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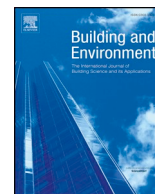
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Personal control and environmental user satisfaction in office buildings: Results of case studies in the Netherlands

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ABSTRACT

Personal control is one of the influential factors for user satisfaction and environmental comfort due to its physical and psychological impacts. This paper aims to identify the relationship between the degree of personal control over indoor environmental conditions and user satisfaction with thermal and visual comfort. Trying to answer the question, field studies on user control were conducted in 5 office buildings in the Netherlands. Occupants assessed their perceived satisfaction online by means of a questionnaire. Based on the dataset, Pearson's Chi-Square test was conducted to investigate the relationship. The results showed that a higher controllability leads to more satisfaction in terms of thermal and visual comfort. The research also revealed the psychological impact of personal control on user satisfaction by showing differences in perceived satisfaction according to “no control” and “do not have” between thermal and visual comfort. Personal control of ventilation was the most significant factor influencing the satisfaction with thermal comfort. These findings provide support to workplace management and to the design of personal environmental control systems.

1. Introduction

User satisfaction, in terms of indoor comfort, is a subjective topic. According to Fanger [1], there is no thermal environment that makes everybody satisfied. In that sense, user control is an important issue for an individual's thermal comfort. There are many studies dealing with automated control of building systems and control strategies for shading devices [2–4] and lighting with occupancy sensors [5], in order to manage the energy consumption in an efficient way. Moore [6] found that some people overused the personal lighting control although they do not feel uncomfortable, and people had negative opinions due to partial failure of the system [7]. Occupant interactions indeed influence energy performance and consumption [4]. However, systems fully automated for energy efficiency may incur a risk of serious occupant dissatisfaction. Aghemo, Blaso, and Pellegrino [5] stated that although automatic control has potential energy savings, user control is important to correct the defects of the automatic system.

The importance of user control at work has been dealt with in various studies. The studies identified that greater direct individual control leads to higher thermal comfort [8–11], higher satisfaction [12–14], energy savings [15–17], and productivity in work environments [18]. From a psychological point of view, personal control is an important factor to increase user satisfaction and the employee's

productivity [19–21]. In short, individual control affects not only an employee's satisfaction and thermal comfort but also productivity and energy saving.

User control is often referred to in different ways, such as individual, personal or occupant control. The terms of user control are not clearly defined yet in the built environment. *Personal control* is defined by Greenberger and Strasser [22] as ‘an individual's beliefs at a given point in time, in his or her ability to effect a change, in a desired direction on the environment.’ However, the definition is generic, and it needs to be defined for the built environment. Huang and Robertson [23] used *environmental control* over a workstation as ergonomics-related control, influencing an employee's satisfaction and stress. Karjalainen [24] stated that *occupant control* is the actions occupants take to be comfortable in thermal conditions by controlling the thermostats. Luo and Cao [25] used *person environmental control* as ‘regarding space conditioning systems on occupants’ thermal comfort perception’. In fact, the terms of *personal* or *occupant control* over the indoor environment go along the line of occupant's comfort. Based on previous definitions, this paper uses the term personal control as user actions towards environmental comfort.

Although many researchers have studied the positive impacts of personal control, there are different opinions about personal control and related problems [6–8,24]. One research found that there was no

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big difference in user satisfaction between an office equipped with thermostats and an office having more limitations to users for thermal control, since users did not notice whether personal temperature control works or not [8]. In addition, employees have few chances to control thermostats for an individual's thermal comfort [24]. Karjalainen's study revealed the main reasons of user problems to be that people often did not use individual controls, because the control system was not recognisable or people were not sure whether the control system was operable. Luo and Cao [25] examined whether the thermal comfort improvement was solely influenced by psychological factors or together with physical factors through a chamber experiment. They demonstrated that people were more satisfied with thermal comfort perception only due to psychological reasons of person control. Nevertheless, the result from a chamber experiment may be different from an actual-site experiment. Therefore, the actual use of person control and its impact on user satisfaction in workplaces needs more attention and exploration.

