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# Study on residential environment and workers' personality traits on productivity while working from home

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A R T I C L E I N F O

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A B S T R A C T

Working from home has drawn more attention with the development of information and communications technology and the coronavirus disease 2019 pandemic. Although studies on working from home have been conducted in various academic fields, few have focused on residential environment and personality traits. In the present study, air temperature and humidity of the home workplace were measured and a questionnaire survey was conducted to understand the relationship between residential environment and personality traits and at-home work productivity. The results suggest that comprehensive productivity while working from home improved. However, when examining individual aspects of productivity, the productivity of information processing improved while that of knowledge processing and knowledge creation deteriorated. The results also suggest the importance of improving the residential environment when working from home because productivity while working from home rather than from the office improved with high evaluation of the residential environment. Moreover, productivity decreased for workers with high neuroticism and increased for those with high openness or perseverance and passion, suggesting that some personality traits are more or less suitable for working from home. To improve the productivity of all workers, these findings have practical implications for promoting appropriate maintenance of the residential environment and introducing flexible work styles that account for personality traits.

## 1. Introduction

With the development of information and communications technology (ICT), teleworking, that is, "a work flexibility arrangement under which an employee performs the duties and responsibilities of such employee's position, and other authorized activities, from an approved worksite other than the location from which the employee would otherwise work" [1], has gained attention [2]. Telework can reduce commuting time, office maintenance costs, and energy consumption associated with transportation [3]. It also has health benefits, such as reducing workers' stress and improving their life balance [4]. In recent years, many companies have actively adopted working from home, a type of telework, due to the coronavirus disease 2019 (COVID-19) pandemic [5] as a countermeasure against infection [6,7], and it is expected to become more common in the future.

Numerous studies on productivity while working from home have been conducted, and they suggest that productivity, job satisfaction, and life satisfaction improves while working from home compared with working from the office [8–17]. In a survey of call center employees of travel agencies, Bloom et al. [15] showed that working from home improved productivity by 13%. Kazekami [16] showed that working from home increases life satisfaction, which leads to improved productivity, and that working from home effectively improves productivity for commutes longer than an hour or those during rush hour in crowded trains or buses. However, studies have shown that productivity deteriorates while working from home, when working long hours, or when performing dull tasks, and that the productivity of workers in research positions deteriorates when working from home when compared with workers in clerical positions [11,16,18,19].

In the field of building and environmental engineering, numerous studies on office productivity have been conducted, especially on the relationship between productivity and office environment or indoor environmental quality (IEQ). IEQ comprises elements such as thermal environment, air environment, light environment, and sound

*Abbreviations:* COVID-19, coronavirus disease 2019; ICT, information and communications technology; IEQ, indoor environmental quality; SET, standard effective temperature; TIPI-J, Japanese version of the Ten-Item Personality Inventory.

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environment. Measurement surveys and laboratory experiments have shown that office environment and IEQ significantly affect worker productivity [20,21]. Studies on thermal environment revealed a correlation between productivity and satisfaction with the thermal environment as well as productivity and air temperature [22–31], and findings indicate that people feel more fatigue in humid environments [32]. Studies on air environment have shown that ventilation improves productivity [33–37]. Studies on light environment showed a relationship between illuminance and productivity and that work conditions under low illuminance increase the level of fatigue [38–41]. Studies on sound environment showed that as noise level increases, satisfaction with the environment and concentration decreases and that fatigue increases when working under traffic noise [42–46].

As explained above, many studies on office productivity examined the office environment and IEQ from the perspective of building and environmental engineering. Studies on at-home work productivity have been conducted in various academic fields [47,48], but have dealt mainly with human resources or workforce issues. The relationship between residential environment and at-home work productivity and the relationship between IEQ and at-home work productivity have not been clarified from the perspective of building and environmental engineering. However, residential environment and IEQ seem to affect at-home work productivity.

In addition to residential environment and IEQ, personality traits might also affect at-home work productivity. In the field of psychology, many studies have shown a relationship between personality traits and productivity [49,50]. Moreover, in addition to direct effects, personality traits might indirectly affect productivity. Many studies have shown a relationship between personality traits and IEQ that is sensed, such as thermal environment [51–53], suggesting that IEQ affects productivity by way of personality traits. However, at this time, few studies on at-home work productivity have accounted for IEQ and personality traits. Therefore, the present study aimed to elucidate the relationships among residential environment, personality traits, and productivity while working from home.

## 2. Materials and methods

### 2.1. Outline of measurement survey and questionnaire survey

This study measured the air temperature and humidity of workspaces and conducted a questionnaire survey to understand the relationship between residential environment and at-home work productivity and the relationship between personality traits and at-home work productivity. These surveys were conducted for employees of Company A, an equipment manufacturer. Table 1 and Table 2 show the outline of the survey. Participants were recruited mainly from the Tokyo metropolitan area[1] and were limited to those who regularly worked from home under the COVID-19 pandemic. The survey participants were recruited through a forum that only employees could access. Participants were informed that the questionnaire data would not be used for any purpose other than research, and that the data would be analyzed in an anonymized manner so that participants could not be identified. The survey was administered only to those participants who consented to these terms. Note that Company A encourages its employees to work from home, and at the time the survey was conducted, only 10% of its employees in the Tokyo metropolitan area went to the office, and therefore, almost all the survey participants had been working from home for about 10 months.

**Table 1**
Overview of the measurement survey.

| | |
|---|---|
| Participants | Employees of an equipment manufacturer in Japan |
| Period | February 15–25, 2021 |
| Measuring equipment | Temperature and humidity logger KT-255U (Fujita Electric Works, Ltd.) |
| Measurement parameters (accuracy) | Air temperature (±0.3 °C)<br>Relative humidity (±5%) |
| Interval time | 2 min |
| Measurement place | Participants' desks used while working from home, such as in the living room or private room, depending on the participant. |

**Table 2**
Overview of the questionnaire survey.

| | |
|---|---|
| Participants | Employees of an equipment manufacturer in Japan |
| Period | February 15–25, 2021 |
| Method | Online questionnaire |
| Details of the questionnaire | 1. Evaluation of residential environment<br>a. Evaluation of desk environment<br>b. Evaluation of workspace environment<br>c. Evaluation of home environment<br>2. Understanding participants' attributes (lifestyle, health status, personality traits)<br>3. Evaluation of subjective productivity |

In the measurement survey on air temperature and humidity, temperature and humidity loggers were distributed to workers, who were asked to station the logger on their home workspace desk(s) for two weeks. The questionnaire survey utilized an online questionnaire form. The questionnaire's design accounted for the nested structure from the urban environment to the building environment as well as the work-room environment and desk environment. In addition to environmental elements such as the residential environment (urban, building, workspace, and desk environments), at-home work productivity might also be affected by personal attributes (e.g., age, gender, lifestyle, health, and personality traits). Therefore, in order to understand the evaluation of personal attributes, environmental elements, and at-home work productivity, the questionnaire comprised the following three categories: (1) evaluation of the residential environment, (2) understanding participants' attributes, and (3) evaluation of subjective productivity.

