Short-term acclimatization effects in an outdoor comfort study

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1. Introduction

Urban landscapes can mitigate impacts from global warming, improving outdoor comfort conditions, when well designed and planned, according to principles from Bioclimatic Architecture and from a climate-responsive urban planning perspective.

Methodologies for the assessment of indoor thermal environments through field studies are described in international standards. In contrast, the assessment of outdoor thermal comfort conditions for humans is not included in any international standard. The need for standardizing procedures in this line of research has been stressed by Johansson et al. (2014), when comparing methods used in 26 different field studies over a number of climatic regions worldwide within a latitude range 1.4°N and 57.7°N. With regard to the physiological and psychological adaptation of the subjects, in their majority passers-by, only 3 out of the 26 field studies evaluated included the question whether and for how long the respondent had been outdoors before the survey. Höppe (2002) shows through computer modeling of the skin temperature that three hours would be needed for reaching steady-state conditions in the cold. Skin temperature is an important variable included in outdoor thermal comfort indices such as the German index Physiological Equivalent Temperature (PET), currently used in Germany in human biometeorology and also for urban planning purposes. In warm conditions, steady state is reached more quickly but nevertheless only after approximately half an hour. The short-term adaptation aspect, when simply neglected in outdoor comfort surveys, might bring inconsistent results with implications in the development and validation of outdoor comfort indices and further in the urban planning process.

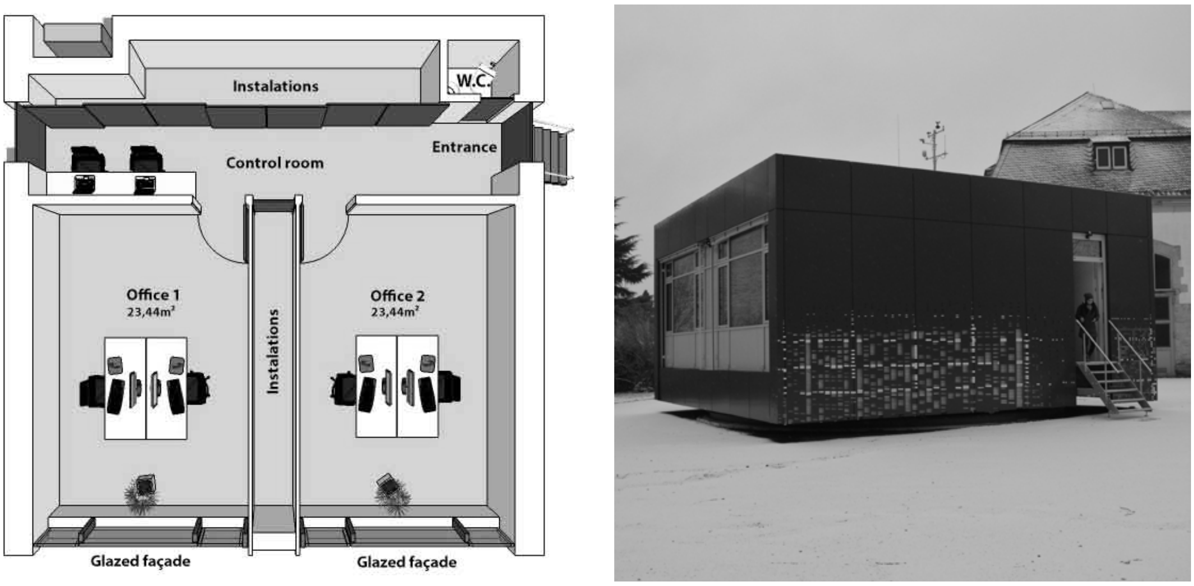
According to the physiological concept of Alliesthesia (Cabanac 1971, 1992) “a given stimulus will arouse either pleasure or displeasure according to the internal state of the stimulated subject”, thus stepping from thermal homogeneity to transient outdoor conditions should create immediate responses that would then diminish with time of exposure. Once the subject was for a long time within a thermally static environment, „with no opportunity for the body to interpret the ‘usefulness’ of a stimulus for thermoregulation“, there is a greater chance that he will more effectively experience thermal pleasure or displeasure under sudden transient conditions. De Dear et al. (2010) tested this hypothesis in a climate-chamber study with step-up and step-down temperature changes. During such experiments, participants were exposed to sudden changes in ambient temperature (drops and rises). The results of this study are pointing to the relevance of the alliesthesia concept to transitional spaces. In a past study, also using a test chamber, de Dear et al. (1993) measured and described the more immediate effect of step-up than in step-down changes on reported thermal sensation; the authors suggest such effect to be related to cutaneous thermoreceptors: cold receptors are located closer to the skin surface than warm receptors.

