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A preliminary study on the sensitivity of people to visual and thermal parameters in office environments

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Abstract

The evaluation of indoor comfort requires a thorough understanding of how human occupants perceive four indoor environmental factors: visual conditions, air quality, acoustic ambience and thermal conditions. Recent studies have found that overall comfort is more than the average effects of these four parameters. Beside their main effects, their mutual interactions play an equally important role in the *perception* of comfort. Thus, to progress regarding our understanding of global comfort, more effort is needed to further investigate the interactions between indoor environmental factors.

For this kind of perceptual evaluation, it is necessary to conduct user studies. In these, subjects' evaluations need to be recorded in addition to the physical parameters that provoke them. Therefore, the sensitivity of people to their environment is the principal parameter around which the studies should be designed.

This paper presents a first evaluation of the sensitivity of people to visual and thermal parameters in real office environments to establish a groundwork for future investigations. From this cross-sectional observational study, we concluded that possible effects of interactions between factors are difficult to see when the conditions are more or less comfortable. In that case people are not enough sensitive to environmental changes.

Keywords: visual sensation, thermal sensation, questionnaire, cross-sectional study, interactions.

1 Introduction

In recent decades, major efforts have been made to understand and control the factors that affect people's comfort, health and well-being inside buildings (WHO, 2000). These are influenced by physical and social factors such as age, gender, country of origin, working position, etc., but also by four indoor environmental factors: indoor air quality, acoustic ambience, visual and thermal conditions (Bluyssen, 1992). Over the last century, many studies have investigated the influence of such parameters on comfort, but only one at a time, which resulted in specific comfort models (e.g., thermal comfort) (Fanger, 1970), standards, guidelines (ASHRAE, 2004; ISO, 2005) and quantitative indices (Carlucci et al., 2015). Such models provide threshold values for light, temperature, noise and air quality when taken in isolation. However, all these indoor factors apply simultaneously and it is their combination that we experience and respond to (Bluyssen, 2013; Laurentin et al., 2000). It becomes clear that no single parameter of the indoor environment can be evaluated on its own. Thus, to improve our

understanding of the influence of environmental parameters on human responses and perceptions in indoor environments, it is necessary to further study their combined effects and interactions.

Recently, the guideline ASHRAE 10P (ASHRAE, 2010) made an attempt to inventory these possible interactions, considering them exclusively as physical phenomena, e.g., that the visual radiation (both natural and artificial) produces heat which ultimately warms up the building and its occupants. However, interactions might also occur on a psychological and physiological level, implying that the environmental parameters could affect human beings indirectly, through not immediately recognisable ways. So, it is necessary to conduct user studies to investigate subjects' reactions and perceptions of particular environmental stimuli. In doing this kind of evaluation it is necessary to resort, at least to some extent, to methods from psychophysics. Psychophysics is defined as the quantitative branch of the study of perception, that examines the relations between physical stimuli and the sensations they affect (Baird and Noma, 1978). Psychophysics has been extensively used in both visual and thermal comfort studies (Hopkinson, 1963; Houser and Tiller, 2003; Nicol et al., 2012) and it has helped to understand the relation between people's sensations and the environmental parameters they are exposed to (e.g., apparent brightness and the light level). According to psychophysics literature, people are able to measure the stimuli they are exposed to and hence evaluate them with scales of sensation, discrimination tasks or detection tasks (Ehrenstein and Ehrenstein, 1999).

Therefore, it seems possible to study the effects of the interactions of indoor factors on comfort perception by conducting user studies. Subjects, exposed to a particular combination of environmental variables, should be able to grade them on a scale of comfort. By measuring the indoor environmental parameters and users' responses to them, it should be possible to determine the effects of indoor factor interactions on people's perception of comfort. To be able to set up and design proper user experiment, it is necessary to know in advance the parameters to study and how to measure them. Since users' perception is the means and the goal of studies on interactions, the sensitivity of people to stimuli in their environment can be a good indicator of how such studies should be designed. This implies that it is necessary to understand the ranges of values within which people are sensitive to environmental stimuli. In other words, what must be investigated is whether conditions in real environments are sufficient to provoke significant responses of users, or if studies must be run in more extreme environments.

