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Impacts of energy retrofits on hygrothermal behavior of Finnish multi-family buildings

Virpi Leivo[a], Mihkel Kiviste[a]*, Anu Aaltonen[a], Mari Turunen[b], Ulla Haverinen-Shaughnessy[b]

[a]Tampere University of Technology, P.O. Box 600 Tekniikankatu 12, Tampere 33101, Finland
National Institute of Health and Welfare, P. O. Box 95, Kuopio 70701, Finland

Abstract

This paper presents impact of energy retrofit on hygrothermal behavior in three multi-family buildings. One of the buildings underwent deep energy retrofitting, one had focused energy retrofits, and one building was a non-retrofitted control building. The average indoor temperature during heating season was relatively high in all studied buildings. The temperatures near the coldest spot of the building envelopes were within guideline values, and some improvements could be noticed in the deep retrofitted building.

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Keywords: Energy retrofit, multi-family building, temperature, thermal index.

1. Introduction

In 2010, European Commission issued the recast of Energy Performance of Buildings Directive (EPBD), in order to reduce the building energy consumption and strengthen the energy performance requirements, requiring that by the end of 2020 all new buildings are so-called nearly zero-energy buildings (nZEBs). Also existing buildings subjected to major retrofits meet minimum energy performance requirements adapted to the local climate [1]. Finnish standards for energy efficiency of buildings are already relatively high, limiting the potential for reducing energy loss throughout the building envelope. According to a recent survey, over 90% of the Finns are satisfied with indoor temperatures

* Corresponding author. Tel.: +358-40-373-2514.
E-mail address: mihkel.kiviste@tut.fi

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during winter, and there is no difference between Northern and Southern Finland in this respect [2]. Nevertheless, the EPBD is being implemented in Finland, which could have impact on hygrothermal performance on new and retrofitted buildings.

With respect to Finnish housing stock, most of the existing apartment buildings have been constructed in 1960-1980 [3] and part of them has already been renovated. In addition, a large quantity will be renovated in the next few decades, providing an opportunity to improve energy efficiency. From the environmental health point of view, a new decree on housing and health was issued in 2015 [4]. The decree has specified new action limits, while the guideline values [5] are still the same. According to the decree, the indoor temperature should be between +18…+26 °C. Recommended guideline [5] for “good level” of room temperature is 21 ºC and “adequate level” is 18 ºC. During the heating season, indoor temperature (T) should not exceed 23… 24 ºC. The surface temperature of building envelope should not be lower than +16…+18 °C. The indoor relative humidity (RH) should be between 20…60 RH%.

Thermal index is a relative value which takes into account surface, indoor and outdoor temperatures. It is defined as a difference between internal surface temperature and external temperature, divided by the difference between internal temperature and external temperature (Equation 1) [6].

$$f_{Rsi} = (T_{s,min} - T_o)/(T_i - T_o) \qquad (1)$$

where $T_{s,min}$ is minimum surface temperature, T_o is outdoor temperature (°C) and T_i is indoor temperature (°C). Based on Finnish housing health guide, the limit values for thermal index (f_{Rsi}) are 0.87 and 0.81 for external walls and 0.97 and 0.87 for floors, respectively.

This paper is focused on assessment of hydrothermal parameters in selected Finnish multi-family buildings. The used methods are reported in INSULAtE-project report [7].

2. Case studies

2.1. Case study buildings

Multi-family buildings that were planned to be retrofitted during the 5-year INSULAtE-project were eligible for the study. The study area included several regions in Finland (Tampere, Hämeenlinna, Imatra, Helsinki, Porvoo, Kuopio). The buildings were chosen from among volunteers: primary criteria were planned retrofits, which had to be related to energy efficiency and finished before the fall of 2015. Also some control buildings, which were not retrofitted during the project, were included. The case study buildings were divided into three groups:

- Deep energy retrofitted (DER) buildings, represented more comprehensive energy efficiency measures, addressing multiple systems at once (e.g. adding thermal insulation the building envelope, changing windows, changing heating and ventilation system).
- Focused energy retrofitted (FER) buildings, which included system upgrades (e.g. changing windows or installing heat recovery into exhaust ventilation system).
- Control buildings (CONTROL), where no energy retrofit actions were performed.

