

The Effect of the Heating System on the Occupant's Thermal Comfort and Optimum Room Air Temperature

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Abstract. Experiments were repetitively held in the laboratory of a research centre on a group of twenty-four participants for four different heating systems. All were of same age and wore similar clothing. Half were male and half female. During these 288 experiments objective indoor environment parameters (air temperature, globe temperature, relative humidity and air velocity) were measured, as well as subjective parameters (body surface temperatures) during low-intensity physical activity. Participant's satisfaction with the thermal comfort was observed. They evaluated their perceptions on questionnaires. The thermal comfort of participants and influence of the type of heating system was evaluated based on these answers. On the basis of these subjective perceptions, acceptable air temperatures for control of various heating systems were evaluated.

1 Introduction

The research hypothesis was based on the assumption that different heating systems use would require different temperature controls, as occupants would sense heat differently under the various thermal conditions created. These results may be beneficial for further research and development of optimal controls of heating systems in terms of thermal comfort.

To confirm this hypothesis, we carried out a series of experiments for different temperatures and different heating systems. These experiments were done under the same conditions. The occupants sat at the same place in the lab and their clothing remained the same at all temperature levels.

It is important to determine optimal indoor environmental parameters (to reach thermal comfort) and minimize the energy demand of buildings, as well as create a healthy indoor environment.

The data analysis presented in this paper is based on measured data and questionnaire survey-collected data from a large experiment conducted with a group of twenty-four participants. They subjectively assessed their thermal comfort in laboratory test chambers under various heating system conditions. [1]

The charts presented in this paper primarily focus on this subjective assessment of the indoor environment created by different heating systems. It further explicates how human adaptations functioned during the 100 - minute experiment.

1.1 Methods

1.1.1 Measurement

Four electrical heating systems were chosen to measure and assess thermal comfort related to convection heaters, floor heating, ceramic heating panels and ceiling heating (ceiling foil). Experiments were carried out with varied thermostat settings on each of these systems.

Single experiments were carried out after the thermal environments became stable on the required temperature value. Thermal environments were investigated on three steady-state temperature levels. One of these levels was the optimal level for the chosen heating system. This optimal level was a result of previous experiments held in the laboratory which were also confirmed by the thermal manikin thermal conditions assessment.

The experiments were carried out repeatedly on twenty-four subjects of similar age, clothing and physical activity with regard to the nature of the experiment. There were 12 females and 12 males present. The main experimental focus was on detection of the differences in perception of the thermal environment.

1.1.2 Questionnaire survey

During completion of the questionnaires, participants performed a non-routine sitting-reading activity with a magazine or book. In the 5th, 50th and 95th minutes of the experiment, participants were prompted to fill out a set of subjective assessment questionnaires. After completing the 3rd set, they were prompted to return to the entrance hall of the climatic chamber.

In the climate chamber, the winter outdoor conditions were simulated in the corridor. The window between the corridor and the test chamber was closed during the experiment. (See Fig. 1 and 2.)

One key question of the subjective assessment related to temperature in the questionnaire was *Is the objectively calculated optimal temperature really comfortable?* According to the previous experiments held in the laboratory with the thermal manikin, optimum temperatures were determined. These optimum temperature values and other values (T⁺; T⁻) used during the experiment are shown in the Fig. 4 thermostat settings.

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In order to confirm these results, we asked the actual participants questions concerning their thermal sensations. The question of subjective perception was evaluated as \rightarrow *I feel cold* (1) / *I feel warm* (100) and responses were compared on the chart.

