Assessment of Indoor Environmental Quality in Existing Multi-family Buildings in North-East Europe

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Abstract

Sixteen existing multi-family buildings (94 apartments) in Finland and 20 (96 apartments) in Lithuania were investigated prior to their renovation in order to develop and test out a common protocol for the indoor environmental quality (IEQ) assessment, and to assess the potential for improving IEQ along with energy efficiency. Baseline data on buildings, as well as data on temperature (T), relative humidity (RH), carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), nitrogen dioxide (NO_2), formaldehyde, volatile organic compounds (VOCs), radon, and microbial content in settled dust were collected from each apartment. In addition, questionnaire data regarding housing quality and health were collected from the occupants. The results indicated that most measured IEQ parameters were within recommended limits. However, different baselines in each country were observed especially for parameters related to thermal conditions and ventilation. Different baselines were also observed for the respondents' satisfaction with their residence and indoor air quality, as well as their behavior related to indoor environment. In this paper, we present some evidence for the potential for improving IEQ along with energy efficiency in the current building stock, followed by discussion of possible IEQ indicators and development of the assessment protocol.

Highlights: (3-5 sentences)

- Comprehensive information including building characteristics, measured IEQ, and occupants' responses were investigated in a large set of multi-family buildings.
- Most measured IEQ parameters were within recommended limits, however, thermal conditions and ventilation adequacy were frequently compromised.
- Substantial differences in indoor environmental conditions at the baseline indicate a need of different levels and stages of energy efficiency improvement.
- Possible IEQ indicators are recommended to complement building energy audits and energy performance certificates (EPCs).

Keywords: Environmental monitoring; Exposure; Questionnaire; Residential buildings; IEQ Indicators

1. Introduction

Both European and national housing surveys have reported housing quality problems linked to indoor environmental quality (IEQ) and occupant health. For example, multinational databases (including ENHIS, EU-SILC survey, and WHO LARES survey) have identified various housing quality problems in European countries, such as indoor air pollutants, dampness and mold, and noise (Lelkes and Zólyomi, 2010; WHO, 2007, 2010). In EU26, over 50% of the total burden of disease associated with indoor exposures has been estimated to be caused by $PM_{2.5}$ (i.e. particles with a diameter smaller than 2.5 μm) originating from outdoor air. Other relevant indoor exposures associated with the burden of disease include radon, smoking, biological aerosols, and volatile organic compounds (VOCs) (Hänninen and Asikainen, 2013).

The latest continuous national survey (around 13,300 households per year) from England reported increased energy efficiency (EE) by standard insulation measures (i.e., cavity wall, loft, and double glazing increased from 14%, 3%, and 30% in 1996 to 40%, 34%, and 79% in 2012, respectively). However, 4% (970,000) of homes remained with dampness and 3% with overcrowding problems. (DCLG, 2014). In Finland, a national questionnaire based housing and health survey (1312 responses) reported over 90% of the respondents being satisfied or quite satisfied with their residence. However, the satisfaction varied by type of dwelling, and many housing quality problems were reported: 10% were unsatisfied or rather unsatisfied with indoor air quality (IAQ), 8% reported too cold winter temperatures, 29% reported too hot summer indoor temperatures, 22% reported a daily traffic noise disturbance, and 5% reported moisture or mold damage (Turunen et al., 2010).

The World Health Organization (WHO) resolution on environment and health has called for policies to protect public health from the impacts of major environment-related hazards such as those arising from climate change and housing (WHO, 2004). Concurrently, the Energy Performance of Buildings Directive (EPBD) has established targets for reduction of energy consumption. Both new and existing residential buildings are targeted, promoting nearly zero-energy buildings (nZEBs) (EUR-Lex, 2013; Marszal et al., 2011) and energy retrofits (Brown et al., 2011; Buvik et al., 2011; Cali et al., 2011; Lefèbver et al., 2011). The directive also aims to develop energy performance certificate (EPC) to become a real, active energy label of houses. In addition to energy efficiency, a more comprehensive auditing approach taking into account IEQ could lead to an optimal resolution with health co-benefits.

It is recognized that the building renovation processes can result in both increased energy efficiency (Brown et al., 2011; Buvik et al., 2011) and improved indoor climate and comfort for the residents (Lefèbver et al., 2011). However, rebound effects have also been reported, for example increased noise levels due to inappropriate installation of mechanical ventilation systems (Brown et al., 2011), and increased exposure to indoor pollutants (Derbez et al., 2014).

A limited number of studies worldwide have addressed the potential effects of improved energy efficiency on health (Green, 1999; Green et al., 2000; Hopton and Hunt, 1996; Iversen et al., 1986; Thomson et al., 2001). The WHO Housing and Health Program implemented a health-monitoring project in Frankfurt, Germany, with 131 insulated and 104 non-insulated dwellings, which indicated that thermal insulation had a positive impact on thermal conditions; however, direct association between thermal insulation and health effects were weak and limited to small prevalence differences of respiratory diseases and colds (Braubach et al., 2008). In the UK, government supported energy efficiency improvements under the Warm Front scheme. For example, energy efficiency improvements were delivered in total of 268,900 households between April 2007 and March 2008. Two reviews of the impact of this initiative have been published. The results provided evidence that Warm Front home energy improvements were accompanied by appreciable benefits in terms of use of living space, comfort and quality of life, and physical and mental well-being (Gilbertson et al., 2006). In the remaining cold homes, residents were less likely to have long-standing illness or disability, but were more likely to experience anxiety or depression (Critchley et al., 2007). In New Zealand, improving insulation of dwellings in low income communities (1350 households) showed increased bed temperature with improved health (Howden-Chapman et al., 2007).

In many European countries, a large proportion of the population resides in multi-family buildings. Therefore, they represent a potential target group for national programs supporting energy efficiency improvements. For example, the Housing Finance and Development Centre of Finland allocates funds for energy improvements for approximately 3,000 buildings, and estimated amount of energy saved is as much as 1.5 TWh per year (Heljo, 2007). The annual budget of the energy improvements for the year 2014 was about € 16.5 million. In Lithuania, a national program for renovation of multi-family buildings started in 2005 with up to 50% state support of renovation costs, and expected energy savings of 1.7 TWh per year (Stankevicius et al., 2007). The effects of these programs have not been systematically assessed. Overall, assessment of effects of energy improvements of buildings on IEQ and health is often neglected. Methodologically robust intervention studies supporting improved energy efficiency by means of improved IEQ and health are needed.

As a response to the climate and building stock, Northern European countries (inc. Finland, Sweden and Norway) have historically been approximately on the same level with respect to the standards (e.g, insulation requirements for building envelope)(EPBD, 2013). While the current standards in Baltic countries (inc. Lithuania, Latvia and Estonia) are also similar, a large proportion of their multifamily buildings have been constructed during the period of former Soviet Union with notable differences in the standards(BEEN, 2007). Due to the similarity with respect to climate, building stock, and standards(Economidou et al., 2011), Finland and Lithuania can be used as examples representing Northern and Eastern European countries, correspondingly. In addition to building characteristic, the existing building stock in Finland and Lithuania has distinct premises with respect to energy sources, distribution and use, as well as ways in implementing national policies within EU(YM, 2013).

This paper analyses IEQ and occupant satisfaction in Finnish and Lithuanian multi-family buildings that are waiting to be renovated. Baseline differences between countries are discussed, together with the differences between measured and occupant reported IEQ parameters. With these analyses, we aim to identify possible IEQ indicators and further develop a suitable assessment protocol to complement building energy audits and EPCs. Further on, we aim to assess potential for IEQ improvement in building energy efficiency campaigns similar to the national programs in Finland and Lithuania.

2 Materials and methods

2.1 Study design, recruitment and schedule

Multi-family buildings that were planned to be renovated within the following year were eligible for the study. The study area included several regions in Finland (Tampere, Hämeenlinna, Imatra, Helsinki, Porvoo, Kuopio), and Kaunas region in Lithuania (Figure 1). The buildings were chosen among volunteers, of which renovation was related to energy efficiency and fitting into the project schedule (renovations to be finished by the fall of 2014). Recruited apartments were selected through volunteer occupants who signed "willingness to participate" form. The occupants did not receive any compensation for their time participating in the study.

