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Local cooling in a warm environment

H. Pallubinsky[a,*], L. Schellen[a,b], T.A. Rieswijk[c], C.M.G.A.M. Breukel[c], B.R.M. Kingma[a], W.D. van Marken Lichtenbelt[a]

[a] Department of Human Biology and Movement Sciences, NUTRIM, Maastricht University, The Netherlands
[b] School of Built Environment and Infrastructure, Avans University of Applied Sciences, The Netherlands
[c] Priva, De Lier, The Netherlands

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ABSTRACT

Public and commercial buildings tend to overheat. Recent studies indicate individual comfort systems based on local climatization can improve occupant satisfaction and simultaneously decrease the energy load of buildings. This study evaluated the effect of local cooling in both women and men on indicators of occupant satisfaction: thermal sensation, thermal comfort and skin temperatures.

All measurements were conducted in a climate chamber (Priva, the Netherlands) with an ambient temperature of 32.3 ± 0.3 °C (mean ± SD). In total, 16 healthy young men and women were exposed to different local cooling conditions for 45 min: face cooling, back cooling, underarm cooling, foot sole cooling and 30 min of combined face-underarm cooling. The cooling conditions were separated by 30 min of 'no cooling'. Thermal sensation and thermal comfort were evaluated with VAS-scales. Skin temperatures (26 sites) were measured using wireless temperature sensors. 'Face cooling' and combined 'face-underarm cooling' significantly improved thermal sensation and comfort compared with 'no cooling' for both women and men. Women had significantly higher skin temperatures compared with men.

Local cooling of the face alone and face and underarms combined are effective ways to improve thermal sensation and thermal comfort in a warm thermal environment.

1. Introduction

One third of the primary energy supply is used for the ventilation and air-conditioning of commercial and public buildings; mainly to achieve occupant satisfaction [1]. Nevertheless, thermal comfort is often not achieved. In addition, the overheating of buildings became a hot topic in the Western world in the recent years [2,3]. The risk of overheating is a consequence of a combination of very high insulating construction materials and the heat load of occupants and equipment. Moreover, global warming worsens the scenarios. As a result of the overheating problem, the energy demand of buildings rises to ensure thermal comfort for the occupants. To prevent energy costs from increasing and simultaneously keeping occupants satisfied, efficient and creative low-energy cooling techniques are needed. It has been suggested that individualized comfort systems might be promising alternatives to overall air conditioning, especially for those buildings/building areas that host largely sedentary occupants (e.g. offices and open plan offices) [4–8].

Today, many buildings have a tightly controlled indoor climate as determined by the ASHRAE Standard 55 and ISO Standard 7730, based on Fanger's predicted mean vote model (PMV) [9–12]. Creating a thermal environment conforming to these standards means that very little ambient temperature variation is tolerated. Since a large number of building occupants report thermal discomfort, even though the recommendations of the standards are met, the question is whether these (PMV-) standards are actually suitable.

The large level of perceived discomfort (especially in summer [13]) might be due to significant inter-individual differences in the thermal sensation and thermal comfort of building occupants: physiological parameters such as sex, age, body composition, metabolic rate, insulation, acclimation, behavioral parameters such as physical activity and clothing behavior, and individual preferences for ambient temperature might have a considerable effect on an individual's perception of the thermal environment [14,15]. A study among young Europeans indicated that the preferred ambient temperature may vary by as much as 10 °C [38].

Recent investigations confirmed that individually attuned comfort systems have the potential to save a significant amount of energy (up to 50% compared with overall air-conditioning), and

* Corresponding author at: Universiteitssingel 50, 6229 ER Maastricht, The Netherlands.
E-mail address: h.pallubinsky@maastrichtuniversity.nl (H. Pallubinsky).

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improve individual occupant satisfaction [7]. Applying individually attuned local cooling may allow an increase in overall indoor temperature without negatively affecting the occupant's thermal comfort. Moreover, individualized local cooling provides the possibility for building occupants to create their own preferred thermal environments tailored to their individual needs at a given moment.

To optimize the design of individual local cooling systems, it is necessary to evaluate the impact of different local cooling conditions and different target regions of the human body (actuators) on thermal comfort. Furthermore, regarding the anticipated automated control of individual local cooling systems ('human in the loop' comfort systems), it is important to study possible indicators, i.e. physiological parameters (e.g. local skin temperature) that correlate to thermal comfort. Considering the overheating problem we introduced above, we especially focused on the optimization of occupant comfort in a warm environment. It is crucial to evaluate the individual response of women and men with respect to local cooling in mild heat, since there is barely any data available. Moreover, there is lack on information about the response and effectiveness of different cooling conditions on physiological parameters and thermal comfort of women and men.

