Investigating recommended temperature zones and clothing assumptions in the assessment of classrooms' thermal environment

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Abstract. There has been a lot of research over recent years on children's thermal comfort, which highlighted the different needs of young children compared to adults. These findings pose a challenge to designers on how to best meet these needs. This paper focuses on recommended temperature zones and assumptions used in standards through a case study in a grade school in Gothenburg, Sweden. Six classrooms were investigated in three buildings of the same school. The indoor temperature was measured using small-scale data loggers programmed to log at 5-minute intervals for a period of 5 months (mid-December to early-June). Thermal comfort questionnaires were also distributed to children throughout the monitoring period. A total of 45,000 temperature readings corresponding to assumed occupied hours and approximately 2,000 thermal sensation votes and clothing insulation values are used in the analysis. Results indicate that assumed occupancy schedules may differ to real use, leading to overestimation of time when indoor environmental parameters are outside recommended ranges. Children's clothing insulation was found to be lower than assumed in standards in both winter and summer. Omitting to account for such differences may lead to misinterpretation of indoor environment assessments and design solutions.

Keywords: Thermal comfort, Indoor environment quality, School buildings, Children, clothing insulation.

1 Introduction

Over the last years a number of studies in schools found differences in thermal sensation and comfort between children and adults [1-6] and highlighted that methods and criteria currently used in the design and evaluation of school environments may not match the children's needs or the conditions experienced in classrooms. Part of the issue may lie in assumptions used when assessing children's thermal comfort, which is the focus of this paper.

For the prediction of thermal comfort six parameters are used; four environmental: air temperature, radiant temperature, air speed and relative humidity, and two personal: metabolic rate and clothing insulation [7]. Considering possible differences in these parameters in spaces occupied by adults or children, the personal parameters would be the most influential. A sensitivity analysis has also shown that the majority of current indices used for predicting thermal comfort are most influenced by personal variables [8]. Guidance on calculating metabolic rate and clothing insulation can be found in standards ISO 8996 [9] and ISO 9920 [10] respectively. However, in most applications direct measurements of these parameters are not possible and therefore tables with standard values are used [7, 11]. In relation to school environments, there is lack of specific data for children [12], hence the same tables are used under the assumption that children's clothing, metabolic rate and adaptive behavior are comparable to adults' in offices.

This study investigates assumptions used in the assessment of the thermal environment in schools through a case study in six classrooms in Sweden, focusing on the recommended temperature zones in current standards and the role of clothing insulation.

1.1 Clothing insulation in thermal comfort assessment

The thermal insulation provided by clothes has a considerable impact on thermal comfort and clothing adjustment is probably the most powerful behavioral action to restore comfort. Clothing insulation is the "equivalent uniform thermal resistance" on a human body [10] expressed in clo (1 clo=0.155 $m^2 \cdot K \cdot W^{-1}$). The unit was introduced for the representation of the insulation required to keep a seated person comfortable at 21^oC and corresponds to the insulation of a suit with normal underclothes [13], a work outfit that was common in office buildings in the 1970s.

In the standards, recommended temperature ranges are typically calculated for clothing insulation equal to 0.5clo and 1clo for summer and winter respectively [7, 11, 14]. If there is no information on clothing, thermal and energy evaluations are performed with these two values, which affect the design of buildings and HVAC systems, the energy use and the operation of buildings [15].

European Standard EN15251 on 'Indoor environmental input parameters for design and assessment of energy performance of buildings' recommends temperature ranges for classrooms based on the above standard assumptions. For "clothing ~1.0clo" the temperature range for heating in a category II building (normal level of expectation) is 20.0-24.0^oC, whilst the range for cooling with "clothing ~0.5clo" is 23.0-26.0^oC [14]. The Public Health Agency of Sweden provides temperature ranges which also apply to classrooms (20.0-23.0^oC) [16], without any reference to corresponding clothing levels. In reality, these ranges should be adjusted based on actual clothing levels and activities found in schools. Such approach is included in a Swedish document with guidelines for school environments developed in the 1990s [17]. An example can be seen in Table 1. The proposed relationships however are still based on Fanger's PMV model, which was developed with adult subjects and has been found to be inappropriate for young children [1-6]. Being developed in the 90s, it may also be rather outdated regarding typical school clothing.

Table 1. Example of the relationship between activity, clothes and appropriate indoor air temperature for comfort, taken from [17], translated to English.

