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Energy retrofits in multi-family buildings in north-east Europe: the impacts on thermal conditions

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Abstract

We have conducted a project to develop a common protocol for indoor environmental quality (IEQ) assessment and to assess the effects of energy retrofits on IEQ. This paper focuses on thermal comfort, which was first assessed based on 2-month continuous monitoring in 16 multi-family buildings (94 apartments) in Finland and 20 buildings (96 apartments) in Lithuania during heating season before retrofits. In addition, corresponding data after retrofits were available from three buildings (17 apartments) from Finland and seven (30 apartments) from Lithuania. Two data loggers per apartment were placed to evaluate Tw and RHw (warm area), and Tc and RHc (coldest spot). Questionnaire data regarding housing quality and health were collected from the occupants. The results before retrofits indicated high Tw (>23 ºC) for a large proportion of time in Finnish apartments, whereas opposite trend was observed in Lithuania. After retrofits, proportion of time with high Tw was higher while proportion of apartments with low RHw was lower in Finland, whereas in Lithuania, about one fourth of the apartments had higher Tw and RHw, hence fulfilling the national guidelines. The average absolute humidity was higher after retrofits in both countries, especially in Lithuania (by 15%). Occupant responses indicated improved thermal comfort. Therefore, potential effects of energy retrofits on occupants' thermal environment and satisfaction were demonstrated, and simply adjusting indoor temperature could help to save energy. Further analysis is needed to include the effects of outdoor conditions, as well as overall IEQ to the assessment.

Keywords: retrofits; multi-family buildings; thermal comfort; questionnaire

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1. Introduction

As a response to fulfill the reduction of energy consumption from Energy Performance of Buildings Directive (EPBD)[1], building retrofit campaigns for existing buildings have being implemented in many EU member states [2, 3]. Recent research has demonstrated that it is possible to improve indoor environmental quality (IEQ), health and wellbeing of building occupants along with improved energy efficiency. However, the impacts are influenced by several factors (e.g., building, climatic, cultural, social, economic) and often differ from country to country [4].

INSULAtE project (www.insulateproject.eu) aims to develop a comprehensive assessment protocol taking into account both energy efficiency (EE) and IEQ, which could lead to a more optimal resolution with health co-benefits. This paper focuses on assessing how retrofitting of multi-family buildings may affect thermal comfort, which in turn has shown to have direct effects on users' productivity [5]. The key idea is to compare measured and perceived thermal comfort pre and post retrofits in two countries (Finland and Lithuania) with distinct premises with respect to building stock, climate, and standards.

2. Methods and materials

2.1. Building recruitment, monitoring and questionnaire

Recruited sample included 16 buildings (94 apartments) from Finland and 20 buildings (96 apartments) from Lithuania. The baseline monitoring and questionnaire data collection occurred from December 2011 to April 2013. Post-retrofit data collection started in October 2013 and is expected to be finished in May 2015. At this point, post retrofit data were available from three Finnish buildings (17 apartments) and seven Lithuanian buildings (30 apartments). Information concerning building characteristics and condition (including dimensions and volume, types of heating and ventilation systems, and renovation history) was collected from the building owners by a questionnaire.

This paper focuses on two months continuous monitoring of temperature (T) and relative humidity (RH). Two loggers per apartment were placed. One logger was placed for the warm area (Tw and RHw), i.e., in middle of the living room with the height of 1.2-1.5 m above ground corresponding to human breathing zone when seated. The other logger was placed for the coldest spot (Tc and RHc), i.e. spot with minimum inner surface temperature detected by thermographic camera or IR-thermometer (usually by the balcony door). Other measured IEQ parameters included PM, CO, CO_2, VOCs, formaldehyde, NO_2, radon (data not shown). Occupant questionnaire data included occupants' background; information related to the building and living environment; physical, biological and chemical conditions; hygiene; and occupant behavior, health and well-being[6].

2.2. Retrofits

The retrofits varied by buildings, mainly including: 1) full facade (including the base) thermal insulation (usually 20-30 cm of EPS or in some cases mineral wool on external walls); 2) roof thermal insulation (solar collectors were installed on the top of the roof in some cases); 3) improving heating and hot water systems (e.g., replacement of heating system trunk pipelines with new ones, new thermal insulation for piping system); 4) improving ventilation and heat recovery systems (e.g., new fans in attics/roofs; installation of adjustable air vents on the top part of the plastic windows; 5) replacement of old windows with more efficient windows, glazing of balconies or terraces, replacement of doors, etc.

