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Comfort is more than just thermal comfort

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Abstract
This paper aims to open discussion about multisensory interactions inj the area of the indoor environment. It is based on a brief and incomplete literature review. Some directions for future research are indicated.

Introduction

In the 21st century it should be possible to achieve an indoor environment which people perceive as better than "just" comfortable – i.e. where people will be pleased (delighted) with the indoor environment (Heschong 1979). Of course this goes much further than thermal aspects, because it also involves air quality, lighting and acoustics. All these aspects of the indoor environment interact with each other. Or do they have independent effects on the perceived comfort?
Here we want to define the scope of the problem with a first overview of some key literature.
We considered four main aspects of the indoor environment: thermal comfort, air quality, lighting and acoustics. Starting from the assumption/situation that all relevant environmental parameters are within the required range according to by the current standards, the aim of the paper is to attempt (on the basis of literature review) to answer the following questions:

1) Is there room for improving the environment relative to the current standards?
2) *Interaction A*: If two or more parameters are (slightly) outside the preferred range, do they reinforce each other or do they have independent effects? (e.g. if it is a little bit cool, would you feel cooler/warmer when it is also a little bit too noisy?)
3) *Interaction B*: Would it be possible to counteract a negative effect with a positive one? (e.g. a little bit too noisy, but extra light)

Thermal Comfort – current standards

Current standards (EN-ISO 7730: 2005, ANSI/ASHRAE 55: 2004, EN 15251: 2007) are based on Fanger's Model of thermal comfort (figure 1) which takes into account only physiological reactions to physical aspects of the indoor environment. Auliciems introduced later his Psycho-physiological model of thermal perception (figure 2), which is based on Fanger's model but takes also into account thermal expectations, climate-cultural practises & norms and past thermal environment.

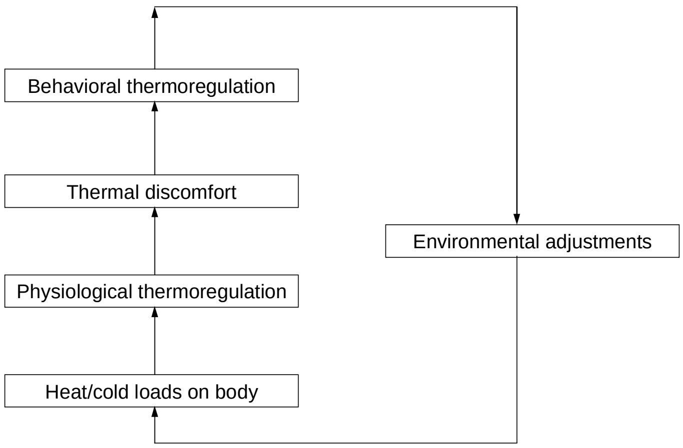

Figure 1 Thermal comfort model from Fanger (ISSO 74)

