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Components of Comfort in the Office and its Individual Differences

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***Abstract*—People, especially office workers spend most of their days indoors. Designers and builders try to realize comfort in the office, which improves the productivity and wellness of workers. The present research investigated the components of subjective comfort in an office environment and revealed its individual differences. We gathered data from office workers and university students working in their offices using a combination of the experience sampling method and the evaluation grid method. The results showed that comfort was composed of various factors such as thermal factor, inside factor, sound factor, humidity factor and others. Although the thermal factor was the most dominant for subjective comfort, the relative frequency of these factors varied between participants. To investigate these individual differences, we conducted a cluster analysis and found three clusters: the balanced, thermal and inside clusters. The three clusters focused on different aspects of the environment. In addition, though subjective comfort related strongly with subjective productivity, the objective index of the thermal environment (predicted mean vote; PMV) failed to predict the participants' subjective comfort and productivity. These results revealed that even in an environment where PMV indicates relatively good thermal conditions, thermal factors can cause discomfort. That is, to realize comfort in an environment, we need to be concerned with subjective indices and individual differences in addition to objective ones such as PMV.**

Keywords—comfort, productivity, indoor environment, office, individual differences

I. Introduction

The office environment is important for the wellness of office workers. With an increasing interest in wellness within an office environment, the WELL certification was introduced in 2014. The WELL certification is "the premier standard for buildings, interior spaces and communities seeking to implement, validate and measure features that support and advance human health and wellness" [1]. Academic research has also focused on the factors relating to wellness, such as comfort, productivity, job satisfaction and wellness itself. These factors are affected by the office's environment, which includes things such as indoor air quality, office design and relationships between workers.

The office environment has been especially important in the age of Information Communication Technology (ICT). ICT not only affects the way people work at their offices [2] but it enables unprecedented applications such as real-time thermostats that incorporate software based on a comfort equation [3]. These technologies allow people to have proper environments that suit their preferences, needs and wants.

Although many studies have pointed out factors that affect indoor environments, an overall picture has not yet been found. This is because most of these studies have focused on sole factors (such as thermal factors, air quality and so on) and investigated their effects. This has made it difficult to compare the effect sizes of these factors.

The absence of an overall picture leads to another problem. It is unclear how environmental factors affect evaluations of the environment. That is, though previous studies have supposed the effect of independent variables on the dependent variables, the detailed mechanisms underlying these effects have not been determined. For example, a warm temperature may make a room more comfortable, but this warmth may also make people sleepy and decrease productivity, which results in a less comfortable environment. Therefore, although the use of ICT in a building environment can create a personalized environment that increases workers' wellness, it is impossible to decide what kind of environment should be delivered to individual workers.

In this paper, we focused on comfort in the office as consisting of wellness within it, and we propose a method to reveal the indoor environmental factors that affect comfort. Our model also concerns individual differences in indoor environments by classifying office workers into different types based on the factors that affect their subjective comfort.

In chapter II, we introduce studies that relate to the present study. In chapter III, we test our approach to extracting comfort factors and classifying office workers

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based on the factors that affect their comfort, and we also test the validity of the results. In chapter IV, we make conclusions about our approach and mention some future directions.

II. Related Studies

A. Indoor Environments and Wellness

Many previous studies have revealed the factors that affect evaluations of indoor environments. These studies were conducted according to models in which the physical factors of the environment (independent variable) affected the mental states of the people within it (dependent variable). The independent variables usually included various physical factors such as indoor air quality [4], actual air temperature [5–7], indoor color [8] and ceiling height [9]. Sometimes the independent variables also included mental factors such as satisfaction in the environment [10] and levels of control (e.g., whether the building user could control the temperature of the room) [11]. In addition to these studies, a meta-analysis revealed the factors that consistently affect evaluations of indoor environments [12]. They showed that education level, type of work, psychosocial atmosphere at work and time pressure all consistently affect evaluations of indoor environments. Among these, the thermal factor was the most important factor in improving satisfaction with regard to the quality of the indoor environment.

