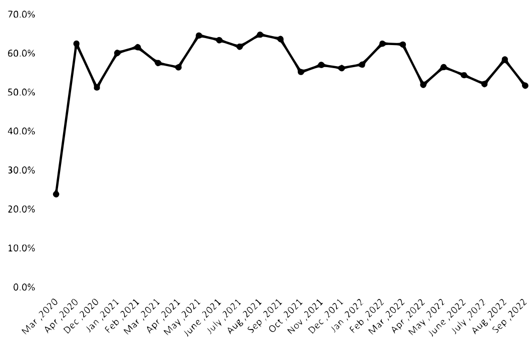

Figure 1: Telework implementation rate among Japanese companies

Table 1: Estimated economic impact of improving indoor air quality in the United States

Source of productivity gain	Estimated annual savings (USD)
Reduced respiratory illness	$6–14 billion/year
Reduced allergy and asthma symptoms	$2–4 billion/year
Reduced sick building syndrome symptoms	$10–30 billion/year
Improved worker performance from changes in thermal environment and lighting	$20–160 billion/year

However, few comparable efforts have been made to support the home workspace. A survey conducted by Daikin Industries found that about 70% of teleworkers experienced dissatisfaction with their home air quality, citing issues such as temperature instability, dryness, and lack of ventilation [6]. Despite growing evidence that thermal comfort influences productivity, centralized solutions for home telework environments remain limited.

To address this gap, we developed an IoT-based system utilizing the "Netatmo Weather Station" to measure key environmental parameters—temperature, humidity, and CO_2 concentration—in the teleworker's environment. Based on the collected data, our system delivers personalized feedback aimed at improving indoor conditions. This paper explores the effectiveness of such a system in promoting environmental awareness and supporting behavioral changes that may lead to improved intellectual productivity during telework.

2 RELATED STUDY

2.1 Telework Situation in Japan

The Ministry of Internal Affairs and Communications defines telework as a flexible work style utilizing ICT to enable more efficient use of time and space [6].

It can be broadly categorized into three types based on location: telework, mobile work, and satellite office work. Since the onset of the COVID-19 pandemic, telework has become increasingly widespread, with many companies adopting it as a standard practice [7].

Telework offers benefits not only for employers and employees but also for broader society. This study focuses specifically on telework, where individuals work from their residences.

2.2 Indoor Environment and Intellectual Productivity

2.2.1 Teaching Bot for Enhancing Indoor Comfort

Hamanaka et al. [8] developed a chatbot integrated with Slack to support indoor comfort. By retrieving real-time temperature and humidity data from a Raspberry Pi 3 sensor, the bot provides users with feedback and visualizations to help maintain optimal environmental conditions. The system enables users to make informed adjustments to their surroundings through simple, interactive queries.

2.2.2 AI/IoT-Driven Intelligent Environmental Control

Nishino et al. [9] designed a system to mitigate drowsiness during desk work using an AI-based alertness detection mechanism. When the system detects reduced alertness via a desk-mounted camera, it automatically adjusts air conditioning to improve worker attentiveness. Evaluated over two seasonal periods with five office workers, the system demonstrated reductions in drowsiness-related productivity losses.

2.3 Novelty of Our Study

Most IoT-based environmental control systems to date have focused on shared office spaces or general home energy usage (e.g., HEMS). However, they often lack consideration for the unique needs of telecommuters working individually from home. Given the diversity of household environments and air-conditioning systems, existing solutions are not readily applicable to home-based telework.

In contrast, our study addresses this gap by developing a personalized information delivery system specifically for telework. The system collects temperature, humidity, and CO_2 data using a commercially available IoT sensor and provides tailored recommendations to help users manage their indoor environment. Unlike systems that automate control, our approach emphasizes behavioral support—encouraging individuals to take actions themselves. To be effective during work hours, the feedback is designed to be clear, timely, and intuitive. The following sections describe the system architecture, experimental methodology, and results demonstrating its effectiveness in supporting productive and health-conscious teleworking.

3 SYSTEM DESCRIPTION

3.1 Overview

The proposed system monitors environmental conditions in home workspaces using strategically placed sensors. It analyzes the collected environmental data and generates real-time notifications aimed at supporting the maintenance or improvement of indoor conditions. Upon receiving these alerts, users can take actions based on the provided recommendations, thereby fostering a more productive and comfortable teleworking environment.