Answering this question is the goal of this preliminary study. In particular, we will focus on the effects of visual and thermal parameters on comfort perception. Through a cross-sectional observational study, we will investigate if people are sensitive enough to visual and thermal stimuli in real conditions to be able to detect significant effects of indoor factor interactions on comfort perception.

In the next sections, the cross-sectional study will be described together with its scope and limitations. We will then report its findings, and finally provide some general observations about the shortcoming of the study and recommendations for future, more advanced research toward the evaluation of indoor environmental factors interactions.

2 Cross-sectional study

In building physics research it is possible to investigate people's response to the physical environment with two different methodologies: test room experiments and field studies. Some recent research has emphasized the need to conduct investigations in real spaces and specific context to achieve results that can be generalized outside the

experimental setting into real architectural environments (Anter and Billger, 2010; Boyce, 2003; Humphreys et al., 2007). For this reason, as a preliminary study, we decided to conduct a field study to investigate the sensitivity of people to physical stimuli in real environments. In particular, a cross-sectional observational study was performed in late fall of 2015 in offices located at the Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland. The study was observational since it was not a real experiment where all the independent variables could be set or controlled. It was cross-sectional since the measurements on each subject were made at a given point in time without repetitions (Olsen and St George, 2004). The fact that neither the outcome nor the type of exposure are controlled by the researcher, and the entire population is under study, differentiate cross-sectional observational studies from cohort and case-controlled ones (Meirik, 2008). A cross-sectional study was chosen because it allowed to run a relatively quick and cheap study to look at prevalence in a population and identify associations (Mann, 2003). Moreover, fatigue or learning curve were not experienced by the subjects since they were tested only once (Coolican, 2014). As a downside, it was very likely to have confounding variables since the experimental environment was not controlled and many different subjects were tested (hence, there was a wide variation between subjective parameters). In addition, this kind of study may not provide information about cause-and-effect relationships since it offers a snapshot of a single moment in time without considering what happens before or after and it may lead to unbalanced groups of people to compare (Mann, 2003). For these reasons, the cross-sectional study can be just used as an exploratory study to determine the likelihood of a particular outcome of interest under exposure to relevant factors, which in our case were comfort perception and visual and thermal exposure respectively.

3 Research methodology

For the purpose of the study described above, three means of data collection were considered: (i) measurements of physical parameters, (ii) online questionnaire and (iii) observations of the researcher.

The thermal parameters taken into account were relative humidity, operative temperature and air temperature, while the visual variables were illuminance at the eye and task level, and glare. Figure 1 shows the devices used for measuring the physical parameters in offices. The air temperature and the operative temperature were recorded by two HOBO data loggers and one Tinytag Talk Thermistor Probe (with the pt100 probe placed inside the globe sphere) respectively, every minute. The two HOBO data loggers also recorded the relative humidity. The illuminance levels were measured with two LMT POCKET LUX 2A illuminance meters, one placed on the desk and the other one fixed on the lens of the camera used for taking HDR images. All sensors were previously calibrated against other reference devices.

People's responses to the physical stimuli were recorded with an online questionnaire related to subjective responses (perception and personal control of the environment) and by direct observations of the researcher. Office conditions recorded at the moment of the measurements included office orientation, outside weather conditions, position of shading system, type of shading system, electric lighting (on/off), window (open/close), distance of subject from window and window position with respect to the subject.



Figure 1. Measurement devices for the preliminary study.

In this preliminary study the design of the questionnaire was particularly difficult since questions and scales from both the visual and thermal comfort points of view had to be considered and merged to give the same relevance and importance to the visual and the thermal part. For the design of the questionnaire the first decision to make was about the type of scale to use in the questions: semantic differential or Likert-type. The first category measures people's reactions to stimulus in terms of ratings on bipolar scales defined with contrasting adjectives at each end separated by empty spaces (Osgood, 1952). The second category includes five, seven or even nine pre-coded responses on a linear scale (Likert, 1932). This latter was selected for this study for two main reasons. First of all, the seven-point scale is the one traditionally used in the evaluation of comfort (e.g., the ASHRAE and Bedford scale). Secondly, the use of semantic differential scale may lead to misleading results since people interpret the empty spaces differently (e.g., they all represent comfort) (McIntyre, 1980). The second important decision for the design of the questionnaire was about its structure. The main constraints were the topics and the length. The focus should be on thermal and visual comfort, but overall comfort and personal control should also be investigated. On the other hand, the length of the questionnaire should not be too long, in order to allow participants to complete it in a maximum of 5-6 minutes. To respect these constraints, the questionnaire was structured in five main parts as following:

