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Passive and active personalized heating systems at a lower indoor ambient temperature

Nick Van Loy, Griet Verbeeck and Elke Knapen

Sustainability group, Arck research group, Faculty of Architecture and Arts, Hasselt University, Building E, 3590 Diepenbeek

Nick.vanloy@uhasselt.be

Abstract. Dwellings in Belgium are comparatively larger than dwellings in other European countries. Moreover, their size is not always in line with the actual occupancy rate. Nowadays, most of these dwellings are heated by a single-zone, mostly convection-based heating system which heats all rooms simultaneously and completely. However, analysis of the effective spatial use shows that residents only use specific spots within a room at different times of the day, thus current heating systems do not correspond to the actual use of space. Nowadays, manufacturers focus mainly on increasing the efficiency of heating systems, while increasing the sufficiency of heating, i.e. using heat only at places where people are staying, can save a large amount of energy. In recent years, personalized acclimatizing systems in office buildings are well researched, especially for comfort improvement. However, less research is focussing on the opportunities of personalized heating as an energy saving option in residential buildings. Therefore, an experiment was performed on passive and active personalized heating systems, tested with 16 subjects, in a simulated living room at an ambient temperature of 18°C. The results of this experiment show that by making use of passive as well as active elements, people can feel comfortable at an indoor temperature lower than the commonly prescribed temperature of 21°C.

1. Introduction

In Flanders, residential buildings represent 17% of the total energy consumption [1] and 50% to 75% of the energy consumption is used for space heating [2]. Thus, reducing energy use for heating can have a significant impact on the total energy consumption. Nowadays, energy savings are mainly driven by high insulation standards, airtightness requirements, energy-efficient appliances and energy-efficient all-air heating systems. However, these measures cause high material consumption and cannot always be executed correctly in older buildings. Furthermore, dwellings are typically heated by single-zone central heating systems, controlled by a central thermostat [3], whereas analysis of effective spatial use shows that residents do not use all rooms completely nor at the same time [4, 5]. Adapting the heating system to the effective spatial use by only heating places where residents actually reside, could lead to more *sufficient* heating. Additionally, it could be a relatively simple and temporary low-cost energy saving alternative for the traditional cost- and material-intensive renovation. Studies [6-8] already showed that human subjects can be comfortable at temperatures below current standards by making use of personalized heating. However, these studies are mostly focusing on office environments where people work behind their desk, while residents at home are able to change their activities and their clothing more often [9]. Therefore, this paper discusses an experiment which evaluated thermal sensation and comfort in a simulated living room environment at 18°C, where participants could opt for additional passive and active personal heating systems.

2. Methodology

2.1. Experimental set-up

The experiment took place between March 26th 2019 and April 5th at the Faculty of Architecture and Arts of Hasselt University in a room with dimensions of 640cm x 310cm x 400cm. The room has windows on the shortest sides but there was no direct sunlight due to a cantilever. In total 16 subjects, 7 males and 9 females, were involved in the experiment. During the call for participants, the participants were instructed to wear typical indoor winter clothing and to bring something with them to read during the experiment (on paper to avoid the heat of electronic devices). The ambient room temperature was pre-set at 17,7 ±0,4 °C and the relative humidity was kept at 55 ±5 % during all experiments. The temperature and relative humidity were both logged every five minutes by a hobo U12-012 data logger.

The experiment lasted 60 minutes in total, with two main phases (figure 1). The room was furnished as a living room with two identical couches with two cushions, the first covered with a normal blanket and a floor mat on the ground (phase 1) and the second covered with a heated blanket (max. 120W) and a heated floor mat (max. 20W) (phase 2). The order of these phases was chosen in order to avoid the effect of a temporal warmer feeling due to the active elements. First, the participants got a brief introduction (5') about the set-up of the experiment and were asked to fill in a survey about their gender and age and the clothing they were wearing on that moment. During the experiment, questionnaires on thermal sensation and comfort were combined with short interviews after each phase. In the first phase, the participants were instructed to make themselves as comfortable as possible. They had to stay for 20' on the couch, but they were free to change every 5' their position e.g. sitting, lying down and to take actions e.g. use of the blanket, the floor mat and the cushions. During this phase, they were surveyed regularly (see 2.2). The subsequent second phase was identical, except that they were now able to use and control the heated elements.