The sample included 16 buildings (94 apartments) from Finland and 20 buildings (96 apartments) from Lithuania. Buildings were added to the study on a continuous basis, and the baseline data collection occurred from December 2011 until April 2013. The renovation usually took place in the following year after the baseline measurements, starting from April 2012.

The assessment protocol includes: 1) building-related assessment for issues relevant to energy efficiency (EE) and structures; 2) indoor environment, including thermal conditions and indoor air quality (IAQ); and 3) occupants' health and satisfaction with IEQ. The selected methods were expected to be both relevant and optimal for this type of the study. Information about available instruments was collected, apriori selection criteria including (technical) properties, accuracy, and reliability. In addition, we considered the instruments' practical applicability for large scale use, and field study logistics (e.g. matching sampling time).

Information about building characteristics and condition was collected from the building owners by a questionnaire, including dimensions and volume, the type of heating and ventilation system, and renovation history. In addition, field technicians collected information on EE and structures (including thermal resistances of building envelope, air tightness, external shadowing and solar facing, heating and ventilation systems and energy sources) using checklists and basic measurements.

A comprehensive IEQ assessment covers four environmental aspects including thermal conditions, IAQ, and visual and aural comfort. Previous studies had indicated the main effects related to energy efficiency surround thermal conditions and the potential for poor IAQ if ventilation is insufficient(Bone et al., 2010). Therefore, measurements of IEQ parameters focused on thermal conditions and IAQ. Aspects related to visual (lighting) and aural (noise) comfort were evaluated by occupants' survey. Data loggers and passive samplers were set up during the first visit in each apartment. Following the first visit, 24 hours, one week, and two months visits for picking up loggers, samplers, and survey responses were scheduled. Heating seasons were targeted for measurements in order to minimize impacts from outdoor environment (e.g., via opening windows).

2.2 Environmental monitoring

Two months continuous monitoring of temperature (T) and relative humidity (RH) was initially planned, which in some cases was extended to one year in order to study seasonal variations. Data were recorded with one hour resolution using data loggers (DT-172 logger, Shenzhen Everbest Machinery Industry Co., Ltd, China). These loggers measure temperature from -40 °C to 70 °C with an accuracy of ± 1 °C, and RH from 3% to 100% with an accuracy of ± 3%. Two loggers per apartment were placed, one for the coldest spot (i.e. spot with minimum inner surface temperature detected by thermographic camera or IR-thermometer, usually by the balcony door) and the other for warm area (e.g., middle of the living room with the height of 1.2-1.5 m above ground, i.e. human breathing zone as seated). All units used in the study were new and recently calibrated by the manufacturer.

During the first visit, indoor-outdoor pressure difference, and air flow through vents in bathroom, kitchen or walk-in closet (if applicable) were measured. Carbon dioxide (CO_2) and carbon monoxide (CO) concentrations were measured every minute during a 24-hour period. New, factory calibrated sensors (HD21AB/HD21AB17, Delta OHM, Italy) were utilized, which measured CO_2 concentrations from 0 ppm to 5000 ppm with an accuracy of ±50 ppm or ± 3%. Side-by-side simultaneous tests before and after the baseline measurements were conducted, based on which replicate precision ranged from 5% to 11%.

Indoor and outdoor 24-hour particulate matter (PM) concentration and size distribution measurements were performed every 1-minute using optical particle counters (OPCs, Handheld 3016 IAQ, Lighthouse Inc, USA). Only PM in 2.5 μm and 10 μm cut-off diameters are discussed in this paper. Further description of the sampling methods and quality elements is provided elsewhere (Prasauskas et al., 2014).

Nitrogen dioxide (NO_2) was measured by passive sampler - Difram100 Rapid air monitor (Gradko, Ltd., England) with one week exposure time. Formaldehyde and volatile organic compounds (VOCs, represented by benzene, toluene, ethyl benzene and xylenes (BTEX) were sampled using Radiello™ Cartridge Adsorbents (Sigma-Aldrich) with one week exposure time.

With respect to radon, two different methods were utilized, in order to adapt the national guidelines for each country. Finland used radon samplers from the Finnish Radiation and Nuclear Safety Authority (STUK) based on the alpha track method with sampling period of two months(Reisbacka, 2001). Lithuania used gamma dose rate measurements (Standard electrets E-PERM^{TM}, Rad Elec Inc.) suggested by the Lithuanian Radiation Protection Centre, with one month measurement period (Pilkyte and Butkus, 2005).

Settled dust was collected on 20 × 45 cm standardized-placed acquisition-surfaces, referred to as settled dust boxes (SDBs), for two months. Field blanks (closed boxes) were placed in a portion of apartments randomly (usually on the top of a shelf). After SDBs were collected from the homes they were transported to the study centers, where the dust was vacuumed onto filter cassettes (0.45µm MCE filter membranes, Zefon International, US) for subsequent microbial analysis. The analysis was carried out in a sub-sample of the homes, using quantitative polymerase chain reaction (qPCR) technique targeting selected fungal and bacterial groups and using previously published qPCR assays and approaches(Haugland et al., 2004; Kärkkäinen et al., 2010; Torvinen et al., 2010; US EPA, 2014). The concentrations of total fungi are reported in this paper.

2.3 Questionnaire responses

Questionnaire data included information concerning occupant perceived housing satisfaction (e.g. thermal comfort, indoor air quality, lighting, and noise disturbance). One adult per apartment was asked to fill in a questionnaire, which have been developed, tested, and used in previous housing and health studies [6]. Some modifications were made for this study, e.g. by shortening the questionnaire. The final questionnaire comprised 49 questions related to the building and living environment; physical, biological and chemical conditions; hygiene; occupant behavior, health and well-being; and background information (e.g. respondent's age and gender). In addition, 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. The study plan was evaluated and approval was obtained from the National Institute for Health and Welfare's Ethical Research Working Group in Finland as well as Approval to Conduct Biomedical Research in Lithuania. Questionnaire data from the 2011 Finnish National Survey were used as a reference (responses from owner-occupied apartments only) [6].

2.4 Data analysis

A macro-imbedded spreadsheet program (Excel 2010, Microsoft Corporation, USA) was applied in the initial data analysis, including quality assurance checks, filtering, summary statistics, graphical analyses, and exception notification. The same period of T and RH measurement (two months) from both countries were analyzed in this paper (excluded data from non-heating reasons, if applicable). Outdoor T and RH data during the corresponding period were obtained from local monitoring stations, i.e. Kaunas region in Lithuania (by Lithuanian Hydrometeorological Service under the Ministry of Environment), and several regions (Tampere, Hämeenlinna, Lappeenranta, Helsinki, Porvoo, Kuopio) in Finland (by Finnish Meteorological Institute under the Ministry of Transport and Communications). Concentrations for continuous measurements, e.g., CO_2, and CO, and PM were calculated only for samples that reached 75% or more of the intended 24 h period (≥18 h). Table S1 summarizes these data during the study period.

For continuous variables, correlation coefficients were calculated. Descriptive statistics such as frequencies, means, and variances were calculated. Normality assumptions of continuous variables were examined and outliers were identified. Univariate and bivariate analyses were used to study the characteristics of the study population and to look at the crude associations between the variables of interests. Kruskal-Wallis nonparametric tests were used for differences in medians, and F and Tukey's tests for means. Questionnaire data were analyzed for descriptive statistics (e.g., frequency distributions, comparisons of means, 95% confidence intervals) and compared to corresponding reference data available from Finland.

We also used PS Power and Sample Size Calculation program Version 3.0.43 to produce rough estimates of detectable differences for a building that would utilize the same IEQ assessment protocol in five or ten apartments to obtain a mean response as compared to the whole population means (using standard deviations) based on our samples of 94 Finnish and 96 Lithuanian apartments. In this analysis we used probability of .8 and α .05. Due to large variability and / or skewed distributions, estimates were not produced for CO, PM, BTEX, radon, or fungi.