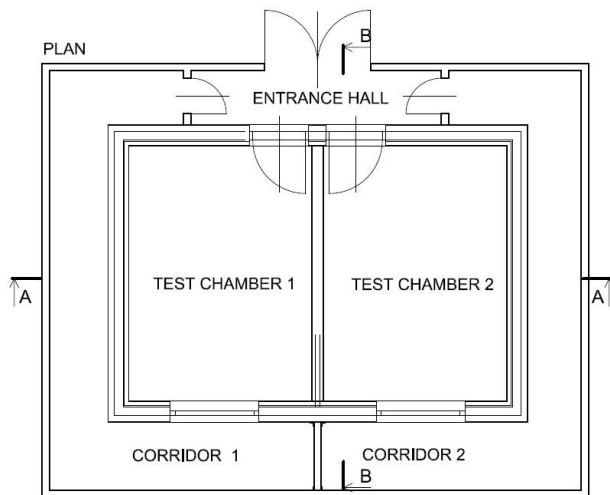


Fig. 1. Climatic double test chamber plan [1]

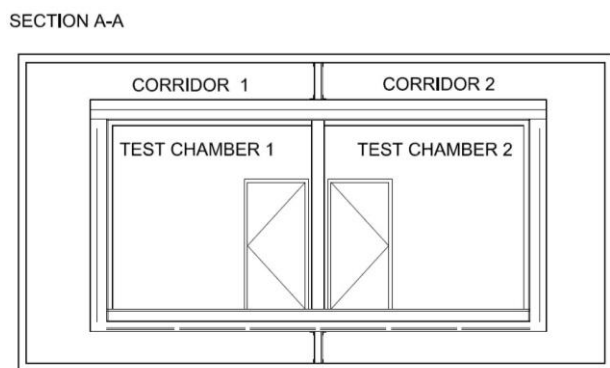


Fig. 2. Climatic double test chamber section [1]

Results are divided to male and female lines in the charts. Results depended on the air temperature (abdominal temperature of sitting occupant 0.6 m above the floor) and on the time period of the experiment (experiment - test 1, test 2 and test 3). A total of 3 tests were completed by each participant for each temperature. The first one taken by each participant when entering the climatic chamber, the second in the middle of the experiment and the third at its conclusion.

1.1.3 Occupants and clothing

Participants first sat in the preparation room, where they adapted for 30 minutes to the indoor environment because outdoor temperatures were sometimes close to freezing.

Participants declared that they were in a healthy state, without stress or feeling hungry. They were selected at age groups from twenty to forty years in age because of metabolic rate concerns. Most were university students.

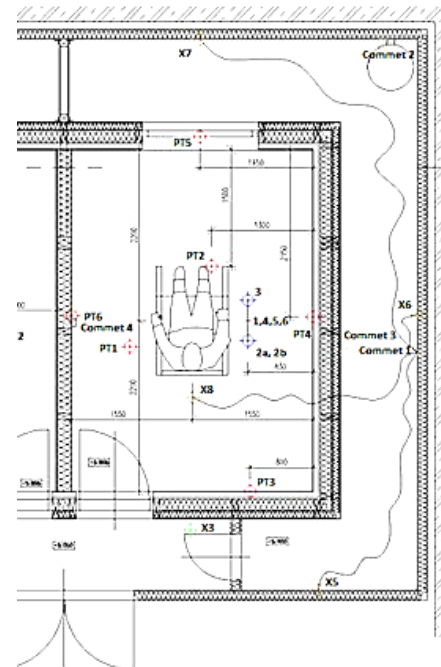


Fig. 3. The experimental layout. [1]

THERMOSTAT SETTINGS T_{SET}	T-	T_{OPT}	T+
Convection heater	20,0 °C	22,5 °C	24,0 °C
Ceramic heating panel	20,0 °C	22,0 °C	24,0 °C
Floor heating	20,0 °C	22,0 °C	24,0 °C
Ceiling foil	20,0 °C	22,5 °C	24,0 °C

Fig. 4. Thermostat settings

Thermal resistance of their garments (or insulation of the garment) I_{cl} was estimated from data reported in the standard ČSN EN ISO 9920 Ergonomics of the thermal environment - Assessment of thermal insulation clothing and resistance of clothing against evaporation [2], or may be calculated on the basis of empirical formulas given in this standard. Participants were required to wear underwear, trousers, a T-shirt and light sweater or sweatshirt. The thermal resistance values were calculated in the range $I_{cl} = 0,6$ to $0,8 \text{ clo} = 0,093 \text{ m}^2 \cdot \text{K} / \text{W}$ to $0,124 \text{ m}^2 \cdot \text{K} / \text{W}$.

