# Subject Assessment of Thermal Transition in a Museum: a Case Study

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## ABSTRACT

Thermal sensation and comfort evaluation schemes typically address thermally adapted people under static circumstances. A disregard of thermal evaluation processes pertaining to transitional states may result in inappropriate temperature settings, inefficient thermal control, and poor thermal comfort. Thus, recently studies have been carried out, which consider thermal perception under dynamic (transitional) conditions. This paper represents an example of such a study. It investigates people's subjective thermal sensation assessment immediately after a spatial transition, i.e., entering or exiting a building or moving between different spaces within a building. Field experiments were conducted in the Museum of Art History (Kunsthistorisches Museum) in Vienna, Austria. Multiple groups of participants moved through a predefined route throughout the building. This route involved five spatial transitions. Immediately after each transition, the participants expressed their thermal sensation vote (TSV) via a questionnaire. Participants' responses were analyzed in the context of monitored temperature differences between the spaces along the participants' route through the building.

**KEYWORDS:** Field study, thermal sensation, spatial transition

## 1 INTRODUCTION

Heating, ventilation, and air-conditioning technologies and systems are typically deployed to provide desirable indoor thermal environments for human occupancy. However, if occupants go through spatial transitions involving noticeable temperature differences, typical thermal comfort evaluation schemes, which are geared toward thermally adapted individuals (see, for example, ASHREA Standard 55, 2004 and ISO 7730, 2005) may not apply. People are frequently exposed to such transitional states, for example when they enter or exit a building or when they move through differentially tempered rooms within a building. A disregard of thermal evaluation processes pertaining to transitional states may result in inappropriate temperature settings, inefficient thermal controls, and poor thermal comfort conditions.

Subjective thermal sensation and comfort evaluations of transitional states have been addressed in past research. For example, Chun and Tamura (1998) investigated the difference in thermal responses between a stable conditioned space and a transitional space. Authors emphasize the importance of temperature change for the perception of thermal comfort. In a recent paper, Parkinson et al. (2012) indicated that sudden changes in ambient temperature can induce thermal pleasure, given a positive alliesthesial effect. However, the same environmental step change invoked a displeasure response when the core temperature was stable. Chun and Tamura (2005) also conducted a laboratory-based study involving subjects walking through controlled cambers in sequence. They suggest that thermal comfort perception at a certain point in time is influenced by antecedent thermal conditions. de Dear et al. (1993) indicated that the thermal sensation responses immediately after a transition involving temperature increase have been reported to be close to the responses after adaptation, whereas the thermal sensation responses immediately after a temperature decrease dropped initially to return to a stable level after adaptation. Likewise, Arens et al. (2006) investigated thermal sensation and thermal comfort in time series including rapid temperature changes. Their results show that the thermal sensation and thermal comfort reach their final state shortly after a spatial transition. Nakano (2003) suggests that transitions involving large temperature intervals towards thermal neutrality result in correspondingly large improvement of thermal comfort feedback. Hwang et al. (2008) demonstrated differences between the thermal comfort perceptions of visitors versus resident staff in public spaces. Chen et al. (2011) studied thermal sensation as well as skin temperature after a transitional state. They suggest that temperature difference should be limited to 4 K in order to maintain adequate thermoregulatory function.

## 2 RESEARCH DESIGN

Field experiments were conducted in the Museum of Art History (Kunsthistorisches Museum) in Vienna, Austria. Figure 1 schematically illustrates floor plans and the experiment’s spatial arrangement. “E” denotes the external environment and the numbered spaces are conditioned indoor environments. During the experiments, we measured continuously indoor air temperature and relative humidity around the facility.

Experiments with participants (students at the Vienna University of Technology) were conducted in the beginning of June 2012 over a period of 2 days from 10 am to 5 pm. The outdoor temperature range in this period was between 17.2 and 23.0 °C, and the indoor temperature range was between 20.0 and 25.7 °C. The number of participants in the experiments was 77 (63% female, 34% male) and the mean age of participants was 22±3. The participants were divided into 8 groups, each consisted of up to 10 individuals. The composition of the groups was basically random.

Participants moved in groups along two predefined routes, each route involved five spatial transitions as summarized in Table 1. The thermal resistance of the participants’ clothing was about 0.6 clo. Participants spent at least 10 minutes in each space engaged in low activity (standing, walking a few steps) prior to each transition (walking from one room to another). In literature (Arens, 2005 and Nakano, 2003), adaption phases of 10 to 20 minutes have been found appropriate. Immediately after each transition, the participants expressed their thermal sensation vote (TSV) via a questionnaire using a 7 points scale (-3: cold, -2: cool, -1: slightly cool, 0: neutral, 1: slightly warm, 2: warm, 3: hot) (ASHRAE, 2004). In the treatment of the results, the votes of ten participants constituting each group was averaged and processed for further analyses and interpretation. The main reason for this approach was to fact that all members of each group experienced similar thermal conditions before and after the transition. Moreover, this grouping facilitated a more clear representation and visualization of the results without changing the main trust of the statistical analyses and the associated results.

