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Impact of Available and Perceived Control on Comfort and Health in European Office Buildings

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ABSTRACT
The objective of this study was to find out how perceived control and access to control options like operable windows and thermostats affects comfort and health of European office workers. For this, the HOPE database was re-analyzed which contains data from indoor environmental quality surveys with around 6200 employees in 60 office buildings that are placed all over Europe. Statistical analyses were conducted to find out what the impact is of available controls on the perceived control of building occupants. Furthermore the effect of perceived control on comfort and health was determined.

No significant relation was found between *available* controls and perceived control apart from available solar shading. Between *perceived* control and comfort or health, multiple significant correlations were found.

Our findings suggest that designing future office buildings with the right *mix* of controls will lead to healthier and more comfortable building occupants.

KEYWORDS
Personal control, Individual control, operable windows, adjustable thermostats, building related symptoms.

1. INTRODUCTION
The design of modern office buildings (often with relatively complex building service systems and sealed façades) seems to be based upon the assumption that maintaining a predefined set of environmental variables (temperature, CO_2 concentration, etcetera) by definition assures the comfort and satisfaction of building occupants.

However, occupants in many of these new office buildings are not satisfied with the indoor climate (e.g. BOMA 1997). An often heard explanation is a 'lack of options for personal control' (Mendell & Smith, 1990). Several studies have shown that the amount of perceived personal control over the indoor climate positively relates to a decrease in complaints over the indoor climate. Hedge et al (1989) conducted a large field study in 47 English office buildings. They analysed their data to find out what factors cause 'Sick Building Syndrome' (building related symptoms). One of their main conclusions was that symptoms like dry eyes, dry throat, stuffy nose, itchy eyes

and lethargy had the highest prevalence in air conditioned buildings without operable windows. One of the possible underlying causes that was identified by the authors was 'limited possibilities for personal control on temperature and fresh air supply'. Zweers et al (1992) conducted a large epidemiological study in 69 Dutch office buildings and came to comparable conclusion as Hedge et al (1989): less options for personal control leads to a higher risk for building related symptoms. A meta-analysis study by Mendell & Smith (1990) concluded that building related symptoms (and also occupant dissatisfaction) is more prevalent in buildings with complex HVAC systems. Also these authors concluded that limited possibilities for personal control might play an important role.

It is clear that personal control is of great importance to obtain satisfaction with the indoor climate. However, little is known about which aspects are important to have personal control over. Is it primarily about offering the right amount of building controls to occupants (e.g. operable windows, adjustable thermostats) or is it also important to address the more psychological issue of *perceived* control?

Note in this context that Paciuk (1990) points out that personal control actually can be three things: 1. Available control, 2. Exercised control and 3. Perceived control. Available control is 'the degree and type of control made available by the environment (building, HVAC-system, etc.)'. Exercised control is defined as 'the relative frequency in which employees engage in several types of thermally-relegated behaviors in order to regain thermal comfort when needed'. Perceived control addresses the level of influence of building occupants. According to Paciuk (1990), the level of perceived control is related to the available controls and exercised control.

The first objective of this study was to determine the impact of available controls on perceived control in office buildings. The second objective was to determine the impact of perceived control on comfort and health in office buildings.

2. METHODS

In this study data from the HOPE database (HODA, see http://hope.epfl.ch) has been re-analyzed. HODA contains data from the HOPE project (Health Optimisation Protocol for Energy-efficient Buildings) in which 60 European office buildings with over 6200 building occupants have been surveyed. The aim of the HOPE project was to derive and test new guidelines for energy-efficient and healthy buildings. The data was gathered as follows: first, the researchers inspected the office buildings to determine the building characteristics and the properties of the HVAC-system. Secondly building occupants of the surveyed buildings were invited to participate in a questionnaire about their perception of the indoor environmental quality at their workspace. More information on the methods used in the HOPE study is presented by Roulet et al (2006).

For the analysis in this study, first relevant questions were selected from the HOPE building checklist to determine the available controls for each office building (table 1). Secondly, relevant questions were selected from the occupant questionnaire (table 2). These specific questions were related to perceived control, thermal comfort, perceived air quality and building related symptoms.

