THERMAL COMFORT IN NURSERIES

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ABSTRACT

The mean skin temperatures as well as the temperatures of the hands, feet and forehead of small children were measured in nurseries at air temperature of 20 and 22◦C. Differences were studied between babies remaining still, babies crawling on tiling, wooden floors or rubber foam groundsheets and older walking children.

The results suggest that an air temperature of 22◦C leads to skin temperatures comparable to those observed for resting adults in comfort, while 20◦C seems to induce a slight but overall cooling of the body and a large cooling of the extremities for the babies remaining still.

The materials of floor covering should be taken care of and preference should be given to low conductivity materials.

Assuming that the optimum skin temperatures are the same for children than for adults, it appears that the PMV-PPD approach can be used to predict that particular comfort condition provided an increase of 20 wm^{-2} is taken into account for the metabolic rate of the small children.

Key words: thermal comfort, babies, floor covering

INTRODUCTION

The method of determination of the thermal comfort conditions originally developed by Fanger (1972) has received international approval and has formed the subject of ISO standard 7730 (1984) and ASHRAE Standard 55-1992. These standards apply to healthy men and women. To our knowledge, their validity in the case of small children has never been investigated. Several recommendations or even regulations have been formulated concerning the day nurseries and the recommended air temperature in Belgium is 20◦C. The basis for this recommendation is unknown. These environments raise specific problems, considering the small height of the children, therefore their position near the ground and usually in the coldest air layers, and the presence of adults with higher activities and therefore preferring relatively low temperatures.

The objectives of this research were (1) to verify whether 20◦ of air temperature is acceptable for nurseries, (2) to study the applicability of the ISO standard 7730 (1984) for small children and, additionally (3) to determine the impact of the different floor coverings.

MATERIAL AND METHOD

The day nursery where the study was made includes two sections. The first one, devoted to the small children (3 months to 18 months) includes two play-rooms, one with tiling and the other with wooden floor. The second section is devoted to the older children (18 months to 3 years). It includes a play-room with tiling.

Three categories of children were formed:

1. 5 motionless children (M), 3 to 6 months old (mean = 4 months)
2. 5 babies crawling on the floor (C), aged 7 to 11 months (mean = 9 months)
3. 6 older children (S), walking for more than 3 months and aged 18 months to 3 years (mean = 24 months).

The first group was observed while resting still on the groundsheet, the second group (C) on three occasions, while crawling on tiling (CP), on wooden floor (CW) or on groundsheet (CG) and the third group while playing in the play-room with tiling. The groundsheet consisted of a 15 mm thick rubber foam.

The heating system consisted of ordinary hot-water radiators equipped with thermostatic valves.
In order to check the evolution of the air temperature and the humidity in the different rooms according to time and according to the external climatic conditions, thermohygrographs were placed inside in each of the play-rooms and outside (at 1.4 m from the ground) during three weeks. These recordings made possible to validate point measurements made in the different rooms. These measurements were made using an indoor climate analyzer Brüel & Kjaer 1213, recording the air temperature (t_a, ◦C), the relative humidity (RH, %), the air velocity (V_a, m/s) and the plane radiant temperature (t_{pr}, ◦C). The mean radiant temperature was computed from the 6 plane temperatures recorded in three orthogonal directions according to ISO 7726 (1985). Measurements were made at six different heights and at six locations in each room in order to check the spatial uniformity of the climatic conditions. The six heights adopted were the heights of the head, the abdomen, and the ankles of an adult (1.7, 1.1 and 0.1 m) as well as of a two years old child (0.86, 0.52 and 0.05 m). On the basis of these measurements, three heights only were kept for the measurements made during the study: 1.4 m (average of the heights of the head and abdomen of an adult), 0.7 m for the children and 0.05 m for the ankles of the children. The mean air temperature was calculated as the average of the temperatures at the three heights with a double weight for the one measured at 0.7 m from the floor. The floor temperature was measured using a YSI series 700 transducer sticked on the floor and connected to a Digitec 5810 thermometer. All instruments were checked and/or calibrated before and after the measurements.

The properly so called study consisted of comparing the skin temperatures of the children in two different conditions characterised by mean air temperatures of 20 and 22◦C.
These two temperatures were chosen, the first one on the basis of the Belgian recommendations for the nurseries and the other (22◦C) using the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) indices proposed by ISO 7730 (1984) (see discussion below).
The thermal clothing insulation of the children was estimated on the basis of ISO standard 9920 (1992). The mean thermal insulation was estimated to be equal to 0.9 $\pm$ 0.1 clo. This corresponds to a short sleeved body shirt, a T-shirt, a sweater, a baby's napkin (until two years old), shorts, trousers (training, jeans or velvet), socks and shoes.

