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Evaluating thermal comfort in a Swedish block of flats: A methodological comparison

Annette Henning[1], Amir Sattari[1]*

[1] Department of Energy, Forests and Building Technology, Dalarna University, Falun, Sweden

**Corresponding email: ami@du.se*

SUMMARY
Two methodological approaches have been used to investigate thermal comfort among occupants in a Swedish block of flats; measurements and thermal comfort standards on the one hand, and qualitative interviews on the other. The purpose with this paper is to present, compare and discuss results from these two radically different methods. The results coincide concerning variations of thermal comfort throughout the day, but are much less in accord in results where occupants express, or are presumed to complain of, thermal discomfort. The interviews show that female occupants tend to suffer more from thermal discomfort than male occupants, a result which is absent in the measurement methodology. The results give support to suggestions that gender aspects should be taken more into account when determining and controlling thermal comfort. The differing results also point at the importance of complementing standardized thermal comfort measurements with surveys or qualitative interviews.

KEYWORDS
Thermal comfort, indoor climate, occupants, methods comparison, gender

1. INTRODUCTION
'Tjärna Ängar' is one of the 'million-program areas' that were constructed throughout Sweden in the 1960s and 70s. Like other similar housing areas, Tjärna Ängar is now in considerable need of renovation. In collaboration with a municipal housing company, an interdisciplinary research team is testing careful and energy-efficient ways of renovating the residential blocks. One of the buildings, as well as the occupants of this building, is particularly in focus during the ongoing research- and renovation process. During the first phase of the research project, the research team focused on renovation plans and the state of the buildings before the practical renovation work is started up in February 2017.

The main objective of this paper is to present and compare some first results concerning thermal comfort in the non-renovated buildings. Two widely differing methods have been used, the one entailing standardized comfort measurements, the other qualitative interviews on subjective perceptions of thermal comfort.

2. METHODS

The research has been carried out in three of the forty similar three-storey buildings in this housing area in a mid-Swedish town. The buildings hold thirty-six flats altogether, and each flat has an exhaust ventilation system with water-borne radiator elements as heating means. Hot water and thermal heating is provided through a heat exchanger connected to the district heating system.

Two quite different methods were used to study the indoor climate of this building. The one method was to use thermal comfort standards and measurements to evaluate predicted indoor comfort. Much less frequently used within the indoor climate research field is the second method; interviewing. Rather than looking at thermal comfort through a mere technical lense (Leijonhufvud and Henning, 2014), or by using the more common surveys or laboratory studies (Engvall et al. 2009; Nicol et al. 2012), the qualitative interview was chosen as the most suitable method for collecting in-depth information on specific occupant experiences.

The interviews were made in November and December 2015, and the measurement in February 2016 and January 2017. Outdoor temperatures held between – 7° C and + 6° C during interviews and around - 2° C to + 5° C during measurements. According to the housing company, indoor temperatures are kept at a minimum of 20.5°C daytime and 19°C night-time.

Indoor climate measurements

Two 24-hour indoor climate measurements were carried out in empty flats in two similar buildings. Four environmental factors for assessing thermal comfort were measured; air velocity (m/s), mean radiant temperature (°C), relative humidity (%), and air temperature (°C). A "Testo 480" instrument (digital temperature, humidity and air flow meter) was used to measure the "occupied zone" (Boverket, 2016). Consequently, measurements were made for sitting occupants in the living room, with 1.0 metres distance from windows (outer wall) and 0,6 metres above the floor level. The measuring instruments were placed on the horizontal plane at both 0.1 metres and 2.0 metres above the floor, and on the vertical plane at 0.6 metres from the inner walls and 1.0 metres from the outer walls, windows and doors.

