Humans and Warm Environments

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VALORISATION

The present thesis describes human physiological responses and behavioural coping to warm environments as well as the influence of prolonged exposure to elevated temperatures (passive mild heat acclimation) on human health, thermoregulatory behaviour and thermal perception. Moreover, a practical approach with respect to the management and optimisation of individual thermal comfort in warm thermal environments is presented. The valorisation potential of this thesis will be described in terms of societal and economic relevance, and implications for specific target groups, future research and possible applications for industrial development.

What is the societal and/or economical relevance of this research?

The design of indoor spaces has developed and changed a lot over the past decades, to make them, amongst other things, as comfortable and optimally tempered as possible for the occupants. This is especially true for most developed countries, where people nowadays are hardly ever exposed to the variation of outdoor conditions, as people spend the greatest part of their time (more than 90%) indoors (1). Based on earlier research, thermal neutrality was assumed to be the most *comfortable* for the majority of building occupants (2), and was thus manifested in the standards for indoor environments (ASHRAE Standard 55 (2) and ISO Standard 7730 (3)). Up until today, these standards are retained, albeit that some parts are criticized by many, and for several reasons. For example, operating a building on a tightly controlled set point, and not tolerating a reasonable amount of variation, costs a lot of energy. To date, roughly one-third of the primary energy supply in the Western World is used for heating, air-conditioning and ventilation of buildings (4). Moreover, reasonable doubt has been expressed about the healthiness of such uniform indoor environments (5-10).

Measures taken to comply with the strict indoor air guidelines described above, combined with efforts to reduce energy costs, have led to the use of highly isolating construction materials, which puts buildings at risk for overheating (11). Therefore, in the future, even more energy will have to be spent to condition our indoor spaces, especially in summer. Due to climate change and global warming, the scenario will progressively become more serious. Della-Marta *et al.* (12) have shown that between 1880 and 2005, the frequency of hot days in Western Europe has almost tripled and summer heat waves nowadays last twice as long. By the end of the 21st century, countries in central Europe are expected to experience as many hot days as are currently encountered in Southern Europe (13). Hence, events such as the extreme and unusual European summer heat wave of 2003 will likely not be as unusual any more in the near future: people living in Western and Central Europe will soon be exposed to warm environments more often and more frequently – both indoors and outdoors.

A vast amount of studies previously investigated the effect of intense, mostly exercise-induced heat acclimation programs on a variety of health-related outcomes and performance parameters (examples include (14-20)). However, the influence of passive exposure to only moderately increased temperatures, which more realistically reflects (summer) day-to-day temperature challenges, is largely unknown.

The scenario presented above clearly demonstrates the need for sophisticated information on the effect of passive and relatively mild heat stress on the human body. In the context of the above-discussed consequences of climate change and overheating of buildings, it is crucial to evaluate the impact of warm environments on human health as well as evaluate available (physiological and behavioural) coping mechanisms with elevated temperatures.

Therefore, this thesis examined several aspects of acute and longer-term exposure to mild heat on human physiology, health, thermal perception and thermoregulatory behaviour. Physiological and behavioural coping with high ambient temperatures was evaluated, as well as the impact of prolonged exposure to elevated temperatures on parameters of human metabolic and cardiovascular health. Furthermore, potential strategies to retain and restore thermal comfort in warm environments were also assessed.

For which target groups outside the scientific community are the results of this thesis interesting?

Firstly, the results yielded from the studies presented in this thesis are of great value for the general population of Western and Central Europe, particularly with respect to health and wellbeing in warm environments. We have shown that, to a certain degree, exposure to elevated temperatures elicits adaptive processes of the thermoregulatory system. Both healthy young as well as overweight elderly individuals exhibited significant physiological adaptations upon repeated exposure to mild heat. Furthermore, it has been shown that albeit the general perception of heat being a stressor, especially for the cardiovascular system and in vulnerable populations, we found that exposure to passively induced mild heat acclimation elicited favourable health effects such as a reduction of blood pressure in both healthy young and overweight elderly participants. Moreover, a significant improvement of glucose metabolism in the form of reduced fasting plasma glucose and fasting plasma insulin levels was evident in an overweight elderly population, after passive mild heat acclimation. Regular exposure to mild heat might therefore be considered as an (add-on) treatment option for high blood pressure and (onset) type 2 diabetes.