- overall comfort perception (including specific questions on noise, air quality and general questions on preferences for a comfortable environment);
- thermal comfort perception (including questions about thermal sensation, comfort and preference, but also about humidity and air movement);
- visual comfort perception (including questions about light intensity sensation, comfort and preference, but also about glare, quality and quantity of view to the outside);
- personal control (inquiring about actions that subjects took during the previous hour and that they would like to do at the moment of the questionnaire);
- personal information.

These parts were always presented in this order, except for the thermal and the visual sections that were randomised between subjects. Depending on scenario and users' responses, each questionnaire consisted of 24 to 30 questions. For example, if the light was on in the office, a question was asked to inquire about glare from electric light. In case an action was taken to improve comfort in the hour before the questionnaire, an

additional set of 1-4 questions was asked to understand why the user did it. The same occurred if the user indicated that they wanted to do something to improve their comfort at the moment of the questionnaire, to inquire why they did not do that action until asked.

The first three parts of the questionnaire related to comfort were designed as Likert-type scale, while the last two related to personal control and information, were designed as multiple choice (with the order of the choices randomized within each question). The sections about visual and thermal comfort were similar in order to be comparable. They began with three subjective measures for visual and thermal perception, i.e., sensation, satisfaction/comfort and preference. The questions about sensation were designed as a seven-point Likert-type scale. The ASHRAE scale was used for thermal comfort (de Dear, 1998) and a comparable one for visual comfort. The “sensation” questions were:

- Thermal: right now, how do you feel in this environment?
Cold/ cool/ slightly cool/ neutral/ slightly warm/ warm/ hot
- Visual: how do you rate the current light level on your desk?
Very low/ low/ slightly low/ just right/ slightly high/ high/ very high

The second category of questions regarding satisfaction was designed as a six-point Likert-type scale and referred to the general comfort scale from the SCATs project (McCartney and Fergus Nicol, 2002). The two “satisfaction” questions were:

- Thermal: how satisfied are you with the current thermal environment?
Very satisfied/ satisfied/ slightly satisfied/ slightly dissatisfied/ dissatisfied/ very dissatisfied
- Visual: how satisfied are you with the current visual environment?
Very satisfied/ satisfied/ slightly satisfied/ slightly dissatisfied/ dissatisfied/ very dissatisfied

Finally, the category about preference was designed as a five-point Likert-type scale and derived from the McIntyre thermal preference scale (used also in the SCATs project).

The two “preference” questions were:

- Thermal: would you like the thermal environment to be:
Much warmer/ a bit warmer/ no change/ a bit cooler/ much cooler
- Visual: would you like the visual environment to be:
Much brighter/ a bit brighter/ no change/ a bit dimmer/ much dimmer

The thermal comfort part also included questions regarding humidity and air movement (assessed with a seven-point Likert-type scale), whereas the visual comfort part also dealt with glare (Wienold, 2010), and the quality and quantity of view (assessed with a six-point Likert-type scale).

For the overall comfort part, a seven-point Likert-type scale was adapted to assess sound level and air quality (Levermore et al., 1999; Wargocki et al., 2000), whereas a general question on overall comfort was designed as a six-point satisfaction scale. Finally, the questions on personal control and behaviour were derived from Ackerly et al. (2012). At the end of the questionnaire, subjects were asked for demographic information (e.g., age and gender).

4 Results

27 offices were analysed in this study, with a total of 50 subjects. Of the subjects interviewed, 39 were men and 11 women. 19 subjects were between 21-25 years old, 26 between 26-30 years old and 5 above 30 years old. The majority of participants had lived in Switzerland for more than a year (41 subjects) and the rest for less than a year (4 subjects), or less than six months (5 subjects).