3. Results

3.1 Building characteristics

Table 1 summarizes characteristics of the buildings studied in both countries. The recruited buildings were similar by age (constructed 41 vs. 42 years ago) and floor area (3,502 vs. 3,529 m^2). In Finland, the floor area of the apartments averaged 69 m^2 (± 17 m^2); ten buildings (63%) had balconies; seven buildings had energy class certification available (1 in class B, 6 in class C or D), and six had documented renovation history available. In Lithuania, the floor area of the apartments averaged 58 m^2 (± 12 m^2); all buildings had balconies, and the information for energy class certification and renovation history was not available. Most of the buildings had district heating (75% in Finland, 95% in Lithuania), and other buildings had water circulated radiators or local central heating/fireplace. The majority of the buildings (81%) in Finland had mechanical ventilation with mechanical exhaust; while all buildings in Lithuania had natural ventilation (some buildings had mechanical exhaust equipment in the kitchen and bathroom).

3.2 Exposure levels

Table 2 shows the concentrations of measured parameters, including T and RH in the coldest spot (Tc and RHc) and warm area (Tw and RHw), CO_2, CO, PM, NO_2, formaldehyde, BTEX, radon, and fungi. Guideline values from the WHO [24], as well as European(EC, 2008) and national levels (Finland [MSAH, 2003] and Lithuania [LRS, 2007, 2009]) are also presented. The percentage of apartments (average levels) that failed the guidelines was calculated, considering WHO values as a priority, then EU, and finally the national levels.

In Finland, average levels of Tc and RHc in all of the apartments met the national guidelines. Tw in five apartments (5%) was lower than 21 ºC (lowest 19.3 ºC), and in 34 (36%) apartments higher than 23 ºC (highest 24.9 ºC). RHw in all apartments was below 60% (highest 49.0%) and in 27 (29%) apartments below 20%. In Lithuania, Tw in 54 (61%) apartments was lower than 20 ºC (11% below 18 ºC, lowest = 14.4 ºC). RHw in 32 (36%) apartments was below 40%, and 5 (6%) exceeded 60% (highest = 69.5%). It was estimated that with a sample size of five apartments, it is possible to detect 2.1 ºC difference in the mean Tc and 1.4 ºC difference in the mean Tw as compared to the whole population sample in Finland, whereas the corresponding differences would be 2.9 ºC and 2.1 ºC based on Lithuanian buildings. With a sample size of ten apartments, it is possible to detect 1.5 ºC differences in mean Tc and 1.0 ºC difference in Tw in Finland, and 2.1 ºC difference in Tc and 1.5 ºC difference in Tw in Lithuania. With respect to RH, the detectable differences were 9-10% in Finland and 13-14% in Lithuania with sample size of five apartments, and about 7% (Finland) and 9-10% (Lithuania) with sample size of ten apartments.

The percentage of T and RH exposure over time is presented in Figure 2. The Finnish apartments had higher than the recommended temperature (Tw > 23 ºC) during 40% of the measurement period (Figure 2.A), while the Lithuanian apartments had lower than recommended temperature (Tw < 20 ºC) during 54% of the measurement period (Figure 2.B). T and RH in the coldest spots and warm areas were significantly correlated, e.g., T_C and Tw had Spearman correlation coefficients of 0.60 in Finland and 0.73 in Lithuania (Table 3). The correlation coefficients between indoor and outdoor T (Tc and To, Tw and To) were 0.60 and 0.42 in Lithuania and 0.30 and 0.24 than in Finland, respectively.

Two (2%) apartments in Finland and 26 (30%) in Lithuania had 24-hour average CO_2 concentrations higher than 1200 pm; and 4% and 41% were above 1000 ppm, respectively. For 8-hour maximum values, 5 (5%) apartments had levels ≥ 1200 ppm in Finland and 27 (31%) in Lithuania (data not shown). CO_2 concentrations during occupied periods were considerably high in Lithuania. It was estimated that with a sample size of five apartments, it is possible to detect 236 ppm difference in the mean CO_2 in a Finnish building (170 ppm with N=10) and 500 ppm (361 ppm with N=10) difference in a Lithuanian building, correspondingly, as compared to the whole population means. CO was detected in two apartments in Finland with negligible concentrations (<1 ppm). Twenty eight apartments in Lithuania had low CO concentrations, however below the national guidelines.

In both countries, there were some apartments where the PM levels exceeded the guideline values, e.g., 6 (7%) and 5 (5%) apartments for indoor $PM_{2.5}$ (25 µg m^{-3}) in Finland and Lithuania, respectively. Outdoor PM levels were relatively high in Lithuania, e.g., 24 (28%) apartments for $PM_{2.5}$ and 15 (18%) for PM_{10}

exceeding guideline values, but the concentrations varied between apartments within the buildings. Highest variation observed for a building with four apartments measured, where $PM_{2.5}$ levels varied from 17.4 to 55.8 µg m^{-3}, while PM_{10} varied from 24.9 to 236.9 µg m^{-3}. Indoor-outdoor (I/O) ratios for $PM_{2.5}$ and PM_{10} averaged 1.6 ± 3.0 and 1.9 ± 2.1 in Finland; and 1.2 ± 2.3 and 1.5 ± 2.2 in Lithuania, respectively. Non-parametric (Spearman) correlations for hourly $PM_{2.5}$ between indoor and outdoor were relatively lower (r=0.39 in Finland; r=0.46 in Lithuania), as well as hourly PM_{10} (r=0.29 and 0.25, respectively).

Concentrations of NO_2 averaged 6.6 ± 3.7 µg m^{-3} (N=82) in Finland and 14.03 ± 7.89 µg m^{-3} (N=88) in Lithuania, with highest levels of 22.60 µg m^{-3} and 43.77 µg m^{-3}, respectively. It was estimated that with a sample size of five apartments, it is possible to detect 4.7 µg m^{-3} difference in the mean NO_2 concentration in a Finnish building (3.4 µg m^{-3} with N=10) and 10.2 µg m^{-3} ppm (7.4 µg m^{-3}) difference in a Lithuanian building, correspondingly, as compared to the whole population means.

Formaldehyde concentrations exceeded 30.0 µg m^{-3} in three apartments in Finland (maximum 40.0 µg m^{-3}) and 21 apartments in Lithuania (maximum 51.4 µg m^{-3}). It was estimated that with a sample size of five apartments, it is possible to detect 9.0 µg m^{-3} difference in the mean formaldehyde concentration in a Finnish building (6.5 µg m^{-3} with N=10) and 13.6 µg m^{-3} (9.8 µg m^{-3}) difference in a Lithuanian building, correspondingly.

BTEX levels averaged 9.3 ± 14.0 µg m^{-3} in Finland and 22.8 ± 25.2 µg m^{-3} in Lithuania. The average concentrations of benzene, toluene, ethylbenzene, and xylenes in Finland were 3.5, 3.1, 0.6, and 4.3 µg m^{-3}, respectively; 6.8, 10.1, 1.9, and 8.0 µg m^{-3} in Lithuania. In Finland, fifteen apartments had low radon concentration (< 20 Bq m^{-3}), and rest of the apartments (N=79) averaged 72 ± 60 Bq m^{-3}. Five apartments reached the level of 200 Bq m^{-3} but were lower than 320 Bq m^{-3}. In Lithuania, radon was measured in 45 apartments, among which one was below detection limit and two measurements failed. Overall, radon levels were within national guidelines (400 Bq m^{-3} for buildings built before 1992).

Analysis of levels of total fungi in the sub sample of measured apartments indicated different sources' attribution of indoor microbial content. Total fungi in indoor settled dust and RH levels were significantly correlated, i.e. Spearman rank correlation coefficients were 0.61, 0.43, and 0.37 for RH in the coldest spot, warm area, and outdoor, respectively (data not shown).