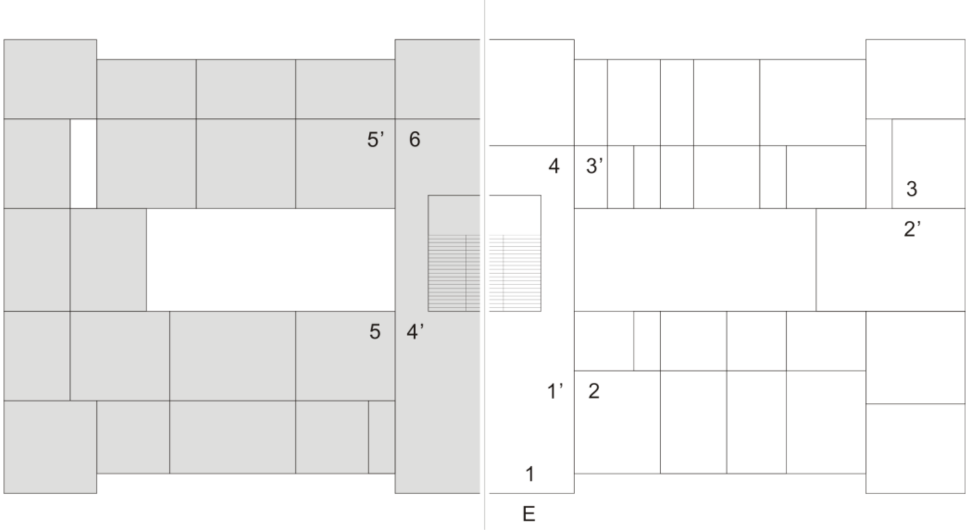

Figure 1: Schematic illustration of the test spaces (left part: first floor; right part: ground floor)

Table 1 Circulation plan for route 1 and route 2

| Spatial transition | Route 1 | Route 2 |
|---|---|---|
| 1 | E_1 | 6_5’ |
| 2 | 1’_2 | 5_4’ |
| 3 | 3’_4 | 4_3’ |
| 4 | 4’_5 | 2_1’ |
| 5 | 5’_6 | 1_E |

To compare participants' expressed thermal sensation vote (TSV) with steady-state thermal comfort model predictions, we calculated for all instances the PMV (Predicted Mean Vote) values using measured indoor environmental variables (i.e., air temperature, relative humidity) and known personal factors (clothing, activity). Mean radiant temperature was assumed to be equal to the measured room air temperature and the mean indoor air velocity was set to be 0.15 m.s-1. As to participants’ activity level, a value of 1.7 met (ASHRAE, 2004) was used for PMV calculations.

## 3 RESULTS AND DISCUSSION

The main results of the experiments are shown in a number of Figures below. Figure 2 shows a comparison between participants’ expressed thermal sensation vote (TSV) immediately after a spatial transition (before adaptation) and corresponding calculated PMV values. The observed regression line indicates that the range of participants’ TSV evaluations following a transition is much larger than the PMV predicted. Moreover, TSV expressions immediately after transition include values below zero (indicating cold perception), whereas the corresponding PMV values are all above 0. These results indicate the PMV prediction may not appropriate for participants’ TSV evaluation immediately after a transition.

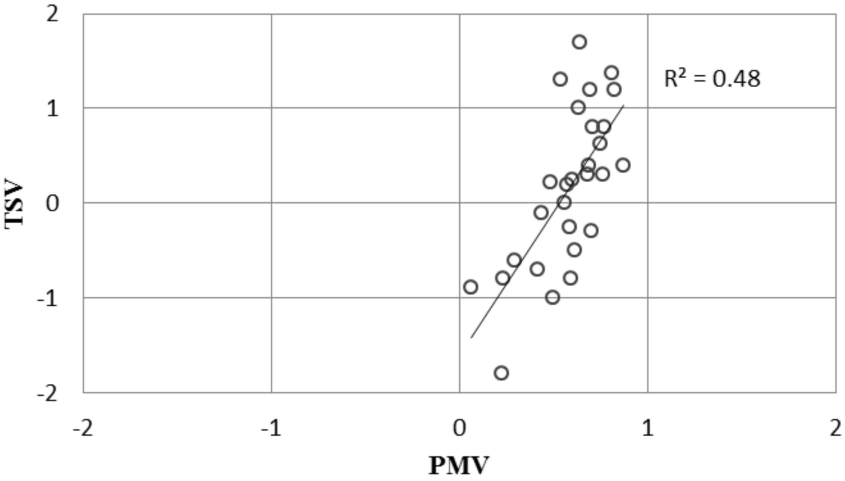

Figure 2: Participants' thermal sensation vote (TSV) immediately after transition versus calculated values of PMV

Figure 3 shows the change in thermal sensation vote (TSV2-PMV1) following a spatial transition as a function of the temperature difference between the start and end rooms (θ2 – θ1). Thereby, TSV2-PMV1 denotes the differences between participants' thermal sensation vote immediately after transition (before adaptation) and before transition. Hence, increase in TSV is positive, whereas, decrease in TSV is negative. Note that TSV2 is based on reported user expression, but PMV1 values were calculated (based on conditions in the start room). The result show a good correlation between the change in thermal sensation vote and the temperature difference between the two rooms even through the temperature differences are relatively small. Moreover, as with the results shown in Figure 2, changes in thermal sensation vote are larger that corresponding changes in calculated PMV values.