Within the overall comfort part, subjects were asked to grade the importance of different factors during working hours (4 = extremely important, 3 = very important, 2 = important, 1 = not very important). Figure 2 illustrates the results with a boxplot. The boxes are in order of importance according to the average score, indicated above of each box, with the most relevant factor being on the left hand side of the figure. It is possible to see that the factors can be grouped in three categories according to the spread of the boxes and prevalent grades. The first group includes high importance grades and small spread (factors 1-5), the second one refers to medium/high grades with a big spread (factors 6-8) and the last one illustrates factors with medium/low grades and a big spread (factors 9-11). Two visual and thermal parameters are graded almost in the same way and are in the first group of factors, namely, a comfortable temperature and a comfortable amount of light. Thermal environment and light are also considered the two most important factors in another question of overall comfort. Participants were asked to rank the four indoor environmental factors from the most important (first choice) to the least (fourth choice) in order to improve their comfort during their working hours. Figure 3 illustrates that thermal environment is the factor selected most often as a first choice, followed by light conditions as a second choice. Also, air quality was often chosen as the first factor to change, but still less than the thermal environment. Moreover, the sum of first and second choice votes for air quality is lower than the corresponding sum for light conditions.

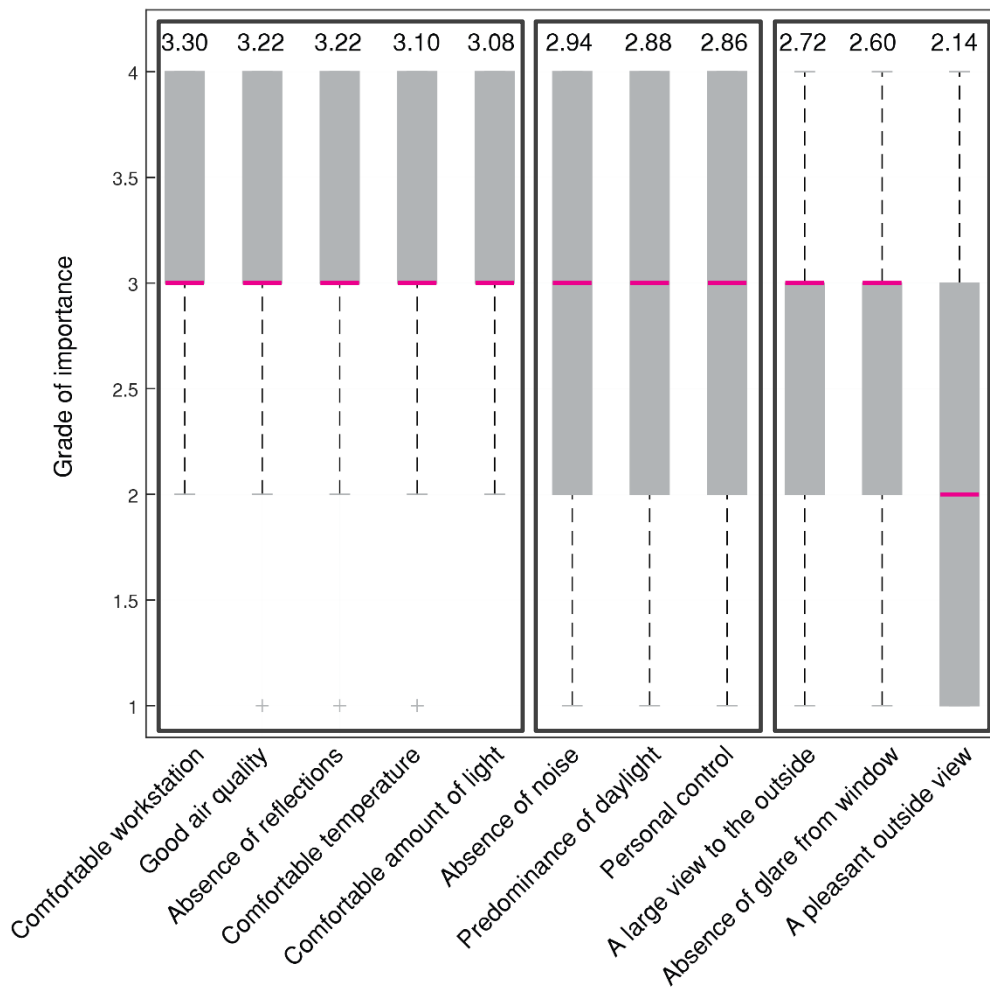


Figure 2. Box plot of the grades of importance of different factors influencing indoor overall comfort.