3.3 Questionnaire

Table 4 presents background information and selected questions related to IEQ in Finland and Lithuania, as well as results from the 2011 Finnish national survey. A total of 142 people (response rate 75%) answered the questionnaire, 83 (88%) in Finland and 56 (58%) in Lithuania. The majority of the apartments in this study were owner-occupied (88% in Finland and 93% in Lithuania). The respondents were relatively older (average age 59.2 in Finland and 54.1 in Lithuania) and a larger percentage was female (61% in Finland and

64% in Lithuania). The average number of occupants living in each apartment was 1.4 and 2.6, respectively. The majority of the respondents (72%) in Finland reported good or fairly good general health, and about 2% a rather poor health condition; while over half of the respondents (56%) in Lithuania reported a good or fairly good health status and 42% satisfactory. Some 32% of the respondents in Finland and 25% in Lithuania thought their health symptoms were related to their home environment.

In Lithuania, about 42% of the occupants had pets (dogs, cats, guinea pigs, birds, etc.) and kept them indoors; 39% had seen signs of pests (live or dead insects or rodents, gnaw marks, excrement, etc.), whereas the corresponding percentages were 12% and 11% in Finland, respectively. About 95% of the respondents in Finland and 69% in Lithuania reported their home being sufficiently spacious. Some 93% of the respondents in Finland and 69% in Lithuania reported being satisfied or fairly satisfied with their residence. In Finland, thirteen respondents (16%) planned to move, among which three were due to the dwelling condition or the dwelling not meeting their needs, and two were due to financial reasons. In Lithuania, four respondents (7%) planned to move, two of them due to dwelling condition or personal needs.

Most of the respondents in Lithuania (82%) reported relative low indoor heating temperature (≤20 ºC), 38% reported too cold temperature, and 16% had adjusted radiator valves (Table 5). In Finland, 28% households reported heating temperature ≥22 ºC, 66% reported suitably warm, and 55% had adjustment behavior. Daily moisture condensation on windows in winter was reported in 37% of the Lithuanian apartments, and occupants tended to open windows daily (e.g., 69% in kitchen, 55% in living room or bathroom). This was much less reported in Finnish buildings. Some 76% of the respondents in Finland and 59% in Lithuania were satisfied or fairly satisfied with indoor air quality. Majority of occupants did not know radon situation of their dwellings (95% in Lithuania and 90% in Finland).

Occupants in Lithuania reported less insufficient lighting in their dwelling (2%) than occupants in Finland (12%). In Lithuania, half of the occupants reported noise disturbance (daily or almost daily) originating from surrounding areas (e.g., traffic or industry), whereas in Finland it was originating from surrounding areas in 26% and from the immediate surroundings (e.g., neighbor dwelling, yard) in 28% of responses.

Occupant reported satisfaction with IAQ was compared with measured parameters. Indoor $PM_{2.5}$, PM_{10}, formaldehyde, RHc and RHw in Finland, and $PM_{2.5}$, NO_2, radon, fungi, RHc and RHw in Lithuania were found slightly higher in the rather unsatisfied or unsatisfied group than in the satisfied or fairly satisfied group, but the differences were not statistically significant. Figure 3 shows the CO_2 concentrations by the satisfaction with IAQ. The CO_2 concentrations in Lithuania were found significantly higher in the rather unsatisfied or unsatisfied group (1086±230 ppm, median=1023ppm) than in the satisfied or fairly satisfied group (940±360 ppm, median=881ppm; $p=0.038$ based on Mann-Whitney U test). The observed association suggest CO_2, which is often associated with ventilation adequacy, as an important indicator of IAQ. Reported indoor T (Table 4) was significantly correlated with measured Tw (Pearson correlation r=0.44 in Finland, r=0.46 in Lithuania, data not shown).

4. Discussion

Some differences were observed in building characteristics between the two countries. On the average, Finnish apartments had fewer occupants, which translate to more spacious living area and could partially explain higher occupant satisfaction and lower CO_2 levels observed, as compared to Lithuanian apartments. Better building insulation in Finland was expected and six buildings had documented renovation history (including previous windows/balcony doors replacement and maintenance), which could be related to less frequent occupant reporting of "too cold" and daily "moisture condensations on windows" responses, as well as lower correlation between indoor and outdoor temperature.

The usage of different types of ventilation systems between the countries could be one of the primary reasons for different levels of indoor pollutant exposures, and could be also related to occupant behavior. Good insulation of the building together with the mechanical ventilation (in Finland) appeared to result in lower concentrations of indoor pollutants and infiltration from outdoor sources; while opening windows and natural ventilation (in Lithuania) could introduce outdoor pollutants and dampness issues (Kotol et al., 2014). Overall, it seems important to help occupants understand how ventilation and occupant behavior affect IEQ.

Significant different baselines in thermal parameters between the countries were observed, with variations between the apartments. The results were in line with occupants' responses. Temperature in the coldest spot (Tc) appears to be a possible indicator of IEQ, and it also correlated with warm area temperature (Tw). However, outdoor temperatures should be taken into account in the interpretation of both of these indoor temperatures, especially if using short term measurements.

Apartments receive different levels of solar loads depending on their orientation, which are rarely evaluated during winter seasons in field studies but appears to contribute to an inconsistent thermal environment. Previous research have studied the possibility to control direct solar radiation during summer season (e.g. by using external shading) as a part of building energy consumption (Kim et al., 2012). This was not addressed in our questionnaire; however, in the future it is possible to analyze the effect of orientation as well as seasonal variations on thermal conditions. The orientation could also explain some of the issues related to a noise disturbance from surrounding areas (vehicular traffic, industry, etc.) and high indoor PM concentration attributed to outdoor sources in part of the apartments.

In addition to the influence of building characteristics and the district heating supply, several other factors should be taken into consideration. For example, control over the indoor climate, such as adjustable radiator valves, has a significant impact on the occupants' satisfaction with IEQ (Becker and Paciuk, 2009; Brager et al., 2004). Occupants, especially older people (Guerra-Santin and Itard, 2010; Kane et al., 2010), appear to prefer warmer indoor environment (Tw>23 ºC) in Finland. This might be a reason for a higher rate of "suitably warm" condition and satisfaction with the Finnish residences. In Lithuania, an opening windows on a daily basis (more than 50%) could be partially related to more frequent reporting of too cold indoor temperature, stuffiness (24%), or unpleasant odors (such as smoke, mold, and sewage). Frequent window opening could introduce challenges for control of thermal conditions, drafts, and outdoor pollutants. In any case, possibilities to control indoor climate also gives the occupants an opportunity to adapt to different thermal environments, which has been reported as a personal preference(Karjalainen, 2009).

Concentration of CO_2 is commonly used as an indicator of ventilation and IAQ. In Finland, low CO_2 levels could be attributed to the use of mechanical ventilation, while higher levels in Lithuania indicated a lesser air exchange with natural ventilation. Somewhat similar trends were seen in PM levels as in CO_2 levels. In general, both indoor and outdoor $PM_{2.5}$ levels were lower in Finland, and the removal of indoor particles was much faster, while in Lithuania, higher indoor $PM_{2.5}$ levels may have resulted from penetration of outdoor sources through building envelopes(Prasauskas et al., 2014) and smoking indoors (15%). Other potential indoor sources of particles include cooking, candle burning (diameter range 0.03–3 μm), etc. (Hussein et al., 2006; Sørensen et al., 2005).

The sampling methods selected for NO_2, formaldehyde, and BTEX resulted in weekly average concentrations. Exposure to NO_2 could significantly increase the risk of respiratory symptoms (Mukala et al., 1999; Rutishauser et al., 1990). Although NO_2 levels were relative low in both countries, short-lasting peak exposure measurements could be considered in future studies to clarify the association between NO_2 exposure and health, as they have been suggested more harmful than long-term average measurements (Berglund et al., 1993; WHO, 2005).

With respect to formaldehyde, according to the Finnish indoor climate classification system (FiSIAQ, 2002), 96% of the apartments in Finland and 77% in Lithuania met the highest requirement of <30 μg m^{-3}. However, this guideline is based on emissions originating from building materials, not from human sources or activities. High concentrations are expected to be originating from new building materials, but such emissions usually decrease as buildings and materials age (Dingle and Franklin, 2002). Considering that the buildings recruited for this study were relatively old, other indoor sources than building materials might be the primary contributor (Hun et al., 2010; Jurvelin et al., 2001), indicting possible long-term exposure for some of the residents, the effects of which is not well covered in the current guidelines or literature. In general, indoor BTEX levels in both countries were often lower than outdoor levels and comparable to other studies (Hun et al., 2011; Schneider et al., 1998; Wheeler et al., 2013). However, higher outdoor concentrations were also observed due to local sources, which could be related to vehicular traffic and industry (Esplugues et al., 2010).