2 Assessment and analysis of the data gained

The data obtained from answers in the questionnaires for four heating systems and three various temperatures were plotted to the charts. Both male and female groups are represented by different lines and colours of lines. Each of these three tests are also is represented by a different line.

Every chart represents thermal perception on its horizontal axis and frequency of answers on its vertical axis. The thermal perception of cold is shown in blue colour, neutral is shown in green and warm in red. Thermal sensations are represented by numbers where 1 means *I feel cold* and 100 means *I feel warm*.

2.1. Convection heater experiment: T-; T_{opt}, T+

On the following figures 5, 6 and 7, results are shown for the convection heaters.

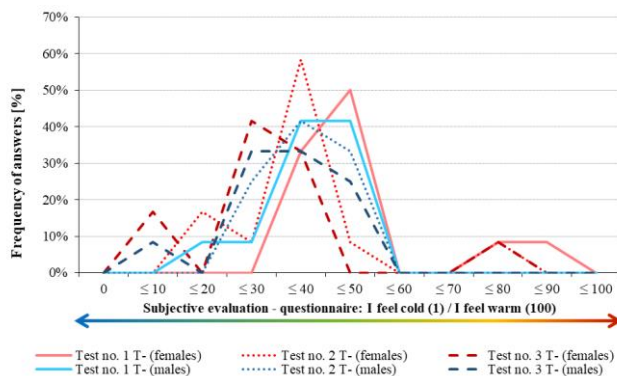


Fig. 5. Convection heater for the T- temperature [3]

From the charts in Fig. 5 to 7, it is apparent that when heating with convection heaters, a change in the perception of heat within the space occurs over time (during the experiment) and when the set temperature is changed. When setting the temperature to $t_{set} = 20.0^{\circ}\text{C}$, occupants in the room sensed cold during the experiment.

When setting the optimal temperature $t_{set} = t_{opt} = 22.5^{\circ}\text{C}$, most occupants (both male and female) felt neutral, that is, in thermal comfort. By setting the temperature $t_{set} = 24.0^{\circ}\text{C}$, occupants already feel warm, but the differences in heat perception are no longer as great over time.

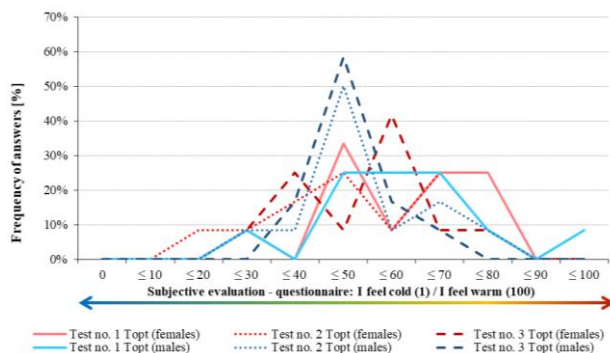


Fig. 6. Convection heater for the T_{opt} temperature [3]

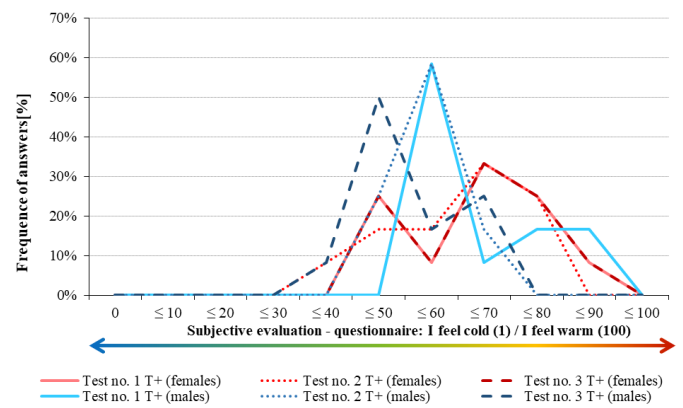


Fig. 7. Convection heater for the T+ temperature [3]

2.2 Ceiling foil experiment: T-; T_{opt}, T+

On the following figures 8, 9 and 10 results for the ceiling foil are shown.