In HODA the available controls were defined for each office building. In this study also the personal scores from the questionnaire were averaged for each building (e.g. comfort and perceived control).
The questions regarding building related symptoms were combined into the Building Symptom Index$_5$ (BSI$_5$). The BSI is based on 5 core symptoms: dry eyes, blocked or stuffy nose, dry throat, headache and tiredness. Each symptom reported by the occupant scores 1. This means that every individual can score any value from 0 to 5 (his or her *Personal* Symptom Index). The average of the PSI for all building occupants of a building is called the Building Symptom Index$_5$ (BSI$_5$).
In other words: in this study office buildings were chosen as the unit of analysis instead of occupants. Notice that on average each building had around 100 respondents.

Since the questionnaire is based upon seven point-scales, non-parametric statistical tests were used. To investigate possible relations between the independent variable 'available controls' and the dependent variable 'perceived control', the Kruskal–Wallis analysis of variance test ($p < 0,05$) was used. Groups of available controls with less than 5 office buildings were omitted from the statistical analysis. Furthermore due to low n (number of office buildings) for groups of available solar devices, the groups were combined in this analysis (e.g. buildings with external solar shading devices versus buildings with internal solar shading devices).

To investigate the possible relations between the independent variable 'perceived control' and the dependent variables 'comfort' and 'health', the Spearman's rank correlation test (2-sided $p < 0,05$) was used. To determine the effect of multiple options of perceived control, the average building scores for questions about perceived control were combined. For example: when one building scored '3' on the seven-point scale for perceived control on temperature and '5' for perceived control on ventilation, the building scored '8' on a 14-point scale for perceived control on ventilation *and* temperature.

3a. RESULTS: Impact of available controls
The most interesting results are presented in figures 1 to 6 (notice that the seven-point scales for perceived control and comfort are reversed for increased readability of the graphs). No significant difference in perceived control on temperature was found (figure 1) between the groups with available temperature controls (Kruskal-Wallis: $p = 0,80$). Also no significant difference in perceived control on ventilation was found (figure 2) between the groups with available ventilation controls (Kruskal-Wallis: $p = 0,46$). Scores for perceived control on temperature, ventilation and perceived control on temperature and ventilation were found (figure 3 and 4) to not differ significantly between groups with(out) available operable windows (Kruskal-Wallis: $p = 0,13$, $p = 0,19$, $p = 012$). No significant difference in perceived control on temperature was found (figure 5) between the groups with(out) available solar shading devices (Kruskal-Wallis: $p = 0,15$). However a significant difference was found (figure 6) when different solar shading devices were combined into 3 categories: no solar shading device, internal solar shading and external solar shading. The mean rank of the control score was found to be significantly higher for external solar shading then for internal solar shading (Kruskal-Wallis: $p = 0,001$).

Table 1. Selected questions from the HOPE building checklist – offices [v8-15-10-2002].

What solar shading devices are present?

- □ None
- □ External louvres
- □ External horizontal blinds
- □ External vertical fins
- □ Internal louvres
- □ Other (specify)
- □ External vertical blinds
- □ External screens
- □ External awnings / canopies
- □ Blind between glazing
- □ Atrium
- □ External shutters
- □ External window films
- □ External overhangs
- □ Internal vertical blinds
- □ Double façade

How are the solar shading devices controlled?

- □ No control (fixed)
- □ Central down, individual up
- □ Individual
- □ Automatic

How is the room temperature controlled?

- □ Manual radiator valve
- □ Central sensor
- □ Manual control in room(s)
- □ Local thermostat at radiator / heating unit
- □ Façade sensor(s) – i.e. outside temperature
- □ According to occupancy
- □ Local thermostat (e.g. on wall)
- □ Zone sensor(s)
- □ Other

What type of control is there for mechanical ventilation?

- □ Central – manual (on/off)
- □ Local – manual (on/off)
- □ Recirculation control
- □ Central - clock
- □ Local - clock
- □ Central – demand control (temperature, CO_2, other pollutant, relative humidity)
- □ Local – demand control (temperature, CO_2, other pollutant, relative humidity)

Are the windows operable?

- □ Yes
- □ Yes, but occupants are not allowed to open them
- □ Yes, some (estimate % office area with operable windows)
- □ No

Table 2. Selected questions from the HOPE occupant questionnaire.

