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Thermal environment in eight low-energy and twelve conventional Finnish houses

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ABSTRACT

We assessed the thermal environment of eight recently built low-energy houses and twelve conventional Finnish houses. We monitored living room, bedroom and outdoor air temperatures and room air relative humidity from June 2012 to September 2013. Perceived thermal environment was evaluated using a questionnaire survey during the heating, cooling and interim seasons. We compared the measured and perceived thermal environments of the low-energy and conventional houses. The mean air temperature was 22.8 °C (21.9–23.8 °C) in the low-energy houses, and 23.3 °C (21.4–26.5 °C) in the conventional houses during the summer (1. June 2013–31. August 2013). In the winter (1. December 2012–28. February 2013), the mean air temperature was 21.3 °C (19.8–22.5 °C) in the low-energy houses, and 21.6 °C (18.1–26.4 °C) in the conventional houses. The variation of the air temperature was less in the low-energy houses than that in the conventional houses. In addition, the occupants were on average slightly more satisfied with the indoor environment in the low-energy houses. However, there was no statistically significant difference between the mean air temperature and relative humidity of the low-energy and conventional houses. Our measurements and surveys showed that a good thermal environment can be achieved in both types of houses.

1. Introduction

The Finnish Ministry of the Environment has issued new energy efficiency regulations for new and renovated buildings (Finnish Ministry of the Environment, 2011). The purpose of the new regulations is to promote energy efficiency and the use of renewable energy in buildings, simultaneously reducing their energy consumption and carbon dioxide emissions. According to the regulations, new buildings must be built as nearly zero-energy buildings (nZEB) after 2020. In addition, these regulations must already be implemented in new state buildings in 2019.

Thermal conditions play a major role in living comfort, indoor environmental problems and symptoms related to the indoor environment (Jaakkola and Heinonen, 1989). Thus, a pleasant air temperature is one of the main goals of ventilation and heating system design and use. A given space has an optimum operative temperature, which corresponds to predicted mean vote (PMV) = 0 (ISO 7730, 1994). The PMV scale is used to evaluate how occupants perceive their sensation of thermal comfort. Predicted percentage of dissatisfied (PPD index) is also used to evaluate the quantitative predictions of the number of thermally dissatisfied people. For example, in winter, when people are dressed in clothes with a thermal insulation of 1 clo and a person's metabolic rate is 1 met, the optimal operational temperature is 23 °C. In summer, when people are dressed in clothes with a thermal insulation of 0.5 clo, the optimal operational temperature is 26 °C. These values are valid when relative humidity is 50% and mean air velocities do not exceed 0.1 m/s. Table 1 provides examples of PMV values (ISO 7730, 1994). A metabolic rate value of 1.0 met corresponds with sitting quietly, reading or writing. When relative humidity is below 50%, the optimal room temperature is 0.3 °C higher for each 10% of relative humidity.

In Finland, the guideline values for dwelling air temperature are given in the Housing Health Code (Housing Health Code, 2014) and National Building Code D2 (National Building Code 2003). Target values for thermal environments are given in the Finnish Classification of Indoor Environment (FiSIAQ, 2008). According to the Housing Health Code, a tolerable air temperature level is 18 °C and

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Table 1
Predicted mean vote (PMV): Activity level 1 met (58 Wm^{-2}), Clothing: 0.5 clo (0.078 $m^2 \times KW^{-1}$), ISO 7730.

Operative temperature [°C]	Relative air velocity [ms^{-1}]							
	<0.10	0.10	0.15	0.20	0.30	0.40	0.50	1.00
23	−1.10	−1.10	−1.33	−1.51	−1.78	−1.99	−2.16	–
24	−0.72	−0.74	−0.95	−1.11	−1.36	−1.55	−1.70	−2.22
25	−0.34	−0.38	−0.56	−0.71	−0.94	−1.11	−1.25	−1.71
26	0.04	−0.01	−0.18	−0.31	−0.51	−0.66	−0.79	−1.19
27	0.42	0.35	0.20	0.09	−0.08	−0.22	−0.33	−0.68
28	0.80	0.72	0.59	0.49	0.34	0.23	0.14	−0.17
29	1.17	1.08	0.98	0.90	0.77	0.68	0.60	0.34
30	1.54	1.45	1.37	1.30	1.20	1.13	1.06	0.86

a good level 21 °C. This temperature should not exceed 23–24 °C during the heating season. It can exceed 26 °C only if this is due to outdoor conditions.