3.2 System Configuration

Figure 2 illustrates the overall architecture of the system. The design is centered on IoT sensors installed across diverse telework environments. These sensors continuously transmit relevant environmental data to a centralized management server. The server not only retains these data in real time but also stores it for longitudinal analysis.

After data collection, the system performs both real-time and historical analysis. This dual-layered processing enables the system to generate personalized feedback—either suggesting improvements or encouraging maintenance of favorable conditions. Once generated, the feedback is sent as notifications to the users.

The following subsections provide detailed explanations of each system component and the logic that governs its operation.

3.2.1 Data Acquisition

The data acquisition module utilizes the Netatmo Weather Station [11] as the primary sensor device. The setup consists of two units: a primary (indoor) module and a secondary (outdoor) module. The indoor module measures variables such as temperature, humidity, and CO_2, while the outdoor module collects contextual environmental data.

The architecture ensures that data from the indoor module is directly transmitted to Netatmo's cloud server via the household's Wi-Fi. The outdoor module relays its data through the indoor module. A key feature of this system is Netatmo ' s account-specific data management, which allows for unlimited storage and access through an Application Programming Interface (API). This makes the system extensible and suitable for integration into custom platforms.

A data management platform developed in our previous work [12] played a critical role in aggregating data from multiple Netatmo devices installed in different households. This was achieved by linking each device to its corresponding user account.

To maintain data freshness and usability, updates are performed every five minutes. The data is stored in BSON (Binary JSON) format using MongoDB, a document-oriented database. The backend is hosted on Heroku, a cloud platform-as-a-service. Table 2 summarizes the development environment.

3.2.2 Information Generator

This module analyzes real-time and historical sensor data to provide personalized recommendations that support a productive indoor environment. It generates four categories of information:

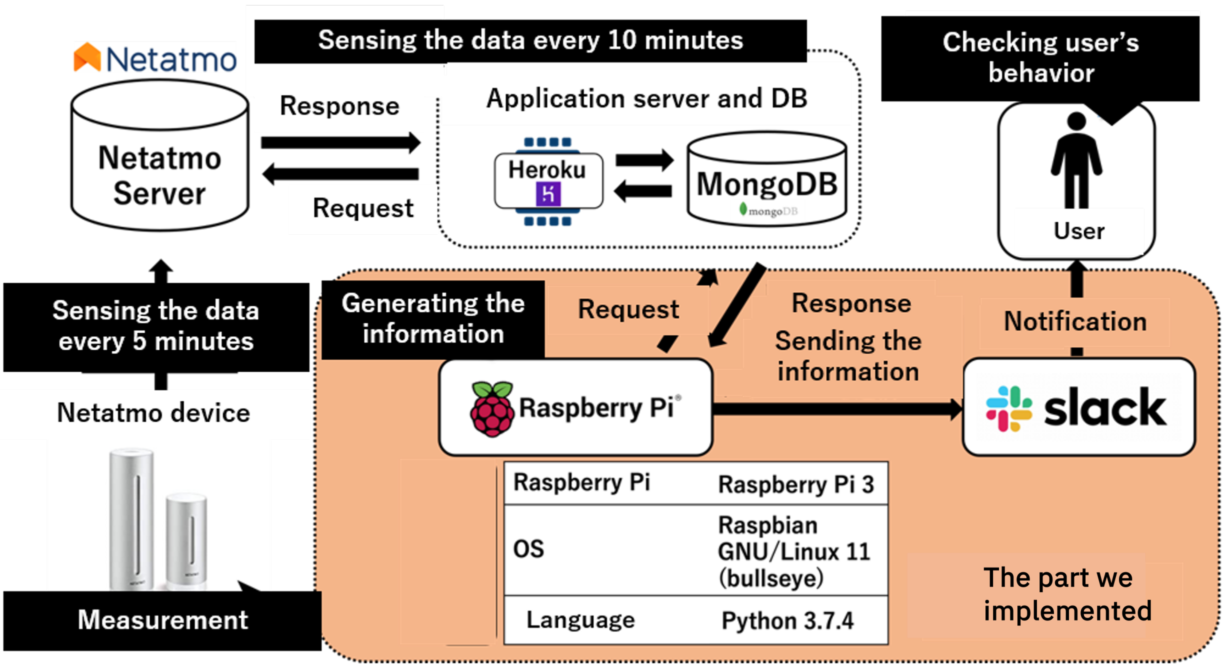

Figure 2: System overview (highlighting the parts we implemented)