The purpose of this paper is to provide an overview of the actual use of person control over the environmental condition systems in offices; to understand the dependency of a user's environmental satisfaction regarding the degree of personal control; and to contribute to designing better user control that enhances user satisfaction at work. This study, therefore, focused on the occupants' rating of environmental satisfaction parameters, divided into two contexts: thermal and visual comfort. In addition, it also investigated whether there were significant relations between the degree of personal control and the user satisfaction in different seasons.

2. Methods

2.1. Data collection

Data were collected in two ways: e-mails containing an online survey link (Qualtrics online survey software), and physical distribution of hard copies. The data were collected in the year 2017. The offices selected are cellular,¹ combi,¹ open,¹ and flex-offices,² equipped with a range of user control systems. Four buildings are energy-retrofitted offices and one is a conventional office. Facility managers from each office participated in individual interviews to collect information about building physics. Interview questions were modified based on the book of 'The healthy indoor environment: how to assess occupants' wellbeing in buildings' [28].

2.1.1. Building information

Fig. 1 displays further details about building information: building structure, WWR, sunshades, glazing type, renewable energy sources, HVAC terminal units, temperature set-points, heat recovery, types of HVAC system, openable windows, HVAC system running hours, and types of thermal control. The four renovated offices have ceiling-mounted heating and cooling, and independent thermostats at each workplace. The non-renovated office case does not offer thermostats nor a ventilation system, only openable window. In the renovated offices, each office has centrally programmed set-points for heating and cooling (each office has slightly different set-points). Occupants can control the temperature within a limit of $\pm 2^\circ\text{C}$ or $\pm 3^\circ\text{C}$ with a thermostat. The background air velocities, checked on a real-time base, were $< 0.1\text{ m/s}$, which did not significantly affect users' thermal perception [25]. The indoor temperature in retrofitted offices was

generally controlled by a local thermostat or by fully automated control by zone sensors. The non-renovated office was equipped with complete manual control.

2.1.2. Respondents demography

Participants of the survey were from five offices in the Netherlands, with a total of 579 (90.9%) completed respondents out of a total of 637 office users approached (see Table 1). The group of respondents comprised 324 (50.9%) of males and 313 (49.1%) of females, both aged 18 to 69. The main age group consisted of 194 (30.5%) 30–39 years old employees, followed by 161 (25.3%) 40–49-year employees. 425 (66.7%) of the respondents were full-time employees (working at least 36 h per week), and 212 (33.3%) were part-time employees. 332 (52.1%) of the respondents answered they have their own desk at the office, 102 (16%) have a fixed desk, shared with 2–3 colleagues, and 203 (31.9%) chose working desk randomly. 58 of the responses were excluded due to missing answers.

2.1.3. Questionnaires

The questionnaires are about satisfaction with the indoor environmental quality (IEQ) and the degree of personal control for individuals' thermal and visual comfort during summer, winter, and mid-season. Fig. A.1 displays original questionnaires and scales used for online survey. The first question asked was "To what extent can you control the following aspects of your workplaces?" (i.e., heating, cooling, operable windows, sunshades, and lighting). Only the variables that affect indoor climate were selected. User control was scaled as follows: 1 = complete, 2 = partial, 3 = no control, 4 = do not have. Prior field study showed that people sometimes were not allowed to open windows for safety reasons. For this reason, the "No control" choice was available for each question. The degree of user control is defined based on literature by de Dear and Brager [29] and Boerstra [30]:

- Complete control: no central control system and full control by users, and they have wide range of temperature control.
- Partial control: having set-points, occupants are allowed to control their own environment within the limited thermal range.
- No control: fully centrally controlled conditions, the control system is installed, but people are not allowed to use it.
- Do not have: no user control system is installed.

The second question was "Can you indicate how satisfied you have been with your work environment during summer?" This question was repeated for each season. Thermal comfort variables were temperature, air quality, humidity, and overall satisfaction; visual comfort variables are lighting, daylight, and outside view. A 5-point Likert scale was used to evaluate their perception. Each option was given a score: 1 = extremely dissatisfied, 2 = somewhat dissatisfied, 3 = neither dissatisfied nor satisfied, 4 = somewhat satisfied, and 5 = extremely satisfied.