Radon levels in Finland (average=96 Bq m^{-3}, 10.4% >200 Bq m^{-3}) were lower than the results from a previous national survey (STUK, 2007). A recent study reported at least 15% of the 16,860 dwellings in low-rise residential building exceeding the guideline in Finland (Valmari et al., 2014). The floor levels of the measured apartment could be a possible reason, as radon infiltrates typically from the soil below the buildings, and levels are higher on the ground floor level (Nazaroff et al., 1983; Wang and Ward, 2002). In Lithuania, the average concentrations were slightly higher in apartments on the first floor (37 ± 23 Bq/m^3) than the second floor or higher (23 ± 12 Bq m^{-3}). Twenty five apartments (60%) had radon concentrations higher than the national average level (19 ± 3 Bq m^{-3}) found in the national survey 2001-2004 (Zielinski et al., 2006).

The two countries differed considerably in total fungal levels as detected with qPCR from settled dust. Differences in outdoor fungal content may partly explain the differences observed in indoor fungal levels (Burger, 1990; Gravesen, 1979). In addition, fungi are carried indoors on clothing and shoes of the occupants, and on fur of the pets (Pasanen et al., 1989). High levels may indicate overcrowding and poor ventilation (Gulliver and Briggs, 2004; Hedge et al., 1989; Rylander and Jacobs, 1994). A number of other factors have also been shown to affect indoor fungal levels, such as firewood or garbage storage(Leppänen et al., 2014; Rintala et al., 2012). There is no agreed upon level of fungi that signifies excess contamination, and no health-based guidelines exists. Future statistical analyses utilizing a broader set of microbial groups will be used to identify patterns and explaining differences observed for indoor microbial exposures in Finnish and Lithuanian apartments.

It should be pointed out that our intention was not to generalize the findings from different regions but to study IEQ and occupant satisfaction at the baseline, to identify possible IEQ indicators, and to develop, test, and refine an assessment protocol that can be used to assess IEQ both before and after renovation, potentially complementing energy audits and EPCs. On the apartment level, the assessment protocol could be used to check the general acceptability of IEQ as well as compliance with national guidelines (providing that the guidelines are not restricted in terms of specific methods used).

In Finland and Lithuania, EPCs are presented on the building level; therefore IEQ assessments could also be conducted on the building level. Our analysis suggested a sample size of five apartments per building to be sufficient to detect meaningful differences for some (but not all) measured parameters as compared to the whole sample means that generally fulfilled the guideline values. It was also noticed that due to larger variability, a sample size of ten apartments per building was often needed to reach the same level of accuracy in Lithuanian buildings, perhaps representative for buildings with natural ventilation and less insulation at the baseline.

On the national level, Finland and Lithuania (as well as majority of other European countries) are lacking representative measurement data on IEQ parameters. With regard to multi-family buildings, the baseline data collected as a part of this study appear useful for reference purposes for as long as more representative data do not exist. Reliable reference data are important when assessing the effects of changes on the population level, for example as a result of new policies and programs implemented in the housing stock.

The results demonstrated generally good agreement between building characteristics, measurement data, and occupants' responses. The use of both objective and subjective indicators will be harmonized based on the post renovation data in the development of the final assessment protocol, which can then be used to set and follow targets for improved IEQ along with improved energy efficiency. Future analyses will also clarify the impact of renovation on IEQ, thus increasing the knowledgebase ultimately leading to more effective strategies to improve environmental sustainability of buildings and occupants' health.

5. Conclusions

Most measured IEQ parameters in Finnish and Lithuanian multi-family buildings that are waiting to be renovated to improved energy efficiency were within recommended limits, however substantial differences in indoor environmental conditions were observed between the two countries. Various measurements, which were included in the assessment protocol, demonstrated a general agreement between building characteristics, measured IEQ, and occupants' responses. Potential for improvements appeared to be largest with respect to thermal conditions and ventilation adequacy, which can be verified using relatively simple measurements. In addition to those indicators, more detailed assessment of IAQ using additional environmental monitoring and sampling, as well as occupants' satisfaction using questionnaires, may be recommended based on further analyses and results of post-renovation assessments.

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Tables and figures

Table 1. Characteristics of the recruited buildings (N is the number of buildings. N=16 for Finland and N=20 for Lithuania).

Variable	Finland			Lithuania		
	N	Average	Percent (%)	N	Average	Percent (%)
Building age, year	15	42	94	17	41	85
Building area, m^2	10	3502	63	15	3529	75
Apartment area *, m^2	84	69	89	95	58	99
Number of floors	11	5	69	20	6	100
Number of apartments	11	50	69	20	45	100
District heating	12	-	75	19		95
Ventilation system						
Mechanical	13	-	81	0	-	0
Natural	2	-	13	20	-	100
Balconies	10	-	63	20	-	100
Renovation history	6	-	38	-	-	-

Table 2. Temperature and relative humidity in the coldest spot (Tc & RHc) and warm area (Tw & RHw), indoor and outdoor PM, CO_2, CO, NO_2, formaldehyde, BTEX, radon, and fungi concentrations (Table shows average, standard deviation, median, and 95th percentile). The guidelines from WHO, EU or national levels are presented.

Parameter, unit	Finland						Lithuania						WHO guideline	EU/National guideline	
	N	Average	SD	Median	95th	Per,%[f]	N	Average	SD	Median	95th	Per,%		Finland	Lithuania
Tc, °C [a]	94	20.45	1.62	20.50	23.00	0	91	17.93	2.23	18.32	20.98	-	-	12	-
Tw, °C[b]	94	22.66	1.06	22.71	24.51	41	89	19.62	1.63	19.58	22.21	61	-	21(≤23-24)	20-24
RHc, %	94	28.14	7.78	26.64	42.91	-	91	48.57	10.61	47.36	68.62	-	-	-	-
RHw, %	94	25.43	7.10	24.18	37.25	29	89	43.50	9.92	43.40	63.77	42	-	20-60	40-60
CO_2, ppm	92	701	182	669	1000	2	88	1027	386	968	1807	30	-	1200-1500	1200
CO, ppm	92	0.02	0.13	0.00	0.00	-	88	0.16	0.46	0.00	1.34	0	8.6(8h); 25(1h)	6.9	2.43 (24 hr)
Indoor $PM_{2.5}$, µg m^{-3}	92	8.97	17.90	4.85	33.15	7	93	11.59	13.15	8.51	26.73	5	25 (24 hr)	40 (24 hr)	
Outdoor $PM_{2.5}$, µg m^{-3}	90	8.57	8.55	6.28	26.58	4	85	20.20	14.58	17.37	48.52	28			
Indoor PM_{10}, µg m^{-3}	92	22.46	32.91	14.04	61.06	8	93	21.90	18.77	18.44	54.75	5	50 (24 hr)	50 (24 hr)	
Outdoor PM_{10}, µg m^{-3}	90	19.97	19.61	13.34	59.76	7	85	32.41	29.95	26.10	81.47	18			
NO_2, µg m^{-3}	82	6.60	3.65	5.63	13.92	-	88	14.03	7.89	13.07	29.95	-	40(1 yr);200(1 hr)	40(1 yr);200(1 hr)	
Formaldehyde, µg m^{-3}	82	17.47	6.92	16.58	29.85	-	95	23.16	10.47	21.15	44.17	-	100 (30 min)	100(30 min) 50	10(24 hr)
BTEX, µg m^{-3} [c]	72	9.27	14.02	5.68	31.06	-	95	22.77	25.21	13.53	80.44	-	-	-	-
Radon, Bq m^{-3} [d]	79	71.52	60.11	50.00	260.00	0	42	26.55	16.36	25.38	68.93	0	100 (1 yr)	400	400
Fungi, Cells m^{-2} [e]	39	149174	379144	27251	797152	-	31	479929	855674	142334	3311887	-	-	-	-

[a] Recommended minimum cold spot temperature is 12 ºC (acceptable temperature at 11 ºC; Finnish Residential Health Guideline);

[b] Recommended room temperature is 21 ºC (acceptable temperature at 18 ºC), and should not exceed 23-24 ºC (Finnish Residential Health Guideline);

[c] BTEX compounds (selected VOCs) refer to the chemicals benzene, toluene, ethylbenzene and xylenes;

[d] Guideline values for buildings in Finland: 100 Bq m^{-3} (new built); 200Bq m^{-3} (built after 1992); 400Bq m^{-3} (built before 1992);

[e] Total fungi concentrations: Cells m^{-2} refers to cell equivalents per square meter;

[f] Percentage of apartments had average concentrations that failed the guideline values (considering WHO as priority guideline, otherwise the EU then national levels).