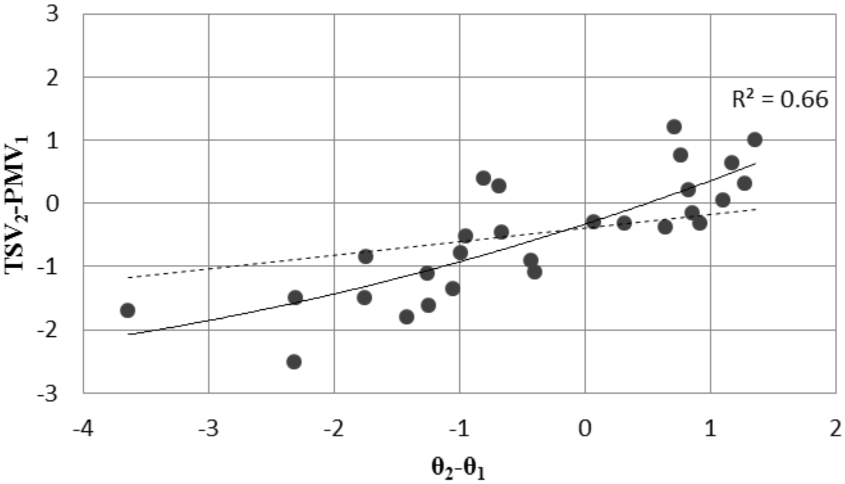

Figure 3: The change in thermal sensation vote (TSV2-PMV1) following a spatial transition as a function of the temperature difference between the start room (θ1) and the end room (θ2). The change in the calculated PMV before and after transition is also shown as a function of temperature difference (dashed line)

These results appear to be in agreement with the similar finding in one of our previous studies involving experiments under controlled laboratory setting (Wu and Mahdavi, 2013). The results of this earlier study suggested that changes in people's thermal sensation vote after a spatial transition could be estimated base on the difference in room temperatures using the following relationship Eq. (1).

$$TSV_2 - TSV_1 = 0.02\ (\theta_2 - \theta_1)^2 + 0.47\ (\theta_2 - \theta_1) - 0.95 \qquad (1)$$

Figure 4 shows a comparison between the empirical results (Figure 3) and corresponding calculations using Eq. (1). As this Figure shows, calculated results using Eq. (1) (dashed line in Figure 4) agree in tendency with experimental results presented in this paper, but are consistently lower. This may be due to the fact, that – as compared to the earlier laboratory experiment – the temperature differences between the museum's different spaces were smaller.

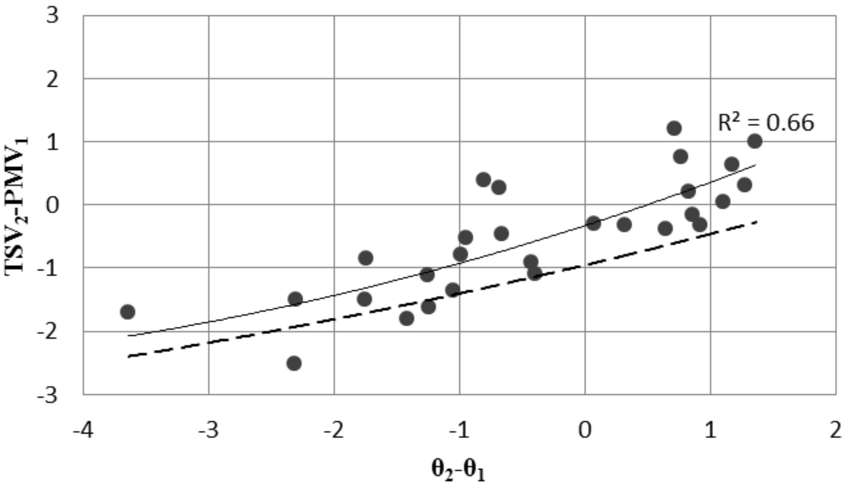

Figure 4: The change in thermal sensation vote (TSV2-PMV1) (black dots, continuous regression function) and the change in thermal sensation vote based on the Eq. (1) (dashed regression function) following a spatial transition as a result of the temperature difference

## 4 CONCLUSION

The results of the present study suggest that occupants' thermal sensation (TSV) immediately after a spatial transition cannot be reliably predicted based on calculated PMV results. Specifically, the spread of actual TSV was found to be larger than those of calculated PMV. Moreover, the collected data suggest that a previously introduced relationship for the estimation of the change in people's thermal sensation vote after a spatial transition (as a function of the temperature difference between the rooms) can correctly reproduce the general tendency, but not the absolute values of the empirical findings.

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