3. Results and Discussion

Based on Finnish housing and health guidelines [7], recommended room temperature is 21 ºC (acceptable temperature is 18 ºC), and it should not exceed 23-24 ºC during the heating season, whereas recommended range for RH is 20-60 %. In Lithuania[8], the recommended room temperature is between 20-40 ºC, and range for RH is 40-60%. We used paired pre and post data to study the impacts of retrofits.

Fig. 1 shows the percentage of time that Tw and RHw were outside the guideline values during the sampling period. After retrofits, Tw below 21 ºC was 7% lower, and Tw over 23 ºC was 6% higher; while RHw <20% was 19% lower in Finland. In Lithuania, Tw below 20 ºC was 26% lower (13% for Tw <18 ºC), while RHw below 40% was 25% lower. Tc and RHc after retrofits could be considered better in both countries, especially in Lithuania where average Tc was 2.3 ºC higher (data not shown).

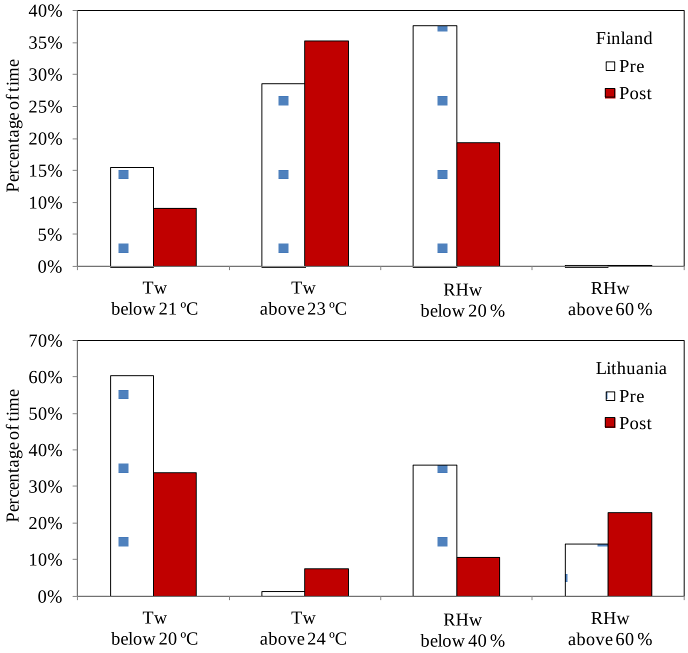

Fig. 1. Percentage of time when indoor temperature (T) and relative humidity (RH) failed national guidelines at pre and post retrofit (N=17 in Finland; N=30 in Lithuania)

Some differences were observed in indoor absolute humidity (AH), seen in Fig.2. In Finland, AH averaged 5.5±0.6 g/m^3 before retrofits and it was slightly higher after retrofits (5.7±1.5 g/m^3). In Lithuania, 15% higher average level was found after retrofit. However, no conclusions can be drawn based on these data before outdoor data have been analyzed.

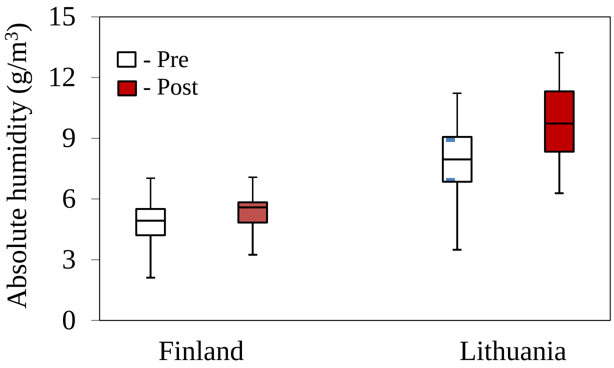

Fig. 2. Indoor absolute humidity (g/m^3) before and after retrofit (N=17 in Finland; N=30 in Lithuania)

Table 1 shows information on occupants' background and perceived thermal conditions from apartments with paired pre and post retrofits data (when available). Respondents' gender and age distributions remained similar. Similar to the measurement, temperature was reported higher (above 22 ºC) in 32% of the apartments in Finland. Some 70% reported temperature "suitably warm" before retrofits, which increased to 78% after retrofits. In addition, increased percentage (13%) reported as "too warm" after retrofits. In Lithuania, all occupants reported temperature above 18 ºC, and higher percentage was reported as suitably warm after retrofit. Cold floor surfaces were reported in both countries both before and after retrofits. Moisture or mold damage to the living space was rarely reported in Finnish apartments, but decreased in Lithuania after retrofits.