The dependent variables included various indices such as subjective symptoms (e.g., headaches and concentration) [4] and the performance of a specific task [9]. More abstract dependent variables included satisfaction toward the thermal environment, sound, and air quality [10] as well as self-reported productivity [11].

B. Comfort and Individual Differences

Previous research has also shown individual differences in the effect of the independent variables. Sex is one example of these individual differences. The "neutral" temperature for Japanese male is 24.3°C, whereas the neutral temperature for Japanese female is 25.2°C [6]. Race can also cause individual differences. The same study found that the neutral temperature for non-Japanese male was 22.1°C [6]. Another factor that causes individual differences is task performance. Positive mood induced by wall color improved task performance more in participants whose performance was better than average [13].

Although an environment might be consistent, the environmental effects on the people inside it sometimes differ. One study revealed that taking a rest after bathing decreased the arousal score of participants over time [14]. Another study revealed that although indoor air quality affects the people inside, those who stayed in the environment longer became insensitive to it [4].

III. Extraction of Comfort Components and User Classification Based on the Comfort Evoking Factors

A. Method

1) Participants: Twenty-three adults (14 office workers [10 males and 4 females] and 9 university students [5 males and 4 females]) participated in the study. The average age of the office workers was 38.1 (with a range from 24 to 56) and that of the university students was 22.7 (with a range from 21 to 24). All office workers had been working in a common room and participated in the study there. They each had their own desks in the room. The university students did the same.

2) Tasks: In this study, we asked the participants to report (a) their sequential staying time at their desk, (b) their subjective comfort and the factors that affected it and (c) their subjective productivity.

The participants reported their sequential staying time by choosing one of the following options: 1: shorter than 5 minutes, 2: from 5 to 10 minutes, 3: from 10 to 30 minutes or 4: longer than 30 minutes.

They then responded about their subjective comfort. First, they rated how comfortable their office was on a scale from 1: very uncomfortable to 7: very comfortable. Afterward, they reported up to three factors that affected their subjective comfort. They also rated how pleasant/unpleasant and how activated/deactivated the factors were in general; this was conducted based on Russell's core affect model [15]. They also rated what kind of factors affected the factors that affected subjective comfort. These questions were conducted with the idea of the evaluation grid method [16]. In the original evaluation grid method, the data are collected by interview. First, the interviewer asks the interviewee (the participant) to compare items and select which one is better. Then the interviewer asks the interviewee, "Why is this one better?" and extracts an abstract value judgement. The interviewer also asks the interviewee, "What is needed for the item to be xxx?" and extracts objective understandings for the items. These responses are summarized and represented as a construct system. In the present study, we simplified these procedures to implement it on the Web and gather multiple responses.

The participants also rated their subjective productivity. They were asked to respond to the question "How would you rate your present work efficiency if your maximum work efficiency in the most proper environment corresponds to 100?"

3) Procedure: We conducted this study from November 26th, 2018, to November 28th, 2018. Over these three days, we sent e-mails to the participants five times a day (at 10:00, 11:45, 13:30, 15:15 and 17:00) and asked for a response to the questionnaire in the Google Forms.

This procedure, which asks participants for immediate responses several times a day in their daily lives, is called the experience sampling method [17]. This method is advantageous in that it can avoid response biases in recall and it can allow for analysis with a high time resolution.

During the study, we measured the predicted mean vote (PMV) [18] in the office using HD32.3 (Delta OHM). PMV is a scale that measures the psychological evaluation of the thermal state in an environment. The PMV is calculated using thermal parameters (air temperature, mean radiant temperature, relative air velocity and vapor pressure in the ambient air) and human parameters (activity level and thermal resistance of clothing), and it is represented on a scale from -3 (cold) to 3 (hot) via 0 (neutral) [19]. The PMV

