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What about children? Implications from their subjective perception and the risk of overheating in schools

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Abstract:
During field surveys carried out by the authors, it was noticed that thermal perception voting of children is not in line with the expected thermal perceptions according to comfort models. Literature indicates that temperature may well be perceived differently by children, as compared to adults. At moderate temperatures, surveyed children seem to experience warmer thermal sensations than expected from the PMV-model. However, at elevated temperatures, children appeared to perceive environments as less warm than predicted by the model. Operative Temperature requirements for buildings (as mentioned in standards like EN 16798-1 and EN-ISO 7730) that are used primarily by children, most importantly schools, may therefore not provide adequate comfort for them. Does this mean that lowered temperature limits for environments where children are the main users should be used? Does this imply that mechanical cooling systems or intelligent passive cooling solutions should become 'obligatory' in school buildings where they can be afforded? Given the consequences of active school building cooling on energy use, it is therefore important to have a good understanding of this apparent discrepancy between how thermal comfort is perceived by adults and children. It is proposed in the paper that the thermal perception of children, and the consequences on the temperature requirements for schools is a subject that needs greater research, understanding and discussion.

Keywords: Thermal comfort, children, perception, physiology, questionnaires.

1. Introduction

Thermal comfort studies increasingly focus on the variations in thermal sensation between individuals. Physiological, psychological and behavioural factors affect thermal perception and contribute to this inter- and intra- individual variation. Recently, Schweiker et al. (2018) reviewed those aspects that have been demonstrated to be drivers for such differences in thermal perception. Physiological factors such as body composition, metabolic rate and adaptation, and psychological aspects such as perceived control have been proven to affect the thermal perception (Schweiker et al, 2018; Boerstra, 2016, Bischof et al. 2007). However, in that review of Schweiker et al. (2018), the demographic characteristics sex and age, which are known to be factors affecting physiological differences, gave no clear drivers for differences in thermal perception. Though the review drew mainly from studies on the relevant effect of older age ranges. Bischof et al. (2007) found that young aged (<30) and females are more likely to report thermal discomfort or thermal dissatisfaction compared to other age groups and males, whereas thermal sensation is not affected by age or sex. In the few studies on the effects as perceived by younger people (<18 years old), these reported that children appeared to prefer lower temperatures compared to adults (Rupp et al, 2015).

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This conclusion is in line with the observations of the authors in the field, who noticed that the thermal sensations of children in schools is often higher ("warmer") than expected, based on the in-situ measured temperature compared to predictions derived from the PVM and the adaptive model.

In the review of Rupp et al. (2015), a distinction is made between different age groups of children. For children aged between 4-6 years old (kindergarten), only few studies have been carried out. These studies confirm that the thermal sensation vote of children is usually higher than compared to the predicted mean vote as defined in e.g. EN-ISO 7730. (e.g. Fabbri, 2013 and Yun et al, 2014).

There are more studies available that were carried out with children aged 7 years and older. Of these, several indicated that children preferred lower operative temperatures than expected from the PMV and the Adaptive Model (e.g. Mors et al, 2011 and Teli et al, 2012). In line with these observations, a field study among Australian school children (at primary and high schools, aged 10-18) showed that the neutral temperature of children was around 22.5°C, which is below the prediction of the PMV model in a warm environment (de Dear et al, 2015). The study also demonstrated that the relation between the AMV of children and the PMV depends on the operative temperature. Below 25-26°C the AMV of children was higher (warmer) than the predicted by the PMV model. However, the votes matched the PMV-model predictions, when the indoor temperature was between 25-27°C. Above 27°C, the thermal sensation votes of the children were lower (cooler) than what is expected by the PMV-model (de Dear et al, 2015). More recently, an analysis of a two databases of primary and secondary Australian school children was performed by Kim and de Dear. They showed that the preferred temperatures of school children were 1-2°C lower than the neutrality predicted for adults using the adaptive model (Kim and de Dear, 2018). Finally, an overview of 50 years of thermal comfort research in classrooms by Singh et al (2019), concluded that for all stages in education, students report feeling comfortable on the cooler side of thermal sensation.