This paper presents hygrothermal analyses focused on selected case buildings, one from each three group.

Table 1. Characteristics of the selected buildings.

	Year of construction	Number of storeys	Ventilation	Construction type	Retrofit actions
DER	1954	4	Natural	Wood-framed walls	Thermal insulation of walls, new windows
FER	1980	7	Mechanical exhaust	Pre-fabricated concrete walls	Heat recovery
CONTROL	1980	7	Mechanical exhaust	Pre-fabricated concrete walls	No actions

2.2. Methods

Measurements were performed in several apartments (seven to eleven) of each building. Indoor temperature and relative humidity values were continuously monitored (once an hour) for at least two months, usually during heating season, by two data loggers both before and after energy retrofits. One logger was placed to the coldest spot of the apartment, based on the measured inner surface temperatures (usually on floor by the balcony door). The other logger was placed to the living area, reflecting the average conditions in the apartment. In addition, outdoor temperature and relative humidity data during the measurement period were obtained from local monitoring stations, maintained by Finnish Meteorological Institute. The measurement range of loggers (DT-172 logger) for T was -40 …+ 70 °C (accuracy ± 1 °C) and the RH range was 3 … 100% (accuracy ± 3%). The inner surface T was measured using thermal imaging camera (ThermaCAM B2, FLIR Systems, range -15…+45 C, accuracy +-2°C or 2%).

The impacts of level of retrofit on hygrothermal conditions of the case buildings were assessed. Thermal index values (see Eq. 1) were calculated based on the continuous measurement data. Also temperature differences between outdoor air, coldest spot, and living area were analyzed for possible trends.

3. Results

Table 2 shows measured average indoor temperatures (T_i), temperatures near the coldest spot of the building envelope (T_c), as well as outdoor temperatures (T_o). Table 3 shows measured average indoor RH (RH_i), RH near the coldest spot of building envelope (RH_c) and outdoor RH (RH_o). The average indoor T_i during heating season was relatively high in all measurements among all buildings, whereas RH_i was near lower action limit value. Overheating appears to be a common problem in Finnish multi-family buildings and remarkable energy saving potential lays on adjustment of heating systems. Reducing indoor temperature would also increase indoor RH. The temperatures near the coldest spot of building envelope were within guideline values, indicating sufficient thermal insulation without any major thermal bridging.

Table 2. The measured average indoor, coldest indoor and outdoor temperatures.

	DER (11 apart. pre/8 post)		FER (8/7)		CONTROL (9/7)	
T_i, °C	Pre	Post	Pre	Post	1st	2nd
Average	22.88	22.77	22.78	22.78	22.72	22.65
SD	1.02	0.80	0.56	0.39	0.58	0.86
Median	23.01	22.78	22.55	22.92	22.62	22.89
5th	21.50	21.83	22.18	22.38	21.99	21.49
95th	24.36	23.86	23.61	23.32	23.52	23.56
T_c, °C						
Average	20.75	20.39	21.06	20.70	19.65	20.38
SD	1.35	0.89	0.91	1.10	1.14	1.49
Median	20.96	20.31	20.75	20.76	19.80	20.18
5th	19.06	19.29	20.10	19.52	18.06	18.61
95th	22.37	21.54	22.44	22.15	21.00	22.50
T_o, °C						
Average	8.55	8.51	2.99	2.08	-2.04	4.01
SD	0.36	0.10	0.05	0.01	0.60	0.18
Median	8.53	8.52	2.98	2.08	-1.90	3.93
5th	8.25	8.38	2.94	2.07	-2.65	3.92
95th	9.12	8.63	3.05	2.08	-1.22	4.29

Table 3. The measured average indoor, coldest indoor and outdoor RH.