2.2. Data analysis

All statistical analysis was carried out using SPSS (version 24.0). User satisfaction variables were structured within two variable groups, thermal comfort and visual comfort variables, by factor analysis with Oblimin rotation (oblique rotation), that assumes that the factors are correlated. Pearson's Chi-Square test was applied to analyse the relation between user control and user satisfaction with indoor environment, and frequency distributions of two or more variables. An adjusted residual value was used to compare the level of user satisfaction and personal controllability. There were two assumptions to conduct the Chi-Square test. First, both independent and dependent variables should be categorical data (i.e., nominal and ordinal level). Second, two variables should consist of more than 3 or 4 independent groups respectively. A 5-point Likert scale for user satisfaction was rescaled to 3 scores: 1 = dissatisfied, 2 = neither dissatisfied nor satisfied,

¹ [26] A. v. d. Dobbela, The Sustainable Office. An exploration of the potential for factor 20 environmental improvement of office accommodation. TU Delft, Delft University of Technology, 2004.

² [27] C. B. Danielsson and L. Bodin, "Office type in relation to health, well-being, and job satisfaction among employees," *Environment and Behaviour*, vol. 40, no. 5, pp. 636–668, 2008.

		Case A	Case B	Case C	Case D	Case E
Structures	Load bearing structure + Thermal layer position					
	Skeleton structure + Thermal layer position					
WWR						
Sun shading		External blinds (south only)	Internal blinds (all sides)	External blinds (all sides)	External screens (south only)	Internal blinds
Glazing type		HR ++	HR ++	HR ++	HR ++	Single glazing
Renewable energy		.	Wind energy from own electricity grid, Sun collector heater	Acquifer system	.	.
Climate ceiling		O	O	O	O	X
Temp. Set point		21 ± 2 °C	21 ± 3°C	20 ± 3°C	20 ± 3°C	X
Heat recovery		O	O	O	X	X
HVAC	Types of HVAC	Heat pump (heating and cooling)	Water cooled chiller + cooling tower	LTES and Heat pump	Water cooled chiller + cooling tower	Hot-water based radiator
Operable windows		O	X	O	O BUT not allow to open	O
System running hours	per week	35 - 45 h	55 h	60 h	80 h	.
Thermal control	Room temperature control	Local thermostat	Zone sensor	Local thermostat, Facade and zone sensor	Local thermostat	Manual control

Fig. 1. Physical building information.

Table 1

Demographic information of respondents.

	Gender		Age					Contract type		User of workstation		
	Male	Female	18–29	30–39	40–49	50–59	Over 60	Full-time	Part-time	Own desk	Shared desk*	Random
Number	324	313	121	194	161	128	33	425	212	332	102	203
Percentage	50.9	49.1	19	30.5	25.3	20.1	5.2	66.7	33.3	52.1	16.0	31.9

Note: shared desk* in this study means sharing work desk with fixed number of people. People cannot randomly choose work desks.

3 = satisfied. The rescaled score provided a simplified interpretation in the cross-tabulation analysis. Two models were built to investigate the relations between comfort satisfaction and personal control parameters. The first model examined the relation between thermal comfort variables and personal control of heating, cooling and ventilation. The second model examined the relation between visual comfort variables and personal control of sun shades and lighting.

In this case, the null hypothesis (H0) was that there is no relation between user control and user satisfaction. The alternative hypothesis (H1) was that there is an relation between user control and user satisfaction. The level of significance was defined as $p < 0.05$, confidence intervals were set at 95%. Since Chi-Square does not provide the strength of relation, effect sizes and a residual analysis were used to investigate a statistically significant omnibus Chi-Square test result. Effect sizes were tested by Cramer's V. Cramer's V, indicating a number

between 0 and 1, was used to examine how strongly two categorical variables are associated. It is calculated using the following formula:

$$\phi_c = \sqrt{\frac{\chi^2}{N(k-1)}}$$

- ϕ_c denotes Cramer's V;
- χ^2 is the Pearson Chi-Square statistic;
- N is the sample size involved in the test and
- k is the lesser number of categories of either variable.