### 2.2. Measurement of air temperature and relative humidity

The physical environmental elements in a workspace that can affect at-home work productivity include air temperature, humidity, radiation temperature, airflow velocity, noise, and illuminance. The present study measured only air temperature and relative humidity using a temperature and humidity logger, given a limited study budget and burden to workers. Physical environmental elements other than air temperature and relative humidity were complemented by subjective evaluation via questionnaire. Workers were mailed the temperature and humidity loggers with the recording already started, and only needed to station the logger on their desk. Although workers themselves did not need to operate the logger, they were advised to avoid exposing the logger to direct sunlight or airflow from an air conditioner and to place it away from devices that give off heat such as a PC. The measurement accuracy of air temperature is ±0.3% and that of relative humidity is ±5%. The measurement interval was set at 2 min.

The standard effective temperature (SET) was used as a comfort index for thermal environment. Table 3 shows the conditions for calculating SET. Air temperature, relative humidity, radiation temperature, and airflow velocity were required elements on the environmental side and clothing amount and metabolic rate on the human body side.

[1] The Tokyo metropolitan area refers to Tokyo and its surrounding prefectures: Ibaraki, Tochigi, Gunma, Saitama, Chiba, Kanagawa, and Yamanashi. These regions belong to the temperate zone under the Keppen climate classification. Tokyo has a humid climate (Cfa) and is characterized by many sunny days, with high temperatures and humidity in the summer and a strong northwest monsoon in the winter.

**Table 3**
Calculation conditions of the SET.

| Environmental Elements | | | | Human Body Elements | |
|---|---|---|---|---|---|
| Air temperature | Relative humidity | Radiation temperature | Airflow velocity | Clothing amount | Metabolic rate |
| *Measured value* | *Measured value* | Air temperature | 0.1 m/s | 1.0 clo | 1.1 MET |

Measured air temperature and relative humidity were used to calculate SET, whereas air temperature was substituted for radiation temperature, which was not measured in this study. Airflow velocity was set at 0.1 m/s, assuming a calm environment. Clothing amount was set at 1.0 clo. Metabolic rate was set at 1.1 MET, assuming sitting work.

### 2.3. Subjective evaluation of residential workplace environment

The first questionnaire item category, evaluation of residential environment, comprises three sections: (a) evaluation of desk environment, (b) evaluation of workroom environment, and (c) evaluation of home environment. The following analysis includes only some of the survey items, so a summary is provided here.

For evaluation of desk environment, degree of satisfaction in the desk and chair used in the workspace was investigated. For evaluation of workplace environment, the space used most often while working from home and degree of satisfaction in the thermal environment, air environment, light environment, and sound environment were investigated. For evaluation of home environment, the form and age of the home and residential environmental performance were investigated. The Comprehensive Assessment System for Built Environment Efficiency (CASBEE) Health Checklist was used to evaluate residential environmental performance. In April 2001, the Committee for Comprehensive Environmental Assessment of Buildings was established as a joint project of industry, government, and academia and supported by the Ministry of Land, Infrastructure, Transport and Tourism Housing Authority. Since then, CASBEE has been continuously developed and maintained. CASBEE has evaluation tools for buildings and urban development, depending on the scale of the object to be evaluated, and these are collectively called the CASBEE family. The CASBEE Health Checklist [54] is a tool developed with reference to the performance evaluation system for houses that has been developed in advance outside Japan [55,56], and it enables non-professional residents to self-check their residential environment performance as to health and comfort. Past studies have shown that residents with higher scores have a higher subjective health condition and lower disease prevalence [54,57]. The CASBEE Health Checklist has 44 questions, each of which scores 0–3 with a perfect score of 132. In this study, participants were asked to evaluate their residential environment based on a shortened version of the CASBEE Health Checklist comprising 22 questions with a perfect score of 66 to reduce participants' burden.

### 2.4. Understanding participants' attributes

The second questionnaire item category, "understanding participants' attributes," surveyed age, occupation, and frequency of working from home, as well as personal attributes such as lifestyle, health status, and personality traits.

The Japanese version of the Ten-Item Personality Inventory (TIPI-J) and the Short Grit Scale (Grit-S) were used as tools to understand participants' personality traits. The TIPI [58] is used in various fields such as social psychology, political psychology, and behavioral economics to measure the Big Five personality traits (extraversion, agreeableness, openness, conscientiousness, neuroticism). The TIPI has two questions for each of the five personality traits, for a total of 10 questions. Each item is rated on a 7-point scale, ranging from 1 to 7, and each personality trait is rated on a scale of 2–14 points. The TIPI-J has been validated for reliability and validity [59].

Grit refers to a non-cognitive trait characterized by perseverance and passion for long-term goals. There is a positive correlation with academic performance (e.g., GPA and SAT) and the Big Five Conscientiousness score [60,61]. The 8-item Grit-S [62] is a short form of the original Grit scale, which uses 12 questions (1–5 points per question) to measures two characteristics (perseverance of effort and consistency of interest) required to achieve a goal. In this study, the Japanese version of the Grit-S [63] was used. The Grit-S consists of 8 questions with 5 points for each question, for a total score of 40 points. The total score is then divided by 8 and rated on a scale of 0–5.

### 2.5. Subjective evaluation of productivity while working from home

Referring to the classification of productivity by the Intellectual Productivity Research Committee established by the Japanese Ministry of Land, Infrastructure, Transport and Tourism [64], questionnaire item category (3) "subjective evaluation of productivity" for understanding at-home work productivity was classified into four factors: (a) productivity of information processing, (b) productivity of knowledge processing, (c), productivity of knowledge creation, and (d) comprehensive productivity, which takes into consideration the first three factors (a, b, and c). For these four types of productivity, evaluations were requested for rates of improvement/deterioration while working from home compared with working from the office. In designing the answer scale, reference was made to the SAP (Subjective Assessment of Workplace Productivity) [65], which is a questionnaire developed by the Japan Sustainable Building Consortium for the subjective evaluation of productivity in offices.