Table 2: Development environment of the platform

Component	Server-side	Client-side
OS	macOS	macOS
Language	Node.js (v10.18.1)	HTML, CSS, (SCSS), JavaScript
Library	express, ejs, crypto, Socket.IO	Vue.js, Bootstrap-Vue, Core UI, Chart.js, Axios
Database	MongoDB	–

Table 3: Ideal working environment

Category	Detail
CO_2 concentration	Less than 1000 ppm
Temperature	17–28 ° C
Relative humidity	40–70%

1. **Current Indoor Environment Status:** Real-time values of temperature, humidity, and CO_2, along with immediate guidance.

2. **Daily Environmental Trends:** Graphical representations of fluctuations throughout the day, annotated with explanatory comments.

3. **Historical Analysis:** Suitability rates for the previous day and week, with averages and actionable advice.

4. **Guided Articles:** Informative content to help users maintain or improve their indoor environment.

To determine optimal indoor conditions, the system references Japanese building environmental hygiene standards [10], as shown in Table 3 [13].

Table 4: Definitions of Information Types

Type	Definition
Type 1	Current indoor environment status (temperature, humidity, CO_2) with immediate guidance.
Type 2	Daily environmental trends (8:00–19:00) with annotated comments.
Type 3	Historical adequacy rates for the previous day/week with averages and advice.
Type 4	Informative articles or tips to maintain/improve indoor environment.

Table 5: Conditional branching and comments in humidity (current status)

Condition	Comment
40–70%	Humidity is within the optimal range. Maintain current conditions.
$< 40\%$	Air is too dry. Consider humidification to reduce fatigue and discomfort.
$> 70\%$	Humidity is high. Ventilate or dehumidify to prevent discomfort and mold.

The system evaluates each metric using predefined conditional logic.

Table 4 summarizes the definitions of the four information types used in this study for clarity.

Table 5 and Table 6 show the rule sets for current humidity and CO_2 conditions, respectively.

Information of type 2 provides visualized summaries and commentary on the fluctuation of temperature, humidity, and CO_2 concentration from 8:00 to 19:00. The conditional rules for interpreting these trends are shown in Tables 7–9.

The system also evaluates how well the indoor environment

Table 6: Conditional branching and comments in CO_2 (current status)

Condition	Comment
< 1000 ppm	CO_2 levels are within the optimal range. Good air quality. Keep maintaining ventilation.
1000–2000 ppm	Slightly elevated CO_2 levels detected. Consider ventilating the room soon.
> 2000 ppm	High CO_2 concentration detected. Immediate ventilation is recommended to avoid fatigue and decreased concentration.

Table 7: Conditional branching and comments in temperature (daily trends)

Condition	Comment
18–28 ° C	Today ' s room temperature was optimal. Maintain this range.
< 18 ° C or > 28 ° C	Readings were outside the optimal range. Adjust temperature for comfort and productivity.

met the defined standards, expressed as an " adequacy rate. " Tables 10–12 summarize these assessments.

Every day at 12:00, the system generates and sends summary reports highlighting the relationship between indoor environmental conditions and productivity. These recommendations are grounded in scientific evidence and are intended to raise user awareness and promote behavior change.

3.2.3 Information Notification

The system implements three types of notification functions, all of which are delivered via Slack [14], a chat-based communication tool. Each participant had a dedicated Slack channel, and a bot named "Indoor Environment Notification Bot" dispatched the notifications. The features include:

1. Periodic notifications that deliver the four types of environmental information previously mentioned.
2. Alerts triggered when humidity or CO_2 levels exceed predefined thresholds.
3. Interactive chatbot responses to user inquiries regarding the current environment.

Details of each function are as follows:

Table 8: Conditional branching and comments in humidity (daily trends)

Condition	Comment
40–70%	Humidity levels were ideal today. Maintain this range.
$< 40\%$ or $> 70\%$	Humidity was outside the ideal range. Adjust to avoid fatigue.

