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Naturally ventilated classrooms: An assessment of existing comfort models for predicting the thermal sensation and preference of primary school children

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ABSTRACT

Current thermal comfort models are based on studies with adult subjects, mainly in offices. There is no assurance however that these models apply to children. This paper presents findings from thermal comfort surveys and measurements of indoor environmental variables in naturally ventilated classrooms in Hampshire, England. School children aged 7–11 were surveyed regarding their thermal sensation and preference in repeated survey runs outside the heating season, gathering about 1300 responses in total. The results were compared to predictions achieved with the two common approaches used in existing comfort standards, the heat balance and the adaptive comfort model. The heat balance model indices PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) were calculated for the survey periods, using the measured physical parameters, estimated values for clothing insulation and four different approaches for determining the metabolic rate. The applicability of the adaptive comfort model was investigated by comparing the comfort temperature equation derived from the survey with the equation used in the European Standard EN 15251. The results suggest that children are more sensitive to higher temperatures than adults with the comfort temperatures being about 4 °C and 2 °C lower than the PMV and the EN 15251 adaptive comfort model predictions respectively.

1. Introduction

There has been extensive research on thermal comfort over several decades, which has led to two main approaches, the thermo-physiological [1–3] and the adaptive comfort approach [4,5]. Both approaches have been developed from the findings of studies with adult subjects and form the basis for existing thermal comfort standards, which include ISO 7730 [6], ASHRAE Standard-55 [7] and, at the European level, EN 15251 [8]. Based on the criteria for offices, these standards also provide comfort criteria for school environments, assuming that determinants of thermal comfort are similar in children and adults. However, factors such as metabolic rate, type of clothing, and level of activity may result in differences in the perceived optimal conditions [9]. Additionally, children have been found to take limited adaptive action to adjust to the indoor thermal environment during class hours [10]. They can add or remove layers of clothing but cannot freely open or close windows or adjust their activity level [11]. There is no assurance that the thermal comfort criteria applicable for adults are also optimal for children's comfort or performance.

Few studies have focused on children's thermal perception in temperate climates. Research conducted in schools in tropical and subtropical regions have explored the applicability of the ASHRAE specifications to those climates [10,12–14]. On a European level, a recent study conducted in the Netherlands investigated the application of the PMV (predicted mean vote) charts and clothing adaptation on a relatively small sample of 79 children [15]. In the United Kingdom (UK), published data sets from school studies date back to the 1970s [16,17]. Overall, there is a general lack of studies related to children's thermal comfort perception [18].

There is however a need for such comfort studies, in particular in relation to school buildings, as the quality of a classroom environment is known to affect children's health, well-being, learning ability and comfort [19]. Temperature is considered to be one of the most important indoor environmental comfort parameters as elevated temperatures may lead to a decline in productivity [20]. In the UK, thermal comfort in schools, in particular outside the heating season, has become an issue of concern as:

- Teachers have reported that they have been experiencing uncomfortably warm thermal conditions inside classrooms during recent summer periods [21].
- Parts of the existing school building stock are unsuitable for high external temperatures, due to characteristics such as low

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thermal mass and highly glazed façades. (Nevertheless, the life of the majority of these buildings will have to be extended further as new school projects have been cancelled due to public finance cuts [22].)
- Predictions for the UK's climate indicate warmer summer temperatures in the future [23], which will increase the overheating risk of naturally ventilated buildings [24].

In the UK, guidelines for the thermal conditions in schools are given in Building Bulletins 87 [25] and 101 [26] and CIBSE Guide A: Environmental Design [27]. However, in terms of thermal acceptability outside the heating season, they are limited to fixed temperature thresholds and overheating criteria. There is no specific information on temperatures deemed comfortable by children.

This paper investigates the applicability of existing thermal comfort models for predicting children's thermal sensation and comfort temperature in classrooms through a field study in a naturally ventilated school. It also looks at the impact of building characteristics on pupils' thermal sensation and preference. Furthermore, the relation of the thermal comfort survey results to the classrooms' long-term measured thermal performance is studied.

2. The case study building

Building B on the aerial view given in Fig. 1 shows the case study building, which is a naturally ventilated primary school in Southampton, Hampshire, UK. The building was constructed in 1978 using a light-weight steel frame construction and prefabricated concrete panels. It is attached to an infant school which was constructed in the same period (building A in Fig. 1). As shown in Fig. 1 (upper right hand side), the case study building consists of two parts which create an enclosed courtyard: a 2-storey L shaped building housing 8 classrooms and computer spaces and a 1-storey building with offices, the hall and kitchen. The study was conducted in the L-shaped building part where most of the school activities take place. The building has single-glazed, top-hung outward opening windows with reflective window film and is internally shaded with manually operated blinds.