## 3. Results

### 3.1. Survey participants

A total of 198 people responded to our invitation to participate in the survey. Households in which air temperature and humidity were not recorded correctly (e.g., no data left in the logger after collection, a logger not received by the start of the measurement period due to an incorrect mailing address) were excluded from the analysis. After excluding the data for 8 participants, finally 190 households were included in the analysis of air temperature and SET. Statistical analysis was performed using SPSS 27.0 and a significance level of $p = 0.05$ was used.

### 3.2. Air temperature, humidity, and SET in workspaces

Fig. 1 shows the distribution of average air temperature, average relative humidity, and average SET in workspaces while working from home according to the measurement survey. First, air temperature and relative humidity during the measurement period were extracted from the loggers. Then, average air temperature, average relative humidity, and average SET were calculated for the period between the average start of the working day and the average end of the working day, as requested in the questionnaire. Note that holidays (Saturdays, Sundays, public holidays, and paid days off) were excluded from analysis.

Average air temperature was 20.1 ± 2.6 °C, with more than 70% of workspaces exceeding the recommended minimum temperature range for winter (18.0 °C) [66]. Average relative humidity was 40.3 ± 10.5%, with about 40% of workspaces within the recommended range (40%–60%) [67]. Average SET was 23.4 ± 2.7 °C, with about half of workspaces in the comfortable range (22.2–25.6 °C).

### 3.3. Residential environment and basic attributes of the home

Fig. 2 shows the CASBEE Health Checklist score (out of 66 points) distribution, which evaluates residential environment from a

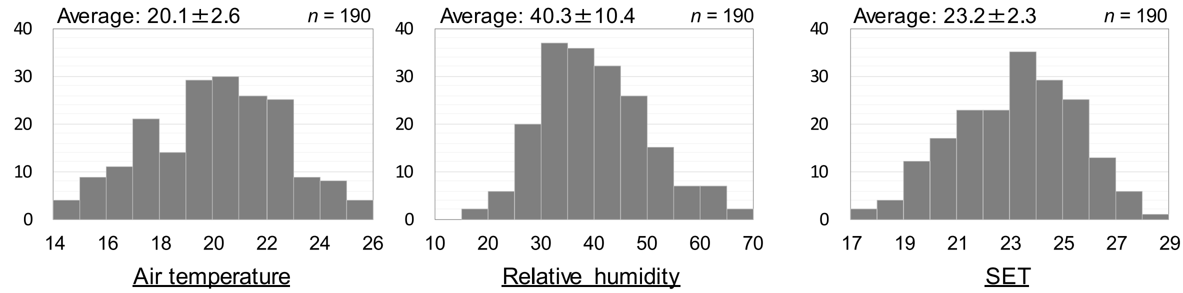


**Fig. 1.** Average values of air temperature, relative humidity, and SET while working from home.

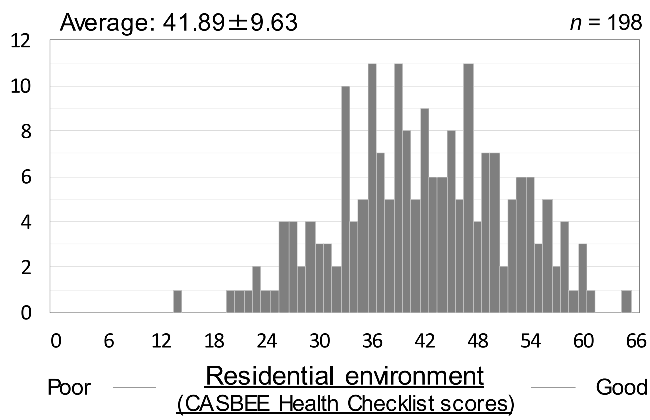


**Fig. 2.** Residential environment of participants.

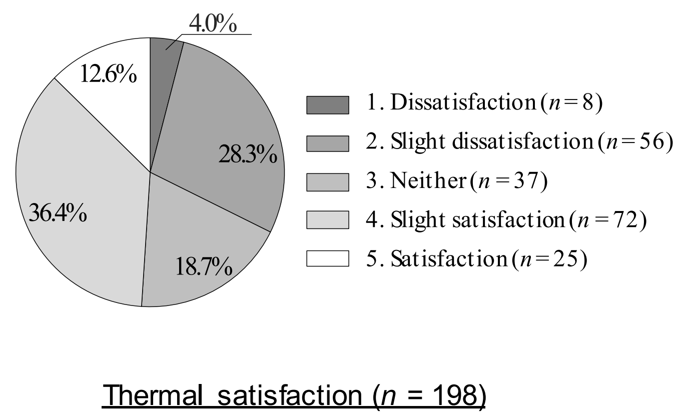


**Fig. 3.** Thermal satisfaction of participants.

comprehensive viewpoint. Average score of the CASBEE Health Checklist was 41.9 ± 9.6 points. Fig. 3 shows the response rate for degree of satisfaction with thermal environment of each workspace. About half of the workers were “satisfied” or “slightly satisfied” with their workspace thermal environment.

Fig. 4 summarizes basic attributes of the workers’ homes. Average age of the homes was 16.7 ± 10.4 years. A private room was the most frequently used workspace (56%). Nearly 40% of workers used a living room or dining room.[2]

### 3.4. Personal attributes and worker productivity

Fig. 5 summarizes workers’ basic attributes. About 70% of workers were male, and most workers were in their 50s. About half of workers were technical staff. More than 80% of workers worked from home four or more times per week.

Fig. 6 shows the distribution of the TIPI-J, which measures characteristics of the Big Five (openness, conscientiousness, extraversion, agreeableness, and neuroticism), and the Grit-S, which indicates perseverance and passion. The distribution was broad across the board, and average values were higher for conscientiousness and lower for neuroticism as compared with previous studies [59].

Fig. 7 shows the distribution of improvement or deterioration of the following factors: (a) productivity of information processing, (b) productivity of knowledge processing, (c) productivity of knowledge creation, and (d) comprehensive productivity. Productivity of information processing tended to improve overall. Productivity of knowledge processing and productivity of knowledge creation tended to deteriorate overall. The improvement in productivity of information processing exceeded the deterioration in productivity of knowledge processing and productivity of knowledge creation, resulting in improvement in comprehensive productivity.