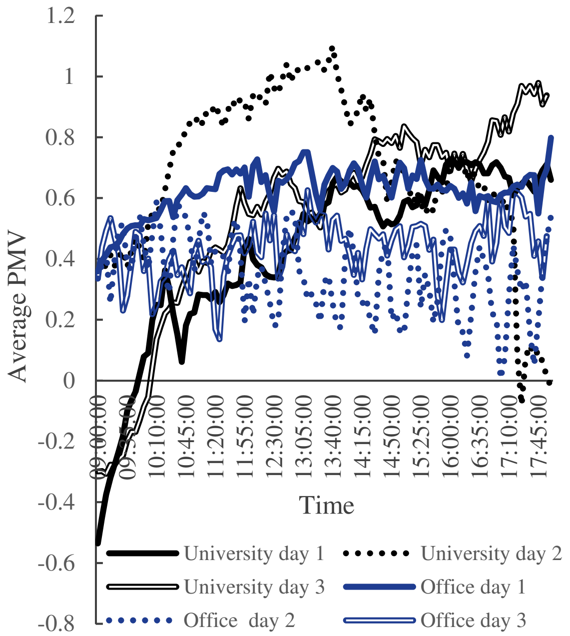

Fig. 1 Average PMV in each condition.

corresponds to the predicted percentage of dissatisfied (PPD). When the PMV is 0, 5% of the people in the environment are dissatisfied with it. When the PMV is 0.5 or -0.5, and 3 or -3, 10% and 80% people are dissatisfied with the environment, respectively [19].

The present study was conducted according to Kwansei Gakuin University regulations for behavioral research with human participants.

B. Results

1) Basic Data: The average response rate of the participants was 78.6% (with a range from 33% to 100%). We compared all responses with those from participants who stayed at their desks for more than 30 minutes in succession and were used to the environment. We found that the general tendency was almost the same. Therefore, we analyzed the data of all the participants.

The average PMV is shown in Fig. 1. The PMV during the study time (from 10:00 to 17:00) was from 0 to 1, which indicates a neutral and slightly warm thermal condition. There was neither an acute increase nor an acute decrease in the PMV. These results indicated that the office was relatively comfortable considering from PMV.

Table 1 The correlation between absolute PMV and subjective comfort and subjective productivity

	Subjective comfort	Subjective productivity
All	-0.06	-0.19
Balance	-0.24	-0.05
Thermal	-0.07	-0.30*
Inside	0.15	0.22

Note: * $p < .05$

a) Subjective Comfort and Factors That Affect it: The responses of the participants were summarized using E-grid [20]. First, we sorted the participants' responses that represented similar meanings into common categories. For example, the response "cold" and "slightly cold" represented almost the same meaning; thus, they were both put into the category "cold." We then applied a 0.15 threshold so that the whole construct system could be easily understood. The participants' construct system is shown in Fig. 2. The left side of Fig. 2 represents the higher items (abstract judgement of value), and the right side represent the lower items (objective understanding). The items connected with lines indicate that the right item evoked the left item. In the present study, we focused on comfort and set it at the top of the hierarchical structure.

Like the studies that have pointed out the importance of thermal factors [12], more than half of the factors in Fig. 2 related to thermo (temperature itself and things related to temperature). This result indicates that in an environment where the thermal condition is controlled, which is indicated by the PMV (Fig. 1), thermal comfort is not perfectly realized. This is also supported by the weak correlation between the absolute PMV and subjective comfort (Table 1).

Other factors relate to inside (mental state and personality of the participants), sound (noise and silence in the environment), humidity (moisture in the environment) and others. One interesting finding derived from Fig. 2 is