Table 9: Conditional branching and comments in CO_2 (daily trends)

Condition	Comment
< 1000 ppm	Great condition. CO_2 levels were consistently low. Maintain ventilation.
≥ 1000 ppm	Some elevated CO_2 readings detected. Increased ventilation is recommended.

Table 10: Temperature adequacy and comments

Adequacy Rate	Comment
$> 80\%$	100% adequacy with average temperature of 23.3 ° C. Maintain range.
60–80%	Adequacy rate was 74% (avg: 18.9 ° C). Nearly optimal.
40–60%	Adequacy rate was 50% (avg: 16.2 ° C). Improvement needed.
$< 40\%$	Only 19% adequacy (avg: 13.2 ° C). Adjust temperature to optimal range.

(1) Periodic Information Delivery The system sends scheduled updates during work hours. These are concise to avoid interfering with the user ' s workflow. Figure 3 shows a sample notification of information type 1, where the system delivers current indoor environmental values and simple status messages. Figure 4 illustrates a time-based CO_2 trend graph corresponding to information type 2.

(2) Real-Time Alerts Sensor data are collected every 30 minutes. When threshold conditions are met, the system sends alert messages with brief evaluation and recommended actions.

(3) Interactive Chatbot for PMV Feedback When a user sends a message with specific keywords (e.g., "working environment"), the chatbot responds with a thermal comfort analysis. This analysis uses the Predicted Mean Vote (PMV) index, which reflects human thermal comfort based on six parameters: four environmental (temperature, humidity, air velocity, and mean radiant temperature) and two personal factors (clothing insulation and metabolic rate).

The PMV index ranges from -3 (cold) to +3 (hot), with 0 indicating thermal neutrality. The system estimates:

- Air velocity: assumed 0.1–0.3 m/s
- Radiant temperature: equal to room temperature
- Metabolic rate: fixed at 1.3 METs (sedentary desk work)

Table 11: Humidity adequacy and comments

Adequacy Rate	Comment
$> 80\%$	100% achievement (avg: 50%). Maintain 40–70%.
60–80%	84% adequacy (avg: 44%). Close to target.
40–60%	50% adequacy (avg: 39%). Fatigue may increase. Improve humidity.
$< 40\%$	Only 18% adequacy (avg: 20%). Active humidification recommended.

Table 12: CO_2 adequacy and comments

Adequacy Rate	Comment
> 80%	Excellent air quality maintained (avg: *e.g.* 620 ppm).
60–80%	Adequacy rate was 72% (avg: *e.g.* 1,050 ppm). Satisfactory.
40–60%	Adequacy rate was 50% (avg: *e.g.* 1,400 ppm). Improve ventilation.
< 40%	18% adequacy (avg: *e.g.* 2,100 ppm). Increased CO_2 risk. Ventilation needed.

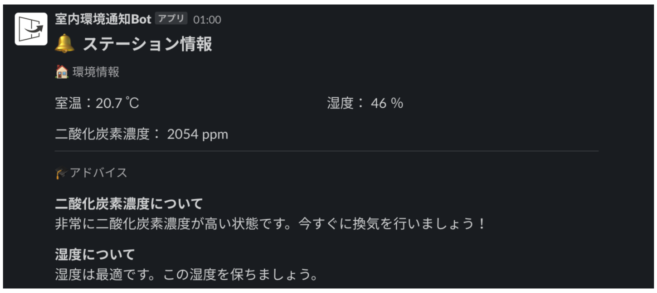

Figure 3: Example of information type 1: current indoor environmental status notification

- Clothing insulation: selected by user from Table 13 [16]

Based on the user's input, the system calculates the PMV value and returns tailored feedback.

4 EXPERIMENT

4.1 Overview of the Experiment

The main objective of this experiment was to evaluate the effectiveness of the proposed system in promoting environmental awareness and behavioral change in telework environments. Using the Netatmo sensor system, indoor environmental data were collected over a period of 33 weekdays between November 10 and December 28, 2022. Based on the collected data, personalized environmental feedback was generated and delivered to participants.