According to the National Building Code, the design value of air temperature is 21 °C for the heating season and 23 °C for the summer season. The temperature should not normally be greater than 25 °C during the occupancy period. However, the air temperature may exceed this value by a maximum of 5 °C if the average outdoor air temperature over a maximum period of 5 h is above 20 °C.

The Finnish Classification of Indoor Environment gives more detailed requirements for thermal environments. It has three categories: S1: “individual or the best quality”, S2: “good” and S3: “satisfactory” indoor environment. Target air temperature values are given as operative temperatures (Table 2).

The energy efficiency demands of new buildings require improved thermal insulation and tightness of the building envelope, and efficient heat recovery of ventilation systems. In addition, renewable energy such as wood, solar energy and geothermal heating are recommended for use in new buildings. The aim of this study was to determine the effect of the energy efficiency regulations on thermal environments in recently built low-energy houses, and to compare the results with those of conventional houses.

2. Materials and methods

2.1. Low-energy and conventional houses, apartment blocks

Seven low-energy and ten conventional houses were selected for the study. One low energy apartment block and two conventional apartment blocks were also included. The low-energy houses and the apartment blocks were built in 2009–2012. Their computationally demanded heat loss was less than that of the buildings that were built in accordance with the regulations of the 2010 building code (National Building Code 2010 D3). The conventional houses and apartment blocks were built in 1959–2011, in accordance with the valid building code that applied to building permission of houses and apartment blocks at that time. The buildings were maintained and repaired but not altered or extended. Fig. 1 presents typical examples of low-energy and conventional houses and apartment blocks studied.

The living area of the low-energy houses was on average 151 m^2 or 46 m^2 per person. They were equipped with mechanical supply and exhaust ventilation that had a cooling system. Floor heating or heating ventilation were the main heating systems in most of the low-energy houses. All single houses were also equipped with a fireplace. Adjustable curtains and blinds were used to regulate thermal environment. Permanent, external solar shading was also utilized. The cooling energy of supply air was produced by a heat pump or by circulating cooling liquid in the ground. More detailed information of the low-energy houses studied is given in Table 3.

The living area of the conventional houses was on average 134 m^2 or 54 m^2 per person. The houses were equipped with mechanical supply and exhaust ventilation, mechanical exhaust ventilation, or a natural ventilation system. Electric or water radiators were the main heating systems in most of the conventional houses. All single family houses were equipped with fireplaces. Curtains and blinds were utilized. There were no renovations that affected energy efficiency. More detailed information of the conventional houses studied is given in Table 4.

The primary energy demands of the five low energy houses (2009–2011) and five older conventional houses (1974–2011) was known. The average calculated primary energy demand was 120 kWh/m^2 a (85–136 kWh/m^2 a) in the low energy houses, and 323 kWh/m^2 a (203–577 kWh/m^2 a) in the conventional houses (Holopainen et al., 2015).

Table 2
Target values for operative temperatures depending on outdoor temperature T_{out} (FiSIAQ, 2008).

	S1 Individual	S2 good	S3 satisfactory
Operative temperature T_{op} [°C]			
$T_{out} \leq 10$ °C	21.5[a]	21.5	21.0
$10 < T_{out} \leq 20$ °C	$21.5 + 0.3 \times (T_{out}-10)$[a]	$21.5 + 0.3 \times (T_{out}-10)$	$21.0 + 0.4 \times (T_{out}-10)$
$T_{out} > 20$ °C	24.5[a]	24.5	25.0
Deviation allowed from set value [°C]	±0.5	±1.0	±1.0
Maximum value of operative temperature [°C]	T_{op}+ 1.5	$T_{out} \leq 10$ °C: $T_{op} + 1.5$ $10 < T_{out} \leq 20$ °C: $23 + 0.4 \times (T_{out}-10)$ $T_{out} > 20$ °C: 27	$T_{out} \leq 15$ °C: 25 $T_{out} > 15$ °C: $T_{out,max} + 5$
Minimum value of operative temperature [°C]	20	20	18
Stability of environment [% of operating time]			
Office and school spaces	95	90	–
residential spaces	90	80	–

[a] In category S1, the operative temperature is adjustable in each room/apartment within a range of $T_{op} \pm 1.5$ °C. If several people occupy the same room, the target level of air temperature is the target value shown in the table.