The mean skin temperature (t_{sk} ◦C) was used as an indicator of comfort. ISO standard 9886 (1992) recommends to evaluate the mean skin temperature from local measurements made at 4, 8 or 14 points on the body. Although the weighting schemes with 8 and 14 measuring points are recommended in thermal conditions close to neutrality, we adopted a scheme with 4 points only in order to reduce the handling (dressing and undressing) of the babies and therefore the unpleasantness of these measurements for the children. The four points scheme proposed by Ramanathan (1984) was preferred to the one described in ISO 9886 (1992) as this made possible to define a mean temperature of the body surface covered by the clothing, not taking into account the hands and feet. This scheme includes the measurement of the skin temperature on the arm,the chest,the thigh and the calf. The mean skin temperature is then calculated using 0.3, 0.3, 0.2 and 0.2 respectively as weighting coefficients. The skin temperature measurements were made using an infrared detector (Ultrakust M 202) averaging the temperature on a skin surface of about 1 cm². In addition, the temperature of the back and the palm of the right hand, the back and the sole of the right foot as well as the forehead were also recorded by the same procedure. The

data were not recorded when the children had a fever (rectal temperature higher than 37.5◦C).

RESULTS

During the observation period of three weeks, external temperatures varied between -6 to 10◦C during the day and -8 to 6◦C during the night; the relative humidity was between 60 to 80%. Air temperature inside was low during the weekends as the heating system was shut down. The heating was started at 6 am each morning while the babies arrived on and after 8 am. The air temperature reached and remained at 20 or 22◦C from about 10 am to 6 pm. Maximum amplitudes of fluctuations over the whole day and from day to day were of the order of magnitude of 1◦C, as attested by the thermohygrograph recordings. The relative humidity was 50% $\pm$ 10% at all times. The climatic conditions inside could therefore be considered to be constant and independent of the external climatic conditions.

The analysis of the measurements made at the different heights and locations in the play-rooms showed that:

- there was a vertical temperature gradient but three measurement heights only could be kept (that is 140, 70 and 5 cm) with differences less than 1◦C;
- the spatial differences were negligible except near the radiators and windows. These areas were closed to the children, so that only one measuring site could be used.
- the air velocity was very low and less than 0.10 ms^{-1} in all points of the area;
- the relative humidity was identical at all positions;
- the differences (less than 1◦C) between mean radiant temperatures and air temperatures were negligible.

The average floor temperatures were 18.5, 18.5 and 19.0◦C on the tiling, wooden floor and groundsheet respectively and for the air temperature of 20◦C. They were respectively 19.5, 20.0 and 21.0◦C at the air temperature of 22◦C. They varied very little by less than 0.5◦C except very locally near the windows and the heat radiators.

The climatic conditions remaining about constant after 10 am, it was decided to record skin temperatures at two occasions only, in the morning, at about 11 am, and in the afternoon, at about 3 pm.

The potential influence of the time of measurement (am vs pm), of the children themselves, and of the ambient temperatures on the skin temperatures were studied using an analysis of variance. This analysis did not show any difference between the skin temperatures recorded in the morning and in the afternoon. Variations between children were also insignificant in each group. On the contrary, the differences recorded for the two air temperatures (20 and 22◦C) were very significant for all local skin temperatures and for all baby categories at the exception of the babies crawling on the wooden floor.
Figures 1, 2 and 3 give for the 5 observed categories (motionless children (M), children crawling on tiling (CP), on wooden floor (CW) and on groundsheet (CG), and the older children (S)), the means plus or minus one standard deviation of the mean skin temperature as well as the temperatures of the forehead, the right hand and the right foot in the two climatic conditions.

At the air temperature of 20◦C, the mean skin temperature of the clothed surface did not vary significantly between the five different groups: the range was between 32.2◦C and 32.8◦C. This mean temperature was significantly greater by 0.5 to 1◦C (in average 0.8◦C) at the ambient temperature of 22◦C and differences between the groups were even smaller, of the order of 0.3◦C.
The forehead temperatures were systematically but not statistically significantly lower by 0.6◦C at

20◦C than at 22◦C. Again they did not differ significantly between the five groups.
On the contrary, local temperatures were significantly different between the five groups. At 20◦C, two main groups could be formed, the babies remaining still and those crawling on tiling showing temperatures of the hands and feet lower by 2 to 4 degrees compared to the others. The average temperature of the sole of the right foot for the motionless children reached a very low 26.9 $\pm$ 1.0◦C.
At 22◦C, only the group of motionless children appeared to have lower temperatures and for the feet only. The more intense cooling of the extremities observed for babies on tiling for the ambient temperature of 20◦C disappeared almost completely, the differences between the two conditions being of the order of magnitude of 4◦C.
It is worth noting that the four adults taking care of these children unanimously preferred the air temperature of 20◦C and judged in average the 22◦C air temperature environment as slightly warm.