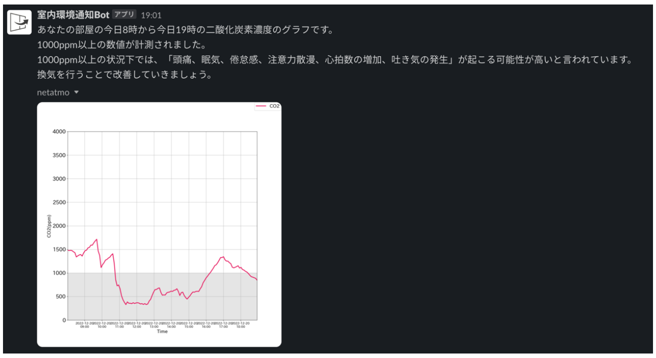

Figure 4: Example of information type 2: CO_2 trend notification

Table 13: Relationship between clothing type and insulation level (clo) [15]

Clothing Type	Clo Value
Collarless short-sleeve shirt and shorts	0.3
Short-sleeve shirt and pants	0.5
Long-sleeve shirt and pants	0.7
Long-sleeve shirt and jacket/sweater	1.0
Thick suit and vest	1.5

Table 14: Participant attributes of the study

Attribute	Participant A	Participant B	Participant C
Age	50s	40s	20s
Gender	Male	Male	Female
Occupation	Engineer	Technical Sales	Office Worker
Residence Type	Apartment	Apartment	Apartment
Workplace Location	Study	Living Room	Living Room
Workplace Size (m^2)	18	22	14

In addition to sensor data analysis, structured interviews were conducted before, during, and after the experiment to assess participants' perceptions of system usability, relevance, and impact on their telework practices.

4.2 Participant Demographics

Three participants residing in the Kanto metropolitan area and engaged in telework took part in the experiment. They ranged in age from their 20s to 50s and represented diverse occupational backgrounds. Table 14 summarizes their demographic and environmental attributes, based on responses to pre-, mid-, and post-experiment questionnaires.

4.3 Experimental Method

This section outlines the procedures used to implement the experiment, including device preparation and participant setup.

4.3.1 Participants

Before the start of the experiment, the following preparatory steps were taken:

1. Creation of user accounts for both Netatmo and Slack platforms.
2. Configuration of devices and association with corresponding user accounts.
3. Delivery and installation guidance for each participant.

Table 15 lists the components included in the experimental device kit.

Participants were instructed to place the indoor module in their telework workspace, and the outdoor module in a semi-protected location such as a veranda or window area, avoiding direct exposure to rain and wind.

Table 15: Contents of the experimental kit

No.	Details
1	Netatmo Weather Station outdoor module
2	Netatmo Weather Station indoor module
3	AC adapter for the indoor module
4	Kit bag
5	Covering letter

4.3.2 Pre-experiment Questionnaire

A preliminary survey was conducted to understand participants' baseline awareness of their teleworking environments and potential areas for improvement. The questionnaire was implemented using Google Forms [17], and was inspired by a similar survey developed by Daikin Industries [18], [19].

Participants were asked about housing type (e.g., detached house, condominium, apartment), environmental conditions (e.g., dust, temperature, humidity, ventilation), and the presence of issues such as mold, stale air, or noise. Additionally, they were asked to indicate which improvements they considered necessary, such as updating furniture (e.g., desk, chair, monitor), enhancing appliances (e.g., air conditioners, humidifiers), or routine cleaning habits.

4.3.3 Questionnaire During the Experiment

Although all participants primarily worked remotely, occasional office visits occurred. Since the study focused on telework, participants were asked to complete a daily survey using SurveyMonkey [20]. The questionnaire recorded their work location, working hours, and their evaluation of both the work tasks and environmental conditions.

4.3.4 Post-experiment Questionnaire

To evaluate the effectiveness of the system and capture any shifts in participants' environmental awareness, a post-experiment questionnaire was administered. Table 16 summarizes the questionnaire items.

5 EVALUATION

The aim of this study was to improve the quality of telework environments. This section evaluates the effectiveness of the proposed system in achieving that goal, based on experimental outcomes.

5.1 System Evaluation

To assess system performance, we analyzed how consistently it delivered information to participants on their work-from-home days.

The system generated four types of environmental notifications, along with alerts triggered by bi-hourly monitoring of humidity and CO_2 levels. It also featured a chatbot that responded to participant inquiries regarding the current environment.