Activity	Clothing combination			
	Sports clothing	Summer clothes (shirt, shorts)	Winter light indoor clothing (sweater, trousers)	Winter warm indoor clothing (costume)
Schoolwork, sitting	28.0 °C	24.0 °C	23.0 °C	21.0 °C
Schoolwork, standing	26.5 °C	23.0 °C	20.0 °C	17.0 °C

2 Methods

The study presented here includes long-term measurements and thermal comfort surveys in a grade school in Gothenburg, Sweden. The school is housed in 9 buildings, seven of which were built in the turn of the 18th to the 19th century and two in the end of the 20th century, which have all been refurbished. The surveys took place in 6 classrooms located in 3 of the 9 buildings.

The study follows in most parts the methodology previously used in UK schools [2, 18]. However, this time an extended version of the same thermal comfort questionnaire was used, translated into Swedish. The questionnaire consists of 9 questions covering thermal perception, comfort and adaptive behaviour. Approximately 16 surveys were conducted in each classroom during class and at least 20 minutes after breaks or other non-sedentary activities. This ensures as much as possible consistent metabolic rates throughout the study. At the time of the surveys measurements of the environmental parameters affecting thermal comfort were also taken (air temperature, globe temperature, air speed, relative humidity).Ventilation rates were not measured as the focus of the study is on thermal comfort and the parameters directly affecting it. Details on the instruments and measuring procedures can be found in an earlier publication [19]. In this paper answers in two of the questions are used: 1) thermal sensation vote on a 7-point scale and 2) clothing items worn, using a clothing item checklist.

For the long-term measurements of air temperature and relative humidity in the classrooms small Madgetech dataloggers were used. They were placed on pinboards in the classrooms at a height of approximately 1.5m and away from heat sources and direct solar radiation. The loggers were programmed to take and store measurements every 5 minutes.

3 Results

The long-term measurements were processed so that only temperatures during school days are used. All the holidays, weekends, out-of-term dates and out-of-school hours were removed. The remaining data reflect the hours that classrooms are expected to be occupied, between 8:30-15:00. However, breaks or other activities outside the classrooms within school hours could not be subtracted from the dataset as every classroom had breaks and classes at different times.

It should be noted that for the assessment of the thermal environment operative temperature data should be used so that both convective and radiative effects are taken into account. However, in this study only the air temperature was monitored continuously in the classrooms. In a previous investigation in three school buildings with different construction and thermal mass, the difference between operative and air temperature was found to be very low [20]. The same investigation was conducted here, using 90 sets of simultaneous measurements of air (T_a) and globe (T_{op}) temperatures for various outdoor weather conditions. The average difference between T_{op} and T_a was 0.1 (σ=0.1), which is very small and lower than the manufacturer-stated accuracy of the air temperature sensor. Furthermore, the measured air speeds during surveys were always below 0.1 m/s. Therefore, the monitored air temperatures are used without any correction.

3.1 Classrooms' thermal environment

The average air temperature of the classrooms in the heating period (Dec-Apr) was 21.5^{o}C (σ=1.1) and in the non-heating period (May-Jun) 24.5^{o}C (σ=2.1). Fig. 1 shows the classrooms' average daily temperatures in relation to the outdoor daily temperature and the recommended ranges based on EN15251 [14]. The indoor temperatures on average in most classrooms and on most days were within recommended ranges. There are however a number of datapoints outside the ranges, mainly in classrooms 4 and 6. It appears that these classrooms' average daily temperature follows the outdoor temperature changes more closely than the others, which is most probably due to building characteristics. E.g. classroom 4 is naturally ventilated (through window opening) at the top floor of the building with three sides exposed to outside conditions.

Fig. 2 and Fig. 3 show the distributions of the 5-minute measurements of air temperature and relative humidity per classroom during expected occupied hours for the two seasons investigated (heating/non-heating). In winter there are several measurements below 20^{o}C, e.g. 33% in classroom 4 and 23% in classroom 6 (Fig. 2). In the non-heating season there is exceedance of the recommended upper limit in all classrooms, ranging from 18% of the measurements in classroom 5 to 35% in classroom 4. Relative humidity is overall relatively low in winter with an average of 31.5%, while in the summer it increases to 38.5%. However, when the air temperature is within the comfort range, as in the majority of the time here, the effect of humidity on thermal sensation is modest [21].