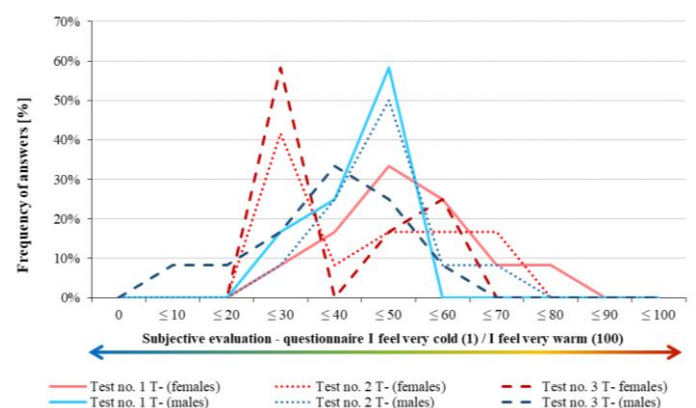


Fig. 8. Ceiling foil for the T- temperature [3]

From the figures in Fig. 8 to 10, it is evident that heating by the ceiling foil causes a change in the perception of heat in the space (as in the case of heating by a convector) over time (during the experiment) and when changing the set temperature. When setting the $t_{set} = 20.0^{\circ}\text{C}$, occupants in the room begin to sense cold during the experiment.

When setting the optimal temperature $t_{set} = t_{opt} = 22.5^{\circ}\text{C}$, most people feel neutral in a given space, that is, in warmth. By setting the temperature to $t_{set} = 24.0^{\circ}\text{C}$, occupants begin feeling slightly warm to warm, but the differences in heat perception have not changed much over the course of time.

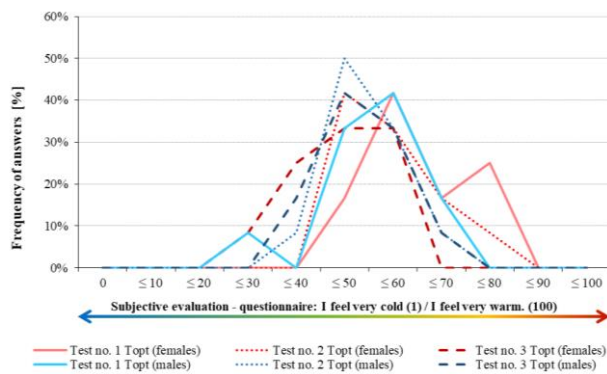


Fig. 9. Ceiling foil for the T_{opt} temperature [3]

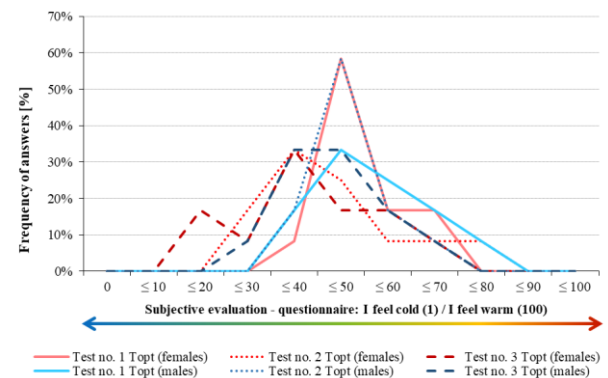


Fig. 12. Floor heating for the T_{opt} temperature [3]

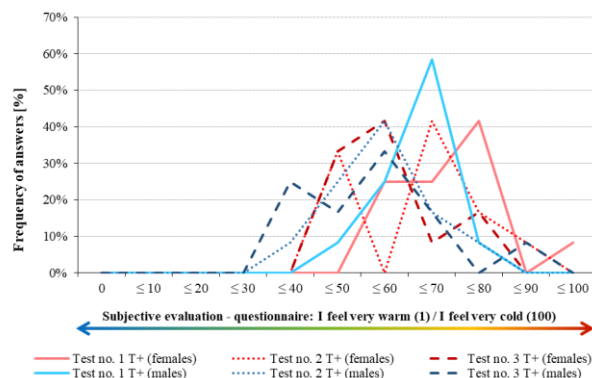


Fig. 10. Ceiling foil for the $T+$ temperature [3]