Table 16: Post-experiment questionnaire items

No.	Question
1	Where did you position the indoor module?
2	Where was the outdoor module placed?
3	What are the dimensions of the room where the device was set up? (in square meters)
4	Was the installation process for Netatmo intuitive?
5	Was the notification frequency of once per hour satisfactory?
6	Please elaborate on your answer to question 5.
7	Was receiving a daily summary notification at 19:00 suitable for you?
8	Please elaborate on your answer to question 7.
9	Was the 8:00 AM summary notification (recapping the previous day/week) convenient?
10	Please explain your response to question 9.
11	Was the 12:00 PM informational column notification helpful?
12	Please explain your response to question 11.
13	Do you have further comments regarding the column feature?
14	Which type of indoor environmental data did you find most valuable?
15	In your opinion, did the system improve your work environment?
16	What aspects of your home environment present challenges when telework? (Select all that apply.)
17	Are there tools or devices you are considering investing in to enhance your telework experience?

Table 17 summarizes the number of notifications delivered, separated by participant and time of day (during vs. outside working hours).

We define the "adequacy rate" for a variable (temperature, humidity, or CO_2) as the percentage of measurements that satisfy the standard in Table 3 during work hours (8:00–19:00) on teleworking days:

We define the "adequacy rate" for a variable (temperature, humidity, or CO_2) as the percentage of measurements that satisfy the standard in Table 3 during work hours (8:00–19:00) on teleworking days. It is calculated as the number of measurement samples that meet the standard divided by the total number of measurement samples taken during work hours, multiplied by 100:

$$\text{Adequacy Rate (\%)} = \left(\frac{\text{samples within standard}}{\text{samples during work hours}}\right) \times 100 \quad (1)$$

Table 18 presents the calculated provision rates for each participant and information type.

5.2 Questionnaire Evaluation

Following the experiment, participants were asked to complete a post-experiment questionnaire. This section summarizes the results related to system usability, notification interval preferences, and perceived usefulness of the delivered

Table 17: Number of notifications delivered during the experiment

Function	Type	Participant A		Participant B		Participant C	
		Work hours	Off hours	Work hours	Off hours	Work hours	Off hours
Notification	Type 1	182	296	160	349	82	134
	Type 2	20	20	9	-	-	-
	Type 3	13	14	5	-	-	-
	Type 4	13	14	5	-	-	-
Alert	Humidity	42	149	0	0	0	0
	CO_2	94	7	255	537	7	45
Chatbot	–	0	0	0	0	0	0

Table 18: Information provision rate (system availability)

Type	A	B	C
Type 1	84%	84%	83%
Type 2	83%	83%	83%
Type 3	100%	100%	100%
Type 4	100%	100%	100%

Table 19: Participants' evaluation of improvements in their work environment (5-point scale)

Information Type	A	B	C
Type 1	4	4	4
Type 2	5	5	4
Type 3	3	5	4
Type 4	4	5	4

information.

5.2.1 Device Installation Difficulty

System usability was evaluated based on the ease of device installation. Participants rated the difficulty on a 5-point scale, where 1 indicated high difficulty and 5 indicated ease. The average rating was 4.5, suggesting that the installation process was generally straightforward and accessible.

5.2.2 Notification Frequency Evaluation

Participants evaluated the frequency of each type of information notification using a 5-point scale, where higher values indicated greater satisfaction with the interval. Table 19 presents the results.

Participants noted that Type 3 notifications, which provided daily or weekly summaries, were helpful in establishing awareness early in the day. However, Type 4 notifications delivered at noon were more difficult to engage with, as they coincided with the lunch period (12:00–13:00).

5.2.3 Perceived Usefulness of Information

Participants were also asked to evaluate the usefulness of each type of information. Ratings were based on a 5-point scale, where 5 indicated the highest perceived value. Types 2 and 3, which correspond to daily summaries, were grouped together. Table 20 summarizes the responses.

Table 20: Perceived usefulness of each information type (5-point scale)

Information Type	A	B	C
Type 1	3	5	4
Type 2 and 3	5	5	4
Type 4	3	5	4

5.3 Improvement of Work Environment

This section examines how the proposed system contributed to improving participants' work environments.

5.3.1 Quantitative Evaluation

Quantitative assessment was conducted using environmental data collected during telework days. Metrics included average temperature, humidity, and CO_2 concentration, along with an evaluation of consistency and stability. Figure 5 visualizes these metrics.