### 3.5. Cross-tabulation of residential environment and productivity while working from home

Fig. 8 shows the results of cross-tabulation of indoor air temperature and comprehensive productivity while working from home and those of cross-tabulation of SET and comprehensive productivity while working from home. From this point on, only analysis results on *comprehensive productivity* are shown. In the cross-tabulation, participants were divided into two groups, a low group and high group at a threshold of 20.5 °C and 23.5 °C, with reference to median values of air temperature and SET, respectively (air temperature: 20.3 °C, SET: 23.3 °C). The results of the Mann–Whitney *U* test showed no significant difference between the low and high groups for both air temperature and SET.

Fig. 9 shows the results of cross-tabulation between evaluation of residential environment (total score on the CASBEE Health Checklist) and comprehensive productivity while working from home, and degree of satisfaction with the workspace thermal environment and comprehensive productivity while working from home. In the cross-tabulation of residential environment, participants were divided into two groups, a low group and high group, with reference to median values of the total score of the CASBEE Health Checklist (42 points). Results showed a statistically significant improvement in comprehensive productivity as the evaluation of residential environment increased. In the cross-tabulation of thermal satisfaction, participants were divided into two groups, a dissatisfied group (dissatisfaction, slight dissatisfaction, neither) and a satisfied group (satisfaction, slight satisfaction). Results showed a statistically significant improvement in comprehensive productivity as the degree of satisfaction with the thermal environment increased.

[2] A one-room home is a type of home that is designed primarily for a one-person household, which is common in Japan. The living room, bedroom, and kitchen are all in one room.