All in all, (though this overview is not complete) the tendency is clear that children rate the thermal environment differently compared to the above mentioned comfort models. Most studies show that thermal sensation in children seems to be warmer than opposed to adults under the same conditions. Although for higher ambient temperatures, this may not be the case: the study of de Dear et al (2015) showed that the AMV of children is lower (cooler) than the predicted by the PMV model for temperatures >26-27°C. It appears obvious that temperature guidelines for buildings where children are the main occupants (e.g. school and daycare centers), are fitted to their needs. Especially for babies and young children that are recognised as a vulnerable section of the population in case of a heat wave (e.g. German Guideline on heatwave plan development on a regional level BMUB 2017). But do these observations mean that temperature limits in schools should be lowered? And does this imply that mechanical cooling systems or intelligent passive cooling solutions should become 'obligatory' in schools that can afford them? What would be the consequences of cooling school buildings on energy use? In a warming world, with regard to their adaptability, would it be a supportive approach to offer cooler environments for children? We think it is important to have a good understanding of this apparent discrepancy between the reported thermal perception of adults and children. This study was undertaken to explore the potential causes for these differences in thermal perception, and in it the impact of metabolism, subjective evaluation and behavioural changes on children's thermal evaluation of the environment, and influences on children's adaptability are discussed.

2. Metabolic rate of children

The PMV-model uses standardised values of metabolism to consider different metabolic activity in the thermal sensation, but not individual metabolic rates. The definition of the MET unit is based on an "average" male person of 40 years old (Byrne et al, 2005). Likely the metabolic rate that is used as input for the PMV model, is not representative of children's metabolisms. Havenith evaluated metabolic rates and clothing insulation of school children aged between 9 – 18 during different lessons (theory, practical and physical lessons). The metabolic rates (W/m^2) of children were lower than of adults during similar activities (Havenith, 2007). It was suggested that this, especially for younger children, in part can be attributed to their smaller volume to surface ratio. Meaning that their heat loss is relatively high. This observation is opposed to the lower neutral temperatures of children reported in the studies cited above.

However, the actual activity levels during the day will have an important influence on the discrepancy in thermal perception. Children are likely to be more physically active during the day than an average office worker e.g. they are physically active during breaks, and some lessons like gym, and are likely to have an increased metabolism when they get back in class and sitting behind their desk. A Norwegian study monitored the activity levels of preschool children (age 3 or 4) and observed that sedentary behaviour during the entire day was observed between 2.7 to 6.5 hours per day (Andersen et al., 2017). Thereby showing that young children are generally more active than adult office workers. Also for older children (aged 10-18) activity levels appear to be generally higher than office workers. In a field study of de Dear et al. (2015), the average metabolic rate was 1.5 MET, as obtained from a questionnaire with choices between sitting 1.2 MET and active 1.5 MET.

Finally, differences in thermophysiology during exercise are observed among children. Younger children (age 9) have higher skin temperatures during the same exercise than older children (age 13) (Havenith et al., 2019). These higher skin temperatures were accompanied by a lower sweat rate, resulting in less cooling, although it was demonstrated that the younger children have a higher skin blood flow in the forearm as compared to older children. Also the larger surface to volume ratio of children improves dry heat loss. So heat loss strategies differ between children and adults, but do not necessarily put them at a higher risk in higher ambient temperature, not being extreme temperatures (Falk and Dotan, 2008).

From a physiological perspective, part of the reason why children generally prefer lower ambient temperatures, has been shown to possibly be that they are generally more physically active as compared to adults.

3. Subjective evaluation of children

Another explanation for the discrepancy between the thermal sensation of children and adults could be related to the way thermal comfort is investigated, especially the use of different questionnaires for each group, and a further reason that could contribute to deviations in thermal evaluation, may result from differences in interpretation of the thermal sensation scales. Is a child able to respond in a subtle way to a question on a 7-point scale such as the standard ASHRAE thermal comfort scale? Or will children tend to vote more in the extremes than adults? A slightly elevated temperature could trigger an adult to vote 'slightly warm' while a 10-year-old child in the same situation may jump directly from a score 'neutral' to 'hot'.

A recent study amongst university students from different age groups in a temperate climate supports this theory. Young adults, university undergraduate students in their first semester (naïve in terms of building physics and indoor climate) appear to evaluate the importance of indoor environmental aspects in a more pronounced (extreme) way than older students. From this study, it seems that the undergraduate student's indoor environmental concept is divided in two categories: *important* factors (odours, lighting, sound, temperature, ventilation) and *non-important* factors (humidity, air movement). Students on the master's level, who learnt already something about indoor climate, and young adults (<31) working in office environments, reported in a more nuanced manner: their evaluation consisted of a more differentiated picture on the importance of indoor environmental parameters (Hellwig, 2017).