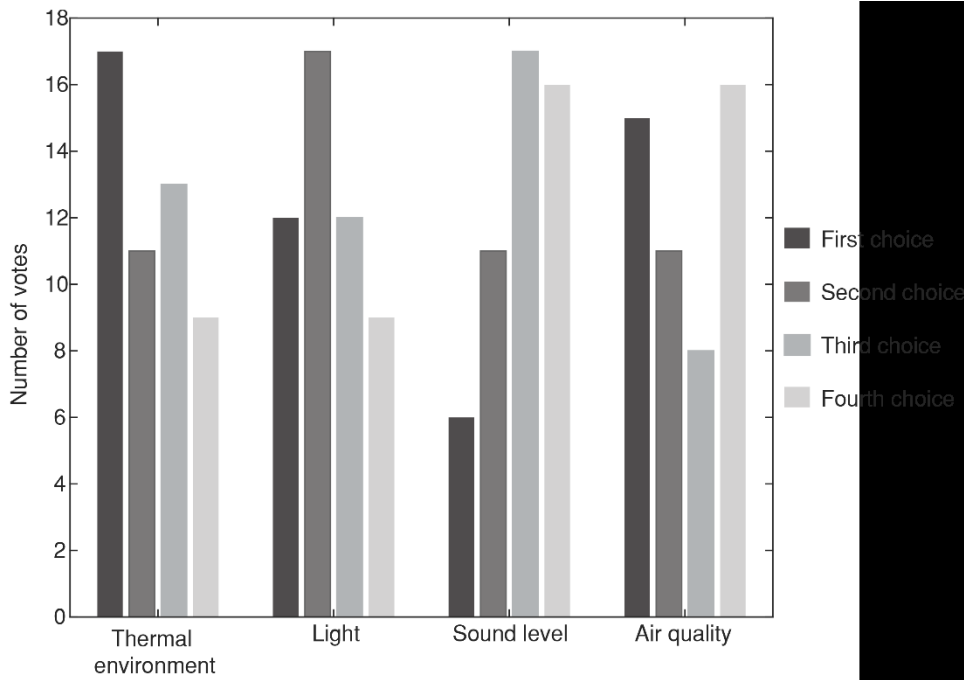


Figure 3. Bar plot of improvement choices.

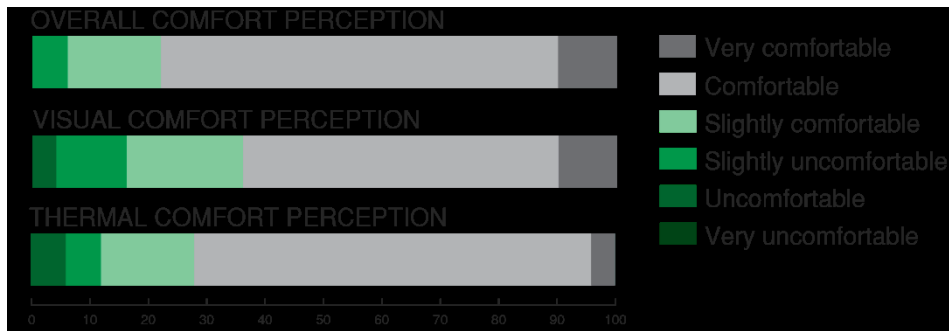


Figure 4. Stacked bar plot of comfort votes.