In this context, the question concerning the time needed for short-term acclimatization gains in importance. Existing thermal comfort standards (all for indoors) suggest that the time needed for adjusting to the thermal environment in thermal comfort surveys depends on the environment itself. For air-conditioned buildings, ISO 7730 recommends approximately 30 minutes of adjustment to the thermal environment which corresponds to the time needed to reach steady-state. For naturally ventilated buildings ASHRAE Standard 55 suggests at least 15-minute occupancy (ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy).

This paper is concerned with short-term acclimatization effects on a subject’s thermal perception outdoors. In addition, the effect of thermal expectation is evaluated, from the presence/absence of visual clues of the outdoor climatic conditions.

2. Methods

The study was carried out in and outside a climate chamber located at the Karlsruhe Institute of Technology, which is composed of two adjacent 24m² offices (Figure 1a and 1b). The climate chamber is described by Schweiker et al. (2014), additional information can be found at the website http://lobster-fbta.de. The Laboratory for Occupant Behaviour, Satisfaction, Thermal Comfort and Environmental Research (LOBSTER) was designed as a semi-controllable climate chamber with operable windows so that the two office spaces with two workstations each would closely resemble a conventional office environment, though with triple-paned windows and a window-to-wall ratio of approximately 75%. An innovative feature of LOBSTER is the fact that it sits on top of a PV tracking system, which allows it to rotate to diverse façade orientations. An innovative feature of LOBSTER is the possibility to rotate it by 355° and thereby changing the façade orientation.



(a) (b)

Fig. 1(a) Floor plan; 1(b) The LOBSTER test facility in winter (January 2015)

For the present study, 16 male German students were tested in groups of two simultaneously in the twin offices. Subjects had an average height of 1.80m (SD 0.06m), weight of 80kg (SD 8.9kg), and were 24.9 years old (SD 3.6). All wore sneakers, t-shirt and jeans inside the offices. Outdoors they wore such ensemble plus fleece pullover and jacket. The insulative value of the clothing was estimated to be 0.5 clo inside and 1.25 clo outside, from the clothing insulation tables of ISO 9920.

While in the office, metabolic rate corresponded to a seated position, reading and doing light work; in the open participants walked around the climate chamber at a regular pace close to 4 km/h, so that similar conditions to the ones predicted by UTCI index were met. Estimated indoor metabolic rate was 70 $W.m^{-2}$ or 1.2 Met (ISO 7730), outdoors 135 $W.m^{-2}$ or 2.3 Met (Bröde et al. 2012a).

Conditions monitored indoors and outdoors were the relevant thermal comfort variables (air temperature, humidity and speed and the mean radiant temperature, the latter calculated according to ISO 7726). For that, two Ahlborn comfortmeters ALMEMO 2690 were used, one in each office, which were continuously monitored by the researchers who would promote slight changes in the air-conditioning system in order to ensure steady-state thermal conditions. The time period inside the chamber was five consecutive hours. During this period other aspects regarding indoor comfort were evaluated in a parallel study (not discussed in this paper). After this 5-hour acclimatization period, subjects were invited to leave the test chamber and walk to a hand-made weather station consisting of two HOBO U12-011 dataloggers. One of the dataloggers was placed within a plastic 15 mm globe painted grey for recording globe temperature; the other one hung inside a 50 cm-long PVC tube for providing shade while allowing natural ventilation to the logger. Spot measurements of wind speed were done using an anemometer (Testo 416 Mini-Vane anemometer), attached to the tripod. Back-up data from the roof-top Thies weather station, located at 6m from ground level, were used in stormy weather conditions. Measurements on soil were close to the respondents, air temperature and humidity sensors at 1.30 m, globe thermometer at 1.2 m and anemometer at approximately 1.6 m.

A standard comfort questionnaire was given to the subjects at three different times: immediately after leaving the test chamber; after 15 minutes of light walk around the LOBSTER facility; and after further 15 minutes walking outside. In this paper, we focus on reported thermal sensation according to the 7-point perceptual judgment scale with a neutral point (ISO 10551), German version (EN ISO 10551:2002).

Food intake and beverages were standardized for all participants, only still water and neutral, sugarless biscuits and fruits were provided during the 5-hours sessions.

Results are analyzed in terms of obtained responses in different time lapses and for three different sessions per participant. In total, 16 sessions were evaluated in the winter season. During those sessions, window orientation and status of openings (open, shut with louvered shading device) were varied according to Table 1. This way the issue of thermal expectation could be evaluated relative to different views of the outdoor climatic conditions for a identical, standardized thermal history prior to outdoor exposure.

While indoors the PMV (ISO 7730) thermal comfort index was used for the thermal evaluation of the rooms together with the subject's own assessment of the thermal conditions at predetermined time intervals, outdoors the UTCI index was employed. Indoor thermal conditions were real-time monitored with the Ahlborn comfortmeters, which were post-processed in the UC Berkeley Thermal Comfort Program WinComf batch-version 1.01 (1994-1995) for assessing PMV data.