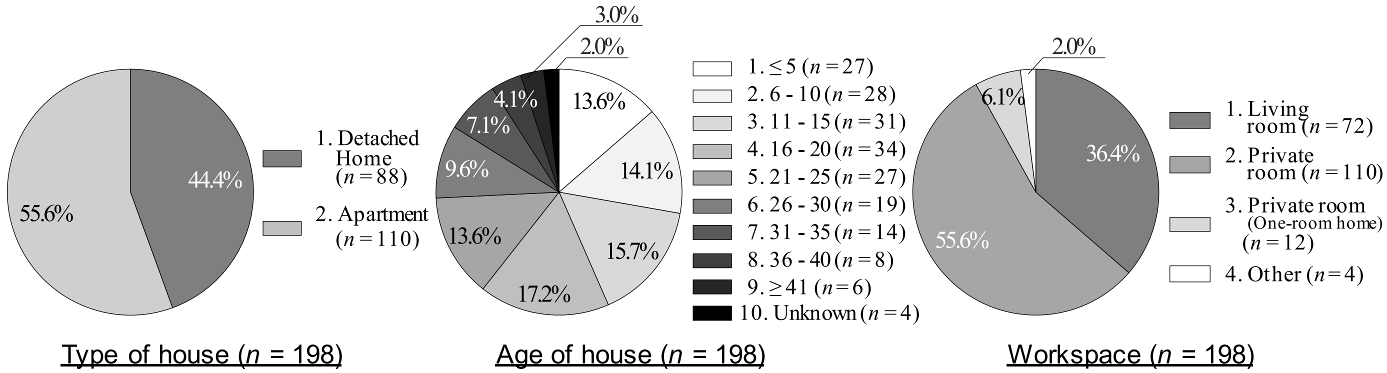


**Fig. 4.** Characteristics of participants' homes.

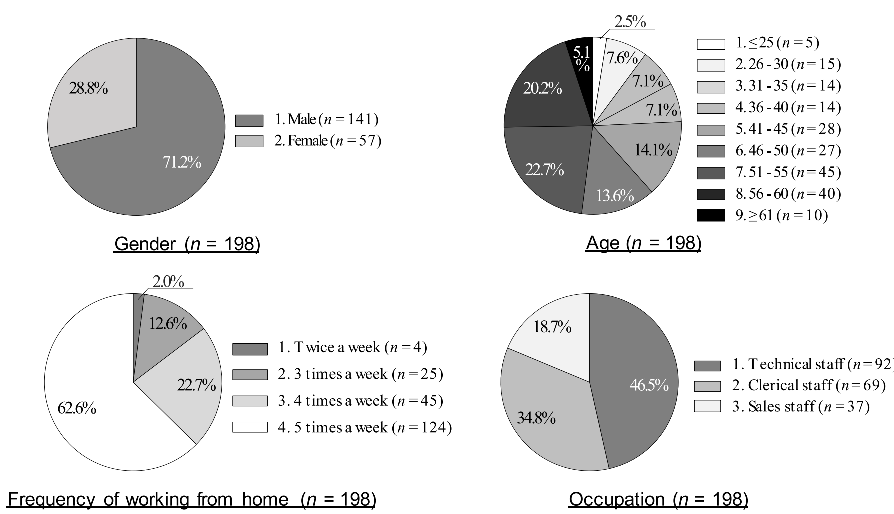


**Fig. 5.** Characteristics of participants.

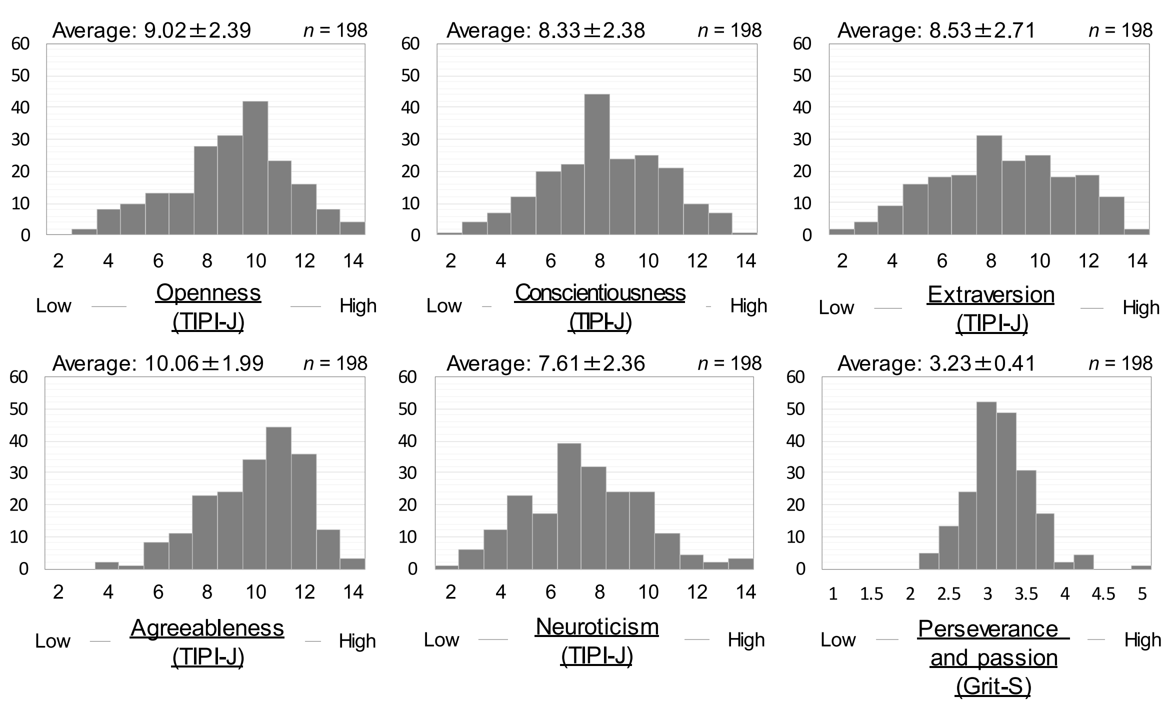


**Fig. 6.** Personality traits of participants.

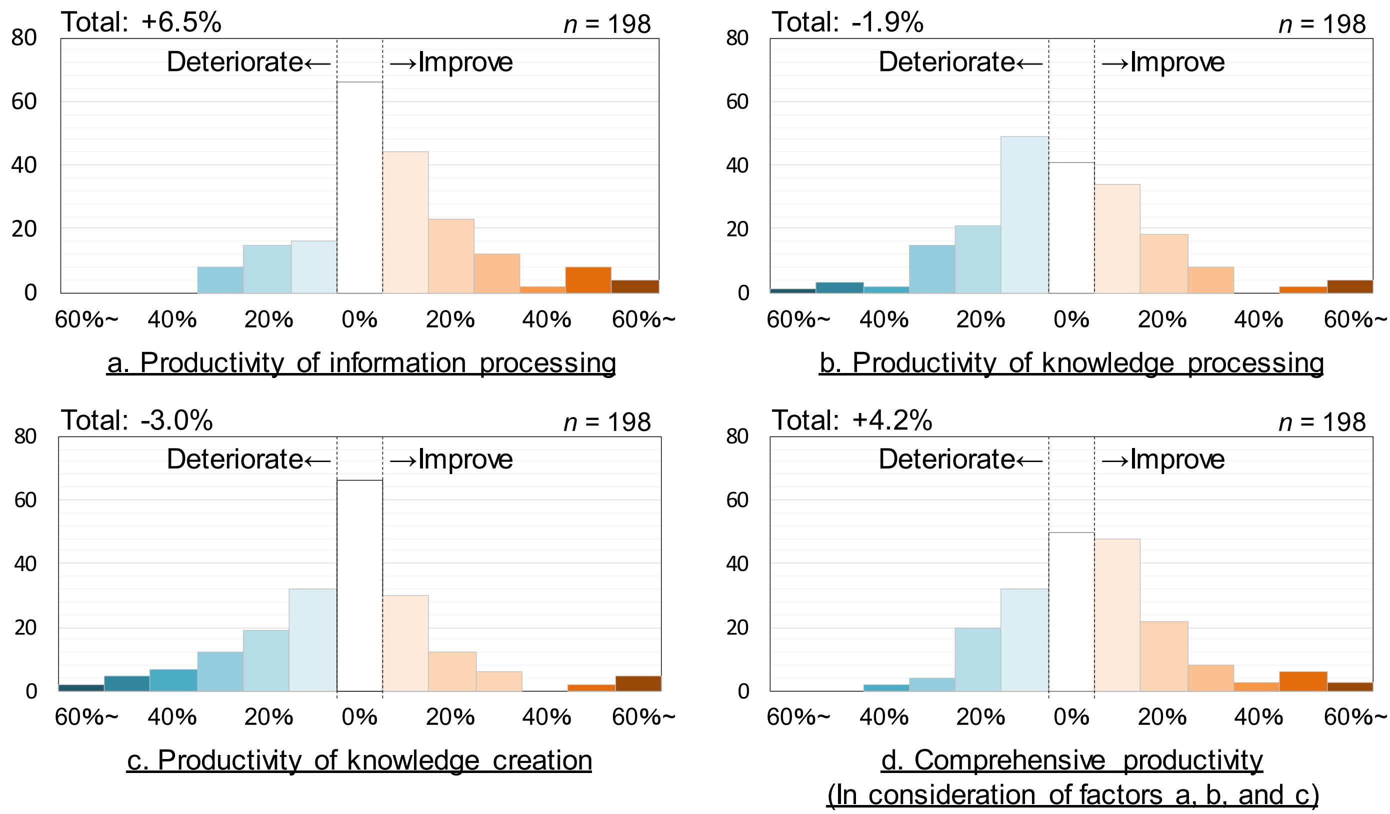


**Fig. 7.** Rate of change in productivity while working from home.

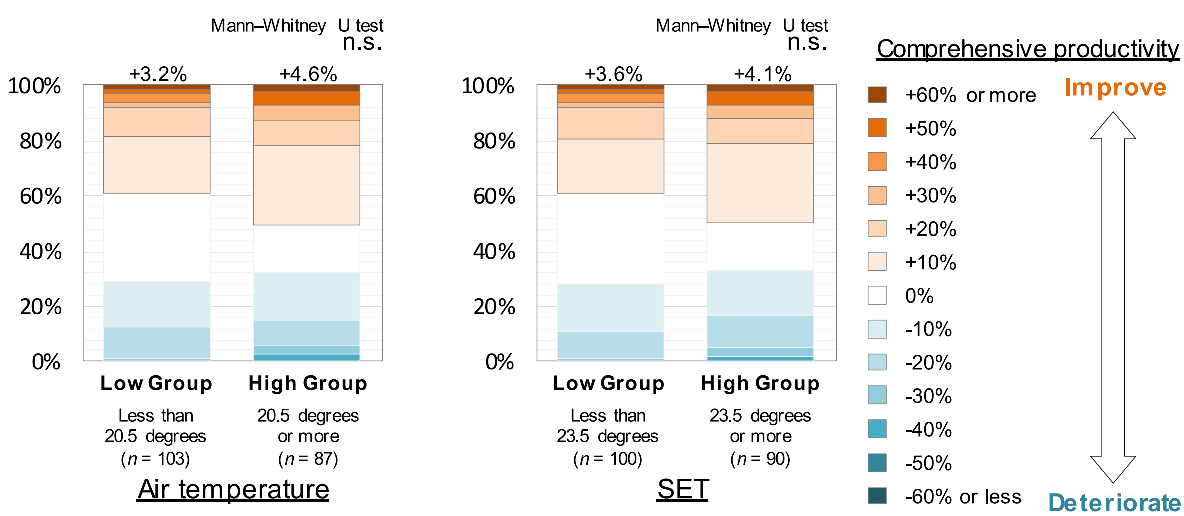


**Fig. 8.** Relationship between air temperature and productivity and relationship between SET and productivity.

### *3.6. Cross-tabulation of personality traits and productivity while working from home*

Fig. 10 shows the results of cross-tabulation of openness (TIPI-J) and comprehensive productivity while working from home, cross-tabulation of neuroticism (TIPI-J) and comprehensive productivity while working from home, and cross-tabulation of perseverance and passion (Grit-S) and comprehensive productivity while working from home. In the cross-tabulation, participants were divided into two groups, a low group and high group, with reference to median values of openness, neuroticism, and perseverance and passion (openness: 9.0 points, neuroticism: 8.0 points, perseverance and passion: 3.25 points). The results showed a significant deterioration in comprehensive productivity the higher the neuroticism score, but a statistically significant improvement in comprehensive productivity the higher the score on openness or perseverance and passion. The results of the Mann–Whitney *U* test showed no significant difference between low and high groups for extraversion, agreeableness, and conscientiousness.