	DER (11/8)		FER (8/7)		CONTROL (9/7)	
RH_i, %	Pre	Post	Pre	Post	1st	2nd
Average	33.46	33.82	26.80	26.66	21.85	27.48
SD	4.19	5.91	3.45	3.92	4.31	3.16
Median	33.57	31.23	27.02	26.42	20.40	26.39
5th	28.17	28.07	22.27	22.06	17.60	24.32
95th	38.68	42.46	31.68	32.12	27.79	32.14
RH_c, %						
Average	37.70	38.08	28.79	30.02	24.08	28.97
SD	4.47	5.79	3.18	3.82	3.87	3.42
Median	38.76	36.24	28.86	31.37	23.92	27.73
5th	31.08	32.85	24.54	24.99	19.29	25.06
95th	42.91	47.29	32.82	34.38	29.28	33.64
RH_o, %						
Average	66.92	71.84	71.25	78.93	67.46	71.63
SD	0.35	0.23	0.40	0.15	0.51	0.36
Median	67.06	71.82	71.34	78.89	67.50	71.51
5th	66.33	71.56	70.68	78.74	66.66	71.43
95th	67.20	72.14	71.69	79.08	67.90	72.19

Calculated thermal index values are presented in Fig. 1. The surface temperature values from thermal imaging camera and measured concurrent indoor and outdoor temperature values were used in calculation. Thermal index values increased in many apartments in DER building. In FER building, thermal index values increased or remained the same. The retrofit actions in FER building were not focused on improving thermal insulation or airtightness, and should not therefore directly effect on surface temperature. The improvement on temperature factor is more likely due to reduced air infiltration after balancing ventilation system. On the contrary, the temperature factor decreased in most of the apartments in CONTROL building. Overall, the thermal index values are quite low as compared to Finnish guideline values. Prior to the surface temperature measurements, measurement devices were set outside to the balcony, which could have affected the surface temperatures causing systematic error to thermal imaging. Therefore, the absolute values are not necessary reliable but the changes in temperature factors are reliable.

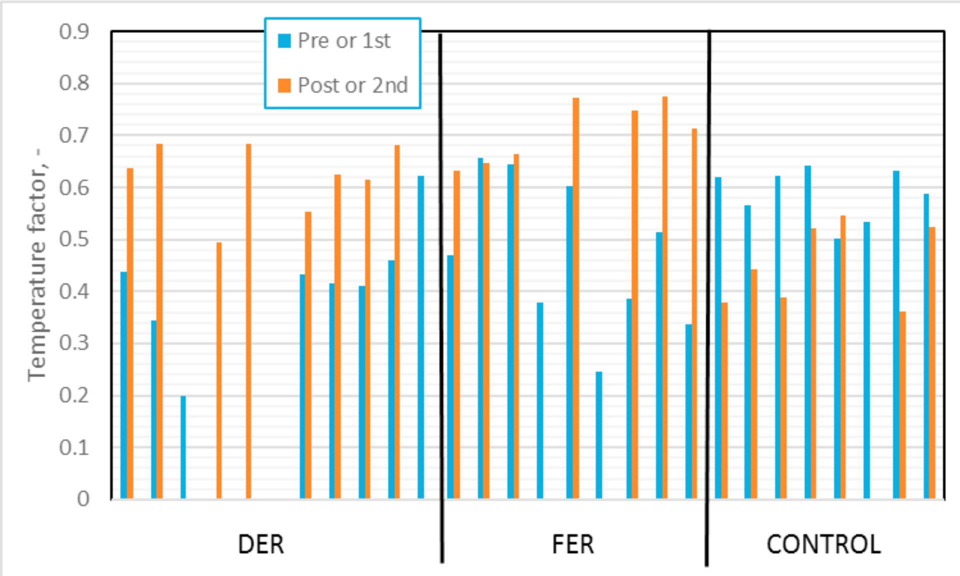

Fig. 1. Thermal index values in the selected case (2) and control (1) buildings.

Conclusions

Following different degrees of energy retrofits of two Finnish multifamily buildings, no major changes in average indoor temperature and RH were observed. However, thermal index values appeared to increase especially in the building that underwent deep energy retrofitting, which could also result in improved thermal comfort.

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