The case study building is a typical example of a light-weight post war school in the UK. The school has reported overheating incidents in the past, which is probably related to characteristics such as: morning solar gains due to the North-East and South-East orientation of the classrooms, a glazing to wall ratio of approximately 40% (Fig. 1, bottom), large outdoor tarmac areas, a lack of vegetation and shading, the flat bitumen roof, the light-weight construction, single glazing and a lack of wind exposure.

3. Thermal comfort survey and environmental monitoring methodology

In order to assess the thermal conditions in the classrooms outside the heating season the dry bulb temperature and relative humidity were monitored at 5 min intervals from March to August 2011. Pupil questionnaire surveys and simultaneous measurements of the indoor environmental variables (as per ISO 7726 [28]) were conducted in line with standard methods used in adult surveys [18]. Approximately 230 pupils aged 7–11 in all 8 classrooms were surveyed 6 times and a total of 1314 responses were gathered. The field studies were carried out on 12 days outside the heating season, from April to July 2011.

In the following, the word "test" refers to a 2-day visit to the school (6 tests in total). The word "survey" corresponds to each classroom investigation. 4 surveys were performed per day, i.e. 8 surveys per test (all 8 classrooms over 2 days) and 48 surveys in total.

Table 1
The scales used in the questionnaire survey.

TSV scale	TPV scale
(+3) Hot	(+3) A lot warmer
(+2) Warm	(+2) Warmer
(+1) A bit warm	(+1) A bit warmer
(0) OK	(0) No change
(−1) A bit cool	(−1) A bit colder
(−2) Cool	(−2) Colder
(−3) Cold	(−3) A lot colder

The survey questionnaire, which is provided in Appendix A, was checked by the teachers prior to the study in order to be comprehensible to children. It included questions about:

(a) the thermal sensation vote (TSV) of the respondent towards the indoor thermal environment, based on the 7-point ASHRAE thermal sensation scale (cold, cool, slightly cool, neutral, slightly warm, warm, hot)
(b) the thermal preference vote (TPV) based on a 7-point scale (a lot colder, colder, a bit colder, no change, a bit warmer, warmer, a lot warmer)
(c) the feeling of comfort
(d) clothing information (whether the respondent was wearing a jumper (pullover) while answering the questionnaire)
(e) the feeling of tiredness
(f) the activity of the respondent prior to the questionnaire

A slightly amended version of the ASHRAE scale (Table 1) was chosen for the thermal sensation vote (TSV) assessment even though some research suggests that the Bedford scale (much too cool, too cool, comfortably cool, comfortable, comfortably warm, too warm, much too warm) might be more appropriate for the evaluation of the acceptability of a thermal environment [13]. The reason for this choice was that the ASHRAE scale was considered easier for young children to understand which was crucial for the reliability of the results. The ASHRAE scale was even simplified based on the teachers' comments/advice. The options "slightly cool", "slightly warm" and "neutral" were replaced by "a bit cool", "a bit warm" and "OK". As can be seen in Table 1, for the assessment of the thermal preference vote (TPV) a 7-point scale was applied instead of the commonly used 3-point scale. This was done in order to facilitate comparison with the TSVs.

The children were not asked about their perception of thermal acceptability, humidity or air speed as undertaken in most similar adult surveys, because teachers found these questions difficult for 7–11-year olds to comprehend. Also, the questionnaire did not include a question about the clothes children were wearing during the survey as this would have made the form too time consuming and gone beyond the children's attention span. After discussion with the teachers, it was decided to include a simple question about whether they wore their jumper, as this changes their clothing insulation substantially and is one of the limited adaptive actions the children can take during the school day.

After the second survey visit, the children showed some discontent about having to repeat the questionnaire. Therefore, in order to ensure the children's continued interest in the surveys, a sticker booklet was prepared and handed out to each pupil. Each time a survey was undertaken, the children received a reward sticker. Furthermore, to achieve ongoing engagement with the topic, the booklets contained individual research tasks related to the indoor climate. These tasks were specifically tailored towards different age groups: i.e. years 3 & 4 and years 5 & 6.