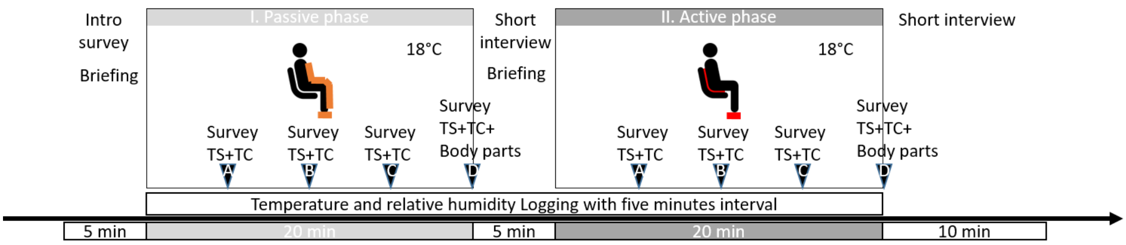

Figure 1: Timeline of the experiment

2.2. Survey on thermal sensation and thermal comfort

During each phase, the participants had to complete every 5' a questionnaire on a tablet about their thermal sensation and thermal comfort (see figure 1 points A,B,C,D) . The ASHRAE 7-point scale was used for questioning the thermal sensation: hot (3), warm (2), slightly warm (1), neutral (0), slightly cool (-1), cool (-2) and cold (-3). The thermal comfort was divided into 6 scales: very comfortable (2), comfortable (1), just comfortable (0,1), just uncomfortable (-0,1), uncomfortable (-1) and very uncomfortable (-2). Additionally, each time they had to specify their human position and actions. At the end of each phase, the subjects had to fill in a more detailed survey about their thermal sensation for seven body parts (head, chest, back, feet, arms, hands and legs). The votes were processed by calculating for every 5 minutes a mean value and standard deviation for thermal sensation and thermal comfort for the whole sample of participants together.

3. Results

Figure 2 shows the overall thermal sensation and thermal comfort of the participants during both phases. During the passive phase, the overall thermal sensation decreased slightly from -0,06 ± 1,14 after 5' from the start (A) to -0,31 ± 1,04 at the end of this phase (D). The overall thermal comfort decreased only slightly from 0,5 ± 0,71 (A) to 0,4 ± 0,68 (D). The change in thermal sensation and comfort can be attributed to the acclimatisation time, which was also mentioned by some of the residents during the short interview. In the active phase, on the other hand, the thermal sensation and the thermal comfort gradually increased as the phase progressed. The thermal sensation increased from 0,38 ± 1,11 to 1,00 ± 0,87 and the thermal comfort from 0,44 ± 0,71 to 0,95 ± 0,64. Comparison of the thermal sensation and thermal comfort of the participants at the end of both phases shows that by providing an active element, the average thermal sensation has raised from -0,31 ± 1,04 to 1,00 ± 0,87. The average thermal comfort of the participants during both phases raised from 0,41 ± 0,68 to 1,01 ± 0,51.

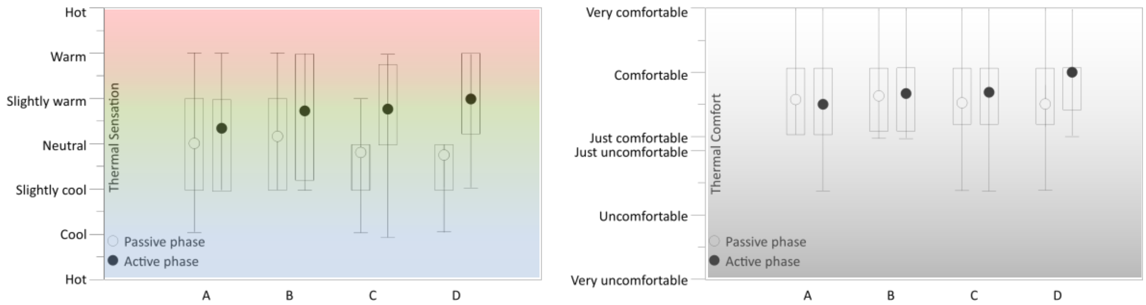

Figure 2: Thermal sensation (left) and thermal comfort (right) at each survey

At the end of each phase, the participants voted for the thermal sensation of the different body parts. Figure 3 shows that the thermal sensation of all body parts increased when the participants used the active elements. The thermal sensation of the back and the legs was improved the most. During both phases, the hands were most often perceived as slightly cool to cold (9 out of 16 participants in the first phase and 7 out of 16 participants in the second phase). The low thermal sensation on the hands can be related to the fact that most of the participants were reading and their hands could not be covered, this was confirmed by the participants during the interview.