Table 3. Spearman correlation coefficients for temperature and relative humidity in the coldest spot (Tc & RHc), warm area (Tw & RHw) and outdoor (To & RHo) in Finland (A) and Lithuania (B) during heating season.

r*	Finland						Lithuania					
	Tc	Tw	To	RHc	RHw	RHo	Tc	Tw	To	RHc	RHw	RHo
Tc	1	0.604	0.296	0.018	0.185	-0.045	1	0.618	0.401	-0.359	-0.067	-0.140
Tw	-	1	0.244	0.124	0.135	-0.128	-	1	0.198	-0.322	-0.366	-0.121
To	-	-	1	0.528	0.52	-0.256	-	-	1	0.189	0.330	-0.142
RHc	-	-	-	1	0.908	0.167	-	-	-	1	0.825	0.219
RHw	-	-	-	-	1	0.159	-	-	-	-	1	0.193
Rho	-	-	-	-	-	1	-	-	-	-	-	1

*All correlations were statistically significant ($p<.05$)

Table 4. Occupant background information and IEQ related responses in Finnish (N=83) and Lithuanian (N=56) case study buildings, and corresponding results from 2011 national survey (N=305) from Finland.

Background information and IEQ parameters	INSULAtE - current project survery				National Survey
	N	Lithuania % (95% CI)	N	Finland % (95% CI)	Finland % (95% CI)
Gender of respondent	55		83		
Female		63.6 (50.9-76.3)		61.4 (51.0-71.9)	62.6 (59.4-65.8)
Male		36.4 (23.7-49.1)		38.6 (28.1-49)	37.4 (34.2-40.6)
Age of respondent (years)	55	54.1 (39.8-68.4)	83	59.2 (46.5-72)	48.8 (46.7-50.9)
Nnumber of occupants	53	2.6 (1.9-3.3)	70	1.4 (1.1-1.8)	-
General health during the past 12 months	55		82		
Good		20.0 (9.4-30.6)		25.6 (16.2-35.1)	-
Fairly good		36.4 (23.7-49.1)		46.3 (35.5-57.1)	-
Satisfactory		41.8 (28.8-54.9)		24.4 (15.1-33.7)	-
Rather poor		0 (0-0)		2.4 (-0.9-5.8)	-
Tenure status	56		83		
Rental flat in a tenement building		1.8 (-1.7-5.3)		2.4 (-0.9-5.7)	-
Rental flat in a housing association building		0 (0-0)		9.6 (3.3-16)	-
Owner-occupied flat/house		92.9 (86.1-99.6)		88.0 (80.9-95)	100 (0-0)
Pets (Dogs, cats, etc) indoors	52	42.3 (28.9-55.7)	82	12.2 (5.1-19.3)	-
Signs of pests indoors					
Rodents (mice, rats, etc.)	51	13.7 (4.3-23.2)	80	0 (0-0)	0.7 (0.2-1.3)
Insects (furniture beetles, cockroaches, etc.)	51	25.5 (13.5-37.5)	81	11.3 (4.4-18.1)	8.2 (6.4-10.0)
Smoking indoors	53	15.1 (5.5-24.7)	75	0 (0-0)	-
Dwelling spacious enough	55	69.1 (56.9-81.3)	83	95.2 (90.6-99.8)	81.3 (78.7-83.8)
Satisfaction with the dwelling	54		83		
Satisfied		20.4 (9.6-31.1)		48.2 (37.4-58.9)	40.9 (37.7-44.2)
Fairly satisfied		48.1 (34.8-61.5)		44.6 (33.9-55.3)	48.5 (45.2-51.8)
Rather unsatisfied		18.5 (8.2-28.9)		4.8 (0.2-9.4)	6.2 (4.6-7.8)
Unsatisfied		13.0 (4-21.9)		2.4 (-0.9-5.7)	3.3 (2.1-4.5)
No opinion / Cannot tell		0 (0-0)		0 (0-0)	0.3 (-0.1-0.7)
Satisfaction with indoor air quality	51		80		
Satisfied		19.6 (8.7-30.5)		33.8 (23.4-44.1)	30.8 (27.8-33.9)
Fairly satisfied		39.2 (25.8-52.6)		42.5 (31.7-53.3)	52.1 (48.8-55.4)
Rather unsatisfied		21.6 (10.3-32.9)		17.5 (9.2-25.8)	13.8 (11.5-16.0)
Unsatisfied		17.6 (7.2-28.1)		3.8 (-0.4-7.9)	3.0 (1.83-4.07)
No opinion / Cannot tell		2.0 (-1.8-5.8)		2.5 (-0.9-5.9)	0.0 (0.0-0.0)
Indoor temperature during heating season	51		79		
Under 18 degrees Celsius		31.4 (18.6-44.1)		1.3 (-1.2-3.7)	1.0 (0.3-1.6)
18-20 degrees Celsius		51.0 (37.3-64.7)		16.5 (8.3-24.6)	17.4 (14.9-19.9)
20-22 degrees Celsius		15.7 (5.7-25.7)		54.4 (43.4-65.4)	52.8 (49.5-56.1)
22-24 degrees Celsius		2.0 (-1.8-5.8)		25.3 (15.7-34.9)	24.3 (21.4-27.1)
Over 24 degrees Celsius		0 (0-0)		2.5 (-0.9-6)	1.6 (0.8-2.5)
Moisture or mold damage in main living space					
Kitchen	42	26.2 (12.9-39.5)	79	1.3 (-1.2-3.7)	-

Bedroom(s)	48	39.6 (25.7-53.4)	79	0 (0-0)	-
Living room	41	31.7 (17.5-46.0)	79	0 (0-0)	-
Bathroom	43	37.2 (22.8-51.7)	66	4.5 (-0.5-9.6)	-
Other living space	10	10.0 (-8.6-28.6)	35	2.9 (-2.7-8.4)	-
Insufficient lighting in dwelling	47	2.1 (-2-6.3)	81	12.3 (5.2-19.5)	
Daily/almost daily noise disturbance from					
Inside the dwelling	35	14.3 (2.7-25.9)	77	5.2 (0.2-10.2)	-
Building's ventilation, plumbing, etc.	30	10.0 (-0.7-20.7)	79	11.4 (4.4-18.4)	-
Immediate surroundings (e.g., neighbors, yard)	43	27.9 (14.5-41.3)	79	27.8 (18-37.7)	-
Surrounding areas (traffic, industry, etc.)	44	50.0 (35.2-64.8)	77	26.0 (16.2-35.8)	-

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Table 5. Information about the buildings and living environment in Finnish (N=83) and Lithuanian (N=56) case study buildings, and 2011 national survey (N=305) from Finland.