Participant A: Maintained stable temperatures, but experienced fluctuation in humidity. CO_2 concentration remained moderate, though environmental stability was inconsistent.

Participant B: Maintained stable temperature and humidity, but CO_2 levels were unstable across telework days.

Participant C: Demonstrated stable environmental conditions across all parameters.

5.3.2 Qualitative Evaluation

Qualitative insights were derived from post-experiment questionnaires. Table 21 summarizes participants' self-reported actions related to environmental control.

While basic monitoring practices were in place before the experiment, Table 22 reflects improvements in how participants used the data to optimize their work environments.

6 DISCUSSION

6.1 Information Notification System

This section discusses the functionality and effectiveness of the information notification system based on evaluation re-

Figure 5: Environmental data of a representative participant

sults.

The system was designed to periodically deliver four types of environmental data aimed at improving participants' work environments. In addition, it included an interactive chatbot feature for on-demand feedback. The system demonstrated stable performance overall, as reflected in high data provision rates.

A notable exception occurred between November 14 and 21, during which the system experienced downtime due to an authentication issue with the Heroku server hosting the backend. This incident temporarily interrupted the delivery of Information Types 1 and 2. Nevertheless, the core functionality of the system remained unaffected and resumed normal operation after resolution.

Despite the inclusion of the chatbot, participants predominantly interacted with the automated notifications. Limited usage of the chatbot may be attributed to work-related constraints or user preferences for passive, rather than active, feedback mechanisms.

Table 21: Actions taken to manage the telework environment

Question	A	B	C
Do you use air conditioning, humidifiers, or ventilation to regulate your telework environment?	Yes	Yes	Yes
Do you monitor room temperature, humidity, and CO_2 concentration using any equipment?	Yes	Yes	Yes

Table 22: Participant evaluation of work environment improvement (5-point scale)

Question	A	B	C
System's contribution to a good work environment	5	4	5
Intent to continue improving the work environment	5	5	5

6.2 Discussion Derived from Questionnaire Results

This section discusses key insights gained from the pre-, mid-, and post-experiment questionnaires.

6.2.1 Information Notification System

Post-experiment responses indicated generally positive impressions of the information notification system. Participants found the four categories of presented information useful, particularly appreciating the clarity and conciseness of hourly notifications.

6.2.2 Improvement of Work Environment

Participants reported increased awareness of environmental conditions due to system feedback. Table 23 presents the nature of work and the total number of workdays during the experiment, based on mid-experiment responses.

For example, Participant A noticed low humidity levels in early December and began using a humidifier after receiving notifications. Conversely, despite frequent CO_2 alerts, Participant B made no changes, citing concerns such as room temperature drops, external noise during meetings, and a tightly packed schedule. These insights suggest that while the system effectively raised awareness, behavioral change was also influenced by environmental and contextual constraints.

Suggestions for automating environmental regulation were noted. However, integrating automated HVAC or ventilation

Table 23: Type of work and total days during the experiment

Type of Work	A	B	C
Office work	0	2	5
Meetings	11	14	3
Programming	12	0	0
Document writing	13	12	3
Thinking	5	5	0
Other	0	0	0

controls may present technical challenges. The primary barrier was information presentation, and improvements in that area (as discussed in Section 6.1) may foster stronger behavioral responses.

6.2.3 Questionnaire Considerations

The questionnaires were useful in evaluating the effectiveness of the system in enhancing awareness and promoting action. While some participants already had awareness of temperature, humidity, and air quality issues, the post-experiment feedback revealed increased motivation to act on this information.

Additionally, daily work-from-home tracking via the mid-experiment questionnaire successfully contextualized behavioral data. Future improvements may include querying participant schedules in advance to deliver more tailored environmental recommendations, such as optimal ventilation timing.

7 CONCLUSION AND REMARKS

Over the course of a two-month experiment, we evaluated a system designed to support behavioral improvements in telework environments through personalized environmental feedback. The results confirmed the system ’ s potential utility in raising awareness and encouraging positive behavioral change among participants.

However, certain limitations were also identified. Notably, the use of Slack as the primary communication channel posed challenges, particularly in terms of reviewing historical messages due to its chat-oriented design. These insights will inform future iterations of the system, including potential improvements to information delivery interfaces and automation features.

