Thermal conditions and occupant satisfaction in energy retrofitted buildings in Finland

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Abstract. In this paper different factors effecting into thermal comfort are compared with results of housing diaries. The data was collected in a project which object was to demonstrate the effects of energy retrofits on IEQ and occupant health. Data from existing 46 multi-family buildings (218 apartments) were collected both before and (usually about one year) after energy retrofits, including various thermal condition and indoor air quality (IAQ) measurements combined with occupant surveys. Measurements were performed during two winter months. The relatively high indoor temperatures observed in apartments before the retrofits indicated overheating. After the retrofits, the average temperatures remained unchanged. The temperature even in the coldest spot, i.e. place where coldest inner surface temperature was detected by thermographic camera or IR-thermometer (usually by the balcony door) was quite high, about +20,3 °C. According to 2-week diaries, considering perceived housing satisfaction, the occupants were quite satisfied with the IAQ. In 11-point scale considering daily perceived disturbance, (0 “not at all” and 10 “intolerably”) the average was less than 1 considering indoor temperature, humidity, draught and stuffiness/ poor IAQ. The differences before and after were not statistically significant, except considering stuffiness/ poor IAQ, which was reported less disturbing after the retrofits (Mann-Whitney U-test, p=0.001). The indoor thermal conditions were quite good and occupant satisfaction were relatively high even before the energy retrofits and remained about the same after the retrofits.

Keywords. IEQ, occupant satisfaction, thermal comfort
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1. Introduction

The Energy Performance of Buildings Directive 2010/31/EU (EPBD) and the Energy Efficiency Directive 2012/27/EU promote policies that will help achieve a highly energy efficient and decarbonised building stock by 2050. In October 2020, the Commission presented its renovation wave strategy, as part of the European Green Deal. Its objective is to at least double the annual energy renovation rate of buildings by 2030 and to foster deep renovation [1]. Most of the residential buildings (about 70% of the building area) in the EU-27 countries have been constructed before 1980, in Finland about 65% [2]. Therefore, there is an important energy saving potential in old multi-family buildings, which are also in need of renovation as many construction parts have reached their expected service life.

Thermal comfort is commonly defined as “condition of mind which expresses satisfaction with the thermal environment” [3].

This paper is focused on assessing impacts of energy retrofits on indoor thermal conditions (temperature (T) and relative humidity (RH)) and comparing the results with housing diaries, collected from the occupants. Measurements following the same protocol were performed in multifamily buildings before and after retrofits in Finland and Lithuania (two countries located in Northern Europe). This paper presents results from Finland. The purpose of the whole project (INSULAtE) was to demonstrate impacts of energy retrofits on indoor environmental quality (IEQ) and occupant satisfaction, and to develop a common assessment method of these impacts on building and national levels [4].

2. Case studies

2.1 Case study buildings

Case study buildings were selected from

volunteering multi-family buildings that were planned to be retrofitted during the project, and where about five apartments per building were willing to participate in the measurements before (Pre) and after the retrofit (Post). Also some buildings, which were not retrofitted during the project, were included as control buildings. Retrofitted buildings were divided into two groups: focused energy retrofit buildings (FER), where only one retrofit action was performed, and deep energy retrofit buildings (DER), where several retrofit actions addressing multiple building components were performed. Majority of the case study buildings were built in 1960-1980 and typical outer wall was prefabricated concrete element where thermal insulation is between concrete slabs. A total of 46 multi-family buildings (218 apartments) were included: 39 retrofitted (30 FER and 9 DER) cases, as well as seven control buildings. The most common retrofit action was changing new windows (U-value of old windows 2,1 W (m-2 K-1) and new 1,0 W (m-2 K-1)) and/or installing heat recovery system to exhaust ventilation system, which then became mechanical ventilation with heat recovery (MVHR) (Figure 1). Deep energy retrofits were performed only in 11% of the case buildings.

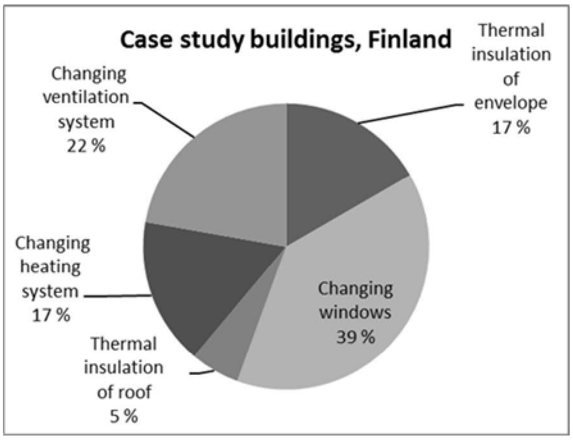

Fig. 1 – Performed energy retrofits.

Most typical U-values of the structures of case buildings were: outer walls U= 0.40 … 0.28 W(m-2 K-1), roof 0.40 … 0.36 W(m-2 K-1), floors 0.40 … 0.29 W(m-2 K-1), windows 2.1 W(m-2 K-1) [5].

