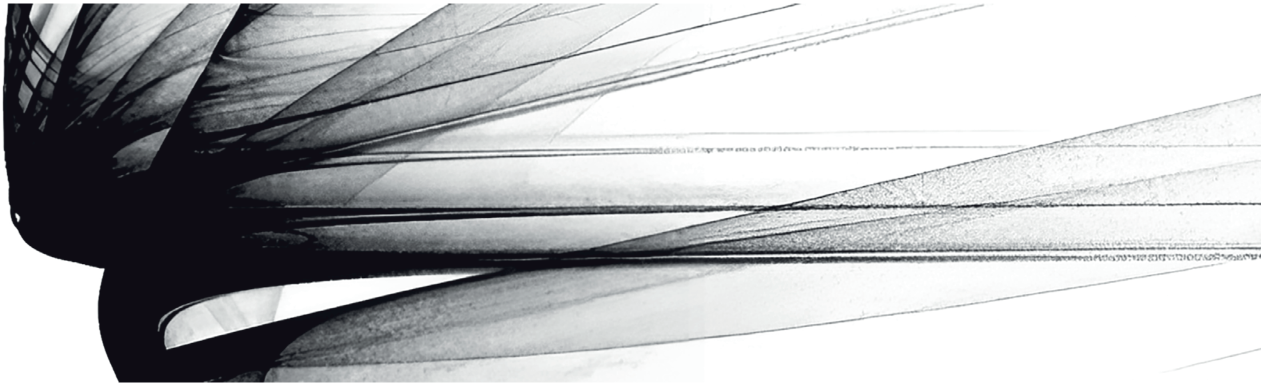
# Personal environmental control systems



# Impact

**What is the main objective of the thesis, and what are the most important results and conclusions?**

The main objective of the thesis is to find possible win-win solutions using Personal Environmental Control Systems (PECS) in combination with indoor temperature variation to reduce the energy consumption of buildings related to heating, ventilation and air-conditioning (HVAC) systems while satisfying a varied set of occupants' needs (comfort, health and productivity). The central research question is how indoor temperature control can be relaxed to allow more temperature variations in order to stimulate human thermoregulation while respecting thermal comfort and performance on an individual level.

In **Chapter 2,** a specific design guideline was proposed for the *Personal Comfort System* (PCS, the temperature-PECS). It revealed that the local thermal discomfort distribution over the body determines the PCSs' effectiveness and that PCSs should eliminate local thermal discomfort by targeting it directly or indirectly. Moreover, moderate local heating/cooling does not affect skin temperatures in most unheated/uncooled body segments. A novel PCS was, therefore, designed to efficiently warm the extremities (the coldest body parts in mild cold) and cool the head (the warmest body part in mild heat), leaving the rest of the body (such as the torso) exposed to a healthy temperature variation. In **Chapters 3** and **4,** the empirical study showed that, using the designed PCS that targets extremities, winter indoor temperatures in offices may be lowered to as much as 17˚C in dynamic conditions while respecting individual thermal comfort. Meanwhile, a healthy cold stimulation to human thermoregulation can indeed be sustained and thermal discomfort does not necessarily affect performance in mildly cold conditions. Furthermore, the designed PCS boosted pleasure and arousal in 17-25˚C, and at 25°C the head-cooling component of the designed PCS enhanced average complex cognitive performance, improved air quality and air freshness perceptions, and mitigated eye strain. In **Chapter 5,** a high CCT may further improve thermal comfort, cognitive performance, arousal and alertness in cold conditions. In **Chapter 6**, a *Personal Lighting System* (PLS, the light-PECS) can also be used to select the beneficial CCT while improving visual comfort and mitigating eye-related symptoms. The conclusion is that, by using the designed PCS, indoor temperature can be relaxed to a mild cold condition (e.g., 17˚C in a dynamic condition) to stimulate human thermoregulation while respecting thermal comfort and performance on an individual level. In addition, a PLS may further contribute to this by selecting beneficial CCT while assuring visual comfort.

**What is the contribution of the research to science and society?**

This thesis presented possible practical solutions to lower winter indoor temperature while respecting thermal comfort, performance and healthy thermal stimulation. These approaches imply a potential of up to 40% energy saving and may benefit (metabolic, cardiovascular and circadian) health in the long term (**Chapter 7**). It directly and indirectly helps alleviate the pressure of the energy crisis, climate changes, sustainability and obesity prevalence. In addition, this thesis provides specific design guidelines for PCSs to realize a healthy, comfortable and optimal office environment. It helps to guide the development of the PCS industry.

This doctoral thesis also contributes to a new understanding of thermal comfort. The discovered relations between thermal comfort and human thermoregulation/performance suggest that the indoor temperature doesn't necessarily need to be controlled in a neutral, static and uniform way to satisfy thermal comfort. It encourages future research to explore possible approaches to realize thermal comfort and performance in dynamic, non-neutral and non-uniform conditions at minimal energy demand. For example, the adaptive thermal comfort model stipulates a wider comfortable temperature range than what is commonly practiced in air-conditioned buildings, thereby promoting a dynamic thermal environment. However, it is mainly used for *evaluating* the indoor climate in natural-ventilated buildings, not for *controlling* it. The insights of this thesis suggest that it is worth exploring whether the adaptive thermal comfort model can also be used for indoor temperature control in air-conditioned buildings. In addition, this thesis showed the cross-modal effects of light CCT on thermal comfort, implying that cross-modal correspondence exists in the built environment. However, most standards and research investigate these multiple environmental factors in isolation. To holistically design an indoor environment that is beneficial for occupants with a low energy consumption, this thesis facilitates further studies to focus on multi-domain interactions in built environments (e.g., interaction between acoustics and temperature).

**To whom are the research results relevant?**

The insights and outcomes of this thesis are interesting for researchers, consultants, practitioners, industrialists, and standardization committees in the indoor environment domain. For *researchers*, the protocol and findings in this thesis can be used for designing new studies related to PECS or light-temperature interactions (**Chapters 2-7**). For example, the possible factors influencing the effectiveness of the PCS are discussed in **Chapter 2** and a theoretical framework for understanding the effect of light CCT on thermal comfort is presented in **Chapter 5**.

For *practitioners* (e.g., building managers), this thesis provides practical solutions and directions to apply a lower winter indoor temperature range while respecting occupants' needs (**Chapter 7**). For *industrialists* (e.g., furniture and installation technology companies), the beneficial effects of PECS (PCS and PLS) shown in this thesis imply a potential business market for PECSs to be used in offices (**Chapters 2, 3, 4, 6 and 7**). For *standardization committees,* the results in this thesis provide quantitative data for making future standards related to PECSs (PCS and PLS) and light-temperature interaction (**Chapters 2-7**). For example, **Chapter 3** showed that personal comfort systems targeting the extremities could provide 80% thermal acceptance rates at 17˚C.

To reach the audience mentioned above, the insights and findings described in this thesis have been (or will be) published open-access in scientific journals to make them available for everyone. Moreover, the research in this thesis has been delivered at various national and international scientific congresses and outreach events in the domains of building services and thermophysiology. Meanwhile, the primary results are disseminated using the internet and social media, such as Twitter, LinkedIn and Research Gates.