Interviews on thermal sensations

Fifteen adults from ten households were interviewed in their homes. The overall aim with these interviews was to get a better understanding of the occupants own experiences of the indoor climate, but also of how they tended to handle possible discomfort. The qualitative interviews had a semi-structured form (Bernard, 2006), and house-touring (Pink, 2004), comparisons and memories (Pink, 2006) were used to facilitate communication. Research questions were formulated in close collaboration with the technical climate and building experts of the research team. Out of the fifteen interviewed occupants, there were eight women and seven men. Five of them were aged forty-five to sixty. The other ten were between twenty-five and thirty-five years old. In six households, householders had Somali backgrounds, while in the remaining four, their backgrounds were Kurdish. Interpreters were used in half the cases.

3. RESULTS

Results from measurements

The measurements from 2016 indicate that an average of 31 % of the occupants should be dissatisfied with the thermal comfort, while the 2017 measurements indicate 12 % dissatisfied (the difference probably due to the old one-pipe radiator system). Both measurements indicate that the predicted reaction of the occupants on an hourly basis would vary quite a lot over the day. Thus, between 35 and 39 % of the occupants are predicted to be dissatisfied between midnight and seven o´clock in the morning and between six o´clock in the afternoon to midnight. However, only 10 % would be dissatisfied around 10.00 in the morning (figure 1). In accordance with this, the average occupants are assumed to experience the climate as "slightly cool" on all hours except around lunchtime, peaking at 11 o´clock, when they are assumed to perceive it as somewhere between "slightly cool" and "neutral".

The analysis of measurement results have been made in accordance with the European standard EN ISO 7730:2005, which has been adopted as the Swedish standard SS-EN ISO 7730:2006 (Swedish Standard Institute, 2006). From this page onwards, it will simply be called "the standard". As suggested by the standard, the two concepts PMV and PPD are used here to describe the approval or disapproval (among occupants) of the thermal environment, as indicated by the measurement results.

PMV stands for "Predicted mean vote", and grades predicted thermal sensations according to the following scale: + 3 = "hot", + 2 = "warm", + 1 = "slightly warm", 0 = "neutral", - 1 = "slightly cool", - 2 = "cool", - 3 = "cold". The term PPD stands for "Predicted percentage of dissatisfied occupants". In Sweden, a PPD between 15 and 20 % is labelled "bronze", while between 10 and 15 % is labelled "silver". The best criteria is "gold" with a PPD of less than 10 % (that is, less than 10 % of occupants are assumed to complain), while a PPD above 20 % is considered unacceptable in both summer and winter (Sweden Green Building Council, 2011). In analysing measurement results according to PMV and PPD, normal indoor winter clothing (0.7 clo) and normal indoor activity (65 W/m^2) were assumed. The selection of the thermal insulation factor 0.7 clo for garments was chosen in accordance with the standard, where 0 clo means no clothing and 3.0 clo means cold outdoor winter clothing. 0.7 clo is chosen according to approximations of the standard for underwear, shirt, trousers, socks, and shoes.