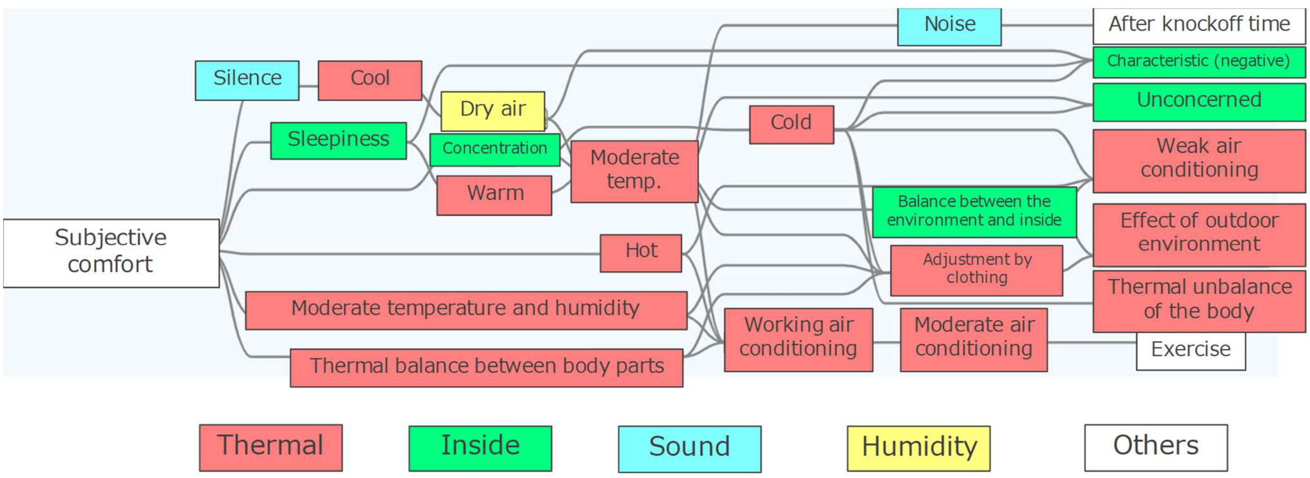

Fig. 2 Components of the subjective comfort and its relationships.

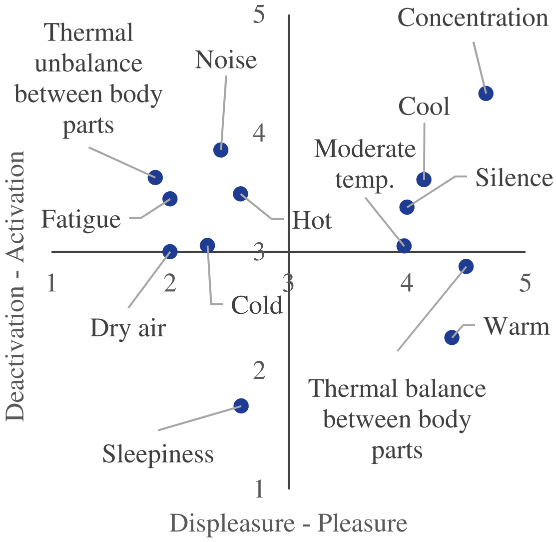

Fig. 3 Circumplex model in office comfot factors.

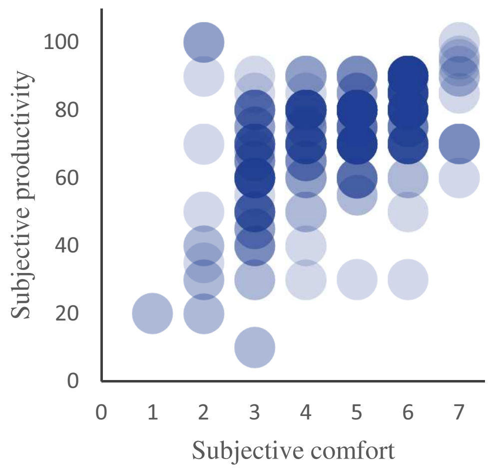

Fig.4 The correlation between subjective comfort and subjective productivity.

that the participants reported the factors that related to productivity (sleepiness and concentration). This might be a specific tendency of the present study, which was conducted in office (and office-like) environments.

Figure 2 not only shows the factors that affected subjective comfort; it also reveals the relationships between them, which sometimes go beyond their categories. For example, "sleep" is an item in inside category, but it is affected by the "warm" factor, an item in the thermal category. These cross-category relationships indicate the importance of considering various factors to reveal overall comfort in an environment.