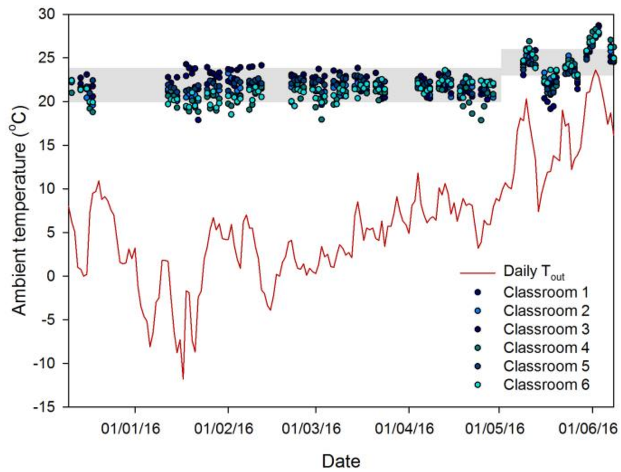

Fig. 1. Average daily ambient temperature and classrooms' average daily indoor temperature for the duration of the study (Dec 2015- Jun 2016). Recommended temperature ranges are based on EN15251 [14].

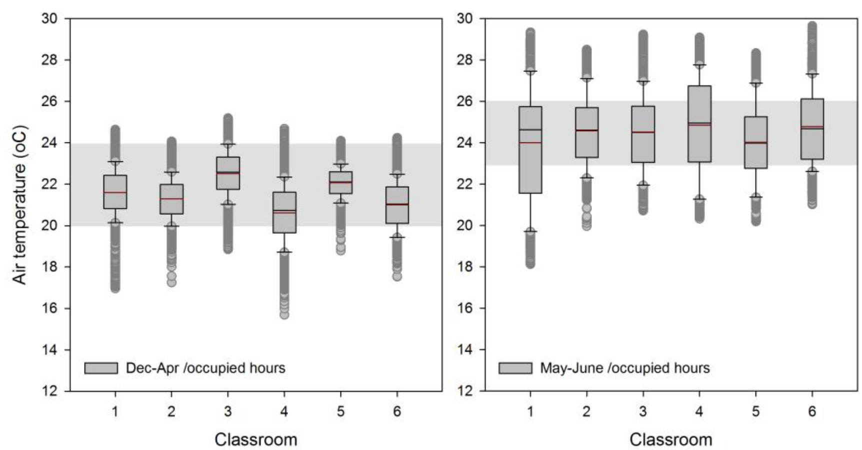

Fig. 2. Distribution of the measured air temperature per classroom (1-6) during occupied hours in the winter and summer months. Box: the 50% of the values; whiskers: the 10th and 90th percentile; dots: outliers; black line: median, red line: mean. Recommended temperature ranges are based on EN15251 [14].

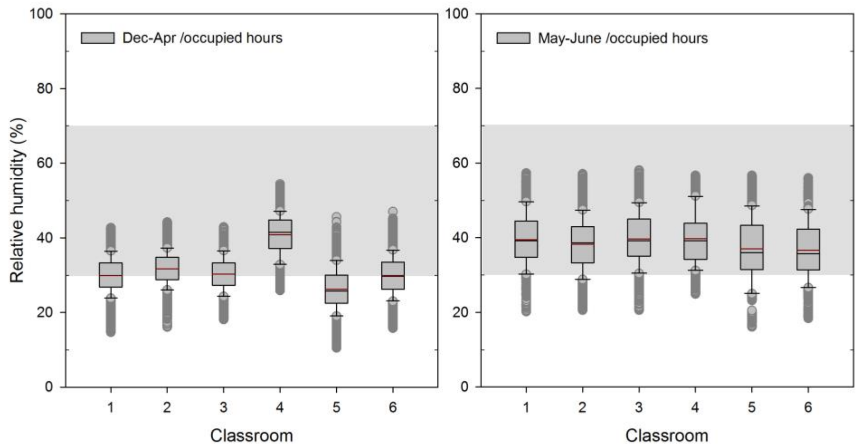

Fig. 3. Distribution of the measured relative humidity per classroom (1-6) during occupied hours in the winter and summer months. Box: the 50% of the values; whiskers: the 10th and 90th percentile; dots: outliers; black line: median, red line: mean.

Overall, the measurements shown in Fig. 2 and Fig. 3 point to a wide range of conditions in the classrooms during the assumed occupancy period. However, the actual schedule of occupancy may vary significantly based on educational practices. It is therefore likely that more time than assumed is spent outside the classroom, which agrees with anecdotal evidence from the teachers and visual inspection of the data. Furthermore, the recommended ranges used above assume typical metabolic rates of around 70 W/m^2 (based on adults) and clothing insulation values of 1 and 0.5 clo for winter and summer respectively. The effect of thermal adaptation, which leads to higher tolerance to temperature typically experienced [13], is also not taken into account. These results therefore do not provide a clear indication of children's comfort.