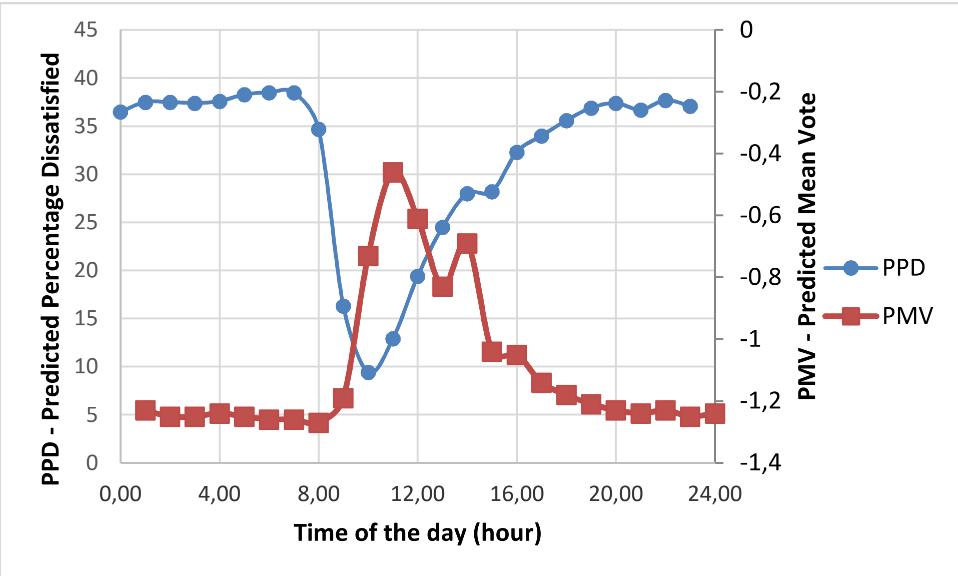

Figure 1. Hourly average PMV and PPD values during a 24-hours period, assuming thermal insulation to be 0.7 clo and metabolic rate to be 65 W/m^2.

Table 1. Average values of the environmental factors of thermal comfort and resulted average PPD and PMV values during a 24-hours period - the average readings of 289 measurements.

	2016 Feb.	*2017 Jan.*
air velocity	0.04 m/s	0.08 m/s

mean radiant temperature	20.7 ˚C	22.5 ˚C
relative humidity	17.8 %	28.5 %
air temperature	21.1 ˚C	22.9 ˚C
metabolic rate (activity level)	65 W/m^2	65 W/m^2
thermal insulation (clothing)	0.7 clo	0.7 clo
PPD - Predicted Percentage Dissatisfied	**31**	**12**
PMV - Predicted Mean Vote	**-1.1**	**-0.6**

Results from interviews

The most general and obvious result from the interviews was the fact that the respective flats were described as either cold or very cold in all the ten households. On questions concerning draught and cold surfaces, twelve householders call attention to the severe draught from windows and/or doors, and eight of the fifteen householders complain of cold, or very cold, In all these households, the occupants found evenings, night-time or mornings (or a combination of these) to be the coldest. floors. Perceptions of insufficient ventilation, and common habits of weathering, closing inner doors and fresh air ducts were also noted.

Another important result was the fact that most of the women seemed a lot more bothered by the cold than their husbands. A clear majority was either stating this gender difference explicitly, or the women would be the ones who emphatically expressed how bad the cold made them feel, as exemplified in the following quotations. For instance, with strong emotion in her voice, one woman stated firmly that “It is *very* cold!! I am freezing *all the time*!”. Another woman complained about her aching feet and how she did not feel well because of the cold. In a similar way, yet another woman described how the cold floor makes her toes go numb, and that she, whenever she gets the opportunity, has to lie down under the bedroom quilt to endure. A fourth woman told us that she, in spite of covering herself up in warm clothes and extra blankets, is not able to keep warm when sitting still to watch TV or video.

Despite the cold floor, no interviewees wore thick over-socks or warm slippers, but were either bare-footed or had thin socks or rubber slippers. Apart from this, also clothing seems to indicate gender variations among these occupants. With only eight women and seven men, it is hard to say anything definite about this, but the degree to which men and women add warmer garments to their basic clothing certainly seems to differ. Thus, during interviews, three of the eight women had added a sweater or cardigan to their ankle-length dress and head cover, were wearing long trousers underneath the dress, or a knitted shawl across the shoulders. Another three women describe how they put on more clothes (such as a cardigan or thick sweater) and/or cover themselves up in a quilt or blanket whenever they feel cold. As a comparison, only two of the seven men had either added a thin sweater to their T-shirts and trousers during the interviews, or would describe how they put on a sweater in the morning.

4. DISCUSSION: COMPARING RESULTS

Results from the two methods coincide well concerning variations of thermal comfort throughout the day. Assessment from measurements indicates that the largest number of dissatisfied occupants should be found before eight o´clock in the morning and after four o´clock in the evening. These results are confirmed by the interviews, which show that the occupants perceive their flats to be coldest in the morning, in the evening, and at night-time. However, having done the measurements in empty flats limits the validity of the measurements because people as constant heat loads have a significant effect on the thermal environment.