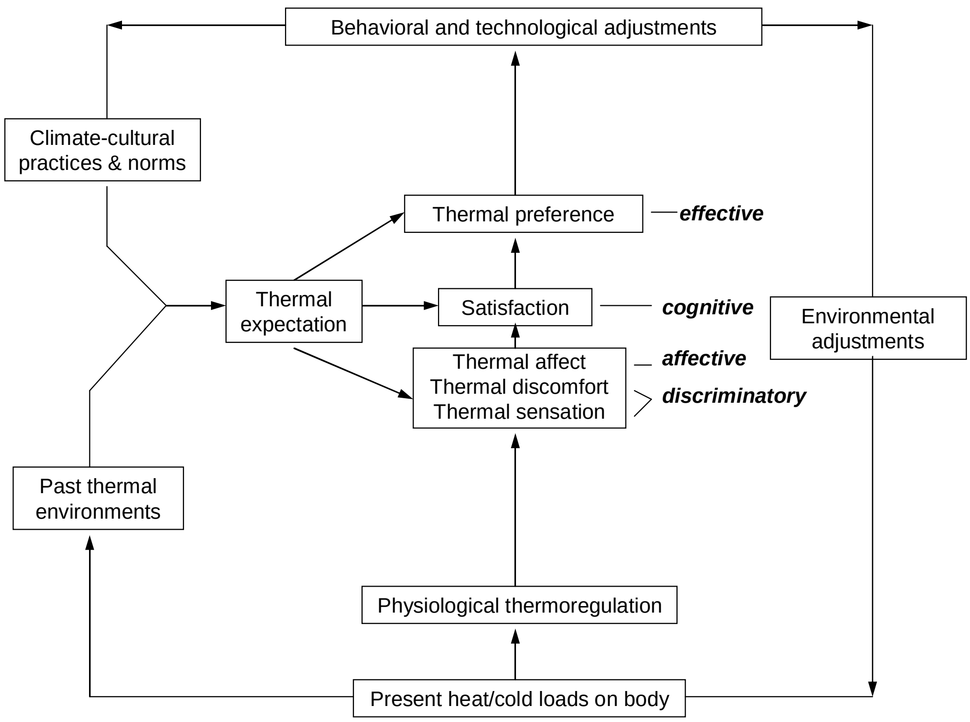

Figure 2 The psycho-physiological model of thermal perception: the adaptive model, (Auliciems, 1997)

Multisensory interactions

People's reaction to the indoor environment is conscious and unconscious. As Candas and Dufour (2005) wrote: "It is well known that the central nervous system integrates all physiological inputs at various sites, and that the resulting sensation may be more or less complex." Toftum (2002) searched for multisensory interactions in the current standards and he concluded that whereas most current standards cover separate aspects of the indoor environment, the CEN Report 1752 covers several aspects, namely thermal conditions, air quality and acoustical conditions. However, each aspect is dealt with separately and the effects of possible interactions between the different aspects on human perception of the indoor environment are not described. In buildings in practice, such interaction will occur. Similar can be said about EN 15251. This standard covers several aspects of indoor environment but deals with them separately. To similar conclusion came van Hoof (2010) who wrote that results of interaction studies have not yet led to an overall understanding of the impact of the total indoor environment on occupants, provide just first steps. According to Bluyssen (2008), the human senses, the so-called "windows of the soul", are basically the instruments we have, to report or indicate whether we feel comfortable by the indoor environment. We judge it by its simultaneous acceptability with respect to heat, cold, smell, noise, darkness, flickering light and other factors.

How important is interaction of the different aspects of the indoor environment? How does it influence occupants vote on the thermal sensation scale? Humphreys (2005) studied data from environmental surveys (the Smart Controls and Thermal Comfort and SCATs project) and he stated that dissatisfaction with one or more aspects of the indoor environment does not necessarily produce dissatisfaction with the environment overall. Conversely, satisfaction with one or more environmental aspect does not necessarily produce satisfaction with the total environment. Building occupants balance the good features against the bad to reach their overall assessment.

Thermal comfort & visual comfort
People are influenced by the level of lighting and illuminance more then they realize. Candas and Dufour (2005) stated that vasodilatation under high illuminance or high temperature colour environments may slightly lower core temperature, which may act on thermal comfort. Webb (2006) in his study about non-visual effects of light wrote that the common lighting systems provide the necessary light for vision and can be selected or adjusted to provide suitable illumination for any task. However, light has other biological effects that influence human physiology, behaviour and mood. Fanger et al. (1977) did research if colour or noise can influence thermal comfort. In their research participated eight women and eight men. In an environmental chamber each subject was exposed to two types of coloured light (extreme red or extreme blue). The subjects preferred a slightly lower (0.4°C) ambient temperature in the extreme red light than in the extreme blue light. Fanger stated that the effect of colour on man's comfort is, however, so small that it has hardly any practical significance.

Thermal comfort & acoustic comfort
Noise is commonly experienced as an unpleasant aspect of the indoor environment. Candas and Dufour (2005) wrote that early research on physiological responses to acoustic stimulation has shown that high noise level can cause vasoconstriction and it might also increase muscle tension and therefore metabolic rate. More studies were done about the influence of noise on thermal comfort. Santos and Gunnarsen (1999) studied optimal levels when two or more parameters of indoor environment are linked. They wanted to determine whether there was a trade-off when temperature was linked to parameters of window opening, draft and noise. During an exposure, the subject was free to optimize the chamber environment by adjusting the operative temperature at a link with window area, draft or noise. Their results show that a decrease in operative temperature of 1^{o}C gives the same decrease in annoyance as approximately 7 dB decreased noise level. They stated that the noise from air conditioning unit will reduce people's willingness to reduce the temperature in warm

room. Clausen et al. (1993) found that $1^{o}C$ change in operative temperature (in a range of $23\text{-}29^{o}C$) have the same effect on human comfort as a change in noise level of 3.9 dB.