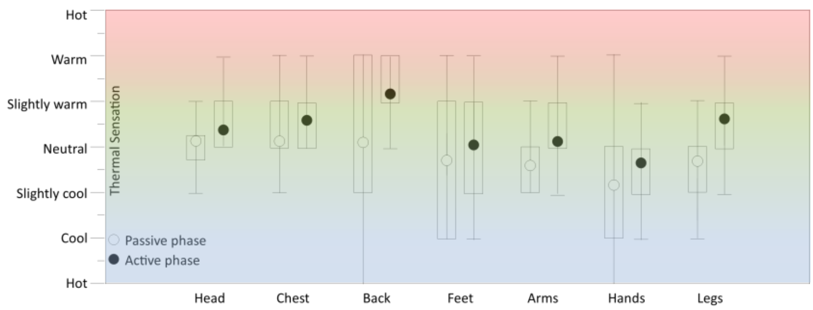

Figure 2: Thermal sensation of body parts at the end of each phase

Despite the fact that participants were allowed to use passive elements in the first phase, only four of them effectively used them. Of those, only one felt neutral and just comfortable while the other three felt slightly cool to cool and just uncomfortable to uncomfortable. Of the participants who did not use any passive element, 42% felt slightly cool and 58% felt neutral and all of them felt just comfortable or higher. No relation was found between the position of the body and the thermal sensation or comfort during the first phase. In the second phase, four out of sixteen participants experienced the heated elements as annoying or too hot. Therefore, three of them turned off the heating, while others changed their position to have a more uniform temperature on all body parts. All participants who switched off the heating element were able to make it comfortable themselves in the passive phase without making use of any element. Analysis of the thermal comfort shows that the participants experienced a higher thermal comfort when they were under the heated blanket than when they were on the heated blanket. Results also show that when participants were under the heated blanket, they experienced a higher thermal sensation at the coldest body parts. This corresponds to the local discomfort while sitting on the heated blanket that the residents noticed during the interview.

A comparison of the thermal sensation and comfort between male and female during the passive phase shows that, for men, the thermal sensation decreased from 0,14 ± 0,83 to -0,71 ± 0,45, and the thermal comfort decreased from 0,74 ± 0,86 to 0,47 ± 0,71. While for women, the thermal sensation increased from -0.22 ±1,31 to 0,00 ± 1,25 and the thermal comfort remained almost equal with 0,31 ± 0,49 at the beginning and 0,36 ± 0,66 at the end. Although this difference is statistically significant, no significant reason, i.e. change of position or action, was found for this difference between men and women. In contrast to the first phase, in the second phase no significant difference was found between the thermal sensation or thermal comfort for men and women. However, it appeared that more men than women experienced the heated elements as annoying or too hot.

4. Conclusions and further research

This experiment evaluated the thermal sensation and thermal comfort of occupants in a room with an overall ambient temperature of 18°C using passive and active elements. The participants were allowed to change their position, make use of the different elements and change the power settings of the element. It has been shown that the active elements can satisfy the participants at a lower indoor temperature and are even able to increase the thermal sensation and thermal comfort of the participants, which is supported by research on personalized heating systems [6-8]. However, this experiment also showed that many residents can feel comfortable using only passive elements.

Although this experiment focussed on a living room environment, similar results are expected in other residential environments. The promising lab results illustrate the potential of personal heating systems that will be further explored in real-life cases as an alternative for the traditional cost- and material-intensive renovation of dwellings. Because the experiment only took 20 minutes twice, the effect on residents' thermal comfort for a longer period is not tested yet. Therefore, in a further study, the local heating will be implemented in real dwellings for one week while the indoor temperature will be decreased to 18°C. Additionally, the energy consumption will be measured and the energy saving potential of this method will be evaluated.

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