Much less in accord is the results where occupants express thermal discomfort, or are assumed to experience and complain about this. Thus, the measurements indicate a PPD, where between

12 and 31 % of the occupants should be dissatisfied with the indoor climate, while interviews showed that all interviewed occupants considered their flats to be cold, and that at least 80 % of them were complaining. Furthermore, measurement results gave an average predicted thermal sensation (PMV) of between – 0.6 and – 1.1 (where 0 is neutral and - 1 is slightly cool). If, as a comparison, interview results are translated into the same scale, the results would land somewhere around - 2.6 (where – 2 is cool and – 3 is cold). Since large parts of the occupants also express strong discomfort and negative sentiments, the measurement results seem to highly underestimate the thermal discomfort of the actual occupants in this specific building.

The interviews also showed that the interviewed women tend to suffer from thermal discomfort much more than the male occupants; a result which is absent altogether in the standardized measurements. The gender variation (which came through in the interviews) fits well into the bigger picture drawn by Karjalainen in his thorough literature review on indoor thermal comfort (Karjalainen, 2012). Karjalainen shows that, when a large number of laboratory and questionnaire studies are put together, a clear pattern arises. It turns out that, irrespective of outdoor climates, women tend to be less satisfied with indoor climates than men, particularly in cooler conditions. Women are also more sensitive to deviations from an optimal thermal environment, and tend to express more dissatisfaction than men in the same indoor thermal environments. All this is clearly in line with our interview results.

Furthermore, the interviews indicate that those who are freezing the most also are those who wear the warmest clothes. When analysing the interview results, the use of warm clothes, blankets or quilts are interpreted as one way by which these specific, predominantly female, occupants attempt to handle thermal discomfort. The basis for analysing measurement results is another. In this case, the results are compared to an estimated generic clothing insulation ('clo value'). The aim here is to assess how satisfied or dissatisfied an average of people in general would be in the measured indoor climate, given certain clothing insulation. The background to this is the standardization goal of achieving as few unhappy occupants as possible (since it is impossible to find a thermal environment that satisfies all individuals). The backside of such a goal, however, is the difficulty of this methodology to detect variations between categories such as gender or age, or to consider the well-being of more vulnerable groups.

5. CONCLUSIONS: EVALUATING TERMAL COMFORT

An important conclusion from this comparison of methods is that, in this specific case-study, the thermal discomfort of the female occupants in particular would have been seriously underestimated if measurements and PMV/PPD-assessments had been the only methodological approach. There is no doubt that, in order to know how to renovate buildings and improve thermal comfort, it is necessary to make careful measurements and estimations. The basic goal behind thermal comfort standards – to achieve as few unhappy occupants as possible – is also commendable in many ways. Still, the "Fangers model of thermal comfort", on which these standards are built, has been criticized for some time now, and various adjustments and complements are continuously suggested (Karjalainen, 2011; Leijonhufvud and Henning, 2014; Nicol et al. 2012; van Hoof, 2008). The adaptive model, where adaptation to outdoor temperatures is suggested, may be the most well-known, developed and accepted of these (Nicol et al. 2012).

However, more relevant for our results here, are some suggestions by Karjalainen (2011) and van Hoof (2008). The stronger sense of discomfort, which we found among our female occupants, is well in line with the results from Karjalainen's review. Therefore, our results support his suggestion that females should primarily be the ones who are used as subjects when examining indoor thermal comfort requirements. If females are satisfied with their thermal comfort, he says, it is highly probable that males are also satisfied (since they tend to be less sensitive to thermal variation). Furthermore, Karjalainen agrees with van Hoof (2008), that thermal comfort for all can only be achieved when occupants have effective control over their own thermal environment. In addition to this suggestion, Karjalainen argues that females, on average, have more need for individual temperature control and adaptive actions than males since they have lower tolerances to deviations from optimal thermal environments.

Finally, the differing results from our two methods point at the value of complementing thermal comfort measurements with qualitative interviews, and that this may be particularly important to consider in cases where more vulnerable occupants are involved. Since one's home and living conditions are essential for health and well-being, an underestimation of occupants' thermal discomfort may lead to serious misjudgements and energy injustices.

6. ACKNOWLEDGEMENT

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