Since Cramer's V does not identify the pattern of relationship, an adjusted residual table was added. The adjusted residual indicates the difference between the observed counts and expected counts divided by an estimate of standard error, which means the larger the residual, the

Table 2

Results of relation analysis between user control and thermal comfort satisfaction using Pearson's Chi-Square test (statistical significance $p \leq 0.05$).

Seasons	User control	User satisfaction	<i>P</i> - value	Effect size
Mid-season	Heating	Temperature	0.003	0.131
		Air quality	0.166	
		Humidity	0.224	
		Overall	0.058	
	Cooling	Temperature	0.049	0.105
		Air quality	0.145	
		Humidity	0.466	
		Overall	0.091	
	Ventilation/ Operable windows	Temperature	$p < 0.001$	0.168
		Air quality	$p < 0.001$	0.167
		Humidity	0.001	0.136
		Overall	$p < 0.001$	0.185
Summer	Heating	Temperature	0.008	0.122
		Air quality	0.253	
		Humidity	0.338	
		Overall	0.570	
	Cooling	Temperature	$p < 0.001$	0.155
		Air quality	0.086	
		Humidity	0.278	
		Overall	0.037	0.107
	Ventilation/ Operable windows	Temperature	0.017	0.116
		Air quality	$p < 0.001$	0.145
		Humidity	0.005	0.127
		Overall	$p < 0.001$	0.165
Winter	Heating	Temperature	$p < 0.001$	0.174
		Air quality	0.145	
		Humidity	0.302	
		Overall	0.041	
	Cooling	Temperature	$p < 0.001$	0.155
		Air quality	0.331	
		Humidity	0.576	
		Overall	0.034	0.109
	Ventilation/ Operable windows	Temperature	$p < 0.001$	0.172
		Air quality	$p < 0.001$	0.148
		Humidity	$p < 0.001$	0.152
		Overall	$p < 0.001$	0.193

Note: *p*-values in bold highlighted are statistically significant ($p < 0.05$). Effect size by Cramer's V indicates 0.04: small, 0.13: medium, 0.22: large.

greater the contribution to the Chi-Square test result [31]. The positive adjusted residuals mean that (depending on satisfaction variables in this study) there are more satisfied or dissatisfied occupants than expected, adjusted for the sample size. The negative adjusted residuals mean that there are less satisfied occupants than expected.

3. Results

3.1. Relationship between user control and satisfaction

User satisfaction is influenced by many factors. In order to explore the impact of each environmental factor, satisfaction variables were integrated into a thermal comfort variable and a visual comfort variable. To apply Pearson's Chi-Square, independent and dependent variables should be independent, and no more than 20% of the cells have expected counts less than 5 [32]. The results of each test showed the expected counts less than 5 were 1 cell (8.3%) or 0 cell (0.0%). Thus, the dataset was qualified to continue with this examination. Table 2 presents the relation between user controllability and satisfaction in the work environment, showing the *p* - value of each variable. The most significant satisfaction factor was temperature, in terms of heating, ($p = 0.003$), cooling ($p = 0.049$), and operable windows ($p < 0.001$) in mid-season. However, the relationship between cooling control and user satisfaction regarding indoor temperature had a relatively weak statistical significance. In particular, controllability of operable windows was the most important user control variable for satisfaction with

thermal comfort in this season, for temperature ($p < 0.001$), for air quality ($p < 0.001$), for humidity ($p = 0.001$), and for overall satisfaction ($p < 0.001$).

Summer measures showed a trend similar to mid-season. Overall, the most significant occupant control system was operable windows in terms of satisfaction with temperature ($p = 0.017$), air quality ($p < 0.001$), humidity ($p = 0.005$), and comfort ($p < 0.001$). The relation between heating ($p = 0.008$) and cooling control ($p < 0.001$), and temperature satisfaction was statistically significant. Unlike mid-season, user control for cooling was strongly related to overall satisfaction as well as temperature satisfaction.