Tab 1 – Breakdown of sessions and configurations

Office configuration	**Dates**
NW orientation of the glazing	15th, 21st, 28th January, 3rd February
SW orientation of the glazing	13th, 22nd, 27th January, 4th February
Shading device on window (external louvers)	14th, 20th, 29th January, 5th February

Outdoors thermal conditions were post-processed with the non-steady state Universal Thermal Climate Index (UTCI), which is based on a multi-node model of human thermoregulation (Fiala et al. 2012) using the approach of equivalent temperature. Values of the UTCI were calculated from the meteorological input parameters air temperature, humidity, wind speed, mean radiant temperature using the regression equation described by the operational procedure (Bröde et al. 2012a). As UTCI requires the input of wind speed at 10 m above ground, wind speed values were scaled-up according to a logarithmic formula, as proposed by the operational procedure (Bröde et al. 2012a). For a direct comparison to the reported thermal sensation votes, the UTCI-Fiala model also predicts thermal sensation (Fiala et al. 2003), termed 'Dynamic Thermal Sensation' (DTS) averaged over a 2-hour exposure for the calculated UTCI values (Bröde et al. 2012b).

Statistical significance was tested either by means of the mixed-model ANOVA for repeated measurements (Littell et al. 1996) or by applying the F-test for testing the equality of variances combined with a t-test for determining the statistical significance of the pair-wise differences found at the 0.05 significance level.

3. Results

Subjects were exposed to almost stable thermal conditions inside the climate chamber, with a short, gradual warm-up phase in the first hour and no significant changes in the predicted mean vote (PMV) during the next four hours. By the time participants left the chamber to the outdoor environment, mean PMV indoors was just around the neutral thermal condition (PMV=0); PMV range for that particular moment, for all 24 sessions (12 days for each office), was from -0.5 to +0.2.

3.1 Reported thermal sensation

As expected for the winter season, the majority of thermal votes obtained outdoors lie within the cold discomfort range (23% of the votes for "-3", 36% for "-2" and 29% for "-1") with a few votes in thermal neutrality (12%). In respect of the three time steps during which the surveys were administered, small though not statistically significant differences were observed between the grouped results for all participants in the 12 experimental sessions (Table 2), with a slight rising trend in intensity towards "-2" or "cool", the most representative thermal discomfort category of the sample.

Tab 2 – Comparison of Thermal Sensation Votes (TSV) in three time steps

	Time step 1	*Time step 2*	*Time step 3*
Mean	*-1,59*	*-1,70*	*-1,72*
SD	*1,02*	*0,88*	*1,10*
Minimum	*-3*	*-3*	*-3*
Maximum	*1*	*0*	*0*

3.2 UTCI calculations versus reported thermal votes

UTCI values as well as the derived predicted "Dynamic Thermal Sensation" (DTS) are shown in Table 3.

The UTCI values did not change significantly with exposure time, as indicated by P-value=0.259 in the mixed-model ANOVA. However, UTCI showed a large variation between the 12 days, with values on one day lying within the "Thermal Comfort Zone" of 18°C<UTCI<26°C (Bröde et al. 2013), cold stress (UTCI<9°C) observed on 9 days and intermediate stress on 2 days.

The DTS scale corresponds to the 7-point scale used in the surveys; the mean for the whole sample (n=36, i.e. three time steps distributed over 12 days) closely resembles reported TSV. The descriptive statistics for the three time steps shows a somewhat lower predicted mean DTS and corresponding minimum-maximum interval for time step 3, relative to the immediate exposure of the participants to the outdoor thermal conditions. UTCI values drop accordingly; the larger fluctuations were found for the third time step (Table 3).

Tab 3 – UTCI and predicted DTS for the three time steps

	Time step 1		*Time step 2*		*Time step 3*	
	UTCI	*DTS*	*UTCI*	*DTS*	*UTCI*	*DTS*
Mean	*5,34*	*-1,73*	*4,91*	*-1,76*	*4,67*	*-1,76*
SD	*6,13*	*0,56*	*6,06*	*0,54*	*6,86*	*0,62*
Minimum	*0,54*	*-2,08*	*-0,68*	*-2,20*	*-2,54*	*-2,33*
Maximum	*20,77*	*-0,20*	*19,60*	*-0,33*	*21,54*	*-0,10*