Perceived control: Selected questions to determine control over the indoor environment.

How much control do you personally have over the following aspects of your working environment?

Temperature	full control	1	2	3	4	5	6	7	None at all
Ventilation	full control	1	2	3	4	5	6	7	None at all
Shading from the sun	full control	1	2	3	4	5	6	7	None at all
Lighting	full control	1	2	3	4	5	6	7	None at all
Noise	full control	1	2	3	4	5	6	7	None at all

Health: Selected questions to determine building related symptoms.

In the past 12 months have you had more than two episodes of :

Symptom[1]	Yes	No
If 'Yes' was this better on days away from the office?	Yes	No

Comfort: Selected questions to determine perceived thermal and olfactory comfort.

How would you describe typical working conditions in the office in **winter**?

Comfort overall in winter	Satisfactory	1	2	3	4	5	6	7	Unsatisfactory
Temperature in winter	Comfortable	1	2	3	4	5	6	7	Uncomfortable
Air quality in winter	Fresh	1	2	3	4	5	6	7	Stuffy
Air quality in winter	Satisfactory	1	2	3	4	5	6	7	Unsatisfactory

How would you describe typical working conditions in the office in **summer**?

Comfort overall in summer	Satisfactory	1	2	3	4	5	6	7	Unsatisfactory
Temperature in summer	Comfortable	1	2	3	4	5	6	7	Uncomfortable
Air quality in summer	Fresh	1	2	3	4	5	6	7	Stuffy
Air quality in summer	Satisfactory	1	2	3	4	5	6	7	Unsatisfactory

[1] *In the HOPE questionnaire these three questions over building related symptoms were asked for 8 building related symptoms: dryness of the eyes, itchy or watery eyes, blocked or stuffy nose, runny nose, dry throat, lethargy or tiredness, headaches, dry, itching or irritated skin. We focused on 5 of them to determine the* BSI_5.

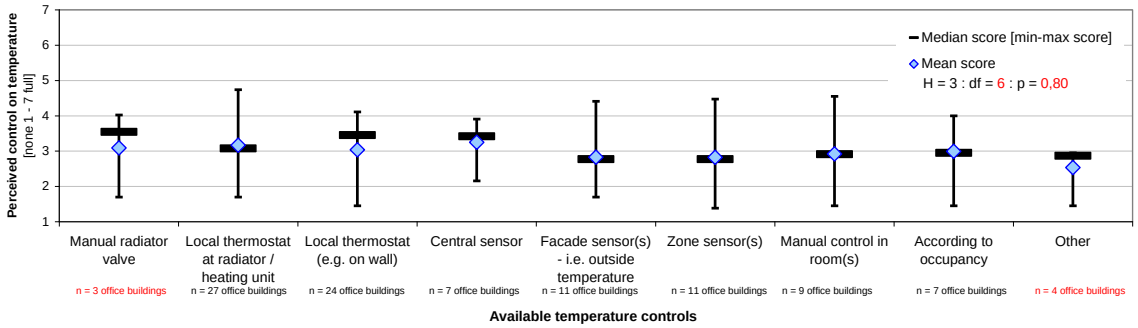

Figure 1. Availability of temperature controls versus perceived control on room temperature.

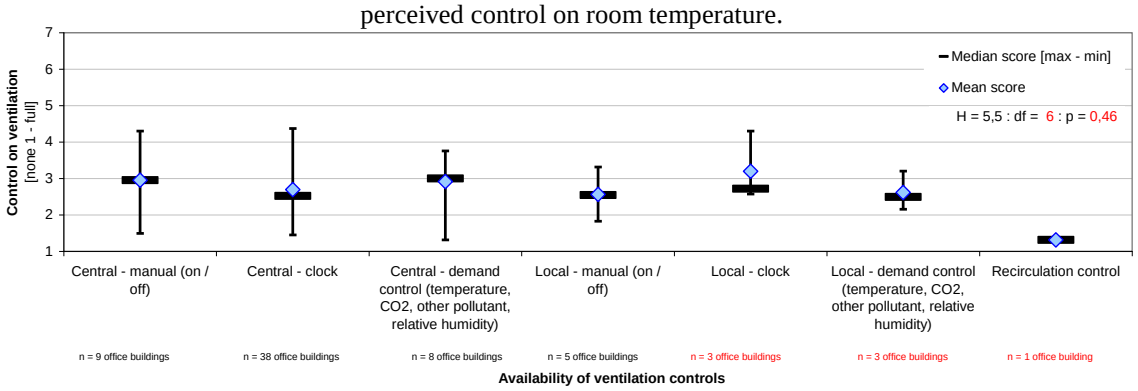

Figure 2. Availability of ventilation controls versus perceived control on ventilation.