DISCUSSION

All the data presented are based on a study involving only 16 small children and indeed additional research is needed to confirm our finding and extend them to other combinations of air temperature, clothing, radiation, ...
Nevertheless, our experimental conditions correspond to a situation frequently met in nurseries and the degree of statistical significance of the results leads already to rather strong conclusions.

Table 1 summarizes the data found in the literature for the skin temperature distribution for resting men in comfort (Olesen and Fanger 1973, Webb 1992) and gives the corresponding results of the present investigation.
Taking into account the standard deviations of these data in the literature and in our research, it is found that the local temperature distribution observed for all the children at 22◦C air temperature is not statistically different from Olesen and Fanger's results, while the distribution at 20◦C is statistically different, especially for the feet and hands of the motionless children.
There is no way of knowing at what temperature these small children are comfortable as obviously they cannot express themselves and as indicators like crying seem not to be associated with such small temperature deviations. From the comparison made above, it can only be said that, if the optimal skin temperature distribution is the same for adults and for children, 22◦C would provide comfort while a temperature of 20◦C would be too low. From Webb's publication, it is known that the threshold of shivering is for adults well below the skin temperatures observed at 20◦C. It is therefore likely that this air temperature is still associated with acceptable skin temperature although with a general cooling of the body. Nevertheless, feet temperatures (sole) of 26.9◦C for the motionless children seem quit low and are certainly not recommended.

The results show also clearly for the crawling babies the influence of the floor covering. While local skin temperatures are not statistically different between standing babies (group S) and children crawling on rubber groundsheet or wooden floor, the hands and feet temperatures are significantly lower for those crawling on tiles. Differences in surface temperatures between the three types of floor covering were quite small and cannot explain these variations between the groups of babies. Differences in thermal conductivity are very likely the reason and it must be recommended to look for floor covering materials with low conductivity (taking into account as well other characteristics such as cleanliness, hygiene, ... out of the context of the present study).

The validity of the PMV, PPD approach for children remains to be discussed.
These indices make it possible to determine the degree of comfort in any climatic condition. This prediction requires the knowledge of the metabolic rate of the exposed persons.
In similar conditions, the metabolic rate of standing, crawling and motionless seated adults would

be about 65, 60 and 50 wm^{-2} respectively, according to ISO 8996 (1990).
The mean skin temperatures of comfort corresponding to these metabolic values, calculated for adults according to Fanger's expression (1972) are respectively 33.9◦, 34.0◦ and 34.3◦C. These figures are systematically larger than those reported in table 1 from the literature and this study.
From these metabolic values and taking into account the climatic parameters and the same clothing insulation value (0.9 clo), the PMV and PPD indices lead to optimum air temperatures of respectively 22.5, 23.5 and 26◦C.
An air temperature of 20◦C would correspond to respectively 16%, 25% and 75% of dissatisfied and 22◦C to 6%, 9% and 39% of dissatisfied for the three groups S, C and M. This indicates that 22◦C would well be accepted by adults standing or crawling but would be felt too cold (PMV = -1.28) by motionless seated adults.
The application of the ISO standard as if the exposed people were adults appears therefore not completely satisfactorily as the predicted skin temperatures are systematically too high and 22◦C would not be acceptable for the three groups.
Many reasons could be advocated to explain these discrepancies. The expressions for the optimum skin temperatures as well as for the heat balance equation were developed for adults and might not be valid for babies. Before questioning this however, the difference in metabolic rate between babies and adults has to be taken into account. It is well known by pediatricians that the basal metabolic rate of babies is greater due to a greater surface to volume ratio, to a relatively greater size of organs with high metabolic rate, such as the viscera and the brain, and to the growing of the child.
According to Fleish (1951), the basal metabolic rate of a baby 1 to 2 years old would be about 60 wm^{-2}. It seems that this figure can be used as an average for the whole group of children from 3 months to 3 years old, considering the interindividual variations in this metabolic rate.
While this basal metabolic rate is therefore about 20 wm^{-2} greater than for adults, there is no reason to assume that the increase in metabolic rate due to the activity differs between adults and small children. These supplements would therefore be about 25, 20 and 10 wm^{-2} for standing, crawling and motionless children respectively and the metabolic rates for the three groups 85, 80 and 70 wm^{-2}.
Repeating the computations made hereabove for the adults, the optimum mean skin temperatures would be 33.3◦, 33.5◦ and 33.7◦C: these estimates correspond remarkably well to what was observed for the children at 22◦C, the differences between these three estimates and due to differences in the metabolic rate being smaller than the interindividual variations.
The comfort air temperatures corresponding to these metabolic rates and predicted by the PMV-PPD approach would be 20.0◦, 20.5◦ and 22.0◦C, with 8% of the group S expected to be dissatisfied at 22◦C and, vice versa, 10% of group M dissatisfied at 20◦C.
This is in accordance with our results and it can therefore be concluded that this adaptation of the metabolic rate for small children appears to lead to consistent results when applying the PMV-PPD indices and the equation for optimum mean skin temperature.