### *3.7. Relationships among residential environment, personality traits, and productivity while working from home*

Next, multiple logistic regression analysis was used to understand the relationships among residential environment, personality traits, and

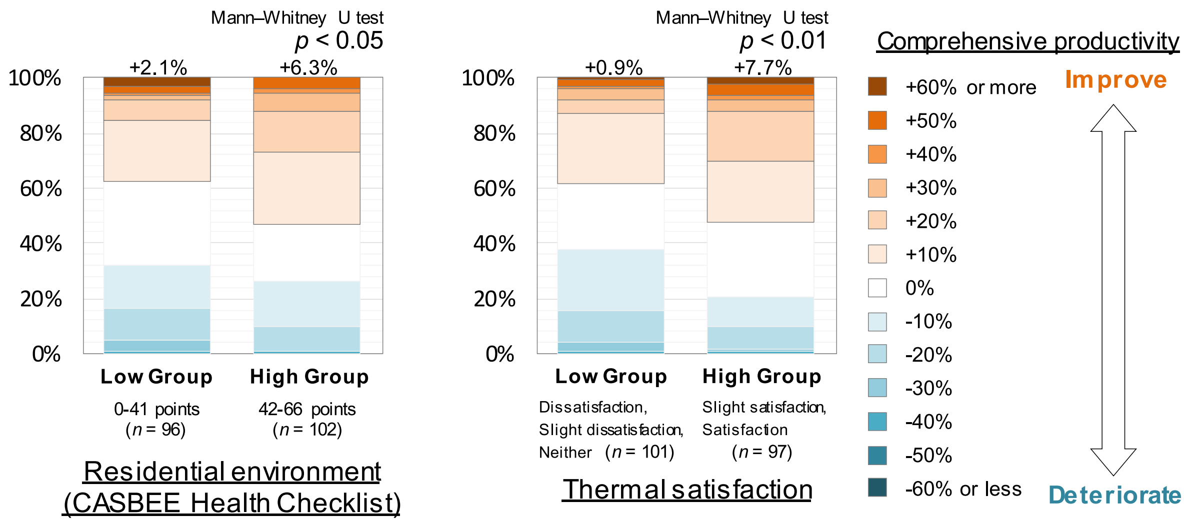


**Fig. 9.** Relationship between residential environment and productivity and thermal satisfaction and productivity.

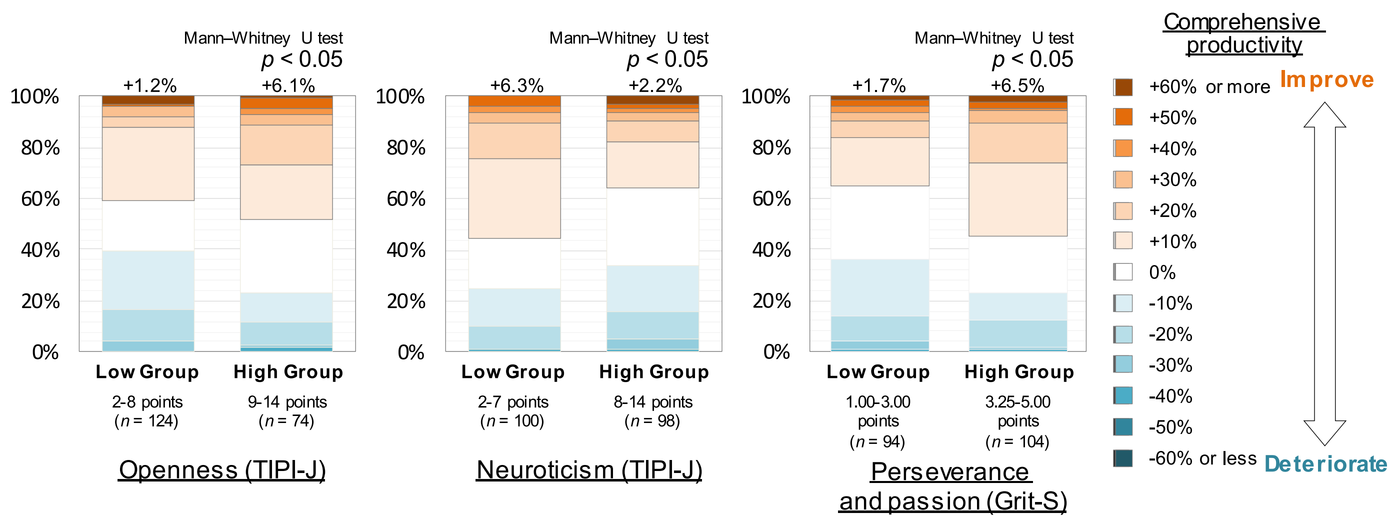


**Fig. 10.** Relationship between personal traits and comprehensive productivities.

productivity while working from home. For binomial logistic regression analysis, the data were divided into two values: (0) non-improvement group and (1) improvement group. The non-improvement group included "no change" to "60% or more deterioration," whereas the improvement group included from "10% improvement" to "60% or more improvement." To identify workers who are suitable for working from home, workers were classified into those whose productivity improved by 10% or more and everyone else. This is because it was not possible to determine whether working at the office or from home is more suitable for those participants who indicated that their productivity remained the same. Independent variables were divided with reference to their median values into a low group and high group. For analysis, the forced imputation method was used due to the low possibility of multicollinearity as there was no strong correlation between the independent variables. Table 4 shows the results of adjusted odds ratios from the analysis. The result of the Hosmer–Lemeshow test was $p = 0.600$, and the percentage of correct classifications was 65.3%.