Table 1. Occupant background information and thermal condition responses in Finland (N=23) and Lithuania (N=14)

Background information and thermal condition	Finland		Lithuania	
	Pre, % (95% CI)	Post, % (95% CI)	Pre, % (95% CI)	Post, % (95% CI)
Gender of respondent (Female)	69.6 (50.8-88.4)	73.9 (56-91.9)	64.3 (39.2-89.4)	71.4 (47.8-95.1)
Age of respondent (years)	63.7 (37.7-89.7)	63.0 (36.6-89.3)	58.0 (27.6-88.4)	58.1 (26.5-89.6)
Number of occupants	1.5 (0.8-2.1)	1.6 (0.9-2.3)	2.4 (1.2-3.7)	2.4 (1.2-3.7)
Typical indoor temperature during the heating season?				
Under 18 degrees Celsius	4.5 (-4.2-13.2)	0 (0-0)	38.5 (12.0-64.9)	0 (0-0)
18-20 degrees Celsius	9.1 (-2.9-21.1)	4.3 (-4-12.7)	38.5 (12.0-64.9)	64.3 (39.2-89.4)
20-22 degrees Celsius	54.5 (33.7-75.4)	65.2 (45.8-84.7)	15.4 (-4.2-35)	35.7 (10.6-60.8)
22-24 degrees Celsius	27.3 (8.7-45.9)	26.1 (8.1-44)	7.7 (-6.8-22.2)	0 (0-0)
Over 24 degrees Celsius	4.5 (-4.2-13.2)	4.3 (-4.0-12.7)	0 (0-0)	0 (0-0)
Temperature conditions				
Suitably warm	69.6 (50.8-88.4)	78.3 (61.4-95.1)	21.4 (-0.1-42.9)	71.4 (47.8-95.1)
Too cold	13.0 (-0.7-26.8)	13.0 (-0.7-26.8)	42.9 (16.9-68.8)	0 (0-0)
Too warm	4.3 (-4-12.7)	13.0 (-0.7-26.8)	21.4 (-0.1-42.9)	0 (0-0)
Draughty	13.0 (-0.7-26.8)	4.3 (-4-12.7)	0 (0-0)	0 (0-0)
Cold floor surfaces, etc.	17.4 (1.9-32.9)	26.1 (8.1-44)	28.6 (4.9-52.2)	21.4 (-0.1-42.9)
Moisture or mold damage in main living space				
Kitchen	0 (0-0)	0 (0-0)	30.0 (1.6-58.4)	25.0 (0.5-49.5)
Bedroom (s)	0 (0-0)	0 (0-0)	64.3 (39.2-89.4)	30.8 (5.7-55.9)
Living room	0 (0-0)	0 (0-0)	45.5 (16.0-74.9)	25.0 (0.5-49.5)
Bathroom	0 (0-0)	0 (0-0)	40.0 (9.6-70.4)	33.3 (6.7-60.0)
Other living space	0 (0-0)	6.3 (-5.6-18.1)	-	-
Windows				
Single pane	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
Double pane	8.7 (-2.8-20.2)	13.0 (-0.7-26.8)	92.9 (79.4-106.3)	69.2 (44.1-94.3)
Triple pane	78.3 (61.4-95.1)	56.5 (36.3-76.8)	7.1 (-6.3-20.6)	30.8 (5.7-55.9)
Quadruple pane	13.0 (-0.7-26.8)	26.1 (8.1-44.0)	0 (0-0)	0 (0-0)

Overall, significant different baselines in thermal parameters between the countries were observed, with large variations between the apartments. The results were in line with occupants' responses. Indoor T after retrofits was often higher than before retrofits in both countries. In Finland, indoor T was in many cases too warm already before retrofits, but in Lithuania guideline values were met more frequently after retrofits. In addition, humidity conditions after retrofits were better in both countries.

4. Conclusions

Energy retrofits have potential positive effects on occupants' thermal environment and satisfaction. IEQ assessment including monitoring of thermal conditions provides useful information that can help to save energy by simply adjusting indoor temperature. Potential effects of outdoor conditions will be included in the further analyses.

Acknowledgements

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