Evaluating Comfort Levels of a Workstation with an Individually Controlled Heating and Lighting System

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Abstract. Comfort complaints, such as high or low temperatures, lack of privacy and concentration loss, are regularly reported in today's offices. Most comfort aspects, such as lighting, ventilation, decoration and climate are regulated on global level, while for optimal comfort experience customized settings on personal level is desired, which requires a more direct personal control. A method is described to evaluate comfort levels of a workstation with individually controlled radiant heating and lighting. The aim is to examine the band-width of peoples' comfort zone of radiant temperature and illumination when doing office work.

Keywords: Office, personal environmental control, workstation, heating, lighting, comfort, energy efficiency, intelligent building.

1 Introduction

Increasingly, workplaces must support rapid technology development and implementation and meet continuous changing work demands of the modern knowledge worker. Measures such as teleworking, open plan offices and working with shared work-stations have been positioned as providing at least partial solutions to many of these challenges (Lee & Brand, 2005; De Croon et al, 2005).

Comfort is rated as one of the most important factors at the office. Ambient features of the environment, like lighting, temperature, noise, presence of windows, have an important influence on attitude, behavior, satisfaction and performance of

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workers (Bauer et al., 2003; Lee & Brand, 2005; Hedge et al., 2009). However, many problems with open offices have been documented, such as noise, lack of privacy, thermal discomfort and concentration loss (Zhang et al, 2010; Lee & Brand, 2005). Apart from office chair, desk and computer settings, the current workplace fits badly with the personal needs and preferences. So far, research has been guided by the search for a universally applicable set of optimum comfort conditions in the working environment. (Cole & Brown, 2011). Most comfort aspects in the current environments, such as lighting, ventilation, decoration and climate are regulated on global level. However, for optimal comfort experience customized settings on a local, personal level is desired.

One of the focusses of 'Intelligent Building research' is using intelligence to provide occupant comfort, wherein a building explicitly enables its users to make appropriate adjustments in their local environmental conditions and at the same time providing and maintaining operational efficiencies in energy use. The challenge for designers and manufacturers is then to support these users with appropriate, ergonomic and understandable user interfaces (Cole & Brown, 2011). Increased personal control over the environment conditions can be realized by providing just acceptable environmental conditions on global level combined with personal fine-tuning on local workstation level. The essence is that on all the settings of light, climate, sound and atmosphere the greatest possible shift is pursued from averaged, spatial settings to individual, local settings. A first example of such a system with individual ventilation at workplace level based on research of Melikov (2004), is on the market.

The scientific literature gives evidence that providing personal control over the working environment (e.g., adjustment of lighting, temperature and air movement) has beneficial effects on comfort, job satisfaction and productivity (Lee and Brand 2005; Bauer ea, 2003; Hedge ea, 2009; Zhang et al., 2010; Veitch et al., 2008). However, in some studies no effects or negative effects are reported as well: e.g. Boyce et al. (2006) found no effects and Veitch & Gifford (1996) found that giving personal control over lighting conditions led to slower work and lower productivity. In this context, it is important to distinguish between real personal control (the availability and the ease of use of the aspects that one can modify in the physical environment) and the experienced control (the experienced personal influence, the importance of the impact and consequences of the use of this influence). The interaction with the environment is an essential part and various factors such as behavior, attitude, (intuitive) design and ease of use play a role in the actual use and proper use of individually controlled environments (Hedge, 2009).

Research on the effects of providing personal control of environmental conditions is in its infancy. Although literature suggest that personal control of environmental conditions is beneficial for productivity, comfort and health, up until now these are not investigated in detail. There is little information on the triggers for exercising personal control over the environmental conditions and on the behavior of personal control over time when office workers are provided with the freedom to adjust their local environmental conditions (Hedge, 2009). There is a need for clarity on aspects such as the values office workers choose and how it affects work performance and comfort experience.

The objectives of the study are to identify the potential of a local individually controlled environment to increase comfort experience and simultaneously maintain or decrease energy use, to study office workers response to the system and to identify design characteristics important for application in practice. This paper describes the method to evaluate comfort levels of a workstation with individually controlled radiant heating and lighting. The aim is to examine the band-width of peoples' preferred comfort zone of radiant temperature and illumination when doing office work. It is intended to find out whether the preferred radiant temperature and illumination differs for different initial values at local and global room level and whether personal fine-tuning affects comfort and task performance.