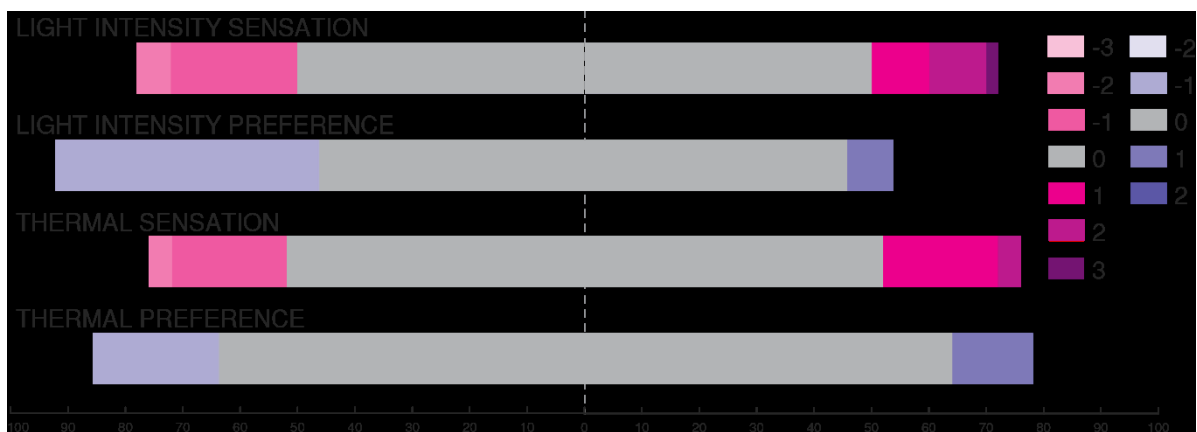


Figure 5. Stacked bar plot of sensation and preference votes.

For visual sensation (S): -3 = very low, -2 = low, -1 = slightly low, 0 = just right, 1 = slightly high, 2 = high, 3 = very high; for visual preference (P): -2 = much brighter, -1 = a bit brighter, 0 = no change, 1 = a bit dimmer, 2 = much dimmer; For thermal sensation (S): -3 = cold, -2 = cool, -1 = slightly cool, 0 = neutral, 1 = slightly warm, 2 = warm, 3 = hot; for thermal preference (P): -2 = much warmer, -1 = a bit warmer, 0 = no change, 1 = a bit colder, 2 = much colder.

Figure 4 illustrates the comfort votes for overall, visual, and thermal comfort perception. In the three cases the grey part is the largest one, indicating that the majority of people was in comfortable conditions. This is due to the fact that both illuminance at the desk level and air temperature were in comfortable ranges and no other uncomfortable environmental factor was present. It is worth noting that some subjects expressed dissatisfaction with the visual and thermal environment (“uncomfortable” vote) but they did not always indicate overall discomfort, which was asked before. The relationship between visual and overall comfort perception as well between thermal and overall comfort perception was investigated with Spearman’s correlation coefficient. There was no significant relationship between visual comfort and overall comfort perception with $\rho = -0.084$ and $p > 0.05$. On the other hand, the two sets of scores of thermal and overall comfort perception correlated positively with $\rho = 0.348$ and $p < 0.05$. Assuming an effect size of 0.348 and a reduction due to the non-parametric test used, power was estimated at only 0.53. This means that the low effect size of the correlation must be balanced by a higher number of test subjects.

Figure 5 shows the sensation and preference vote for both light intensity and thermal questions. In this case too, the majority of participants expressed satisfaction with the parameters, indicated by the grey part of the graph. Thermal sensation and thermal preference values are strongly positively correlated ($\rho = 0.68$ and $p < 0.01$). On the other hand, the correlation between light intensity sensation and preference is less strong (but still positive and significant with a $\rho = 0.315$ and $p < 0.05$). This can be also seen in figure 5, where more subjects wanted a brighter environment (left hand side of visual preference bar) compared to those that complained about a too low light level on their desk (left hand side of visual sensation). This result indicates that even if subjects were in comfortable conditions regarding the light level, they would have still preferred a higher light level on their desk. The importance of having different kind of scales to test subjects’ perception is then proved, either for validating previous responses or for testing different perceptions.