2.2 Measurement methods

Two rounds of measurements were performed: before and after the retrofits. Both rounds were performed in the same season, usually during heating season. The measurements took place between November and April, excluding Christmas holidays.

Two months continuous monitoring of temperature (T) and relative humidity (RH). Two loggers (T range -40 -+ 70 °C, accuracy ± 1 °C; RH range 3 - 100%, accuracy ± 3%) per apartment were placed. The data were logged once per hour. One logger was placed in the occupied zone, e.g., middle of the living room (height of 1.2-1.5 m above ground, i.e. human breathing zone as seated), presented as Tw and RHw. The other logger was placed to the coldest spot, i.e. place where coldest inner surface temperature was detected by thermographic camera or IR-thermometer (usually by the balcony door) (Figure 2), presented as Tc and RHc.

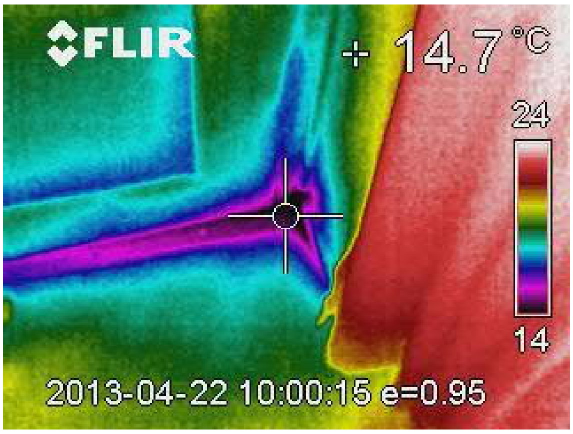

Fig. 2 – Thermographic camera picture, coldest spot on the right (corner), near balcony door.

Occupant surveys were used to collect information concerning occupant perceived housing satisfaction, including thermal comfort, satisfaction with IAQ, lighting, and noise disturbance. All adults living in the apartment were asked to fill in a diary once a day during a two-week period. The diary consisted of two-sided one-page form, including questions concerning symptoms, time consumption, and activities. Fig. 3 shows the question considering perceived housing satisfaction. The issues bothering the occupants at home were assessed in using a 11-point scale, i.e., from 0 to 10, where 0 was the "not at all" and 10 was "intolerably".

4. On a scale from 0 to 10, indicate how much you felt the following things bothered you in your home during the past 24 hours?

	0 - Not at all					←→				Intolerably - 10	
Air pollution, exhaust gas, etc.	0	1	2	3	4	5	6	7	8	9	10
Noise outside your dwelling	0	1	2	3	4	5	6	7	8	9	10
Odours outside your dwelling	0	1	2	3	4	5	6	7	8	9	10
Odours inside your dwelling	0	1	2	3	4	5	6	7	8	9	10
Stuffiness/poor quality of indoor air	0	1	2	3	4	5	6	7	8	9	10
Dust or dirtiness	0	1	2	3	4	5	6	7	8	9	10
Too high an inside temperature	0	1	2	3	4	5	6	7	8	9	10
Too low an inside temperature	0	1	2	3	4	5	6	7	8	9	10
Too high humidity ("moist air")	0	1	2	3	4	5	6	7	8	9	10
Too low humidity ("dry air")	0	1	2	3	4	5	6	7	8	9	10
Draught	0	1	2	3	4	5	6	7	8	9	10
Other*	0	1	2	3	4	5	6	7	8	9	10

* Other, please specify:________________

Fig. 3 – Question in dairy considering housing satisfaction.

3. Results and discussion

3.1 Thermal conditions (indoor average) versus thermal comfort

The average indoor temperatures and relative humidity have been reported earlier [6]. As a summary, average indoor Tw during heating season was relatively high in all measurements among both groups, before retrofits 22.8 °C in FER and 22.7 °C in DER and after retrofits 22.7 °C and 22.7 °C, respectively. The average RHw was low, before retrofits 28.8 RH% in FER and 29.2 RH% in DER and after retrofits 30.5 RH% and 28.2 RH%, respectively. Therefore, overheating was common in the studied apartments.

Table 1 presents results of perceived occupant satisfaction concerning indoor temperature and humidity. Typically, occupant reported "not at all" or slightly disturbance "1" considering temperature and humidity, average was less than 1. The differences between Pre and Post were not statistically significant.

Tab. 1 – Results of perceived occupant satisfaction, temperature and humidity.

Pre or post		Too high tempe-rature	Too low tempe-rature	Too humid	Too dry
Pre	Mean	.6	.6	.2	.9
	Median	.0	.1	.0	.0
	Std. Dev.	1.2	1.2	.7	1.6
	N	159	160	158	162
Post	Mean	.7	.6	.2	.8
	Median	.0	.0	.0	.0
	Std. Dev.	1.6	1.2	.4	1.7
	N	105	105	105	106
Total	Mean	.6	.6	.2	.9
	Median	.0	.0	.0	.0
	Std. Dev.	1.4	1.2	.6	1.7
	N	264	265	263	268

Before the retrofits, occupants reported slightly more "too low temperature" than after the retrofits, but the difference was not statistically significant. Also, reporting of "too dry" indoor air was more common than "too humid", which could be expected during the heating season.