In winter, the relation between heating and cooling, and temperature satisfaction was observed at ($p < 0.001$) and ($p < 0.001$) respectively. According to the Chi-Square value, heating control had a stronger impact on temperature than cooling control. Those variables also affected overall satisfaction for heating, and for cooling. The relation of operable windows with four satisfaction parameters (e.g., temperature, air quality, humidity, and overall comfort) were highly significant over the thermal satisfaction variables.

To conclude, heating control was strongly related to overall satisfaction in mid-season and winter. Cooling control affected overall satisfaction in summer. Conversely, there was no significant relation between heating control with air quality and humidity, and cooling with the same two variables.

Table 3 shows the relation between personal controllability and visual comfort satisfaction. There was a significant correlation between sunshades and satisfaction with 'artificial light' ($p < 0.001$), 'daylight' ($p < 0.001$), and 'outside view' ($p < 0.05$), over all seasons. Controllability of sunshades was an important factor for the overall visual comfort. In addition, there was a significant correlation between lighting control and daylight satisfaction at $p < 0.05$ during whole seasons. The number of Cramer's V revealed that two categorical variables, in general, had weak (< 0.06) or medium effects (< 0.17); only the relation between sunshades and daylight showed a large effect size.

3.2. The dependency of thermal comfort user satisfaction based on the degree of personal control

Tables 4 and 5 summarise the trend of user satisfaction with thermal and visual comfort in relation to the degree of person control. The data includes only statistically significant results ($p < 0.05$). The null

Table 3

Results of relation analysis between user control and visual comfort satisfaction using Pearson's Chi-Square test (statistical significance $p \leq 0.05$).

Seasons	User control	User satisfaction	<i>P</i> - value	Effect size
Mid-season	Sun shades	Artificial light	$p < 0.001$	0.144
		Day light	$p < 0.001$	0.220
		Outside view	0.023	0.113
	Lighting	Artificial light	0.492	
		Day light	$p < 0.001$	0.148
		Outside view	0.165	
Summer	Sun shades	Artificial light	$p < 0.001$	0.147
		Day light	$p < 0.001$	0.172
		Outside view	0.006	0.125
	Lighting	Artificial light	0.199	
		Day light	0.024	0.112
		Outside view	0.116	
Winter	Sun shades	Artificial light	0.001	0.143
		Day light	$p < 0.001$	0.223
		Outside view	0.037	0.108
	Lighting	Artificial light	0.225	
		Day light	0.007	0.124
		Outside view	0.184	

Note: *p*-values in bold highlighted are statistically significant ($p < 0.05$). Effect size by Cramer's V indicates 0.04: small, 0.13: medium, 0.22: large.

Table 4
Assessment of user satisfaction with thermal comfort based on personal controllability.

	Adjusted residual					
	Satisfaction variables	Personal control	Complete control	Partial control	No control	I do not have
Mid-season	Temperature	Heating	2.5	0.8	–3.4	1.9
	Temperature	Cooling	0.5	1.4	–2.7	1.2
	Temperature	Ventilation	2.0	0.9	–3.9	0.5
	Air quality		1.2	–0.9	–4.3	2.8
	Humidity		1.7	–0.8	–3.3	1.6
	Overall comfort		3.4	–0.6	–4.8	1.2
Summer	Temperature	Heating	0.4	0.4	–2.6	2.7
	Temperature	Cooling	2.1	1.7	–3.5	1.2
	Overall comfort		1.2	2.1	–2.5	0.0
	Temperature	Ventilation	0.3	0.1	–2.5	1.5
	Air quality		1.3	–1.8	–3.4	2.8
	Humidity		1.5	–1.0	–2.8	1.6
	Overall comfort		0.7	–1.1	–3.8	3.0
Winter	Temperature	Heating	3.0	0.2	–3.1	2.0
	Overall comfort		2.0	1.1	–2.7	0.8
	Temperature	Cooling	1.4	1.4	–3.2	1.5
	Overall comfort		1.0	2.6	–3.1	0.2
	Temperature	Ventilation	2.8	0.8	–3.1	–0.6
	Air quality		0.8	–1.0	–3.0	2.2
	Humidity		1.9	–1.0	–3.0	1.4
	Overall comfort		2.8	–0.9	–4.0	1.2