We hypothesize that individualized local cooling can effectively improve occupant thermal sensation and comfort in a warm environment. Accordingly, this study aims to:

1. Evaluate the effect of five different local cooling conditions (actuators) on whole-body thermal sensation, thermal comfort and skin temperatures of young, healthy volunteers in a warm thermal environment
2. Identify sex differences in whole-body thermal sensation, thermal comfort and skin temperatures with respect to local cooling in a warm thermal environment
3. Identify potential physiological indicators of whole-body thermal comfort in a warm thermal environment.

2. Methods

2.1. Facilities

The experiment was established in a climate chamber that is located at the laboratory of the 'Priva' company (De Lier, the Netherlands). The chamber dimensions are depicted in Fig. 1. During the experiments, the average ambient air temperature was 32.3 ± 0.29 °C (mean ± SD, as shown in Section 2.5). Air temperature was kept stable by a combination of radiant heating and air conditioning. Floor, ceiling and three walls (Fig. 1) of the climate chamber were built of water-perfused aluminum panels. Water temperature of ceiling and floor panels was set at 29 °C; wall panel water temperature was set at 32 °C and ingoing airflow was set at 35 °C. Relative humidity was not controlled in the present setting. On average, relative humidity was 29.3 ± 3.42%.

2.2. Participants

Sixteen young, healthy volunteers, 8 men and 8 women, participated in the study. Before informed consent was obtained, the participants were provided with detailed information concerning the experimental procedures. Importantly, no information was provided about the conditions and ambient temperature they were exposed to. All participants were normotensive and non-obese. Four women were on oral contraceptives; all other participants did not take any medication that might alter their cardiovascular, hormonal or thermoregulatory responses to temperature changes. Participant characteristics are provided in Table 1.

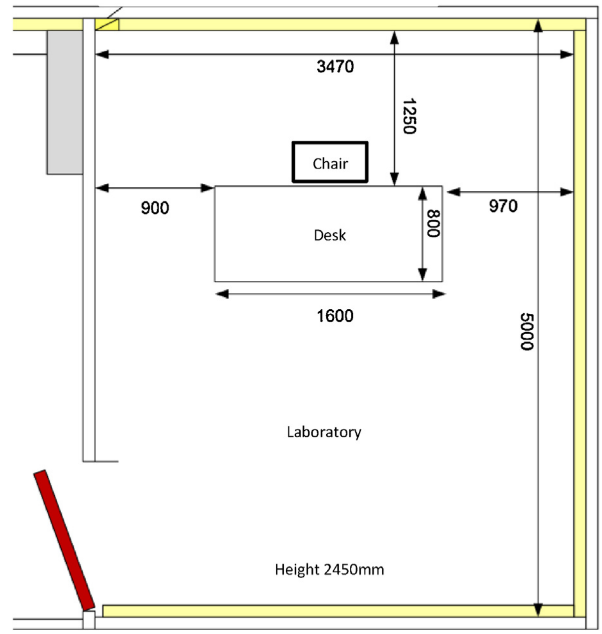

Fig. 1. Laboratory dimensions and desk position. The yellow surfaces indicate water-perfused aluminum wall panels; the ceiling and floor consisted of water-perfused aluminum panels as well. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Participant characteristics.

	Mean ± SD	Minimum	Maximum
Age [years]	23.5 ± 3.5	20	32
Height [m]	1.79 ± 0.11**	1.57	2.00
Weight [kg]	69.1 ± 9.8*	56.5	92.9
BMI [kg/m²]	21.5 ± 2.1	18.4	25.8

* $P < 0.05$.
** $P < 0.001$ difference between women and men.

2.3. Experimental procedures

Participants visited the laboratory between May and July 2014. Average outside daytime temperature (8:00 AM–8:00 PM) was 16.3 °C [16]. Participants arrived at the laboratory at 8.30AM in the morning. In total 26 wireless skin temperature sensors (iButtons, Maxim Integrated Products, CA, USA) were attached to the their skin with semi-adhesive tape (Fixomull® stretch, BSN medical GmbH, Hamburg, Germany). Participants wore their own underwear and additional standard clothing, which consisted of a loose-fit cotton T-shirt, jogging pants and cotton socks (clo ≈ 0.54) [17]. After preparations were finished, participants entered the climate chamber and sat down on a chair (clo ≈ 0.1, Fig. 2) [17–19].

The experiments lasted for 6 h, and in the meantime, participants were allowed to perform regular deskwork (approximately 1.2 METs). Desk and chair were individually adjustable in height to ensure comfortable sitting posture. During the experiment, participants were exposed to five different local cooling conditions that were provided randomly: (1) 'face cooling', (2) 'underarm cooling', (3) 'back cooling', (4) 'foot sole cooling' and (5) combined 'face-underarm cooling'. The different conditions were separated by a 30-min period of 'no cooling', except for the conditions 'underarm cooling' and 'face-underarm cooling'. These were executed consecutively for practical reasons (Fig. 3 provides an example of the time schedule).