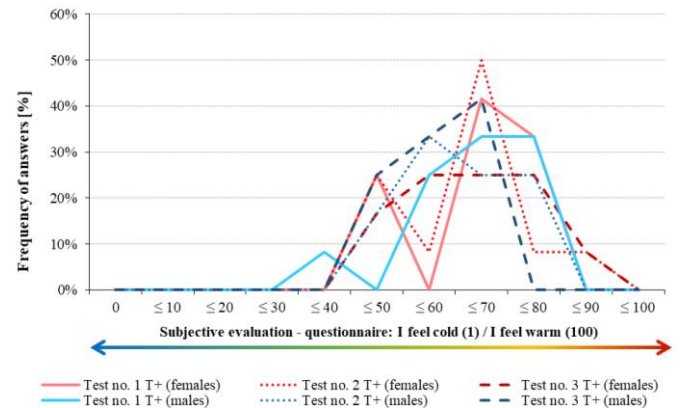


Fig. 13. Floor heating for the $T+$ temperature [3]

2.3 Floor heating experiment: $T-$; T_{opt} , $T+$

On the following figures 11, 12 and 13 results for the floor heating are shown.

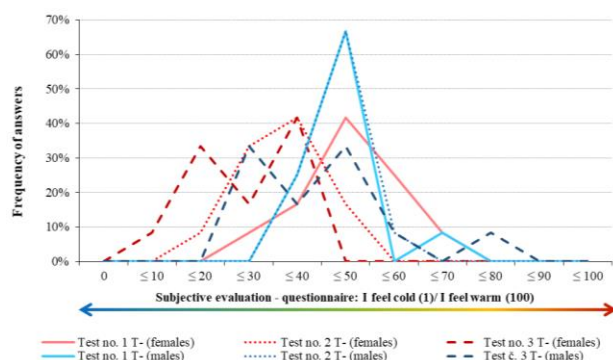


Fig. 11. Floor heating for the $T-$ temperature [3]

As with the convection heater, ceramic panel and floor heating, a change in the perception of heat in the space occurs over time (during the experiment) and also when the set temperature is changed. When setting the t_{set} temperature = 20.0°C , females in the room begin to feel cold during the experiment.

When setting the optimal temperature $t_{set} = t_{opt} = 22.0^{\circ}\text{C}$, most participants (both female and male) feel neutral, that is, in thermal comfort. By setting the temperature $t_{set} = 24.0^{\circ}\text{C}$, they already feel slightly warm to warm, but the differences in heat perception have not changed much over the course of time.

2.4 Ceramic panel experiment: $T-$; T_{opt} , $T+$

On the following figures 14, 15 and 16 results for the ceramic panel are shown.

From the charts in Fig. 14 to 16, it is apparent that when heating with a ceramic panel, heat perceptions change in space (as with convection heater) over time (during the experiment) and a change of set temperature.

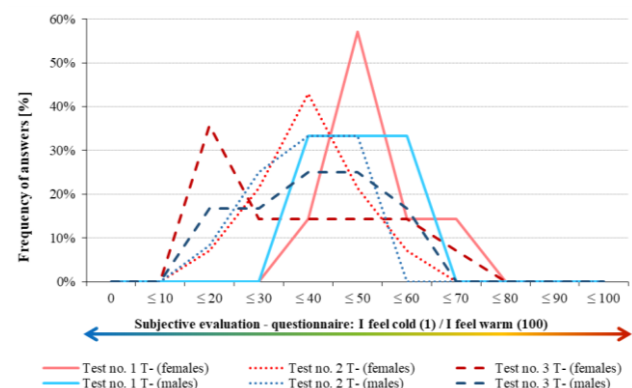


Fig. 14. Ceramic panel for the $T-$ temperature [3]