For the built environment sector, information yielded from this thesis can be of importance for the design of new (healthy and energy-efficient) indoor environments. Thermoregulatory behaviour is an important factor when considering the design and development of indoor spaces, as occupants might, for example, adjust thermostats and operate windows, based on their thermal perception and comfort levels. The latter has significant impact on the performance of a building and on the thermal satisfaction and perceived control of its occupants. Hence, the findings of this thesis might be important for building performance assessments and estimation of energy use of a building. Furthermore, the results reveal that mild heat acclimation induces physiological adaptation, which improves resilience to heat and affects thermoregulatory behaviour. This means for example, that the temperature set-point of a building could be handled less strictly than proposed by the classical PMV model and thus drift more freely with changing outdoor conditions, which is conceptualised in the Adaptive Comfort Model (21-23). On the one hand, this has the potential to save a vast amount of energy for air-conditioning and on the other hand, it may improve metabolic health and create more resilience to heat (so-called ‘temperature training’ for the occupants).

Which concrete products, services, processes or activities can be translated and developed from your research?

The effect of mild heat on human physiology and health has been assessed from a variety of different perspectives. Firstly, the present thesis aimed to study the effect of heat exposure and heat acclimation on human health and wellbeing in the context of global warming, and the thereof resulting more frequent overheating of indoor spaces. The results presented in this thesis show that the human body is able to adapt relatively quickly, within the course of 7-10 days to elevated ambient temperatures, resulting in greater resilience to heat. Importantly, our data shows that this is true for a relatively mild increase of (indoor) ambient temperature up to 35˚C, which might be encountered more frequently in the coming decennia in Western and Central Europe, due to the climate change.

Secondly, considering the results of this thesis from a more practical perspective, we support earlier indications that temperature interventions, such as an individually-tailored heat therapy, might be a useful tool to improve not only cardiovascular health but also glucose metabolism. Although temperature interventions might not (yet) be regarded as stand-alone therapy for cardiovascular as well as metabolic diseases, it might be worthwhile to further investigate options to use temperature treatments as add-on therapies, additionally to the usual standard care.

Thirdly, human physiology and thermoregulatory behaviour are important factors to consider when attempting to design and develop healthy and energy-efficient indoor environments. As mentioned earlier, thermoregulatory behaviour can have significant impact on the performance of a building and on the satisfaction of its occupants. Additionally, local comfort systems can be helpful to save energy while simultaneously providing individually-tailored solutions for occupant comfort optimisation (for example with respect to open-plan office spaces). Recent investigations suggest that individually-attuned comfort systems have the potential to not only restore thermal comfort and satisfaction, but also to save up to 50% of energy use compared with overall air-conditioning. In this thesis, a personalised cooling system had been investigated. The use of a desk fan, possibly in combination with a cooled desktop, is promising approach to efficiently (and inexpensively) improve thermal comfort and thermal sensation in overheated office spaces. The combination of such a personalised comfort system together with a drifting indoor temperature set-point has great potential to save energy while simultaneously retain occupant satisfaction and potentially improve occupant cardiovascular and metabolic health. We argue that the design and configuration of thermal indoor environments should be regarded as an important lifestyle factor, next to healthy diet and physical activity, and thus has to be taken into consideration for a wholesome, balanced life.

Planning and Realisation

Based on the results of this dissertation and on other studies from our research group regarding cold exposure and cold acclimation, two TKI project proposals were recently granted. In the scope of the first one (DYNKA, TKI Urban Energy-TEUE117001), dynamic office environments will be evaluated in the field, in real-life conditions. The second project (PERDYNKA, TKI Urban Energy-1507503) will focus on personalised control of dynamic office environments, also under 'living-lab' conditions. These projects will result in:

1. Ready-to-use dynamic climate scenario's in combination with dynamic lighting that can be implemented in offices.
2. The design of individually-controlled comfort systems for offices combining dynamic indoor temperature and dynamic lighting fixtures.
3. The development of an ICT platform for light and climate control
4. A set of building requirements for physics and installation technique for an optimally healthy, productive and acceptable indoor climate

The results are also expected to be applicable not only in offices but also in other environments such as schools, dwellings and care centres. Indoor climate and health implications are further studied in two EU projects. One project (Horizon2020-EE04-2016) focuses on the energy efficiency of Hybrid Geotabs building energy (heating and cooling) systems. The main goal is to optimise the design strategy of such systems with the explicit inclusion of health aspects. The aim of the other EU-project, (Mobistyle, Horizon2020-EE07-2016-IA) is to motivate behavioural change by raising consumer awareness and by providing attractive personalized systems. Here, the combination of pro-active knowledge services and the effect thereof on energy use, indoor environment, health and lifestyle, by ICT-based solutions will be addressed. All projects are spin-offs, which are partly derived from the studies and study ideas presented in this thesis.

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