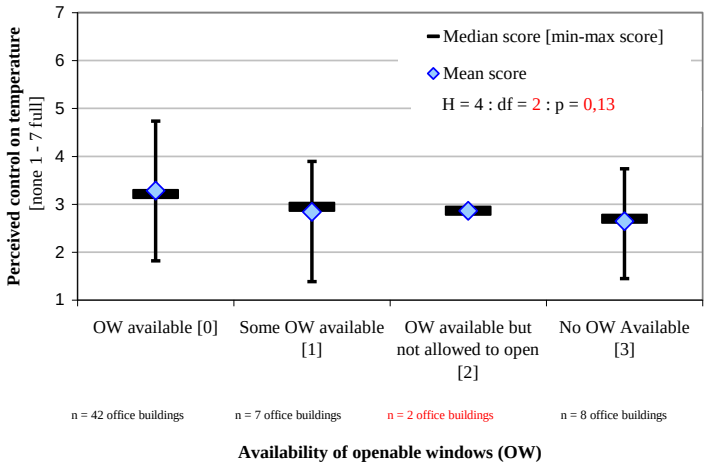

Figure 3. Availability of operable windows versus perceived control on room temperature.

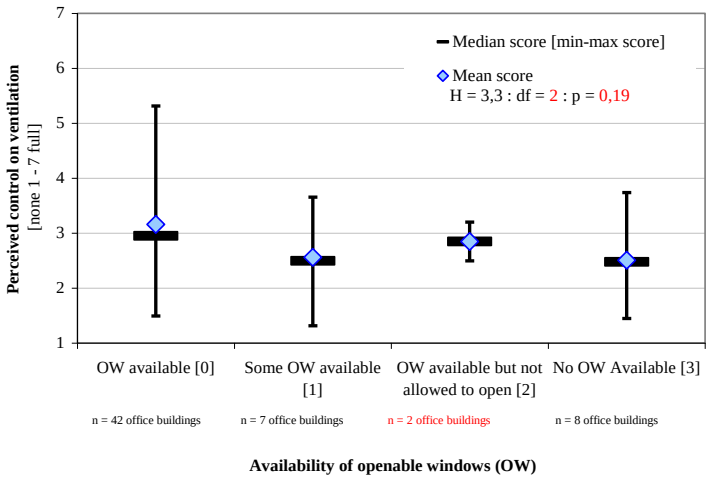

Figure 4. Availability of operable windows versus perceived control on ventilation.

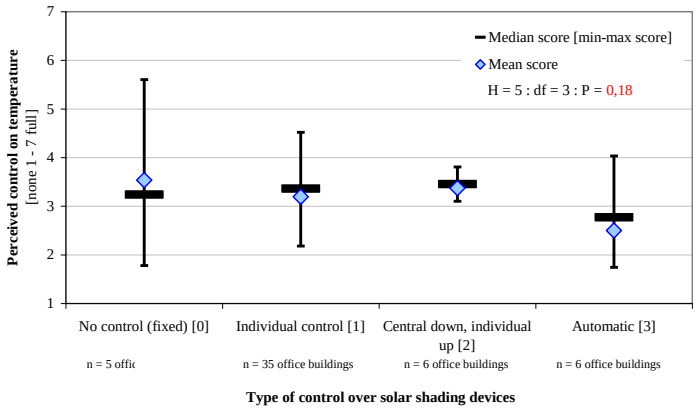

Figure 5. Availability of solar shading devices (no control, individual control, central up individual down, automatic) versus perceived control on room temperature.