CONCLUSIONS

Given the other climatic parameters (mean radiant temperature equal to air temperature, air velocity of about 0.1 ms^{-1} and relative humidity of about 50%), it can be concluded that, for children less than three years old with an insulation value of 0.9 clo, an ambient temperature of 22◦C is adequate. Extra care should however still be taken of the temperature of extremities (feet and hands) for the motionless babies.
An increase in air temperature beyond 22◦C appears not needed by the children provided they maintain a clo value of 0.9. It would be undesirable for the adults taking care of the children who would complain of being too warm.

An air temperature of 20◦C seems to lead to a slight but overall cooling of the body by about 0.8◦C, but to a large cooling of the extremities mainly for the youngest babies motionless.
The PMV-PPD approach appears to predict this result and therefore appears to be valid for children, provided the extra basal metabolic rate of about 20 wm^{-2} is taken into account.
Finally, the floor covering should be looked after and preference should be given to materials with low thermal conductivity such as wooden floors or groundsheets in rubber foam.
The temperature of 22◦C was said comfortable as providing a skin temperature distribution similar to the one observed for resting adults in comfort (table 1). Comfort however is a psychological state and this concept might be less significant for infants than the ideal condition for development. The concept of thermal neutrality was discussed abundantly 20 years ago by Hey (1975) showing, although for premature infants, that a neutral environment is not necessarily associated with optimum performance or optimum survival. Pediatricians should be interrogated concerning the optimum skin temperatures for possibly different categories of small children before we can conduct further researches on the optimum ambient conditions in nurseries and kindergartens.

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FIGURE CAPTIONS

Figure 1 Means plus or minus one standard deviation of the mean skin temperature (1A) and the temperature of the forehead (1B) for ambient air temperatures of 20 and 22◦C
(M = motionless children, CP = crawling on tiling, CW = crawling on wooden floor, CG = crawling on groundsheet, S = older children standing)

Figure 2 Means plus or minus one standard deviation of the local skin temperatures of the hand (2A : back, 2B : palm) for ambient air temperatures of 20 and 22◦C.
(M = motionless children, CP = crawling on tiling, CW = crawling on wooden floor, CG = crawling on groundsheet, S = older children standing)

Figure 3 Means plus or minus one standard deviation of the local skin temperatures of the foot (3A : back, 3B : sole) for ambient air temperatures of 20 and 22◦C
(M = motionless children, CP = crawling on tiling, CW = crawling on wooden floor, CG = crawling on groundsheet, S = older children standing

TABLE CAPTION

Table 1 Skin temperatures for resting man in comfort according to Olesen and Fanger (1973) (ref. 1) and Webb (1992) (ref. 2) and results of the present study at 22◦C and 20◦C air temperatures and for the different groups of children (M = motionless, C = crawling, S = standing)

e 1

dy area	ref. 1	ref. 2	22°C M,C,S	20°C C,S	20°C M
rehead	34.2	35.2	34.2 NS		33.6*
ean (Ramanathan)	33.6		33.3	33.3 NS	32.5***
nd (back)	33.5	33.8	32.3 NS	30.7***	29.2***
ot (back)	32.2	30.5	32.8 NS	31.2 NS	29.0***

Statistically significantly different from ref. 1 p<0.05
Statistically significantly different from ref. 1 p<0.001
Not statistically significantly different from ref. 1