Buildings and living environment	INSULAtE - current project survery				National Survey
	N	Lithuania % (95% CI)	N	Finland % (95% CI)	Finland, % (95% CI)
Facilities	56		83		
Central heating		87.5 (78.8-96.2)		81.9 (73.6-90.2)	-
Mechanical exhaust ventilation		35.7 (23.2-48.3)		28.9 (19.2-38.7)	-
Mechanical support ventilation		14.3 (5.1-23.5)		13.3 (6-20.5)	-
Fresh air vents in bedrooms		30.4 (18.3-42.4)		21.7 (12.8-30.6)	-
Air humidifier		3.6 (-1.3-8.4)		2.4 (-0.9-5.7)	-
Air purifier		5.4 (-0.5-11.3)		1.2 (-1.1-3.6)	-
Gas stove		83.9 (74.3-93.5)		0 (0-0)	-
Fireplace/wood burning oven		3.6 (-1.3-8.4)		0 (0-0)	-
Kitchen vent hood		75.0 (63.7-86.3)		56.6 (46.0-67.3)	-
Sauna		0 (0-0)		44.6 (33.9-55.3)	-
Portion of income spent on dwelling	51		80		
Under 15%		2.0 (-1.8-5.8)		22.5 (13.3-31.7)	19.3 (16.7-21.9)
16 - 25%		11.8 (2.9-20.6)		36.3 (25.7-46.8)	27.5 (24.6-30.4)
26 - 35%		27.5 (15.2-39.7)		25.0 (15.5-34.5)	20.3 (17.7-23.0)
36 - 50%		23.5 (11.9-35.2)		10.0 (3.4-16.6)	13.4 (11.2-15.7)
51 - 65%		17.6 (7.2-28.1)		2.5 (-0.9-5.9)	7.2 (5.5-8.9)
Over 65%		17.6 (7.2-28.1)		3.8 (-0.4-7.9)	5.2 (3.7-6.7)
Windows	52		83		
Single pane		1.9 (-1.8-5.7)		1.2 (-1.1-3.6)	-
Double pane		78.8 (67.7-89.9)		34.9 (24.7-45.2)	-
Triple pane		13.5 (4.2-22.7)		54.2 (43.5-64.9)	-
Window opening in winter daily/almost daily					
Kitchen	54	68.5 (56.1-80.9)	61	14.8 (5.9-23.7)	-
Bedroom(s)	51	72.5 (60.3-84.8)	63	49.2 (36.9-61.6)	-
Living room	51	54.9 (41.2-68.6)	61	16.4 (7.1-25.7)	-
Bathroom	11	54.5 (25.1-84.0)	20	5.0 (-4.6-14.6)	-
Other area	3	33.3 (-20.0-86.7)	8	0 (0-0)	-
Temperature conditions in winter	56		83		
Suitably warm		33.9 (21.5-46.3)		66.3 (56.1-76.4)	71.5 (68.5-74.5)
Too cold		37.5 (24.8-50.2)		22.9 (13.9-31.9)	14.4 (12.1-16.8)
Too warm		7.1 (0.4-13.9)		3.6 (-0.4-7.6)	4.3 (2.9-5.6)
Draughty		3.6 (-1.3-8.4)		21.7 (12.8-30.6)	13.8 (11.5-16.0)
Cold floor surfaces, etc.		32.1 (19.9-44.4)		24.1 (14.9-33.3)	14.8 (12.4-17.1)
Adjusted the thermostat of the radiator valves	50		83		
No		48.0 (34.2-61.8)		39.8 (29.2-50.3)	-
Downwards/upwards		16.0 (5.8-26.2)		55.4 (44.7-66.1)	-
Not possible		36.0 (22.7-49.3)		4.8 (0.2-9.4)	-
Moisture condensation on windows in winter	54		82		
Daily/almost daily		37.0 (24.2-49.9)		2.4 (-0.9-5.8)	-

Weekly		13.0 (4-21.9)		1.2 (-1.2-3.6)	-
Less frequently		35.2 (22.4-47.9)		32.9 (22.8-43.1)	-
Never		14.8 (5.3-24.3)		63.4 (53-73.8)	-
Unpleasant odours present in the dwelling					
Food odours	42	45.2 (30.2-60.3)	85	27.1 (17.6-36.5)	-
Cigarette smoke	34	20.6 (7-34.2)	85	12.9 (5.8-20.1)	-
Mould odour	28	21.4 (6.2-36.6)	67	1.5 (-1.4-4.4)	-
Construction materials	21	4.8 (-4.3-13.9)	69	1.4 (-1.4-4.3)	-
General stuffiness	25	24.0 (7.3-40.7)	73	16.4 (7.9-24.9)	-
Sewer odour	31	22.6 (7.9-37.3)	75	10.7 (3.7-17.7)	-
Smoke odour	30	13.3 (1.2-25.5)	69	2.9 (-1.1-6.9)	-
Odours from traffic	36	30.6 (15.5-45.6)	72	5.6 (0.3-10.8)	-
Elevated radon concentrations	54		80		
No		5.6 (-0.6-11.7)		10.0 (3.4-16.6)	31.5 (28.4-34.6)
Yes		0 (0-0)		0 (0-0)	1.0 (0.3-1.7)
Do not know		94.4 (88.3-100.6)		90.0 (83.4-96.6)	62.6 (59.4-65.8)
Symptoms associated with home environment	40	25.0 (11.6-38.4)	71	32.4 (21.5-43.3)	-

Figure 1. Maps showing the study locations, and regions of recruited buildings

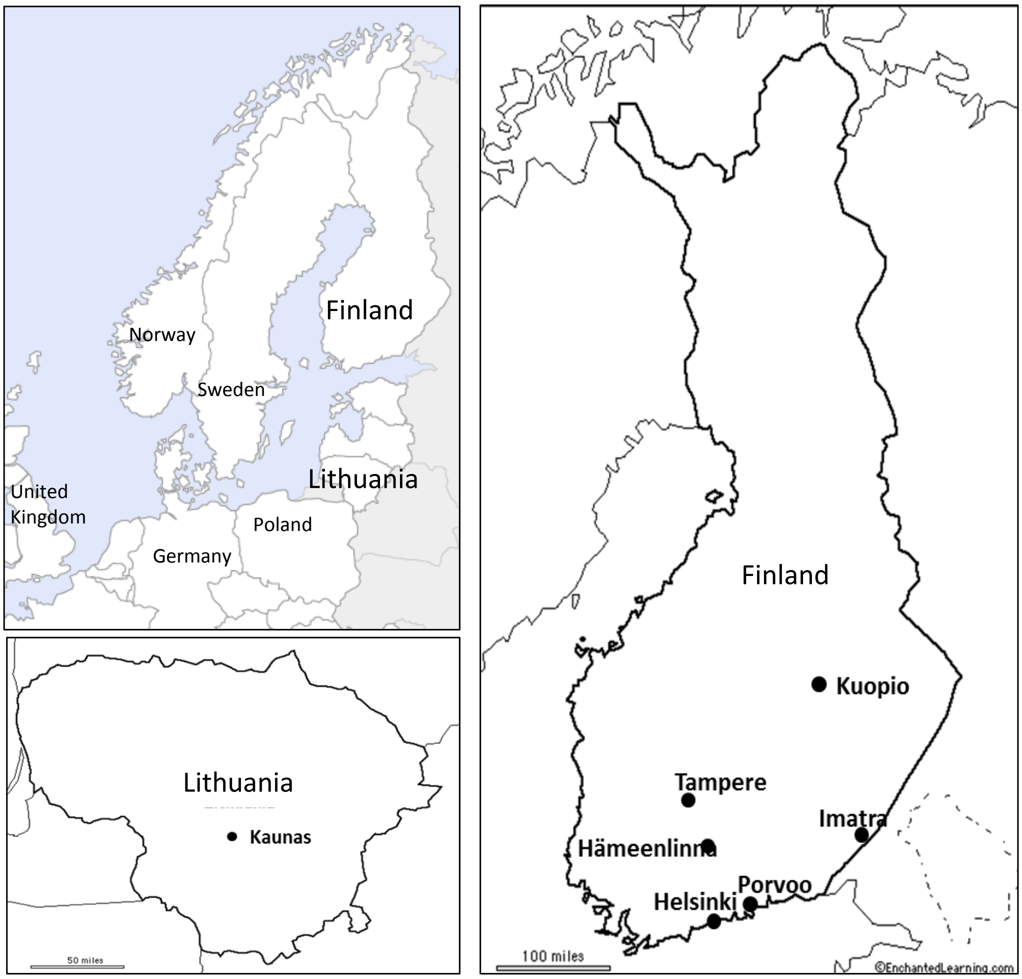


Figure 2. Percentage of temperature and relative humidity over time in warm area (Tw and RHw) and the coldest spot (Tc and RHc) in Finnish and Lithuanian case study buildings.