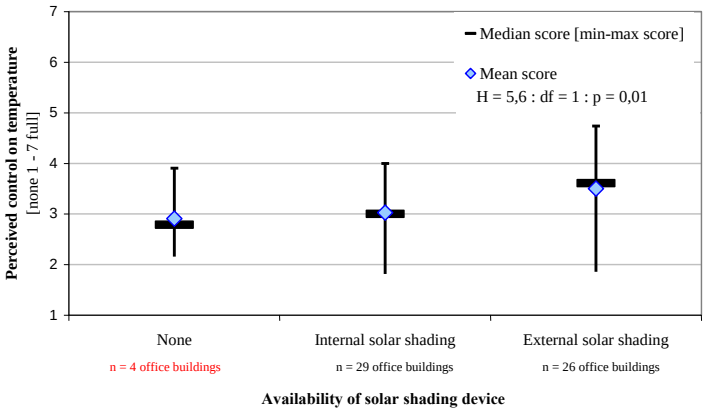

Figure 6. Availability of solar shading devices (internal / external / none) versus perceived control on room temperature.

3b. RESULTS: Impact of perceived control

The results of the analysis concerning the impact of perceived control on comfort and health are grouped into three categories: results concerning the winter situation, results for the summer situation and results concerning building related symptoms.
The most interesting results are presented in figures 7 to 14 (notice that the seven-point scales for perceived control and comfort are reversed for increased readability of the graphs).

Effect of perceived control on comfort during winter

For the winter situation the strongest correlation (figure 7) was found for control on temperature and perceived temperature during winter [comfortable – uncomfortable] (ρ_s=0,40; 2-sided p=0,00). Perceived control on temperature also correlated with perceived overall comfort during winter (ρ_s=0,27; 2-sided p=0,03). Perceived control on noise was found to correlate (figure 8) with perceived overall comfort during winter (ρ_s=0,34; 2-sided p=0,00). Furthermore no significant correlations were found between single control options and comfort, perceived air quality and building related symptoms.

When the scores for perceived control were combined for the winter situation, the strongest correlation was found for perceived control on temperature + ventilation in relation to overall comfort during winter (ρ_s=0,32; 2-sided p=0,02). Perceived control on temperature + shading from the sun and perceived control on temperature + ventilation + shading from the sun also were found to correlate with overall comfort during winter (ρ_s=0,31 / ρ_s=0,30 ; 2-sided p=0,02). A correlation was found between perceived control on temperature + ventilation and the perceived air quality during winter [fresh – stuffy] (ρ_s=0,25; 2-sided p=0,04).

Effect of perceived control on comfort during summer
For the summer situation the strongest correlation was found for control on temperature and overall comfort during summer (ρ_s=0,32; 2-sided p=0,01). No correlation (figure 9) was found between perceived control on temperature and perceived temperature during summer [comfortable – uncomfortable] (2-sided p > 0,05). Perceived control on temperature did however correlate (figure 10) with perceived air quality during summer [satisfactory – unsatisfactory] (ρ_s=0,27; 2-sided p=0,03). Furthermore no significant correlations were found between single control options and comfort, perceived air quality and building related symptoms.

When the scores for perceived control were combined for the summer situation, a correlation was found for perceived control on temperature + ventilation in relation to overall comfort (ρ_s=0,30; 2-sided p=0,01). Perceived control on temperature + shading from the sun and perceived control on temperature + ventilation + shading from the sun also were found to correlate with overall comfort (ρ_s=0,29 / ρ_s=0,30 ; 2-sided p=0,02). An average correlation was found between perceived control on temperature + ventilation and the perceived air quality [satisfactory – unsatisfactory] (ρ_s=0,28; 2-sided p=0,03).

Effect of perceived control on building related symptoms
No correlation (figure 11) was found between perceived control on temperature and BSI_5 (p>0,05). Also no correlation (figure 12) was found between perceived control on ventilation (p>0,05). A correlation was found between perceived control on noise and BSI_5 (ρ_s=-0,44; 2-sided p=0,00). Furthermore an average correlation was found between perceived control on lighting and BSI_5 (ρ_s=-0,27; 2-sided p=0,04).

When single options for perceived control were combined, a quite strong correlation (figure 13) was found between perceived control on temperature + ventilation and BSI_5 (ρ_s=-0,44; 2-sided p=0,00). Perceived control on temperature + ventilation + shading from the sun + lighting (figure 14) and perceived control on temperature + ventilation + shading from the sun + lighting + noise also were found to correlate strongly with BSI_5 (ρ_s=-0,37 / ρ_s=-0,43 ; 2-sided p=0,00).