Note: adjusted residual numbers in bold highlighted mean the largest contribution to satisfaction.

hypothesis, claiming no statistically significant relation between independent and dependent variables was rejected. The adjusted residual of the satisfied variable was only compared to observe contribution of each cell, and important numbers were highlighted.

Table 4 shows that, in most variables, ‘complete control’ ranked as highest adjusted residual level (minimum 1.9, maximum 3.4), while ‘no control’ ranked lowest (minimum –4.8, maximum –2.7). For air quality, ‘I do not have’ for ventilation control was highly related to satisfaction in all seasons. In mid-season, occupants tended to be more satisfied with temperature perception and overall comfort according to the following degree of heating control and ventilation: ‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’. However, having complete cooling control did not mean people were more satisfied with temperature perception. The heating system affected satisfaction more than cooling. For satisfaction with air quality regarding ventilation control, the majority of occupants were satisfied with the condition of ‘do not have’ followed by ‘complete’. This result showed people were satisfied either when they had total ventilation control or they do not have personal control at all.

In summer, the results showed the same order of preferred heating and cooling control as mid-season (‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’). Although there was a statistically significant relationship between heating control and temperature satisfaction, occupants did not care about the heating control as shown in Table 4. For user satisfaction, cooling control was important on temperature and overall comfort. Occupants had different preferences about the degree of ventilation controllability compared to personal heating and cooling. Occupants were more satisfied with the indoor climate according to controllability in the following order: ‘do not have’ > ‘complete’ > ‘partial’ > ‘no control’.

During winter, cooling control was not an important factor. For temperature and overall satisfaction, complete heating control was the largest adjusted residual level, while no control had the smallest one. The results of ventilation control showed that people were likely to be more satisfied with the following degree of control (‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’) in temperature satisfaction. In terms of air quality, occupants were satisfied with the degree of ‘do not have’ > ‘complete’ > ‘partial’ > ‘no control’. On the other hand, people who could completely control the ventilation were relatively more satisfied than those who did not have control.

3.3. The trend of user satisfaction with visual comfort based on the degree of personal control

Table 5 illustrates the trend of user satisfaction with visual comfort according to the degree of person control regarding sunshades and lighting. Overall, occupants working without personal control of sunshading and lighting were least satisfied with light quality and outside view. ‘Complete control’ of sunshading and lighting had the greatest contribution to satisfaction with visual comfort, while ‘I do not have’ often ranked lowest. Although people who were not allowed to use personal control were relatively more satisfied with visual comfort than those of ‘do not have’, people were still irritated by the fact that they could not personally control sunshading and lighting.

Interestingly, mid-season and summer had similar patterns. In terms of lighting and daylight, people were likely to be satisfied following this order: ‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’. People who did not have personal control were less satisfied than those who had a control system but could not use the system. Results suggest people were less dissatisfied about lighting and daylight when they could not use the sunshade control system than when they did not have sunshade control at all. It can be explained that even though the indoor environment without personal sunshade control was not appropriate for the satisfaction, people accepted and adjusted to the fact that their workplace does not provide personal control. However, respondents tended to be satisfied with outside view according to the degree of sunshades control: ‘complete’ > ‘partial’ > ‘no control’ > ‘do not have’. It is assumed that although people could not use the control system, they were aware of the existence of the control system, therefore less dissatisfied than the people who did not have control over sunshading. People were sensitive with outside view when the workplace was not equipped with control over sunshading.

In winter, the tendencies for user satisfaction in lighting, daylight and outside view were different from the results of mid-season and summer. Still, complete control made occupants more satisfied with lighting and outside view. Having sunshades in mid-season and winter was quite important regardless of whether they were able to control it.

