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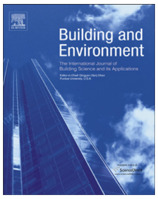

# Analysing thermal comfort perception of students through the class hour, during heating season, in a university classroom

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A B S T R A C T

Indoor to outdoor transitions, and the subsequent occupant adaptation, impact thermal perception of occupants and their evaluation of a building. A mixed methods thermal comfort study in a classroom of Eindhoven University of Technology was conducted to provide a better understanding of thermal perception of students as they move into and adapt to their classroom environment. Data was collected over two weeks during heating period, with different heating set-points. A total of 384 students, in seven undergraduate level lectures, participated voluntarily. The thermal sensation vote, obtained at different time points through classes — 10 min, 20 min, and 45 min — was found to be significantly different ($p < 0.05$). In the start of a lecture, perception varies primarily depending on the outside temperature, operative temperature, gender, and where the occupant came from. Comparing the two weeks' observations, second week having a 1.5 °C lower set-point, revealed that the most considerable differences occurred in the immediate response phase after indoor–outdoor transition. For nearly 20 min post transition, participants retain a thermal memory of their last exposure, gradually adapting as the lecture proceeds.

## 1. Introduction

Educational buildings need to stimulate student productivity and learning. Studies show a reliable association between classroom thermal environment and air quality with student performance and well-being [1]. Simultaneously, as the need for low-energy buildings grows, classrooms must also follow suit. Standards, such as ISO 7730, EN15251 and ASHRAE Standard 55, provide guidelines on indoor comfort in classrooms. Yet, several studies note high levels of dissatisfaction among students regarding thermal comfort and air quality in classrooms and student thermal preference not being accurately reflected by the provisions in relevant standards [2–6]. This is even true for classrooms in developed countries [7]. In contrast to office workers — who are often the primary target of thermal comfort standards — students are frequently moving between different rooms, or even buildings, and have different clothing patterns. Thus, at least part of the comfort mismatch may be ascribed to standards neglecting students' transitional thermal comfort needs. What may exacerbate classroom thermal discomfort issues are the high occupant density and restrictions on occupant behaviour. Such restrictions make clothing adjustments the single most favoured means of adaptation for students [2].

To save energy and to improve the thermal comfort in a university classroom, standards could prescribe more dynamic/flexible ranges, supporting heterogeneity and individual based needs [8,9]. However, for such dynamic standards to be successful, a better understanding of thermal comfort in classroom and student perception and expectations is needed.

Thermal comfort research has primarily focussed on occupants in steady conditions, including the two most popular comfort models in current use: the PMV and adaptive thermal comfort models. There have been relatively fewer studies dealing with thermal comfort during spatial transitions. Some such studies have looked into clothing adjustment effect [10], consumption of food and/or beverages [10–12], and changes to activity level [13]. Change of thermal sensation vote, during spatial transition across environments with different thermal conditions, has been noted to relate to the temperature difference between the two spaces [14]. Most studies agree that the change in thermal perception subsequent to spatial transitions cannot be accurately gauged using the

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PMV model [14], especially for an outdoor–indoor transition [7,15]. It is pertinent to note here that the studies mentioned so far were mostly conducted in climate chamber set-ups and not in the field. Other studies have used real world settings with participants recruited for the specific study. The results from such studies suggest that the impact of transitioning across different thermal environments upon occupant perception depends on the history of exposure [16,17], as well as the magnitude of the changes, with abrupt jumps being more likely to be perceived than changes $<2\,^{\circ}C$ in magnitude [16]. However, when subject to temperatures that are perceived by the occupants as uncomfortably cold or warm, transitions of even 1 °C are noticed [16].

Field investigations — with actual occupants in real buildings — are rare. This work tries to address the gap using a transverse thermal comfort study in a classroom of the Eindhoven University of Technology. We aim at improving provisions for classroom thermal comfort by gaining a better understanding of responses to spatial transitions in thermal environment and the corresponding breadth of occupant flexibility. This should be helpful in achieving optimal energy usage for thermal comfort. It was also envisaged that this study can act as a pilot, with an exploratory conception, to help the design of future similar studies in the field, involving actual occupants.