We chose items that the participants used more than five times and plotted them on the displeasure – pleasure and degree of arousal axes (Fig. 3). The factors on the right side would improve comfort, and those on the left side would deteriorate comfort.

b) Comfort and Productivity: Figure 4 shows the relationship between the participants' subjective comfort and their subjective productivity. As shown in Fig. 4, subjective comfort and subjective productivity showed a strong positive correlation (r = .54).

Table 1 shows that the PMV failed to predict subjective comfort and subjective productivity. This might be due to the fact that the present study was conducted in an environment whose thermal condition was well controlled (with PMV ranges from 0 to 1). The other reason behind this weak correlation might be individual differences. Although the PMV reflects part of the individual differences by considering metabolic equivalent of task and the clothing amount of individuals, other individual differences such as thermal sensation and thermal unbalance between body parts were not considered.

2) Classification of the Participants: We classified every response of the participants (the factors that directly affected comfort) into seven categories: thermal, humidity, light, sound, smell, inside and others.

As shown in Table 2, although the thermal factor was the most frequent, the factors that affected comfort differed across participants. Additionally, the frequency of each

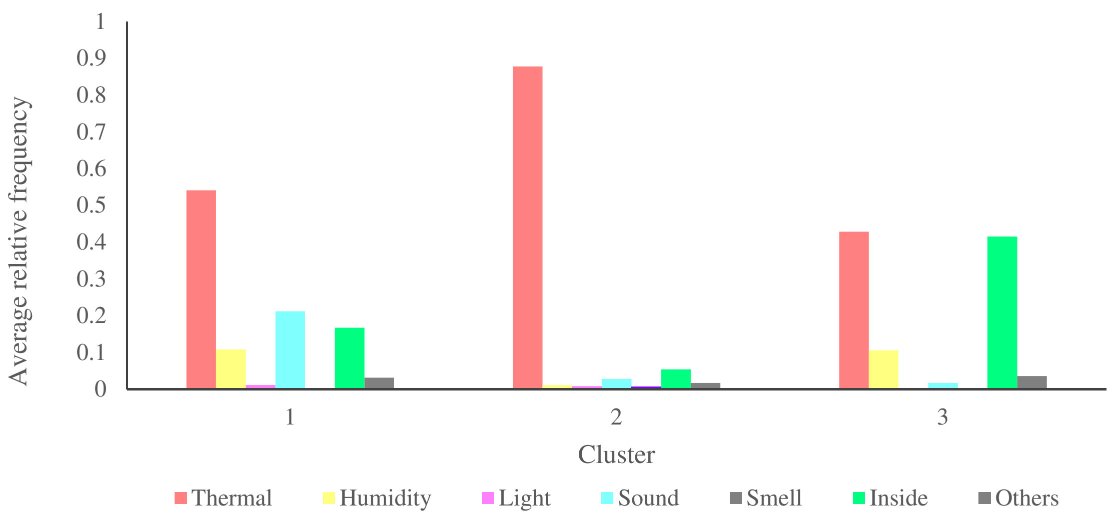

Fig. 5 Average relative frequency rate of factors which directly affects subjective comfort.

Table 2 Variation of the relative frequency of each factor

	Thermal	Humidity	Light	Sound	Smell	Inside	Others
Minimum	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	0.25	0.06	0.35	0.12	0.44	0.11
M	0.75	0.04	0.01	0.07	0.01	0.13	0.02
SD	0.20	0.07	0.02	0.10	0.02	0.14	0.04

factor varied between participants, which indicates that the individual differences in these factors compose comfort.

We conducted a cluster analysis based on the participants' response categorization data (Table 2). We applied three clusters with regard to the number of participants in every cluster. Figure 4 shows the characteristics of the clusters. We named cluster 1 ($n = 5$) the balanced cluster because the participants in this cluster reported that factors in various categories affected their comfort. Cluster 2 ($n = 15$) was named the thermal cluster due to the fact that the participants in this cluster reported that their subjective comfort depended mainly on thermal factors. Cluster 3 ($n = 3$) was named the inside cluster because the participants in this cluster reported that the factors that affected their comfort contained many inside factors.