4. DISCUSSION
The range of perceived control between buildings in HODA is limited (all scores are in the range 1,5 to 5 on a seven point-scale). This can indicate that no buildings were included in the database in which the occupants perceived very good control or it indicates that people tend to avoid extreme votes (i.e. ‘1’ or ‘7’) when filling in the questionnaire.

Concerning the link between available and perceived control: in this study available control was found to have no significant effect (except for solar shading) on perceived control. This suggests that it doesn’t matter for the level of perceived control whether building occupants have access to operable windows, wall thermostats etc.. Other studies (e.g. Hedge et al, 1989) did found a link between available controls and perceived control, health and comfort. An explanation for these different outcomes might be the limited variety of available controls and the limited number of buildings in HODA.

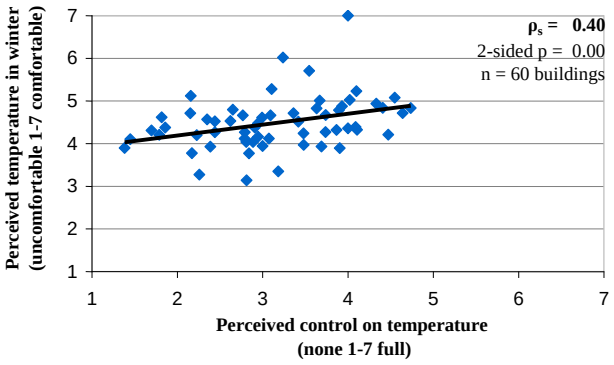

Figure 7. Perceived control on room temperature versus perceived temperature (comfortable – uncomfortable) during winter.

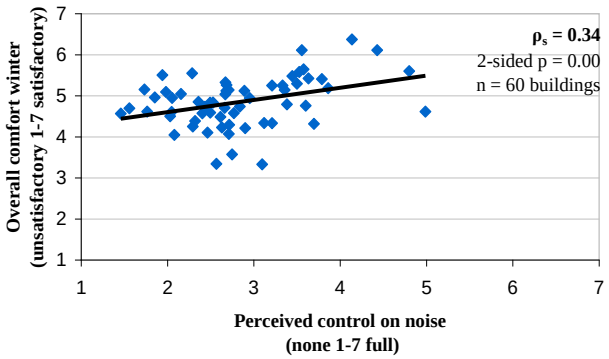

Figure 8. Perceived control on noise versus overall comfort during winter.

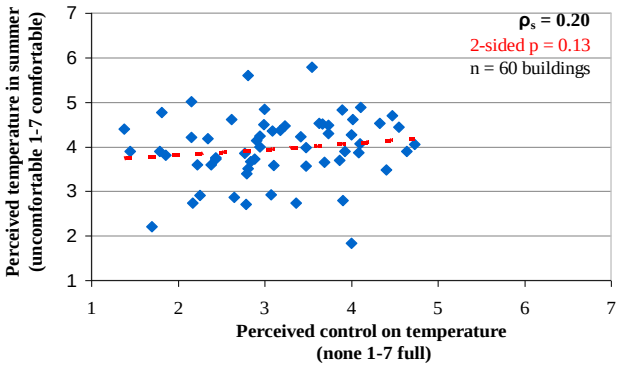

Figure 9. Perceived control on room temperature versus perceived temperature (comfortable – uncomfortable) during summer.

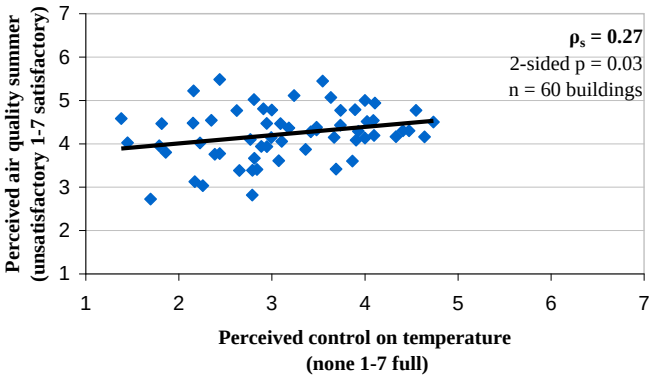

Figure 10. Perceived control on room temperature versus perceived air quality during summer.