It was observed in the data of the ProKlimA study (Bischof et al. 2003) that in general young people (<31 years) report more extreme responses (warmer, less satisfied, less comfortable etc.) than older people on issues of indoor environmental quality (Hellwig, 2005). The hypothesis proposed to explain these outcomes is that young people tend to report in an exaggerated way, rather than reporting in a balanced or differentiated way because they have not yet collected many individual experiences with indoor environments, they may simply reflect the social norms about the indoor climate because they in fact simply adapt to those conditions they normally occupy, within limits.

Additionally, it can be discussed that if the "neutral" is the desired thermal sensation for school children. From the analyses of the Australian studies, it was observed that school children prefer a thermal sensation that was slightly cooler than neutral (Kim and de Dear, 2018). In their study, this effect is explained as a seasonal effect where students prefer 'a cooler than neutral sensation in a hot and humid climate and a 'warmer than neutral' sensation in a cool climate. However, subjective votes reported in de Dear et al. (2015) from Australian school children show no extreme voting, instead subjective vote of "slightly warm" at about 27°C to "slightly warm" to "warm" at about 29°C.

Finally, contextual factors can affect thermal perception. In adults, it has been demonstrated that there is a relationship between thermal perception, humidity and perceived indoor air quality (Toftum 2002). Therefore, thermal perception in schools, may be influenced by suboptimal indoor air quality (often a problem in schools due to high occupancy levels). For the contextual factors, it would be interesting to compare thermal perception of teachers and students.

4. Clothing behaviour of children

With an increasing age, around secondary school, children become better in making adjustment to restore thermal comfort such as changing clothing level. The ability to make these changes are important to obtain thermal comfort, especially in naturally ventilated buildings (Singh et al., 2019). Depending on the country and school protocols, children have freedom in choosing their clothing insulation. In the field study of de Dear (2015), the average clothing insulation was 0.45 clo, where the indoor temperature was between 18-31°C. This indicates that children can wear shorts and t-shirt to remain thermally comfortable at higher ambient temperatures.

Young children, especially, are more dependent on their care givers to make behavioural changes, or changes in their environments. However, to make adequate changes from the perspective of a child, it is important that the care giver can estimate the thermal state of children. In a study among 6 day-care centres in the Netherlands, thermal sensation from the care givers, the thermal sensations of the children estimated by the care givers and skin temperatures of both care givers and children were monitored. The results show that the skin temperatures, and thermal sensations, of the care givers were correlated. But for the children, there was no significant relation between the skin temperatures of children and their thermal sensations, as estimated by the care givers (Folkerts et al, 2019). These results indicate that it is hard for care givers to adequately estimate thermal sensation of children. The dependency of children on their clothing insulation, may negatively affect their thermal comfort. Also, wearing inflexible school uniform reduces the behavioural adaptability of children in schools.

5. Adaptability of children

The questions raised at the beginning of this paper, whether active cooling of classrooms would be an appropriate answer to the subjective voting of children needs to be discussed very seriously. As known from the adaptive thermal comfort approach, humans adapt to their prevailing indoor environmental conditions (Humphreys, 1976, de Dear and Brager 1998). Active cooling in schools would cause the children to adapt to the narrower temperature band and the lower temperature level. In a warming world, this would likely reduce their acclimatisation level. Non-exposure to warmth remove the stimulus to acclimatise to warm weather, which would diminish the children's adaptability in the long term (Hellwig, 2018). Also cardiovascular health may benefit from exposure to temperature that are just outside the thermoneutral zone (van Marken Lichtenbelt et al. 2017).

A higher impact resulting from climate change is expected for non-acclimatised people, compared to those who are already acclimatised to local climates (Boeckmann & Rohn, 2014). In Australia, a modelled study has shown that a reduced number of days for undertaking outdoor activities are possible for non-acclimatised people in the future, compared with those estimated for the acclimatised population (Maloney & Forbes 2011). Even exposure to mild heat, results in an increased resilience to heat (Pallubinsky et al, 2017). Special guidance for teachers, and parents, on how to support the children in warm periods could be a good solution, changing lesson schedules, encouraging the children to drink more, shifting more exhausting activities to cooler periods etc., and also making "dealing with warmth" a topic of the education.

Field studies confirm that a diverse thermal exposure in classrooms positively accounts for a greater degree in thermal adaptability, for instance children in naturally ventilated classrooms were less sensitive to temperature changes than those in air-conditioned classrooms (de Dear et al, 2015). The range of acceptable temperatures for school children was even estimated to be wider than that of adults (Kim and de Dear, 2018). Seasonal adaptation may also explain why, for high indoor temperatures, thermal sensation of children was lower than expected from the PMV model. All in all, this confirms that it makes sense to expose school children to certain range of indoor temperatures. Keeping in mind that, especially for lower temperatures, thermal sensations of children are generally warmer.