3.3 Thermal conditions (coldest spot) versus thermal comfort (draught)

The average indoor temperatures and relative humidity near the coldest spot of building envelope have been presented in Fig. 4 and 5. Table 2 presents medians, standard deviations, and 95th percentiles for indoor temperature and relative humidity. The outdoor temperature was a higher after retrofits, the median temperature before retrofits in FER buildings was 1.85 °C and after retrofits 2.03 °C. In DER buildings the outdoor temperature was 7,66 °C and 8.30 °C, respectively.

The indoor temperature near the coldest spot of building envelope was higher after retrofits in buildings with deep retrofits (DER), as expected since the thermal insulation of the envelope was commonly improved. Also, the outdoor temperature after retrofits was higher, which could also be influenced to the indoor temperatures.

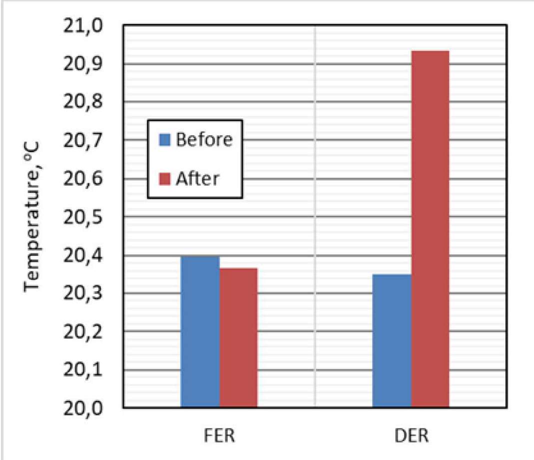

Fig. 4 – Temperature (coldest spot) before and after retrofits.

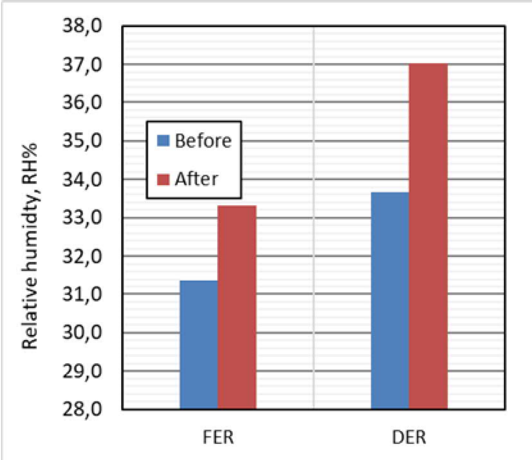

Fig. 5 – Relative humidity, RH (coldest spot) before and after retrofits.

Tab. 2 – Temperature and relative humidity near coldest spot.

T	Pre		Post	
ºC	FER	DER	FER	DER
Median	20.73	20.32	20.79	20.60
Std.dev.	1.63	1.61	1.69	2.44
95th	22.83	22.40	22.58	24.48
N	147	23	103	21
RH	Pre		Post	
%	FER	DER	FER	DER
Median	30.41	34.27	32.24	35.21
Std.dev.	7.99	6.73	7.71	4.70
95th	45.58	42.79	48.19	45.38
N	147	23	103	21

Table 3 presents results of perceived occupant satisfaction concerning stuffiness/ poor IAQ and draught. Occupant reported not at all or slight disturbance considering stuffiness or draught, with an average less than 1. There was no statistically significant difference considering draught between Pre and Post retrofit. However, there was a significant difference ($p=0.001$) concerning stuffiness / poor IAQ, which was reported less disturbing after the retrofits (Fig. 6).

Tab. 3 – Results of perceived occupant satisfaction, IAQ and draught.

Pre or post		Stuffiness / poor IAQ	Draught
Pre	Mean	1.0	1.0
	Median	.4	.2
	Std. Dev.	1.4	1.8
	N	163	162
Post	Mean	.6	.7
	Median	.0	.1
	Std. Dev.	1.1	1.3
	N	105	105
Total	Mean	.8	.9
	Median	.2	.1
	Std. Dev.	1.3	1.6
	N	268	267

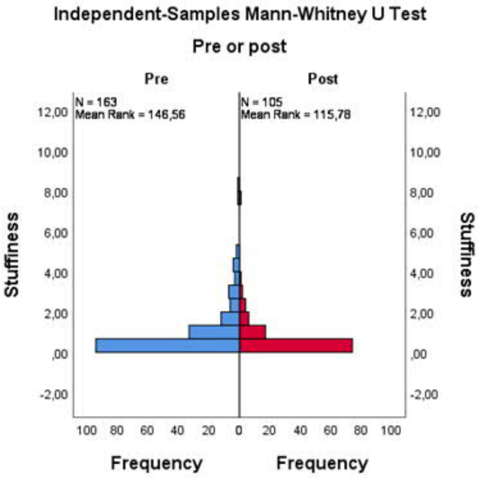

Fig. 6 – Mann-Whitney U-test, perceived stuffiness / poor IAQ.

4. Acknowledgement

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5. References

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Data Statement

The datasets generated and analysed during the study are not available but the authors will make every reasonable effort to publish them in near future.