Table 1 illustrates the correlations between the physical variables measured and the different evaluations of comfort. Only two variables are reported since they were strongly correlated with the other measures (illuminance at the desk level with illuminance at the eye level, and air temperature with operative temperature and relative humidity). The visual votes are positively correlated with the illuminance at the desk level (especially the visual sensation), whereas the thermal votes are not significant correlated with the air temperature. On the other hand, overall comfort is significantly correlated with air temperature (although with a small effect size) but not with illuminance.

Table 1. Spearman correlation analysis. * indicates significant result.

Independent variable	Dependent variable	Spearman ρ	p
Illuminance at desk level	Visual comfort perception	0.28	0.045*
	Light intensity sensation	0.45	<0.01*
	Light intensity preference	0.31	0.028*
	Overall comfort perception	-0.01	0.927
Air temperature	Thermal comfort perception	-0.06	0.675
	Thermal sensation	0.07	0.592
	Thermal preference	0.09	0.502
	Overall comfort perception	0.28	0.048*

Regarding the other environmental factors included in the questionnaire, participants were generally in comfortable conditions. They only complained about bad air quality (38% said it was slightly stuffy), not enough air movement (64% said it was slightly still or too still) and a bad quality of view to the outside (18% of participants were slightly dissatisfied and 14% dissatisfied). These results could have influenced the evaluation of overall comfort.

According to the personal control part of the questionnaire, 70% of the subject made at least one action during the hour before the questionnaire. Mainly, these consisted of opening the window to change air and to feel cooler (48% of the people who made an action), turning on the light (28%), closing the window to feel warmer (25%), and removing a layer of clothing (20%). 54% of the subjects wanted to make an action during the questionnaire, mainly opening the window and increasing the temperature, but they did not do it because the level of comfort was still acceptable or they were too focused on their work. It is interesting to notice that not all the participants who took an action before the questionnaire expressed satisfaction with their conditions, whereas the majority of people who gave a high grade to the overall comfort did not want to take an action. In fact, there is a significant correlation between overall comfort and unwillingness to take an action, with $\rho = 0.471$ and $p < 0.01$.

Finally, we investigated the effects of the interaction of visual and thermal parameters. In particular, we conducted statistical analyses to see correlations between visual parameters and thermal comfort perception and thermal parameters and visual comfort perception. All the results were statistically insignificant. As illustrated in the previous section the majority of subjects expressed satisfaction with their conditions regarding overall, visual and thermal comfort independently of temperature and illuminance levels, which, in any case were mainly in a comfortable ranges (figure 6). The data points referring to subjects who expressed dissatisfaction with the environment were too few to draw significant conclusions about interactions.

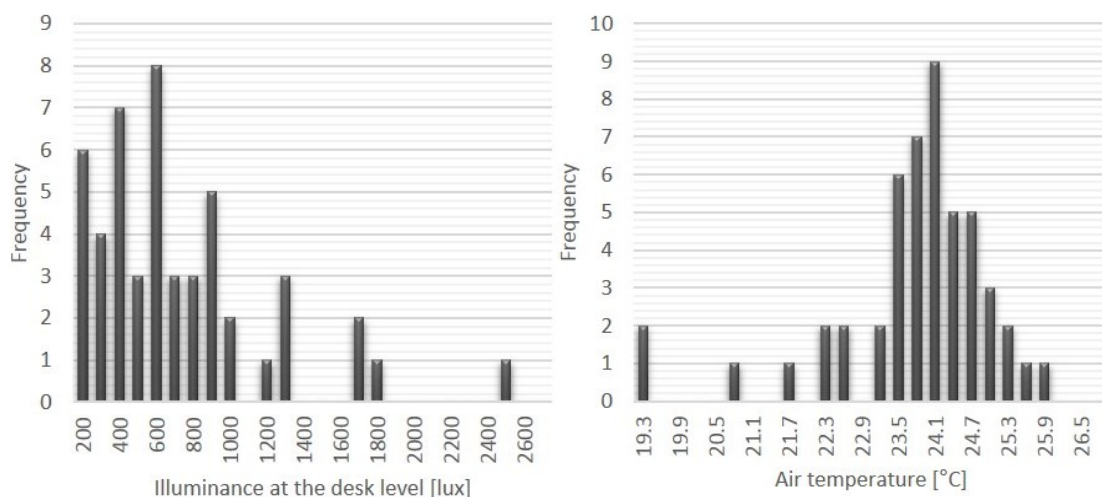


Figure 6. Recorded illuminance and temperature ranges.