In addition, there were different tendencies towards daylight satisfaction and personal lighting control. In general, occupants who could ‘completely’ and ‘partially’ control lighting were more satisfied than ‘no control’ and ‘do not have’. In mid-season and winter, the trend

Table 5
Assessment of user satisfaction with thermal comfort based on personal controllability.

		Adjusted residual				
Satisfaction variables		Person control	Complete control	Partial control	No control	I do not have
Mid-season	Artificial light	Sun shades	1.7	1.1	–1.8	–1.4
	Daylight		5.4	0.9	–3.3	–3.7
	View to outside		1.1	0.9	–1.2	–1.0
	Daylight	Lighting	2.6	1.6	1.1	–3.6
Summer	Artificial light	Sun shades	1.3	1.2	–1.6	–1.4
	Daylight		4.1	1.3	–3.6	–2.4
	View to outside		1.1	0.7	–1.1	–0.9
	Daylight	Lighting	2.1	2.5	0.2	–3.1
Winter	Artificial light	Sun shades	2.2	0.8	–1.7	–1.7
	Daylight		4.3	0.9	–2.4	–3.5
	View to outside		0.7	1.3	–0.7	–1.8
	Daylight	Lighting	2.1	0.8	0.9	–2.6

Note: adjusted residual numbers in bold highlighted mean the largest contribution to satisfaction.

of satisfaction with daylight quality followed the order of ‘complete’ > ‘partial’ > ‘no control’ > ‘do not have’. However, the results of the summer season showed that occupants who could partially control the lighting were most satisfied (2.5 of residual level) with daylight quality in workplaces.

In short, occupants sometimes easily accepted a working environment without having personal control; however, for certain factors, such as thermal comfort, people were more dissatisfied when they could not adjust the thermal conditions than when they did not have thermostats.

4. Discussion

4.1. Personal control studies

This paper identified user satisfaction with thermal and visual comfort according to personal controls through a user survey and statistical analysis. As most studies reported, personal control strongly influences user satisfaction with thermal and visual comfort. Many studies focus on the correlation between window opening behaviour and various parameters (e.g., the location of working desks [33] and indoor and outdoor environment [34–37]) in naturally ventilated office buildings. Raja et al. [37] reported that opening windows and controlling sunshades are the most frequently used behaviour to adjust thermal conditions, and that occupant discomfort is significantly correlated with ventilation. Similarly, the most significant relation was found to be satisfaction with thermal comfort according to the degree of ventilation. Personal control of sunshading was the largest contribution to satisfaction with visual comfort, and it can be relevant to thermal comfort.

Boerstra et al. [38] reported that a significant correlation was observed between perceived control³ and comfort, but there was no correlation between available control and perceived control. Conversely, in their occupants study conducted in 12 mixed mode office buildings, Brager and Baker [14] stated a ‘high degree of direct personal control’ contributed to more than 80% of the occupant’s satisfaction level. Similar to the study by Brager and Baker [14], this study has revealed that a higher degree of personal control leads to more satisfaction with IEQ. Although this study could not compare the same occupants satisfaction level before they had control and afterwards, we could analyse the impact of personal control in depth by collecting data from various target groups. The predominant outcome is that ‘complete

personal control’ showed the highest satisfaction for thermal and visual comfort in most of the cases. In contrast, the most dissatisfied occupants appeared in ‘no control’ or ‘do not have’ groups, depending on which environmental satisfaction variable was analysed.

4.2. Psychological adaption

In general, occupants tended to be least satisfied with thermal comfort when they had no control over the heating and cooling system. Unexpectedly, people often accepted the fact of having no personal thermal controls, which make them dissatisfied with thermal comfort in general. For example, when the workplace was not equipped with personal control, building occupants were rather less dissatisfied than the occupants who could not adjust the personal control. In this sense, they were more intolerant as they acknowledge the personal thermal controls, but they were not allowed to use them or they did not know whether the personal control affects temperature changes or not. This finding may be linked to a statement by Luo et al. [25] that the impact of user control on satisfaction is only related to psychological aspects. It is difficult to say user control only has psychological impact. However, results from this study indicated that the relation between control and satisfaction cannot only rely on psychological impacts of personal control alone, but on both physical and psychological impacts. Therefore, it is clear that occupants should have control over the office environment.