Thermal comfort & IAQ (air pollution, odours)
Similar sorts of results apply to IAQ. Clausen et al. (1993) found that a 1°C change in operative temperature have the same effect on human comfort as a change in perceived air quality of 2.4 decipol. Berglund and Cain (1989) investigated the effect on perceived air quality (freshness, stuffiness, and acceptability) of 20 subjects and they concluded that temperature and humidity influenced not only thermal comfort but also perception of the chemical quality of the air.

Discussion
There are not many studies about multi-interactions of different aspects of the indoor environment which influence overall comfort of building occupants but it is widely known (van Hoof et al., 2010) that overall comfort also originates from other environmental factors than just thermal comfort. Based on our literature research a summarizing table was made (table 1) where not all questions got a reliable answer. Some of mentioned research results contradict each other (thermal & visual comfort) and the validity of some results isn't strong enough to generalize them (thermal comfort & IAQ).

Table 1: Summarization of our questions and answers

	Thermal comfort	Indoor air quality	Visual comfort	Acoustic comfort
Current standards expressed as:	*Neutral*	*Minimum level*	*Minimum level*	*Maximum level*
Can we do better?	*Yes*	*Unknown*	*Yes*	*Yes*
Interaction with thermal aspects	*Not applicable*	*Yes*	*?*	*Yes*

In our literature research about multisensory interactions in the field of the thermal comfort, we found strong evidence that alongside purely physical factors there are other, subjective variables which may influence the perception of the thermal comfort (Heijs and Stringer, 1988). To be able to better visualize our results and to promote a discussion in this particular area, some extensions to the Auliciems' model of thermal perception are suggested (figure 3).

Conclusions
It is clear that more research is needed since our initial questions could not yet be answered satisfactory, as summarized below.

Question 1: Is there room for improving the environment relative to the current standards?
Answer: Yes.
Personal control can help people to adapt the indoor environment to their personal preferences, which don't have to be equal with the standard. (Boerstra, 2010)

Question 2: If two or more parameters are (slightly) outside the preferred range, do they reinforce each other or do they have independent effects?
Answer: Unknown
We didn't find a reliable answer.
Question 3: Would it be possible to counteract a negative effect with a positive one?
Answer: Yes
Although our intension was to find a counteraction in the positive way (can interaction of two or more aspects improve the satisfaction with perceived thermal comfort?), most of the found research was done in the negative way (to minimized dissatisfaction with perceived thermal comfort).

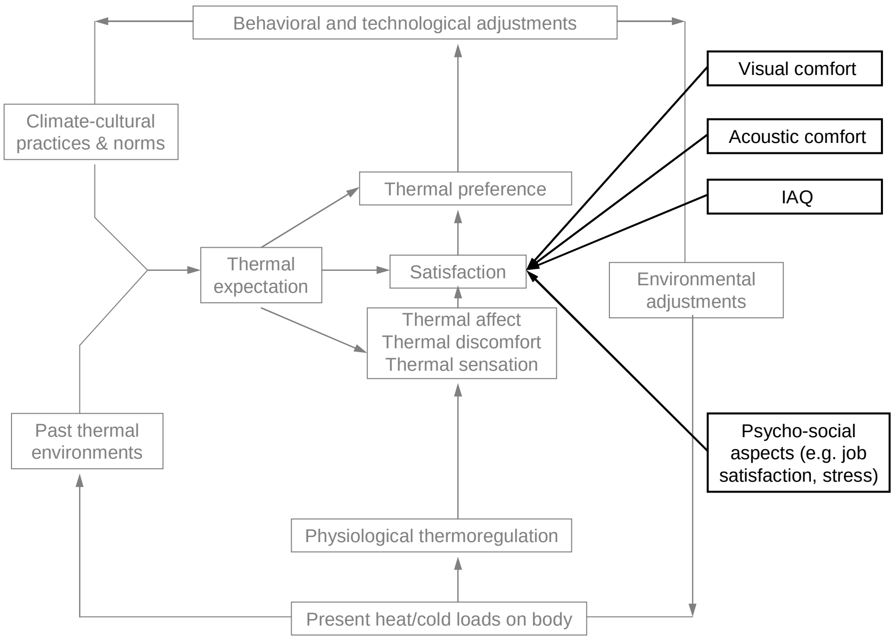

Figure 3 A proposed new psycho-physiological model of thermal perception with IEQ aspects

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