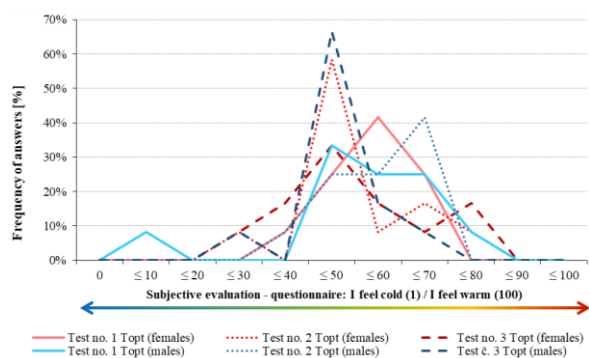


Fig. 15. Ceramic panel for the T_{opt} temperature [3]

When setting the t_{set} to temperature = 20.0°C , occupants begin to sense cold during the experiment. When setting the optimal temperature $t_{set} = t_{opt} = 22.0^{\circ}\text{C}$, most occupants (both male and female) feel neutral, that is, in warmth. When setting the temperature $t_{set} = 24.0^{\circ}\text{C}$, they already feel slightly warm to warm, but the differences in their perceptions of heat do not change much over time.

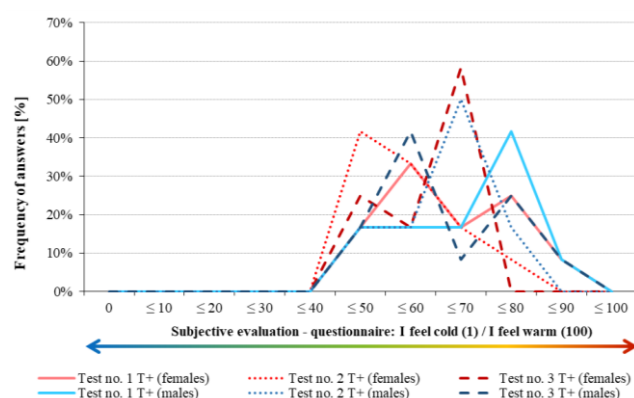


Fig. 16. Ceramic panel for the $T-$ temperature [3]

3 Discussion

Authors would say that the results are valid for occupants who live in moderate climates. Participant's adaptation to the outdoor environment in which they spend their time is not negligible.

These experiments were held in Europe, in the Czech Republic, a moderately continental climate with cold winters and warm summers. The data are valid for those between the ages of twenty to forty who are healthy. [4]

During the experiment, only psychological and physiological adaptations were allowed for participants used to the given thermal environment. The most common form of adaptation (behavioural, clothing modification and adjustment, change of activity, etc.) was not possible during the experiment because of the need to keep its constant boundary conditions.

4 Conclusion

This paper deals with the adaptation of human beings to their indoor environment and the influence of heating systems on their perceptions of heat in the room during sedentary activity. Four heating systems and three different temperatures were monitored. The test group consisted of males and females who subjectively evaluated surrounding thermal environment.

Charts in Fig. 5 to 16 show that temperature perceptions change in space over time and when the set temperature is modified. The graphs of individual heating systems prove that the calculated optimum temperature is particularly pleasant for those exposed to the given space when setting the optimal temperature $t_{set} = T_{opt}$ (throughout the experiment). Occupants preferred higher over lower temperatures. [5]

It is obvious from the results of the individual charts, that participants were more satisfied in a warmer environment and when the set optimal temperature T_{opt} is evaluated as a thermal comfort (neutral sensation). [6]

A comparison of thermal sensations for males and females under each heating system and set temperature follows: The red line (representing females) lies to the left of the blue line (representing males) for panel heating (see figures 14 -16). For floor heating this is not the case (see figures 11 - 13), as there are more coincidences between males and females. For the ceiling foil (Figure 8), the sensations of males and females approach one another. The results for convection heater illustrate that females feel warmer in the given conditions than males for T_{opt} and $T-$ (Figures 6 and 7). This is interesting because, according to metabolic rate, males should always sense warmer than females.

The goal of neutral thermal sensation was mostly achieved by T_{opt} thermal conditions. With $T+$ thermal conditions, some participants sensed it as much too warm. The peaks in the charts moved to the right with increasing temperatures for all systems, which means that the increasing temperatures were perceived under all heating systems investigated.

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