Acknowledgments

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REFERENCES

[1] Keidanren, “Utilization of Telework to Enhance Engagement and Labor Productivity,” https://www.keidanren.or.jp/policy/2022/036_honbun.pdf, accessed May 5, 2025. (in Japanese)

[2] Tokyo Metropolitan Government, “Telework Implementation Rate Survey Results,” https://www.metro.tokyo.lg.jp/tosei/hodohappyo/press/2022/10/11/07.html, accessed May 5, 2025.

[3] Cabinet Office and METI, “Basic Data on the Impact of the Corona Disaster on the Economy,” https://www.cas.go.jp/jp/seisaku/seicho/seichosenryakukaigi/dai7/siryou1.pdf, accessed May 5, 2025.

[4] G. Kawaguchi, et al., “Intellectual Productivity Evaluation in Indoor Environments: (Part 8),” Journal of Air Conditioning and Sanitary Engineering of Japan, (2004).

[5] W. J. Fisk, “Health and Productivity Gains from Better Indoor Environments and their Relationship with Building Energy Efficiency,” Annual Review of Energy and the Environment, vol. 25, pp. 537–566, (2000).

[6] Ministry of Internal Affairs and Communications, “Promotion of Telework,” https://www.soumu.go.jp/main_sosiki/joho_tsusin/telework/, accessed May 5, 2025.

[7] Nippon Telegraph and Telephone Corporation, “Introduction of a New Way of Working Based on Remote Work,” https://group.ntt/jp/newsrelease/2022/06/24/220624a.html, accessed May 5, 2025.

[8] G. Hamanaka, et al., “Implementation and Evaluation of a Teaching Bot for Improving Indoor Comfort,” Research Report on Ubiquitous Computing Systems, No. 9, pp. 1–6, (2017).

[9] J. Nishino, et al., “Research and Development of AI & IoT-based Intellectual Environment Control System,” Proceedings of the Air Conditioning & Sanitary Engineering Society Conference, vol. 8, pp. 381–384, (2019).

[10] Ministry of Health, Labor and Welfare, “Guidelines for the Proper Introduction and Implementation of Telework,” https://www.mhlw.go.jp/content/000759469.pdf, accessed May 5, 2025.

[11] Netatmo, “Smart Home Weather Station,” https://www.netatmo.com/en-gb/weather/weatherstation/indoor-module, accessed May 5, 2025.

[12] K. Matsui, K. Nishigaki, “Proposal and Evaluation of a Method for Collecting Physical and Mental Status Data Using Communication Tools,” IPSJ, vol. 2020-CDS-29, pp. 1–8, (2020).

[13] Ministry of Health, Labor and Welfare, “Standards for Building Environmental Health Management,” https://www.mhlw.go.jp/bunya/kenkou/seikatsueisei10/, accessed May 5, 2025.

[14] Slack, https://slack.com/intl/ja-jp/, accessed May 5, 2025.

[15] National Institute of Health and Nutrition, “METs Table,” https://www.nibiohn.go.jp/eiken/programs/2011mets.pdf, accessed May 5, 2025.

[16] FREE HAND, “Clo Value Laboratory,” http://freehandjapan.com/, accessed May 5, 2025.

[17] Google, “Google Forms,” https://docs.google.com/forms, accessed May 5, 2025.

[18] Daikin Industries Ltd., “Survey on Indoor and Outdoor Air Perception,” https://www.daikin.co.jp/air/life/survey/vol27?ID=air_life_survey, accessed May 5, 2025.

[19] N. Pham, et al., “Comparative Study of Technological Trend Between DAIKIN and Panasonic in the Field of Air Conditioner,” IEEE, Proceedings of PICMET’14: Portland International Conference on Management of Engineering and Technology – Infrastructure and Ser-

vice Integration, pp. 1416–1424, (2024).
[20] SurveyMonkey, https://jp.surveymonkey.com/welcome/sem/, accessed May 5, 2025.

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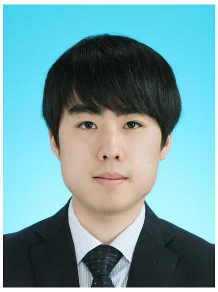

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