5 Discussion

In the preliminary study we encountered some issues that were unexpected and that need more attention in future studies. The first set of issues are linked to the limits of a cross-sectional observational study. First of all, it allows to study just restricted ranges of parameters within which people are not sensitive enough to changes of those parameters, since they fall into comfortable values. Secondly, in a real office there are too many uncontrollable nuisance variables that make results difficult to interpret. A possible solution for these problems is to conduct experiments in a controlled environment, where the investigated variables can be changed until extreme limits (to provoke wider ranges of visual and thermal sensations) and the other variables can be kept constant or in limited ranges. Another solution is to conduct the same field study but in more extreme conditions (i.e., in summer, without cooling systems) and with more subjects to increase the power of the experiment (100 people is the number suggested by Nicol et al. for a transverse study).

The other problems were related to the questionnaire since it was difficult to analyse or some of the questions may have been confusing. For future studies on interactions we suggest the following changes:

- the order of all the questions need to be randomized. The majority of people expressed satisfaction with the overall conditions, but later complained about some other environmental factors when asked.
- The questions regarding visual and thermal perception need to be of the same type. In other words, according to the classification of Parsons (2014), they need to refer either to the environment or to the people (e.g. "how do you perceive the thermal environment?" or "how do you feel now?"). In our case, since personal questions regarding light cannot be asked, questions regarding the thermal aspect also need to refer to the environment and not to the personal sensation. We asked questions about personal perception *in* the environment that may have been misleading and may have resulted in the low correlation between air temperature and thermal votes (ref. table 1). In case of personal questions, physiological measurements may help the interpretation of data.
- Dependent variables need to be continuous in order to analyse the results with parametric statistical tests that are more powerful and provide more information than non-parametric alternatives. It is therefore necessary to transform the ordinal scale into a linear one.
- Different type of scales are necessary to be able to record comfort, sensation and preference, which makes it difficult to compare the results since those questions have different scales. It is therefore necessary to use comparable scales or to calculate a total index for each comfort (overall, visual and thermal).
- It is not sure that people understood all verbal descriptions of the environmental factors we wanted to be rated. It is therefore necessary to instruct participants on the meaning of the words, the scales used and how to apply them to rate a specific aspect of the environment (Houser and Tiller, 2003).

6 Conclusion

The aim of this preliminary study was to investigate people's sensitivity to physical stimuli present in real office environments. In particular, to understand whether users' responses were sufficiently different and strong to draw conclusions about indoor factors interactions. The main finding is that, within the comfortable ranges of real spaces, people's perception of the indoor environment is mainly neutral. For this reason, a cross-sectional study does not allow the investigation of the interactions of indoor factors on comfort perception. Extreme conditions are needed to get significant results because

people are somewhat oblivious to their comfort levels – except when asked specifically – in a large range of conditions around standard comfortable values.

The research conducted allowed to draw some other conclusions as well:

- rating scales must not be the only methodology adopted for the evaluation of subjects' perception. Physiological measurements, observations, adjustment and discrimination tasks should be implemented in the experiments.
- Thermal and visual parameters (especially temperature and amount of light) have been indicated to be among the most important factors influencing people's comfort in office environments. Hence, people are aware of their role and importance for achieving indoor comfort.
- The role of other parameters on comfort is not completely understood. For example, the "quality of the view to the outside" was rated as the least important at first, but was then among the parameters about which people complained the most.

The shortcomings and suggestions of this preliminary study will be taken into account in future investigations on indoor factor interactions. They are planned as test room experiments to have extreme visual and thermal physical conditions and, as a result, broader user responses. Moreover, it will be possible to have more control on the other nuisance variables and on the subjects (e.g., age, gender, clothes). Finally, besides questionnaires, different methods will be used to evaluate people's perception.

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