4.3. Designing the degree of person control

The most essential discussion is which degree of personal control should be designed and planned to increase the satisfaction of individuals and to make them agree with a compromise on the circumstances. Existing post-occupancy evaluation (POE) studies of office buildings have shown that occupants who work in high-performance⁴ buildings are more accepting and generous, even though the thermal environment is out of the comfort range [41]. As a number of studies proposed thermal comfort ranges based on their observation [42–44], personal control mechanisms need to be combined with user comfort ranges.

⁴ A definition by the United States Energy Independence and Security Act 2007, “a high performance building is a building that integrates and optimizes on a life cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations” [40]. A. Lewis, D. Riley, and A. Elmualim, “Defining high performance buildings for operations and maintenance,” *International Journal of Facility Management*, vol. 1, no. 2, 2010.

³ [39] K. A. Wallston, B. S. Wallston, S. Smith, and C. J. Dobbins, “Perceived control and health,” *Current Psychology*, vol. 6, no. 1, pp. 5–25, 1987.

For example, when people did not have personal ventilation in summer, they were most satisfied. The main reason for this may be related to HVAC and thermal control systems. Retrofitted offices were especially equipped with high-performance HVAC systems controlled by zone sensors, combined with local thermostats, so that users did not realise the necessity of a personal ventilation control. Another assumption is that occupants rarely opened windows in summer to avoid high-temperature air to come in. Although Herkel et al. [36] revealed that higher outdoor temperature is more opening windows in a naturally ventilated office, the trend of personal control may change in the case of an actively ventilated office. Brager and Baker [14] stated that mixed manual and automatic window system can have advantages to avoid unpleasant outdoor conditions, such as heavy wind or rain. Therefore, the HVAC system could affect the user satisfaction results in summer.

4.4. Limitations

Despite the importance of personal control, having complete personal control over the indoor environment is challenging. A limitation of this study was that the indoor temperature was not monitored before and after occupants' control of heating, cooling, ventilation, and sun-shading. Therefore, it is difficult to compare the impact of personal control on the indoor environment. Second, it is difficult to explain the reason why 'partial control' sometimes was the strongest factor contributing to building user satisfaction. The findings from the study presented may contribute to a guide for planning personal control in workplaces to achieve great user satisfaction and high occupant comfort. However, this study only focused on user satisfaction without considering differences of energy use so it was impossible to suggest the ideal degree of personal control in relation with both user satisfaction and energy efficiency.

5. Conclusion

This paper examined the environmental user satisfaction based on the degree of personal control in office buildings. This study provides insights into the degree of user control that increases building user satisfaction. The findings suggest a theoretical framework to deal with personal control and occupants' environmental satisfaction.

- Environmental user satisfaction can be increased by providing more freedom and personal control of thermal and visual comfort in workplaces.
- Occupants' control should be designed to differ according to the season.
- To improve user satisfaction, based on the findings of this research, thermal-related personal control should follow the order of 'complete' > 'partial' > 'do not have' > 'no control'. In summer, switching off the local thermostat and changing to fully automated control will have less effect on satisfaction.
- For satisfaction with visual comfort, occupants should have direct personal control of any visual comfort related factors such as sun-shading and lighting.
- Users tend to easier accept the fact that they do not have personal control than that they cannot use an available control system for environmental comfort. However, they tend to be more dissatisfied when they do not have personal control of visual comfort than when they cannot use the devices.
- In an office with a well-performing automated system, the impact of personal control on satisfaction is low.

Next to these points, facility managers should consider the following aspects: (1) implementing the proper degree of personal control by building occupants, such as providing complete or partial control over thermal and visual comfort; (2) identifying the impact of personal

control on energy and its contribution to employee satisfaction; and (3) managing a balance between energy consumption and the degree of personal control.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.buildenv.2018.12.021>.

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