As a housing factor, the odds ratio for residential environment (CASBEE Health Checklist score) was 1.65 and the SET was 1.69. As a factor related to personality traits, the odds ratio for openness (TIPI-J) was 0.96, that for conscientiousness (TIPI-J) was 1.25, for extraversion (TIPI-J) was 0.90, that for agreeableness (TIPI-J) was 0.84, that for neuroticism (TIPI-J) was 0.46, and that for perseverance and passion (Grit-S) was 2.39.

## 4. Discussion

This study measured the air temperature and humidity of workspaces and conducted a questionnaire survey to understand the relationship between residential environment and worker productivity while working from home as well as the relationship between personality traits and worker productivity while working from home. The results suggest the importance of improving the residential environment appropriately while working from home and indicate that some personality traits are more suitable for working from home.

### 4.1. Total productivity while working from home

Comprehensive productivity while working from home improved by approximately 4.2% compared with working from the office (Fig. 7). Bloom et al. [15] attributed at-home work productivity that improved by 4% to "a quieter and more convenient working environment." Also, Choudhury et al. [14] found a 4.4% improvement in productivity with the shift to working from home. The present results were generally

**Table 4**
Binomial logistic regression analysis of productivity while working from home.

| Independent Variables | B | Exp.(B) Odds Ratio | 95% Confidence Interval | *p*-value |
|---|---|---|---|---|
| Residential environment (CASBEE Health Checklist)<br>(0) Less than 42 points, (1) 42 points or more | 0.50 | 1.65 | 0.88–3.10 | n.s.<br>($p = 0.12$) |
| SET<br>(0) Less than 23.5°, (1) 23.5° or more | 0.52 | 1.69 | 0.91–3.11 | n.s.<br>($p = 0.09$) |
| Openness (TIPI-J)<br>(0) Less than 9.0 points, (1) 9.0 points or more | −0.04 | 0.96 | 0.49–1.89 | n.s.<br>($p = 0.91$) |
| Conscientiousness (TIPI-J)<br>(0) Less than 8.0 points, (1) 8.0 points or more | 0.22 | 1.25 | 0.64–2.43 | n.s.<br>($p = 0.51$) |
| Extraversion (TIPI-J)<br>(0) Less than 8.5 points, (1) 8.5 points or more | −0.11 | 0.90 | 0.47–1.74 | n.s.<br>($p = 0.75$) |
| Agreeableness (TIPI-J)<br>(0) Less than 10.0 points, (1) 10.0 points or more | −0.18 | 0.84 | 0.43–1.62 | n.s.<br>($p = 0.60$) |
| Neuroticism (TIPI-J)<br>(0) Less than 8.0 points, (1) 8.0 points or more | −0.78 | 0.46 | 0.23–0.91 | $p < 0.05$ |
| Perseverance and passion (Grit-S)<br>(0) Less than 3.25 points, (1) 3.25 points or more | 0.87 | 2.39 | 1.27–4.48 | $p < 0.01$ |
| Constant | −0.77 | – | – | $p < 0.01$ |
| Percentage of correct classifications (%) | 65.3 | | | |
| Hosmer–Lemeshow test | 0.600 | | | |

*Dependent variable: Comprehensive productivity.
(0) "No change," "−10%," "−20%," "−30%," "−40%," "−50%," "−60% or less than −60%."
(1) "+10%," "+20%," "+30%," "+40%," "+50%," "+60% or more than +60%."

consistent with previous studies and strengthened the knowledge obtained in these studies. However, productivity needs to be examined in more detail, including attention to productivity of information processing, productivity of knowledge processing, and productivity of knowledge creation. According to Dutcher [11], productivity when performing dull (simple) tasks deteriorated, whereas productivity when performing creative tasks improved. However, the present study found that productivity of information processing (simple task) while working from home improved by about 6.5% compared with working from the office, whereas productivity of knowledge processing and knowledge creation (creative tasks) while working from home deteriorated by about 1.9% and 3.0%, respectively, compared with working from the office, showing opposite trends with the previous study. In Dutcher's experimental study, students were employed and compared in a lab that simulated an office and outside the lab; thus, there was no guarantee that work took place at home. However, the present study surveyed people who normally worked in offices but in fact worked from home during the COVID-19 pandemic. As a result, these workers might have accounted for reduced commuting time when considering productivity. These different study conditions might explain the disparity in results. Furthermore, Tokumura et al. [18] found that when working from home, research workers have lower work efficiency compared with clerical workers. Therefore, it is necessary to conduct a detailed analysis in the future that considers the type of job in addition to other factors.

### 4.2. Relationship between residential environment and productivity

According to Nakrošienė et al. [68] and Morgeson [69], adequate workspace is associated with higher productivity. The same trend was observed in the present study, where productivity improved with a good residential environment (Fig. 9, Table 4). Therefore, the importance of improving the residential environment appropriately was suggested when working from home.

There was no statistically significant relationship between air temperature and productivity or SET and productivity (Fig. 8). This is a natural consequence given that temperature and SET do not directly affect productivity, whereas workers' degree of satisfaction with their thermal environment directly affects productivity (Fig. 11). In fact, results showed significantly higher productivity the higher the degree of satisfaction with the thermal environment while working from home (Fig. 9). This result is consistent with studies on offices by Haneda et al. [23], Tanabe et al. [29], and Geng et al. [30], and it shows the relationship between satisfaction with the thermal environment and productivity.