2 Methods

2.1 Experimental Setting

The experiment takes place in a climate room which looks like an ordinary office room. However, to assure a standard situation regarding lighting, the windows are blinded. The base air temperature is kept on 18°C and the room is lit by indirect lighting. A prototype of a workstation with individually controllable local radiant heating and lighting (Figure 1) is positioned in the middle of the room, in such a way that the participants face the door (Figure 2).

The heating system consists of radiant panels which are fixed in front of the participant under the desk and at trunk height. The lighting system is mounted above the desk (2 meters above floor) and consists of dimmable TL lights, which provides direct light on the desktop. The participants are able to adjust the radiant temperature and the illumination level of the local system by pushing a “plus” or “minus” button in a computer screen, without knowing the current radiant temperature or illumination level or contrast level. The color of the desk surface is: RAL 9010. The color temperature of the light (direct and indirect) is 3000K.

2.2 Experimental Design

Radiant Heating

The basic air temperature (T_{air} [°C]) in the experimental room is 18°C, which is lower than comfortable for a sitting person, but reasonable when walking around. The participant, who performs standardized tasks sitting, has the possibility to tune the temperature at his work space by means of local radiant heating panels. The radiant temperature (T_{rad} [°C]) and the air temperature (T_{air} [°C]) at the work space together result in the operational temperature (T_{op} [°C]) at the work space.

In the experimental design of the radiant heating there is one independent parameter: the initial value of the operational temperature ($T_{op;ini}$ [°C]) at the work space. In the experiment two initial values were tested, a low and a high initial value, respectively 18°C and 23°C (Table 1).

Table 1. Initial operational temperature $T_{op;ini}$ at global workspace level, dependent on the air temperature T_{air} and initial radiation temperature $T_{rad;ini}$ due to the radiant panels

$T_{op;ini}$ [^oC]		T_{air} [^oC]
		18
$T_{rad;ini}$ [^oC]	Low (off)	18
	High	23

There are 3 dependent variables:

- The preferred operational temperature ($T_{op;pref}$ [^oC]) at the work space; this is the temperature which was tuned by the participant by turning the local radiant heater up or down.
- The difference between the comfort level before and after tuning.
- The difference between performance level before and after tuning.

Fig. 1. Prototype of the workstation

Illuminance
The experiment room is lit by indirect light with a relative low basic illuminance level (E_{indir} [Lux]), that is too low for working comfortably. The participant is able to increase the illuminance level at his desk via direct light (E_{dir} [Lux]). The indirect illuminance (E_{indir} [Lux]) and the direct illuminance (E_{dir} [Lux]) at the work space together result in the operational illuminance level (E_{op} [Lux]) at the work space.

In the experimental design of the illuminance experiment there were two independent (2X2) parameters (Table 2):

- The indirect illuminance level (E_{indir} [Lux]), which were 150 lux and 300 lux respectively,
- And the initial value of the direct luminance level (E_{dir} [Lux]) at the work space, of which the latter is expressed in the resulting operational illuminance level ($E_{op;ini}$ [Lux]) at the work space, which were 150 or 300 Lux at the low level (depending on the indirect component) and 3000 Lux at the high level.

Table 2. Initial operational illuminance $E_{op;ini}$ at work space, dependent on the indirect illuminance level E_{indi} and initial direct illuminance level $E_{dir;ini}$ due to the direct light

$E_{op;ini}$ [Lux]		E_{indir}[Lux]	
		Low: 150	High: 300
$E_{dir;ini}$ [Lux]	Low (off)	150	300
	High	3000	3000

There are 3 dependent variables:

- The preferred operational illuminance level ($E_{op;pref}$ [Lux]) at the work space; this is the illuminance level which was tuned by the participant by turning the direct lighting up or down.
- The difference between the comfort level before and after tuning.
- The difference between performance level before and after tuning.

2.3 Subjects

Twenty subjects will participate in the study. They are aged between the 35-45 years. The subjects wear a jeans, a cotton long sleeve or blouse, socks and shoes.

2.4 Task

The subjects perform a dual visual memory task as described by Capa et al. (2008). During 3 seconds a letters is shown on the computer screen. The participants have to compare this letter with four letters in a recognition set, which is on the screen for 3 seconds. The goal is to indicate if the letter in the memory set is in the recognition set by pressing the “yes” key or -if the letters is not in the recognition set- by pushing the “no” key with the right and left index finger respectively. The “yes” and “no” key are the ctrl keys at the right and the left of the space bar of a computer keyboard. The keys are indicated with a green (along with the written text “yes”) and red label (along with the written text “no”) respectively. The participants also have 3 seconds to answer. The recognition set changes every time and the probability that a letter appears in the recognition set or not is equal. At the end of each trial, participants receive feedback on their reaction time, which concerns the response speed and the type of error. To increase the difficulty of the task, a counting task is added. The recognition set is presented in either red or green color. Participants are asked to count the number of red recognition sets while carrying out the visual memory search task.