## 2. Methods

The studied classroom (Classroom 8, 15 × 14 × 7 m, CL8) is in the Auditorium of the Eindhoven University of Technology, the Netherlands. Surveys were undertaken during four lectures in the second week (7–11) and three lectures in the fourth week (21–25) of March, 2016. A modified field study protocol was designed, based on existing literature [18,19], to evaluate thermal perception as the class progressed. It consisted of the following steps: collecting information on the building and the conditioning system, environmental measurements alongside subjective surveys, and correlating objective and subjective data.

### 2.1. Building characteristics

Being in the Auditorium's basement, CL8 is windowless and is minimally affected by outdoor elements. It can seat 200 students. Typically, lectures are during the five weekdays and each lecture is scheduled as 2 × 45 min, with a 15 min break in between. The conditioning system in the Auditorium operates in three temperature ranges, depending on occupancy, time of day, and day of the week, as depicted in Fig. 1.

The system does not have seasonal variations and occupancy detection operates in an on/off fashion, independent of the actual number of students. The Building Management System (BMS), which controls the conditioning, relies on a temperature sensor in each classroom. No avenues for occupant control are present. As per requirement, preheated/pre-cooled outdoor air, is supplied under the seats for ventilation. Ventilation air outlets are located in the ceiling. During heating season, the radiator placed under the blackboards is operated since the teacher's position does not have ventilation air inlets. After detection of an empty room, an offset of 30 min is allowed before switching back occupancy state to unoccupied.

### 2.2. Objective measurements and subjective surveys

Prior to the surveys, a set of preliminary, measurements were carried out in the classroom. These confirmed that the ventilation, luminosity, draught, and background noise levels in the room were in accordance with the revised guidelines set for new and renovated classrooms in the Netherlands, targeting “Fresh Schools” [20]. Hence, these parameters were not continually measured during the surveys. During classes surveyed, measurements were done for air and globe temperature, relative humidity, air speed, and CO2 levels. These sensors were put together to create an indoor comfort measurement stand (ICMS), which was located centrally in the room. There were four more temperature sensors spread across the classroom. The set-up for these sensors is shown on a lay-out of the classroom in Fig. 2. The devices were located at about the head/face level for sitting students and they recorded data once every minute. This is also the frequency of the BMS temperature sensor. Specifications of the instruments are given in Table 1. Operative temperature (Top) was calculated using globe temperature and air temperature (Tair) measurements. Air velocity within occupied zone always kept below 0.2 m/s, most of the time being $\leq 0.15$ m/s.

Outdoor temperature data was provided by a BMS measurement location on the Auditorium's roof. These values were used to calculate a seven day prevailing mean outdoor air temperature (PMOAT), based on the arithmetic mean of the daily average outdoor temperature [21].

The subjective survey questionnaires consisted of two parts: a general survey and a set of three right-now surveys. Contents for each part have been enlisted in (Fig. 3 a). Images of the full questionnaires have been provided as Supplementary documents (Supplementary Fig. 1 for general survey questionnaire and Fig. 2 for right-now questionnaire). Optical mark recognition was used to scan the filled up paper responses into a database [22]. Survey time-line is presented in (Fig. 3 b).

The general survey questionnaire was filled at the beginning of lectures. The three right-now surveys were intended to identify students' thermal perception evolution through the class duration. Review of works done in climate chambers and studies on visitors in a museum suggested that people take about 20 min to adjust to an altered thermal environment [9,23]. It is also understood that following a change from higher activity rates to sedentary state, occupants require $\sim 15-20$ minutes to be able to respond to their current thermal environment [6,24]. Hence, the time points for

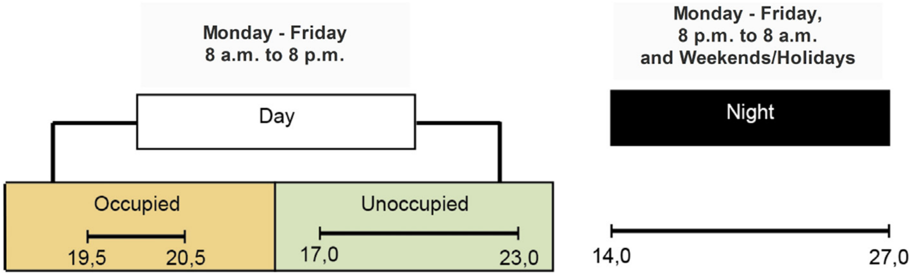

**Fig. 1.** Set-points for the Auditorium's conditioning system.