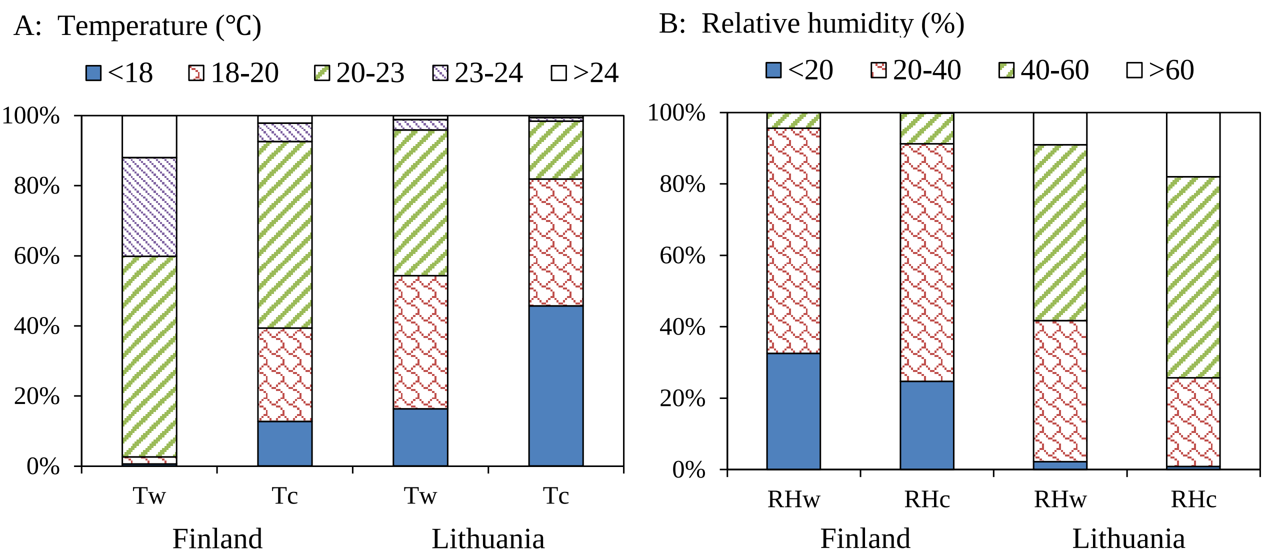
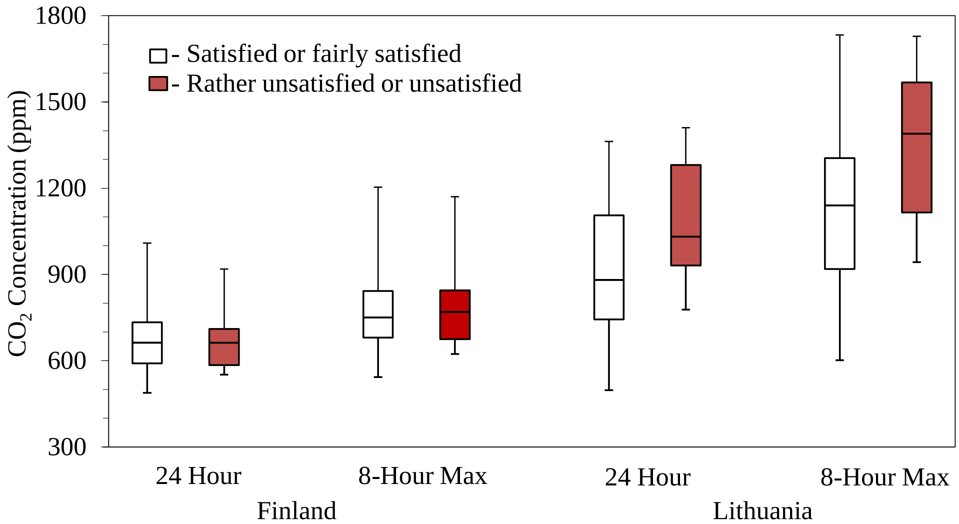


Figure 3. CO_2 levels in Finnish and Lithuanian case study buildings categorized by the satisfaction of indoor air quality in the dwelling (Figure shows median, 5th, 25th, 75th and 95th percentile)



SUPPLEMENTAL MATERIAL FOR

Assessment of Indoor Environmental Quality in Existing Multi-family Buildings in North-East Europe

Table S1. Outdoor temperatures (T, °C) and relative humidity (RH, %) during the sampling period (December, 2011 to May, 2013.). Average and standard deviation values by month are shown.

Country / City / Month	Finland							Lithuania
	Tampere 1	Tampere 2	Hämeenlinna	Lappeenranta	Helsinki	Porvoo	Kuopio	Kaunas
	T, °C							
Decmeber 2011	0.95(2.05)	1.38(1.85)	-	-	-	-	-	1.80(2.80)
January 2012	-6.68(5.27)	-6.51(5.26)	-	-	-	-	-	-2.98(5.65)
Febuary 2012	-8.61(8.12)	-8.70(8.02)	-5.05(5.54)	-	-	-	-	-9.04(8.91)
March 2012	-4.99(6.61)	-4.89(5.30)	-0.17(4.60)	-2.75(5.59)	1.22(1.94)	-	-	1.93(3.97)
April 2012	-	-	3.46(5.27)	1.98(5.85)	4.12(3.60)	-	-	7.74(6.65)
May 2012	-	-	-	7.61(5.11)	10.91(3.77)	12.26(4.64)	-	13.75(5.64)
October 2012	-	-	-	-	-	-	-	7.36(4.53)
November 2012	-	-	-	-	-	-	-	4.82(2.09)
Decmeber 2012	-	-	-	-	-	-	-	-4.28(4.72)
January 2013	-7.35(5.99)	-7.41(6.01)	-	-	-	-	-	-6.67(6.35)
Febuary 2013	-2.64(2.56)	-2.97(2.68)	-	-	-	-	-2.83(3.46)	-1.03(2.45)
March 2013	-7.46(6.11)	-8.00(5.58)	-7.10(6.08)	-	-	-	-9.33(5.61)	-3.83(3.81)
April 2013	2.69(4.79)	1.76(4.91)	2.72(4.60)	-	-	-	2.51(4.72)	5.51(5.61)
May 2013	12.94(5.57)	11.96(4.35)	10.75(4.68)	-	-	-	10.76(4.95)	16.11(5.01)
	RH, %							
Decmeber 2011	92.74(7.82)	90.00(7.56)	-	-	-	-	-	88.32(5.17)
January 2012	91.20(4.17)	89.83(4.12)	-	-	-	-	-	83.66(9.46)
Febuary 2012	87.14(7.94)	85.72(7.40)	89.24(6.59)	-	-	-	-	79.63(9.41)
March 2012	78.69(13.79)	81.1(10.89)	79.4(16.12)	78.65(14.15)	76.71(15.55)	-	-	76.35(15.44)
April 2012	-	-	71.65(20.96)	75.91(17.41)	76.73(16.03)	-	-	66.42(21.24)
May 2012	-	-	-	61.92(20.09)	65.99(18.04)	64.13(21.06)	-	64.07(20.32)
October 2012	-	-	-	-	-	-	-	86.34(9.88)
November 2012	-	-	-	-	-	-	-	89.12(7.43)
Decmeber 2012	-	-	-	-	-	-	-	81.92(7.99)
January 2013	87.28(4.46)	93.33(3.97)	-	-	-	-	-	84.22(6.67)
Febuary 2013	88.06(4.97)	93.64(5.01)	-	-	-	-	89.09(4.18)	82.17(9.30)
March 2013	66.24(20.03)	73.74(17.80)	64.64(19.27)	-	-	-	73.63(16.52)	62.42(16.36)
April 2013	69.98(20.27)	75.42(18.96)	72.05(20.71)	-	-	-	68.78(19.20)	71.52(19.34)
May 2013	64.39(21.00)	69.42(18.65)	63.20(22.60)	-	-	-	66.59(20.99)	68.35(20.41)