We conducted a correlation analysis between subjective comfort and subjective productivity within each cluster. Though the balanced cluster and thermal cluster showed strong positive correlations (rs = .69, .71), the inside cluster showed a weaker correlation ($r = .46$).

The absolute PMV correlated with subjective productivity in the thermal cluster ($r = -.30$) but not in the balanced or inside clusters (rs = -.19, -.05). This indicates that thermo was only an important factor for the comfort of those in the thermal cluster. Previous studies have also shown that actual air temperature poorly correlated with subjective productivity [7]. The present study revealed that the classification of people allows us to shed light on this weak correlation and investigate its details.

IV. Conclusions

A. *Summary of the Results*

In the present study, we focused on comfort in the office environment and investigated its components and individual differences. We conducted the study using the experience sampling method and the evaluation grid method. The results revealed that the components of comfort in the office were mainly composed of thermal factors, though they also included inside factors, sound factors, humidity factors and other factors. There were individual differences in the relative frequency, which is related to subjective comfort. We conducted a cluster analysis and found three clusters: the balanced, thermal and inside clusters. These clusters differed in their characteristics and in the relationships between the PMV and subjective productivity. Only the thermal factors had a significant correlation between the PMV and subjective productivity.

B. *Novelty of the Present Research*

The present study achieved three new findings.

The first finding is that some people complain about thermal factors in an environment where physical thermal conditions are properly controlled. This shows that the PMV is not a perfect indicator of thermal comfort, especially in environments with relatively good thermal conditions (PMV ranges from 0 to 1). This may be because of individual differences in psychological thermal sensations or other factors that PMV cannot consider. This indicates the importance of measuring environmental comfort with more subjective factors. This is also indicated by the result that there was no significant correlation between subjective comfort and PMV (Table 1).

The second finding is that there were individual differences in comfort. Some people focused on only thermal factors (thermal cluster), though others focused on thermal and inside factors (inside cluster) or various factors (balanced cluster). These individual differences indicate that although the thermal factor is the most important for comfort in the office, other factors also affect people's comfort, and the importance of these factors differs between people. The importance of focusing on the individual differences themselves was pointed out by a previous study that used an individual's characteristics [21]. The present study focused more directly on the factors that affect comfort and paved the way for the realization of a personalized comfort environment.

The third finding is that subjective comfort and subjective performance were strongly related. This indicates that comfort may be a good facilitator in realizing a productive office (of course, an opposite hypothesis is that a productive office brings comfort to workers). Previous studies have listed various factors as intermediaries between environment and productivity, such as motivation [5], activation of the idea that relates to the environment [9] and the improvement of information exchange [22]. The present results showed that there is a possibility that comfort relates to productivity.

In addition, we took a novel approach that combined the experience sampling method and the evaluation grid method. This approach allowed us to do two things. It allowed us to extract the factors that affected subjective comfort precisely (i.e., without recall bias), and it allowed us to reveal the relationships between factors that relate to subjective comfort, which helps us reveal the mechanisms that define how environmental factors affect people.

C. Future Directions

Future research needs to consider two things: making the clusters more valid and realizing an actual application.

The number of participants was 23, and this might not have been enough to define the characteristics of the clusters. Future research needs to replicate the present results with more participants, which would allow us to make more reliable inferences about the individual differences.

Although each cluster had its own characteristics, it is still difficult for us to improve the participants' comfort in a systematic way. For example, try to think of a way to improve comfort for the thermal cluster. Those in the thermal cluster have various characteristics. One participant might tend to feel colder than the others and report "It is cold" as the factor that affects his or her comfort. Others might be insensitive to thermal changes, which means they always feel comfortable, and they might report that "The temperature is neutral." A larger sample and a more detailed analysis of the participants' responses is needed to solve these problems.

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