### 4.3. Relationship between productivity and workers' personality traits

The present study further analyzed the relationship between residential environment and productivity while working from home in terms of workers' personality traits. The results show that workers with high openness had higher productivity when working from home than from the office and that workers with high neuroticism had lower productivity when working from home than from the office (Fig. 10). Previous studies have shown that workers with high openness scores are more productive, whereas those with high neuroticism scores are less productive [49,50]. However, these studies are silent on the locations where they were conducted. In the present study, workers with high scores for openness, who may be more intellectually curious and tend to have innovative ideas, might have been better suited to acclimating to changes associated with working from home. On the other hand, sensitive workers with high scores for neuroticism may have felt anxious about the uncertain social situation during the COVID-19 pandemic and rated their productivity lower when working from home compared with working from the office before the pandemic. Therefore, choosing workspaces that account for each worker's personality traits can improve company productivity as a whole. The present results showed

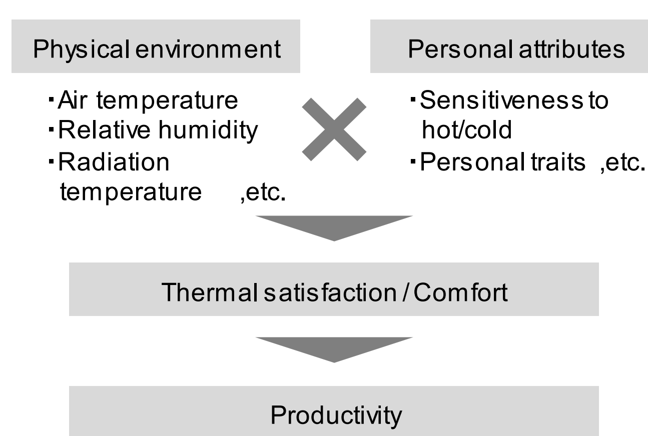


**Fig. 11.** Hierarchy of factors influencing productivity.

that workers with high perseverance and passion had higher productivity when working from home than from the office (Fig. 10). The Grit-S score that refers to individual perseverance and passion had the highest odds ratio among eight independent variables (i.e., residential environment, SET, openness, conscientiousness, extraversion, agreeableness, neuroticism, perseverance, and passion) (Table 4), indicating its strong relationship with at-home work productivity. Grit was shown to be positively associated with academic performance in previous studies [60]. Although the present study analyzed productivity relationships for working adults rather than students, a similar trend was obtained. When working from home, where workers are expected to complete their work alone unlike in the office, workers with high perseverance and passion exhibit improved productivity. Thus, some personality traits are more suitable for working from home.

In the post-coronavirus era, a growing number of people could work from home through further use of ICT with the introduction off online conferencing tools such as Zoom, Microsoft Teams, Skype, Cisco Webex Meetings, and Google Hangout/Meet as well as chat tools such as WhatsApp, Facebook Messenger, WeChat, Slack, and ChatWork. Therefore, these findings have practical implications for promoting the appropriate maintenance of the residential environment to improve productivity while working from home. In addition, introducing flexible work styles, such as establishing a system for selecting workplaces that consider personality traits, will make it possible to improve the productivity of all workers, which will contribute to increased leisure time, improved work-life balance, and improved quality of life. Furthermore, mathematical models (such as that obtained by binomial logistic regression analysis in this study) can also be used to help workers decide whether it is better to work in the office or at home.

### *4.4. Study limitations and future challenges*

This study has some limitations that should be noted. The first issue involves the data collection methodology. In this study, a measurement survey and questionnaire survey were conducted at a single Japanese company, which resulted in bias in terms of gender, age, occupation, nationality, and so on. In addition to the effect of cultural differences, the warm and cold sensations analyzed in this study vary according to the climate of the region where the person was born and grew up. According to Nakano et al. [70], there is a significant difference in neutral temperature, a temperature that feels neither hot nor cold, which is about 2.2 °C higher for Japanese males compared with non-Japanese males. This point should be kept in mind when interpreting the results of this study. Therefore, similar surveys conducted outside Japan might have different results, and it is desirable to conduct similar surveys outside Japan.

The second issue is the method of evaluating productivity. The "productivity" considered in this study was assessed subjectively through questionnaire surveys; therefore, objective measurements should also be conducted.

The third issue is the content of the evaluation of productivity. The "productivity" considered in this study evaluated work performance. According to Bloom et al. [15], working from home improved productivity by 13%, of which 9% was attributed to fewer breaks and sick days. Thus, improved productivity while working at home is greatly affected not only by work performance but also by decreased absenteeism due to sickness or other reasons. Therefore, this study's sole focus on work performance might have underestimated the benefits of working from home. However, the benefits of working in the office might also be underestimated. In an office, a diverse group of people can work together to come up with innovative ideas from the serendipity and unity that arises when working in the same space. These benefits might be impaired when working from home, and so this study might have overestimated the benefits of working from home. Therefore, both aspects of working from the office and from home must be examined in more detail.

Finally, this study could not consider hierarchical structure, including occupation and personal attributes, and so a multilevel analysis should be considered to clarify the productivity effects of each factor. In addition, follow-up studies (e.g., cohort studies) and intervention studies (e.g., randomized controlled trials) should be considered to identify causal relationships.

## 5. Conclusions

This study measured the air temperature and humidity of workspaces and conducted a questionnaire survey to understand the relationships among residential environment, personality traits, and productivity while working from home. Average workspace air temperature was 20.1 ± 2.6 °C and average SET was 23.4 ± 2.7 °C during the winter in the Tokyo metropolitan area, with about half the workspaces in the comfortable range. About half the workers were "satisfied" or "slightly satisfied" with their workspace thermal environment. In this survey, comprehensive productivity while working from home improved by approximately 4.2% compared with working from the office. When examining individual aspects of comprehensive productivity, productivity of information processing improved but that of knowledge processing and knowledge creation deteriorated. Therefore, it is necessary to conduct a detailed analysis in the future that considers the type of job as well as other factors.

Productivity improved with a good residential environment, suggesting the importance of improving the residential environment appropriately when working from home. Moreover, workers with high neuroticism had lower productivity, whereas workers with high openness or perseverance and passion had higher productivity while working from home compared with working from the office. Thus, there are some personality traits that are more or less suitable for working from home.

These findings have practical implications for promoting the appropriate maintenance of the residential environment to improve productivity while working from home. In addition, introducing flexible work styles, such as establishing a system for selecting work styles that account for personality traits, will make it possible to improve the productivity of all workers, which will contribute to increased leisure time, improved work-life balance, and improved quality of life.

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The authors declare no conflicts of interest.

## CRediT authorship contribution statement

**Shun Kawakubo:** Supervision, Methodology, Conceptualization. **Shiro Arata:** Writing – original draft, Validation, Investigation, Data curation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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