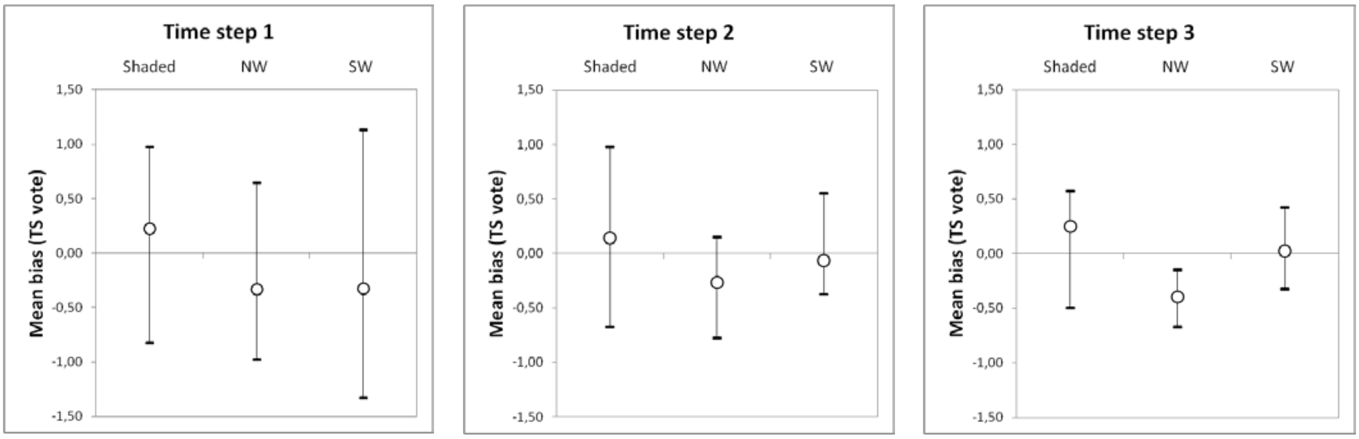
When comparing the individual thermal sensation votes (TSV) against the predicted DTS, the mean bias of estimate (DTS-TSV) diminishes with time of exposure (Table 4). The first thermal sensation vote, reported immediately after the subject had left the chamber, had a slightly higher mean error indicating a slight underestimation bias, and fluctuation (range and standard deviation) than at time step 3, when the subjects had been for half an hour outdoors. This time effect is consonant with the graphs shown in Figure 2, but did not reach statistical significance.

Tab 4 – Mean bias of estimate (DTS-TSV) for the three time steps

	Time step 1	*Time step 2*	*Time step 3*
Mean	*-0,17*	*-0,05*	*-0,04*
SD	*1,08*	*0,73*	*0,90*
Minimum	*-1,80*	*-1,23*	*-1,08*
Maximum	*3,08*	*1,25*	*2,08*

3.3 Effect of psychological expectation

Although the winter experimental sessions were mostly cloudy and not numerous, the effect of thermal expectation can be tested, since participants had three different configurations regarding the view to the outdoor environment: obstructed window (use of shading element, external louvers); view from a southwest glazing orientation; view to a northwest exposure. Expectations regarding the outdoor climatic conditions could thus be enhanced if participants had a clear view of the outside throughout the 5-hour period inside the climate chamber. In this case, the visual clues regarding the outdoor climate could give them a more accurate first guess of how outdoor thermal conditions are at time step 1. Averages of the mean bias between predicted and reported thermal sensation votes using UTCI (Figure 2) suggest that a blocked window for the winter season would translate to an overestimation of the “actual” thermal sensation whereas the sunnier façade (SW) would bring a closer match between reported and predicted thermal sensation. Two-way mixed model ANOVA for repeated measurements showed a statistically significant effect of viewing condition (P=0.015), but no effect for time (P>0.05). However, there is large scatter in the minimum and maximum values; future surveys with a larger sample could confirm or discredit such trend.



a) b) c)

Fig. 2 – Mean bias (DTS-TSV) with minimum and maximum bias as error bars for the three window configurations, a) immediately after leaving the chamber @ time step 1; b) after 15 minutes @ time step 2; c) after 30 minutes @ time step 3

4. Discussion

Höppe (2002) showed the use of steady-state models would be inadequate for outdoors, since the time needed to reach steady-state conditions in physiological terms would be longer than the usual time periods spent outside. In this study, we compare TSV against predicted thermal sensation with the non-steady state index UTCI. Results suggest that the longer exposure time will reduce mean bias of the estimates.

Together with previous research on transient indoor conditions (de Dear et al. 1993) indicating that, when moving from indoors to outdoors during winter time, the initial thermal sensation responses could be biased against cooler TSV, our results support the recommendation to consider only thermal responses for respondents with at least a 15-minute occupancy in outdoor comfort surveys (e.g. Krüger et al. 2013).

The effects of viewing conditions could be related to changes in visual comfort, which may have an effect on thermal comfort. However, this has to be followed by future studies.

The survey was carried out during the winter season; the data base shall be extended by campaigns under warmer spring and summer conditions, allowing more concrete conclusions to be drawn.

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