3.2 Thermal sensation, temperature and clothing insulation

For the comparison of the thermal environment with children's thermal sensation and clothing insulation in both investigated seasons the data from the surveys are used. The operative temperature during the 90 surveys conducted was always above 20^{o}C, which supports the hypothesis that the lower temperatures seen in Fig. 2 are from breaks or other activities outside the classroom, when teachers would open windows for ventilation.

As can be seen in Table 2 and Table 3, the average clothing insulation is consistent between classrooms in the same season, with averages of 0.7clo and 0.38 clo in winter and spring/summer respectively. These values are lower than the assumed values of 1clo for winter and 0.5clo for summer used in standards [7, 11, 14] and that found in Dutch school classrooms 10 years ago [12]. However, this study's average clo for winter is close to the median winter clothing insulation value of 0.69clo found in office buildings [15], suggesting a possible trend towards lower clothing insulation values indoors. At the same time, the average operative temperatures during surveys were between 22.0-23.4^{o}C, which lies in the warm end of the recommended zone but is reasonable, considering the relatively low clothing insulation. There appears to be a trend towards lower clothing insulations and higher indoor temperatures. The causal effect however is unknown, i.e whether clothing choices led to the temperature increase or, conversely, whether children adapted their clothing to their classroom's thermal environment.

Table 2. Mean and standard deviation (SD) of the children's thermal sensation vote (TSV), the operative temperature (T_{op}) and clothing insulation (clo) during surveys in the heating season (winter) by classroom.

Classroom	TSV		T_{op}		Clo	
	mean	SD	mean	SD	mean	SD
1	0.5	1.3	23.0	1.1	0.65	0.15
2	0.3	1.2	22.0	0.7	0.67	0.15
3	0.7	1.2	23.4	0.6	0.70	0.15
4	0.4	1.1	22.8	0.6	0.71	0.15
5	0.0	1.2	22.3	0.3	0.68	0.14
6	0.0	1.1	22.7	0.9	0.71	0.14

In the non-heating season the relationship is clearer, with the children adapting their clothing to the warmer temperatures (Table 3). The classrooms' average operative temperatures during surveys were between 24.3-26.4^{o}C, again in the warm side of the spectrum but clothing insulations are again lower than assumed. The average thermal sensation votes of the children are between 0.4-0.9 scale points, which lie between 'neutral' and 'slightly warm'. Considering the findings that children feel warmer than adults at the same temperatures [2], clothing adaptation succeeded in restoring comfort to a large extent.

Table 3. Mean and standard deviation (SD) of the children's thermal sensation vote (TSV), the operative temperature (T_{op}) and clothing insulation (clo) during surveys in spring/summer by classroom.

Classroom	TSV		T_{op}		Clo	
	mean	SD	mean	SD	mean	SD
1	0.7	1.1	25.3	0.9	0.35	0.13
2	0.7	1.1	25.3	1.0	0.36	0.13
3	0.9	1.0	26.1	0.7	0.35	0.14
4	0.6	1.1	26.4	1.0	0.40	0.14
5	0.4	1.2	24.4	0.8	0.39	0.15
6	0.4	1.2	24.3	0.2	0.45	0.12

4 Conclusions

Standards and guidelines for the indoor environment often provide recommended temperature ranges based on assumed clothing insulation values, metabolic rates and basic adaptive behavior. Although designers and practitioners should adjust these recommendations based on the specific applications encountered, in practice these ranges are mostly used as fixed thresholds. This could lead to misinterpretation of indoor climate and energy assessments.

This paper explored this through a case study in a Swedish primary school. Assessment of the classrooms' thermal environment during assumed occupied hours and using the recommended ranges highlighted issues of temperatures outside the recommended comfort zones both for winter and summer. However, further investigation indicated that part of these values were outside occupancy hours or were due to windows being intermittently opened for ventilation. It is likely that changes in educational practices towards more flexible curricula may have also contributed to this difference. Such developments may be overlooked, especially when it comes to analysing large amounts of data where behaviours and occupancy schedules are difficult to identify.

It was observed that children's clothing insulation was on average lower than the assumed values both in winter and spring/summer (0.7 and 0.4 respectively). Even though this helps to achieve comfort in warm summer conditions without mechanical cooling, in winter it is coupled with high indoor temperatures, which lead to higher heating demand. In either case, these values do not reflect those assumed in standards. It is clear that personal parameters and occupant behavior (teachers' and children's) should be more adequately addressed in guidelines for schools' thermal environment, to improve decision making in the design stage.

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