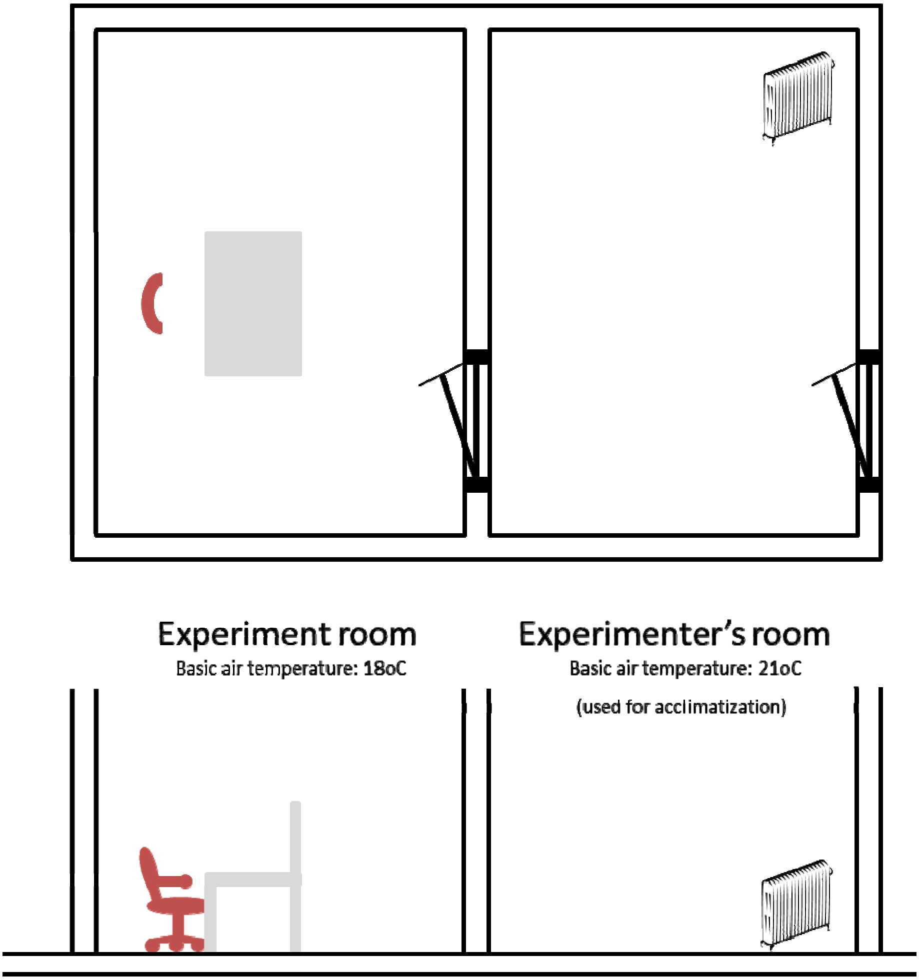

Fig. 2. Experimental setup

One condition consists of 64 trials. Each condition has a fixed number of red recognition sets. Participants are instructed to react as quickly as possible without making errors. Simultaneously, they have to count the number of red recognition sets. At the end of each block of 64 trials, the participants have to indicate the number of red recognition sets. After that, they receive feedback on their performance for both the visual memory search task (average reaction speed and number of errors) as well as the counting task (correct number of red recognition sets).

2.5 Hypotheses

The hypotheses are formulated for radiant temperature (RT), illuminance (I) or both (RT&I) and are divided in three categories:

Hypotheses on the Differences in Preferred Tuning Levels:

H1. There will be intra-subjective differences among the preferred level of tuning (RT&I)

H2. Inter-subjective differences will be larger than intra-subjective differences (RT&I)

H3. The preferred level of tuning of the radiant temperature by the participant is dependent on the initial value of the radiant temperature (RT)

H4. The preferred level of tuning of the direct local illuminance level by the participant is dependent on the initial value of the direct local illuminance level (I)

H5. The preferred level of tuning of the direct local illuminance level by the participant is dependent on the initial value of the indirect room illuminance level. (I)

Hypotheses on the Differences in Perceived level of Comfort:

H6. Measured comfort level is higher after fine-tuning than before. (RT&I)

H7. The comfort level after fine-tuning isn't dependent of the initial value of the radiant temperature. (RT)

H8. The comfort level after fine-tuning isn't dependent of the initial value of the direct local illuminance level. (I)

H9. The comfort level after fine-tuning is dependent of the initial value of the indirect room illuminance level. (I)

Hypotheses on the Differences in Task Performance

H10. Task performance is higher after fine-tuning than before. (RT&I)

H11. Task performance after fine-tuning isn't dependent of the initial value of the radiant temperature. (RT)

H12. Task performance after fine-tuning isn't dependent of the initial value of the direct local illuminance level. (I)

H13. Task performance after fine-tuning isn't dependent of the initial value of the indirect room illuminance level (I)

2.6 Measurements

Temperature

Three types of temperatures are relevant in the experiment: the air temperature T_{air}, the radiant temperature T_{rad} and the operational temperature T_{op}. During the experiment the air temperature is measured continuously in the middle of the room and under the desk, using a shielded air thermometer. The radiant temperature is measured continuously near the participant, using a black-globe thermometer. The total radiant panel power (P_{rad} [W]) is calculated on the basis of a pre-established calibration curve.

The initial and preferred operational temperature $T_{op;ini}$ and $T_{op;pref}$ are a function of the total radiant panel power (P_{rad} [W]). The relation between the total radiant panel power and the operational temperature is calibrated before the experiment. The operational temperature is calculated as the average between the air temperature and the radiant temperature. To produce the calibration curve, the air and radiant temperature are measured at the participant's empty seat.

Illuminance

Using a Hagner lux meter, the operational illuminance (E_{op} [Lux]) is measured at the desk and in the room, using a Hagner lux meter. Also the total direct lighting power (P_{light} [W]) is measured. These parameters are calculated on the basis of a pre-established calibration curve.

The initial and preferred operational illuminance levels $E_{op;ini}$ and $E_{op;pref}$ are a function of total direct lighting power (P_{light} [W]). The relation between the total direct lighting power and the operational illuminance levels at the desk are calibrated before the experiment for the two indirect illuminance levels that are used in the experiment (150 respectively 300 Lux, also measured at the desk). Also the consequence of the ratio of direct and indirect illuminance on the luminance differences in the room are recorded before the experiment, using a photo camera.

Comfort

Subjective measurements of thermal and visual comfort are performed using questionnaires. Thermal sensation is measured in general and for separate body parts (head, neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet), using a VAS scale with verbal anchors on both sides, ranging from too cold to too warm. Thermal comfort is measured using a 4 point scale, ranging from very uncomfortable to comfortable. Visual comfort is measured using questions concerning various aspects of visual perception, also using VAS scales. Comfort is measured before and after tuning of the temperature and illuminance by the participants.

Task Performance

The task performance is indicated by the output of the dual visual memory task (Capa, 2008). The average response time and the number of errors, as well as the correct number of red recognition sets is used as indication for task performance.

2.7 Measurement Protocol

The participant is welcomed in the research lab. During 20 minutes he acclimatizes in a room with a temperature of 21°. During this period, the participant is informed about the study and general participant information is collected. Furthermore, he gets acquainted with the dual visual memory task to avoid learning effects. After the acclimatization, the participant goes in the experimental room and takes place at the workstation (the initial values of the radiation temperature and local illumination are set by the experimenter just before the participant enters the room). The seat and desk are adjusted to the participants anthropometry. Then, the participant sits behind the desk performing a standard reading task. After 15 minutes, the dual visual memory task is performed and the comfort questionnaire is filled in. After 30 minutes, the participant is allowed to adjust the radiation temperature and local illumination according to his preference, while sitting behind the desk and performing a standard reading task. After 45 minutes, the dual visual memory task is performed again followed by the comfort questionnaires. This is repeated three more times for different initial values for radiation temperature and indirect and direct illumination. The different initial conditions are counterbalanced over the participants.

2.8 Data Analysis

GLM repeated measures is carried out using SPSS in order to test the hypotheses.

3 Conclusion

This article merely proposed a method to evaluate comfort levels of a workstation with an individually controlled heating and lighting system. When the applied principles of personal environmental control indeed increases comfort levels, such a work station concept may yield significant progress on personal environmental wellbeing of office workers. Results on the interdependency between preferred and initial values of radiant temperature and illumination give input for the design of individually controlled systems for heating and lighting. Results will be presented at the conference.

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