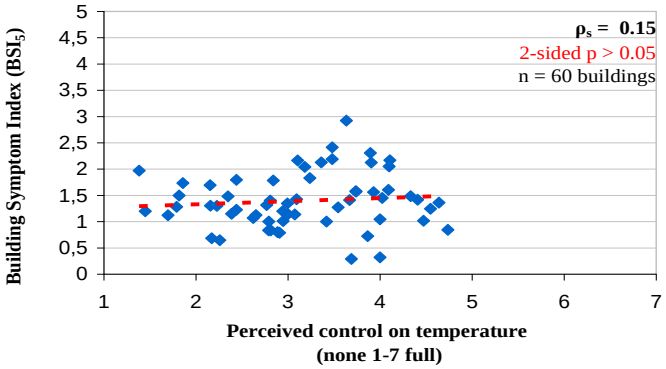

Figure 11. Perceived control on room temperature versus BSI_5.

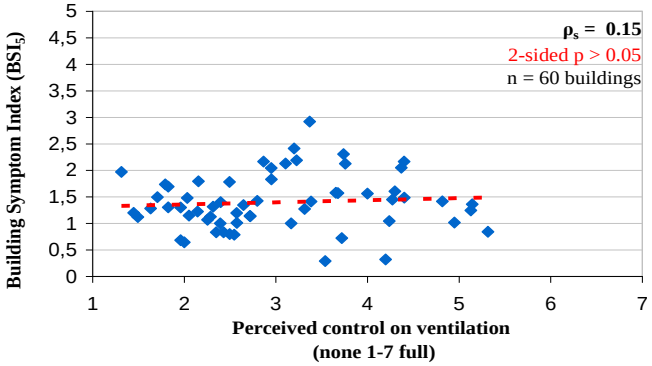

Figure 12. Perceived control on ventilation versus BSI_5.

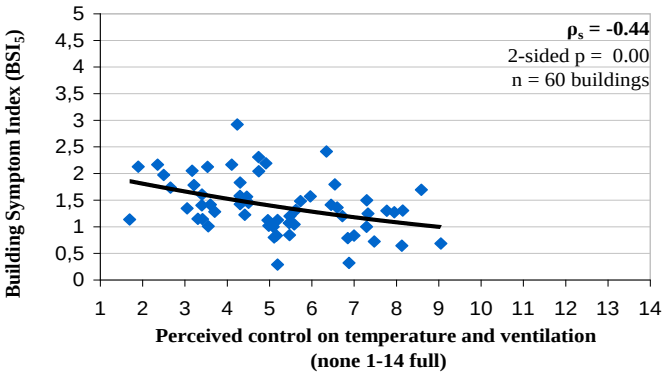

Figure 13. Perceived control on room temperature and ventilation versus BSI_5.

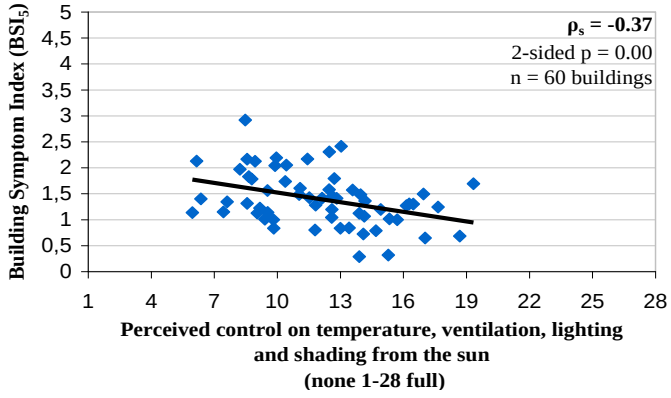

Figure 14. Perceived control on room temperature, ventilation, lighting and shading from the sun versus BSI_5.