6. Practical implication in schools

This overview paper has shown that there are wide range of factors that may relate to the differences in the thermal perception of adults and children. The personal factors that are most commonly used to estimate thermal sensation, such as clothing level and metabolic rate, differ between children and adults, and between an office and a school environment. Moreover, methods of evaluating the thermal responses of children may result in different scores being attributes to the same thermal state, because children may either not understand the question asked, or tend to vote in a less differentiated manner. All together it is not surprising that most field studies observe that different thermal perceptions are experienced by children and adults in similar thermal conditions.

Rather than simply report thermal perceptions of children, organisations should consider the effect of temperature on learning performance when formulating temperature guidelines for school buildings. In accordance with the outcomes from reported studies on thermal preferences in temperatures ranging from 20°C - 30°C, Danish students were shown to perform best under a lower ambient temperature (Wargocki et al, 2019). They found an effect on thermal perception and student performance of increased speeds (1-2% per 1 K), but not on the error rate in students work. The actual span of temperatures affecting children's performance, is probably related to the thermal environment, both indoors and outdoors, to which they have become adapted to (de Dear et al, 2015). A literature overview in de Dear et al (2015) on school children performance also summarised findings on decreased speed of performance in warmer environments, but they reported also that the number of errors in school tests did not tend to increase with elevated temperatures. It can be asked whether it poses a problem if the actual time of a year that such results are reported for are considered. Moreover, it is uncertain whether results from laboratory tests are representative of the effect of temperature on the education of children (Humphreys et al, 2016). Nonetheless, extremely high, or low, temperatures in the classrooms should be avoided.

All in all, the reported thermal perception of children, combined with the higher levels of physical activity in schools of the children, as well as of the teachers, who generally are standing and walking considerably more often than an average office-worker, advocate in favour of lower temperature limits in schools, or more use of the cooling effects of useful opening windows in classrooms. Moreover, due to high occupancy there is an increased risk for overheating, especially if ventilation rates are low, as in areas without opening windows, openable to instantly increase airflow when needed. A sensible starting point in the design of educational facilities, especially primary, schools in moderate climates, is to assume that with rising global temperatures overheating is increasing, and increasingly will become a greater problem compared, than the heating to alleviate cold weather. Therefore extra effort needs to be expended in the appropriate passive design of our school buildings (improved opening windows, solar shading devices, better use of building mass and summer night cooling, etc) and enhance their performance, in relation to warm weather, under every day operation (Hellwig, 2016). High ventilation rates are necessary at times to achieve this in warm and hot periods. Provision of enhance air flow should be designed carefully to prevent draught (especially in cold, windy weather). The correct design and detailing of the building envelope, and its systems, is fundamental to the avoidance of a poor and unpleasant thermal environment in educational buildings.

Although still some effort is put in identifying and explaining learning performance decreases in children due to “non-optimised” conditions, it is questioned whether active cooling would be the right answer to negate this. Logically this will depend on the climate. Also taken into consideration is the fact that artificially lower temperatures potentially also lowers the adaptability of children to higher temperatures. Of course, the currently endemic systematic overheating experienced in schools, particularly modern schools, resulting from the inappropriate design, operation or construction of systems and buildings should be corrected wherever possible, not least because they can considerably extend the overheating periods experienced. Furthermore, peak cooling will increasingly have to be used to avoid extreme indoor temperatures during summer, while maintaining adaptive capacity to higher ambient temperatures, and avoid extensive energy use for cooling. Passive ways of reducing the peak cooling load through timetabling, shifting teaching to cooler times of the day, and moving the locations of teaching activities from the hotter to the cooler parts of the building using thermally landscaped teaching schedules may also prove effective in reducing the effort of cooling for educational facilities.

7. Conclusion

In conclusion, this review highlights the need for temperature guidelines for schools to pay attention to the thermal perceptions of children, that has been shown to differ quite considerably , than reported by adults at the same temperatures. For moderate temperatures (<25°C), study results are quite consistent showing that children perceive the environment as being warmer than do adults. Above these ambient temperatures, the adaptation opportunities available to children, and their level of existing adaptation, potentially plays a large role in which temperatures are perceived as being too warm. In defining appropriate temperature guidelines for schools, a better understanding is needed as to why such differences in perception exist, how it affects learning performance of pupils and students, and to what extent are children safely adapt to the ambient temperatures.

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