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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 in improving IEQ along with energy efficiency in the current building stock, followed by discussion of possible IEQ indicators and development of the assessment protocol.

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 EU 26, 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.,

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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 UK, government supported energy efficiency improvements under the Warm Front scheme. For example, energy efficiency improvements were delivered in a 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 3000 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 (Ministry of the Environment, 2013).

This paper analyzes 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 (Fig. 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, a priori 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 hour, one week, and two month 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 of 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