For instance, HODA does not contain buildings with many combined (and effective) control options. For example none of the buildings has a combination of operable windows, manual control of temperature, manual control of ventilation and solar shading. Also, HODA does not contain any buildings with no control options at all (except for one building). Therefore most of the studied buildings have a more or less comparable mix of available controls which might explain why no significant relation was found between available controls and perceived control. Note that the effect of combinations of available controls on perceived control will be investigated in further studies.
Another explanation is that the categories of available controls in the HOPE project are somewhat limited for this study (e.g. the availability of *local* temperature controls was investigated but the presence of a *central* or *no* control on room temperature was not investigated). Therefore the absence of a link between available controls and perceived control in this study might be caused just by limitations of HODA. This will be further studied in a future study where HODA will be analyzed with the individual building occupants (not the office building) as unit of analysis.

Concerning the link between perceived control and comfort: for the winter situation only perceived control on temperature and noise seems to be important for comfort. All combinations of control options for which correlations were found are combinations including control on temperature. It is expected that these correlations are influenced by perceived control on temperature, or in other words, these correlations emphasize the assumption that control on temperature is the most important control aspect for (thermal) comfort during winter.
The same conclusion applies to the summer situation: perceived control on temperature is the most important control aspect for (thermal) comfort and influences the correlations found for combinations of control options. Surprisingly, between perceived control on temperature and the perceived air quality a positive ('reversed') correlation was found. An explanation for this relation might be that high air temperatures are known to contribute to air quality complaints (see e.g. Fang et al, 1996).

Note that perceived control is assumed to be the independent variable in this study. However due to the limited data in HODA and possibly limitations of our method of analysis, the true causality could not be determined in this study. This means that it is possible that the high comfort scores are the result of good physical conditions while the better perceived control scores are caused by the higher comfort perception. The true causality between perceived control, comfort perception and physical conditions will be investigated in future studies.

Concerning the link between perceived control and health: when looking at the results regarding BSI_5, notice how the single control options (e.g. temperature and ventilation) do not provide strong correlations with comfort etc. but the combined options do. This indicates that only an adequate combination of control options will decrease the amount of building symptoms.

Roulet et al (2006) also analysed HODA; they came to comparable but not exactly the same conclusions concerning the relation between perceived control and comfort and health. Explanations for the differences are for example: the use of BSI_8 instead of

BSI_5, the use of a combined summer/winter score for comfort and a different statistical analysis method. Also Bluyssen et al (2011) re-evaluated the HOPE database. They also found that in general: the more satisfied occupants are with control over thermal indoor environment, the more satisfied they are with their comfort. Bluyssen et al (2011) also found (like this study) that perceived control over noise had a positive impact on perceived overall comfort. Note that in both these studies the impact of *combinations* of perceived control was not investigated. Moreover both studies didn't investigate the impact of available controls on perceived control.

In this study the impact of available and perceived control on comfort and health was investigated. The impact of available and perceived control on productivity will be studied in a future research project.

5. CONCLUSIONS

The first objective of this study was to determine the impact of available control on perceived control. The second objective was to determine the impact of perceived control on comfort and health.

In this study no significant relations were found between *available* controls and perceived control apart from available solar shading. The results suggest that the application of external solar shading will lead to a higher level of perceived control on temperature than internal solar shading.

Some significant relations between *perceived* control and comfort or health were found in this study. Our findings suggest that buildings with a high degree of perceived control on temperature have significantly higher thermal comfort scores during winter. No significant correlation was found between perceived control on temperature in buildings and thermal comfort during summer. Buildings with a high degree of perceived control on temperature were found to have higher scores for overall comfort during summer and winter. For the summer situation, buildings with a high degree of perceived control were found to have better perceived air quality.

Furthermore our findings suggest that buildings with a high degree of perceived control on noise have higher overall comfort scores during winter and significantly less building related symptoms among their occupants. No significant correlation was found between buildings with a high degree of either perceived control on temperature or perceived control on ventilation and the amount of building related symptoms among occupants. Building occupants of buildings with a high degree of perceived control on ventilation *and* temperature did have significantly fewer building related symptoms. In general, occupants of buildings with a combination of perceived control options were found to have less building related symptoms.

This study showed that especially *perceived* control is important. Future studies should point out in what situation occupants perceive a sufficient degree of control and in what situation they do not perceive a sufficient degree of control.

ACKNOWLEDGEMENT

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